Appendix 1: Nengfa Coal Reserve Classification System

Appendix 1: Nengfa Coal Reserve Classification System

The reserve classification, is delineated into four classifications, or grades; A, B, C and D according to the following standards.

For coal deposits which have close-spaced exploration data:

1. Reserves in grade A are delineated from a point of observation or measurement out a distance of 500 m in all directions, forming a circle with a radius of 500 m.
2. Reserves in grade B are delineate from the circle defined by grade A reserves out a distance of 1000 m in all directions from a point of observation or measurement.
3. Reserves in grade C are delineated from a circle defined by B reserves out a distance of 2000 m in all directions from a point of observation or measurement.
4. Reserves in grade D are delineated from a circle defined by C reserves beyond the distance of 2000 m in all directions but can be supported from a point of observation or measurement from greater depths or outside of the mine property boundary.

For coals which are less well known due to widely-spaced exploration data:

1. There are no grade A reserves
2. Reserves in grade B are delineated from a point of observation or measurement out a distance of 500 m in all directions, forming a circle with a radius of 500 m.
3. Reserves in grade C are delineated from a circle defined by B reserves out a distance of 1000 m in all directions from a point of observation or measurement.
4. Reserves in grade D are delineated from a circle defined by C reserves beyond the distance of 1000 m in all directions but can be supported from a point of observation or measurement from greater depths or outside of the mine property boundary.

Appendix 2: Hydrology Well Summary Table

Appendix 2: Hydrology Well Summary Table

Hydrology Well Summary

Well No.	Depth (m)	Well No.	Depth (m)
1001*	422.9	J1602*	295.5
J1104*	305.1	J1603*	389.0
1105*	467.4	1703*	253.5
1203*	287.6	1705*	230.4
J1303*	433.3	1708*	701.0
J1402	291.4	J1701*	263.1
J1404*	320.7	J1702*	428.9
1505*	326.0	13(1)-3	230.3
J1501	261.0	13(2)-3	311.1
J1502	424.2	13(2)-2	285.6
J1503	364.1	13(2)-1	235.5
1603	398.8	0-1	225.3
1604	421.9	0-2*	423.3
1605*	433.0	NA	361.5
J1601*	255.9		

Source: GGPBICG (2002)

Appendix 3: First and Subsequent Well AFE and Proposed Drilling

Appendix 3: First and Subsequent Well AFE and Proposed Drilling

A hypothetical well design and authorization for expenditure (AFE) have been developed for modeling purposes for drilling a directionally drilled well array for pre-mine draining on the Linhua mine. Detailed AFEs and days versus depth (**Figure 1**) are provided as a part of the proposed program. Costs and schedule are considered to be preliminary and for scoping purposes.

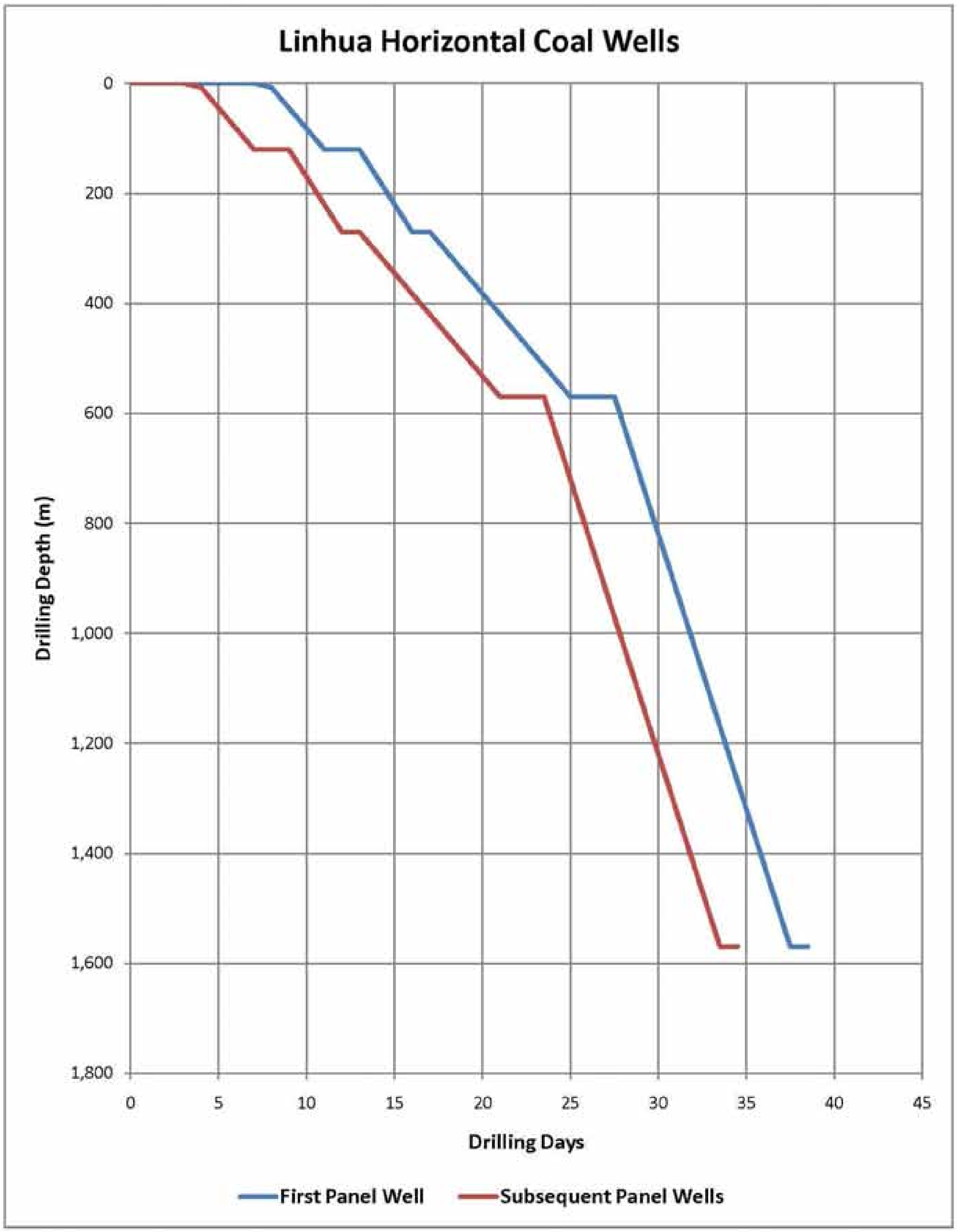


Figure 1: Days Drilling versus Depth Curves

Discussion of the work involved with developing these estimates and the assumptions follow.

Appendix 3: First and Subsequent AFE and Proposed Drilling

Prior to mobilizing the rig, a 40 m by 85 m drilling location would have to be built Reserve and cuttings disposal pits will be constructed off location. It is estimated that 1 km of 3.5 m wide road will have to be constructed per pad. Both power and communications (phone and internet) will be installed on location. Although a minimal number of people will be resident at the well site, provisions for water and sewerage will have to be made. Prior to construction, an environmental assessment must be performed and approved by the local environmental bureau.

A top drive drilling rig with 2,000-2,500 m depth capacity will have to be identified and moved to the site. Tentatively, a total of 6 wells will be drilled in a line parallel to the panel edges, with a per well spacing of approximately 2.5 m to 4.0 m spacing between well centers. Wellheads will be in shallow cellars to allow for the drilling rig to be skidded over laterally as wells are finished. Depth and configuration of the cellars will be based on the drilling rig selected. Conductor casing could be pre-set at approximately 7 m below ground level, but is currently planned to be set with the drilling rig. Wells will be drilled from surface to total depth, and then the rig will be skidded to the next slot.

Conventional water-based drilling fluid mud should be used. Surface sediments (Lower Triassic limestone, mudstone and siltstone) are fairly hard, and penetration rates will be fairly low. Limestone formations are noted to have lost circulation problems (drilling fluid drains from the hole, water flows and karsts. Lost circulation may be a problem in the first 200-400 m drilled.

Surface casing is to be set at 120 m, but may be set deeper if no drilling problems are encountered. Tentatively, 10 ¾ inch casing will be run in a borehole drilled to 13 ½ inch diameter and cemented back to surface. Cementing can be performed by a local Chinese cementing company using local Class G cement with simple additives. After setting this casing, a starter head and a blowout preventer (BOP) will be installed.

A 9 ⅞ inch hole will be drilled to an approximate 240 m kick off point with water based mud, and at this point, mud loggers begin work. The planned build rate is 8˚ per 30 m which will position the borehole to approach 90˚ just above the 9 coal (**Figure 2**). The 4 and 5 coals will be encountered at high angle but this could become a well stability issue. 7 ⅝ inch casing will be set through the 4 and 5 coals, just above the 9 coal and cemented back to surface.

Appendix 3: First and Subsequent Well AFE and Proposed Drilling

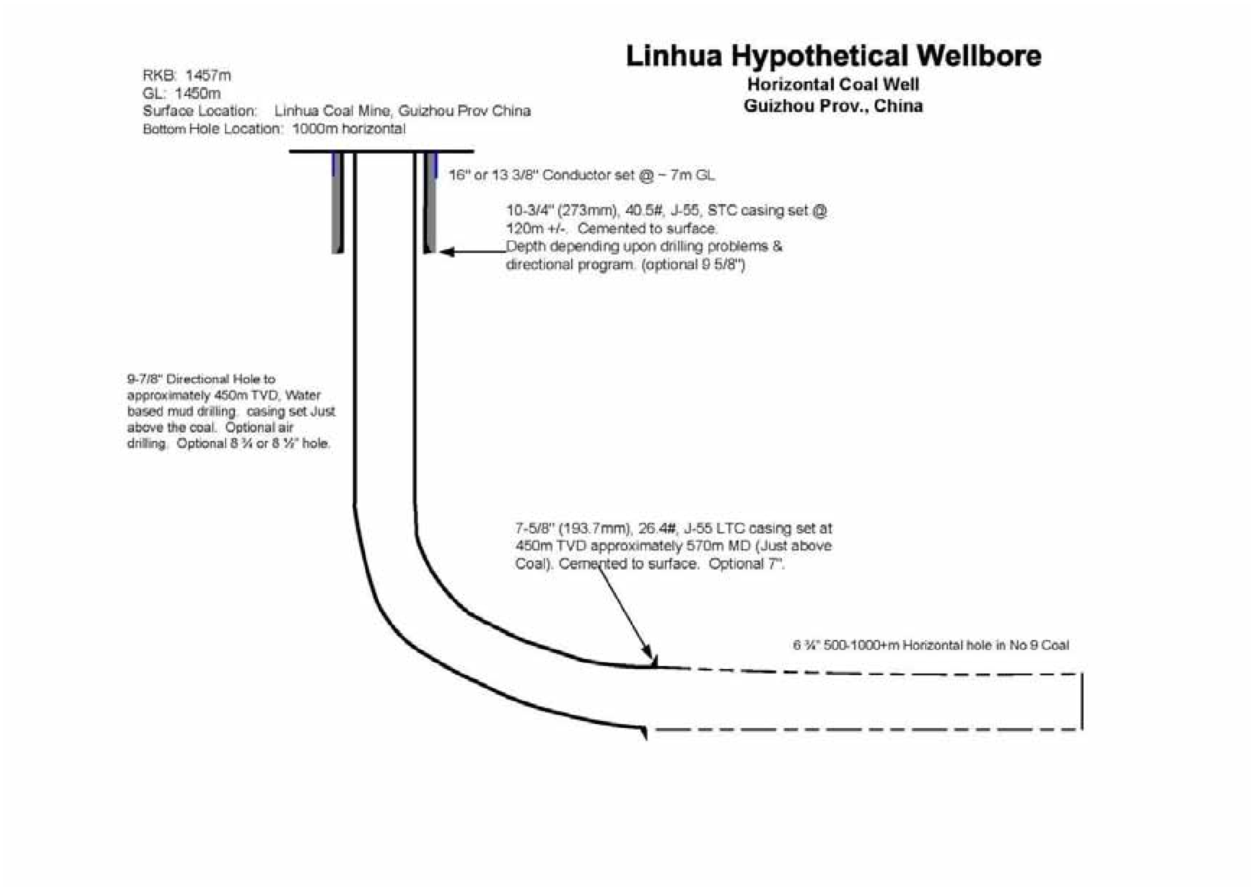


Figure 2: Wellbore Diagram

A 6 ¾ inch production hole will be drilled with water and clear gel sweeps in the coals. Rotary steerable Logging While Drilling and Measurement While Drilling (LWD/MWD) tools will be run in this section of the borehole in an attempt to ensure that 100% of the borehole is placed in the coal and the open hole section has minimal undulations. It is anticipated that coal cuttings samples will be collected and desorbed to determine gas content. After drilling, the well is initially planned for so that casing will not be inserted into the hole (open hole completion). If hole stability is a problem, 4 ½ inch pre-perforated fiberglass casing can be run in to the hole. Once the production hole is drilled, the rig will be skidded to the next slot.

After all holes are drilled in a panel, the rig will move off to the next pad. Production tubing and artificial lift can be installed with a crane. All cuttings will be solidified with cementitious material and buried. Mud and fluids will be hauled off for disposal. At this point production equipment and flowlines will be installed.

Appendix 3: First and Subsequent Well AFE and Proposed Drilling

AFE No.: Linhua Horizontal Coal Drilling
Project:
Well Name: First Panel Well

Country: Guizhou Province, China

Drilling AFE Days: 61 Days
Location Constructic 60 days

Account	**(Gen/Sub)**	**INTANGIBLE DRILLING COSTS**					
301	301	Company Labor				$ -	
	309	Legal/Title Opinions				$ -	
	310	Permitting/Surveying				$ -	
	311	Location, Roads, ROW & Pit				$ 419,706	
		Total area disturbed - not counting roads	10	mu			
		Area Flat Location - Well pad	5	mu			
		Build location 40 X 85m (5mu)	$ 40,000	/mu	$ 200,000		
		Land Acquisition - Rental only - Total disturbed area	$ 1,471	/mu	$ 14,706		
		Environmental Assement, Location Design & Survey			$ 40,000		
		Roads - Average 1km of roads & upgrades/pad			$ 30,000		
		1000 * 3.5 = 3500 m2 = 5.2mu @ $20,000/mu			$ 105,000		
		Power installation			$ 20,000		
		Communications installation			$ 10,000		
		Flowlines & Production equipment - not included					
		Note that wellsite should be able to accommodate a minimum of 3, and up to 10 wells, split costs 6 ways					
	312	Surface Restoration - Not Included					
	313	Testing					
	314	Automobile Expense	120.5	days	$150.00	$ 18,075	
	315	Telephone Expense	$120.50	days	$ 50	$ 6,025	
	320	Mobilization/Demobilization - In overall project costs, charge daywork to skid				$ 150,000	
	321	Drilling - Footage					
	322	Drilling - Daywork	$ 11,000	/day		$ 665,500	
		100MT rig with top drive, rig may have to be larger (to get top drive).					
		Dayrate includes fuel					
	323	Completion Rig - Not included, but required for production					
	324	Reverse Unit					
	325	Swabbing					
	326	Materials & Supplies - Misc Drilling				$ 10,000	
	327	Acidize & Frac					
	328	Perforating					
	330	Drilling Fluids, 500 bbls/well * $150/bbls				$ 75,000	2.4%
	331	Air Package - Not included - offset by mud and rig time if used.					
	332	Mud Treatment Equipment - with rig					
	333	Fluid Disposal - 500 bbls * $6/bbl & Cuttings Disposal 100 m^3 X $50/$m^3$				$ 8,000	
	334	BOP & Wellhead Rental					
	335	Drill/Work String Rental					
	336	Fishing Tool Rental					
	337	Other Rentals					
	338	Welding & Repairs					
	339	Surface Damages					
	340	Bits, Reamers & Stabilizers				$ 75,250	2.4%
			Bits	$/bit			
		17 1/2" TC	0.25	$15,000			
		14" - 12 1/4"TC	0.5	$13,000			
		9 7/8" - 8 3/4" - PDC	1	$35,000			
		6 3/4"-6 1/8" - PDC	1	$30,000			
	341	Fuel - In daywork costs					
	350	Casing Cementing				$ 81,500	2.6%
		Conductor - 25 sks/1mt		$ 1,000			
		Surface - 10 3/4" or 9 5/8" - 300sks/13MT		$23,000			
		Intermediate - 7 5/8" - 7" - 500sks/22MT		$57,500			
	351	Squeeze Cementing/Plug Back					
	352	Wireline Logging - none included					
	353	Coring					
	354	Casing Crews & Laydown Service				$ 15,000	
		Surface		$ 5,000			
		Intermediate		$10,000			
		Production - Not included					
	355	Coal Desorption Test & Mudlogs				$ 21,250	
		Mud Logging	15	$ 750			
		Desorption & Testing		$10,000			
	356	Drillstem Test *(Flow Test)*					
	360	Transportation - Trucking				$ 50,000	1.6%
		Misc. Trucking					
	361	Transportation - Dozer Assist					
	370	Directional Drilling - Day Rate - MWD/LWD/Motors, etc	44.50	Days	$ 15,000	$ 667,500	20.9%
	370	Directional Drilling - Stand By & reconditioning				$ 100,000	3.1%
	371	MWD/LWD Services					
	380	Tubular Inspection				$ 10,000	
	381	Tubular Repairs				$ 20,000	
	385	Plug & Abandonment Costs					
	390	Consultants *(Wellsite & Engineering)*	120.5	Days	$ 2,167	$ 261,149	8.2%
	391	Roustabout & Contract Labor				$ 5,000	
	394	Well Control Insurance					
	395	Contingencies (Budget Only) *20%*		20%		$ 531,791	16.7%
	398	Miscellaneous IDC					
	399	Overhead					
		TOTAL IDC				$ 3,190,745	
		TANGIBLE COSTS					
301	401	Casing 16"	$ 192	7		$ 1,344	
	401	Casing 10 3/4"	$ 120	120		$ 14,350	
	401	Casing 7 5/8"	$ 78	570		$ 44,433	
	401	4 1/2" Fiberglass Liner - Not included	$ 20	1000			
	402	Stock					
	403	Conductor Pipe - 20"					
	404	Line Pipe & Battery Fittings - Not included					
	406	Tubing - 2 7/8" - Not inculded	$ 21	570			
	407	Packer					
	410	Downhole Equip, Pumps & Rods - No Included					
	415	Wellhead Equipment - 10 3/4" X 7 5/8" X 2 7/8" - Larkin & fititngs				$ 20,000	
	420	Flowlines, Valves, Meters - Not included	$15	100			
	421	Water Disposal Lines					
	425	Valves - Oxygen Control					
	429	Water Treatment Facility					
	430	Electrical System - Not included					
	440	Pumping Units - Not included					
	445	Buildings					
	450	Wellsite Construction/Installation					
	451	Gas Compressor					
	460	Trucking					
	470	Other Tangible Equipment					
	471	Pipeline Installation					
	475	Heater/Treater & Separator - Not included					
	480	Tanks & Vessels - Not Included					
	490	Consulting - Construction					
		TOTAL TANGIBLE				$ 80,127	
		Total Well Drilling Costs - First well & Location				**$ 3,270,872**	

Appendix 3: First and Subsequent Well AFE and Proposed Drilling

AFE No.: Linhua Coal Drilling
Project: Subsequent Panel Well
Well Name:

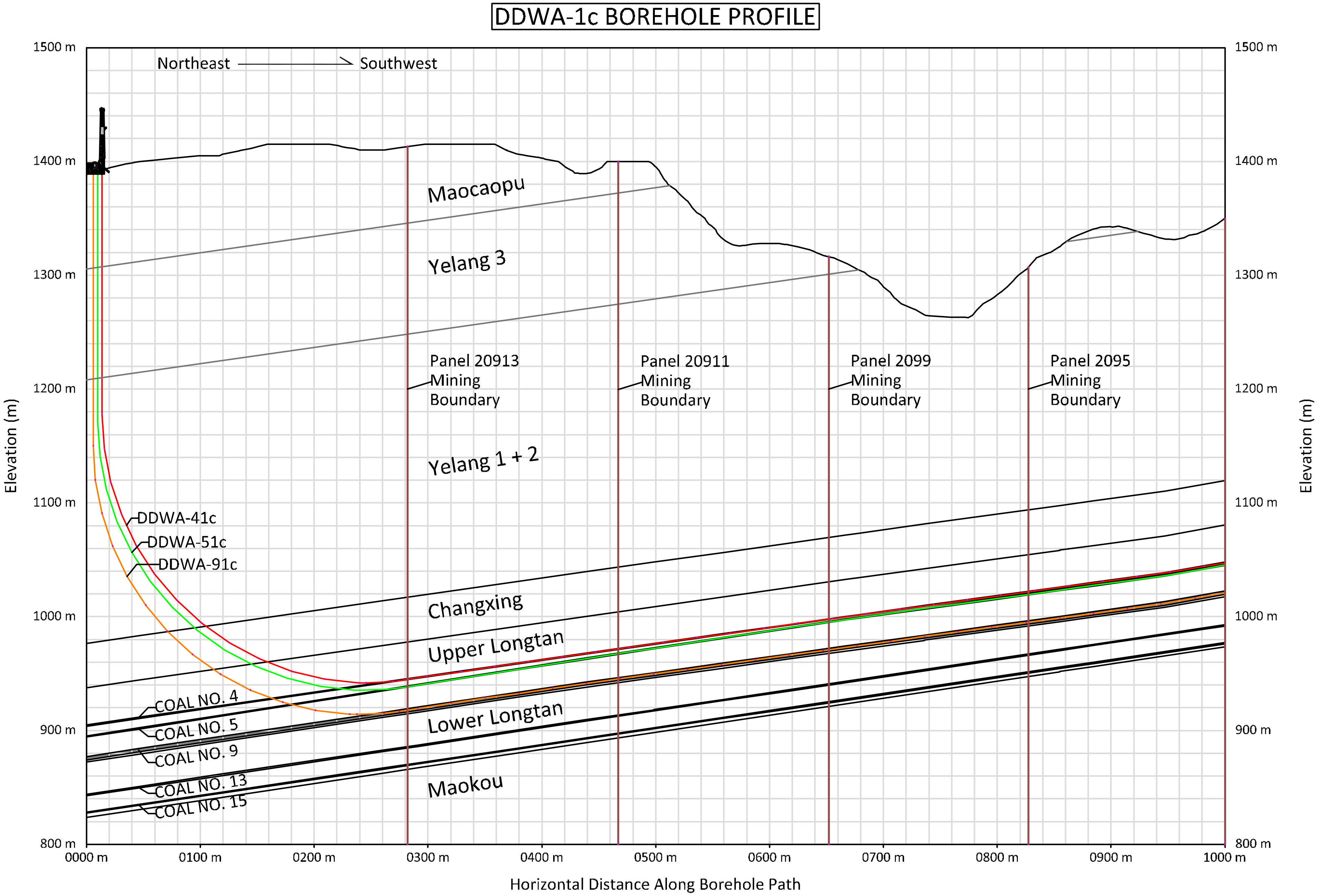
Country: Guizhou Province, China

Drilling AFE Days: 56.5 Days
Location Constructi 0 days

Account (Gen/Sub)		**INTANGIBLE DRILLING COSTS**					
301	301	Company Labor				$ -	
	309	Legal/Title Opinions				$ -	
	310	Permitting/Surveying				$ -	
	311	Location, Roads, ROW & Pit				$ 419,706	
		Total area disturbed - not counting roads	10	mu			
		Area Flat Location - Well pad	5	mu			
		Build location 40 X 85m (5mu)	$ 40,000	/mu	$ 200,000		
		Land Acquisition - Rental only - Total disturbed area	$ 1,471	/mu	$ 14,706		
		Environmental Assement, Location Design & Survey			$ 40,000		
		Roads - Average 1km of roads & upgrades/pad			$ 30,000		
		1000 * 3.5 = 3500 m2 = 5.2mu @ \$20,000/mu			$ 105,000		
		Power installation			$ 20,000		
		Communications installation			$ 10,000		
		Flowlines & Production equipment - not included					
		Note that wellsite should be able to accommodate a minimum of 3, and up to 10 wells, split costs 6 ways					
							yt
	312	Surface Restoration - Not Included					
	313	Testing					
	314	Automobile Expense	56.5	days	$ 150	$ 8,475	
	315	Telephone Expense	56.5	days	$ 50	$ 2,825	
	320	Mobilization/Demobilization - In overall project costs, charge daywork to skid				$ 150,000	
	321	Drilling - Footage					
	322	Drilling - Daywork	$ 11,000	/day		$ 621,500	
		100MT rig with top drive, rig may have to be larger (to get top drive).					
		Dayrate includes fuel					
	323	Completion Rig - Not included, but required for production					
	324	Reverse Unit					
	325	Swabbing					
	326	Materials & Supplies - Misc Drilling				$ 10,000	
	327	Acidize & Frac					
	328	Perforating					
	330	Drilling Fluids, 500 bbls/well * \$150/bbls				$ 75,000	2.6%
	331	Air Package - Not included - offset by mud and rig time if used.					
	332	Mud Treatment Equipment - with rig					
	333	Fluid Disposal - 500 bbls * \$6/bbl & Cuttings Disposal 100 m^3 X \$50/m^3				$ 8,000	
	334	BOP & Wellhead Rental					
	335	Drill/Work String Rental					
	336	Fishing Tool Rental					
	337	Other Rentals					
	338	Welding & Repairs					
	339	Surface Damages					
	340	Bits, Reamers & Stabilizers				$ 75,250	2.6%
			Bits	$/bit			
		17 1/2" TC	0.25	$15,000			
		14" - 12 1/4"TC	0.5	$13,000			
		9 7/8" - 8 3/4" - PDC	1	$35,000			
		6 3/4"-6 1/8" - PDC	1	$30,000			
	341	Fuel - In daywork costs					
	350	Casing Cementing				$ 81,500	2.8%
		Conductor - 25 sks/1mt		$ 1,000			
		Surface - 10 3/4" or 9 5/8" - 300sks/13MT		$23,000			
		Intermediate - 7 5/8" - 7" - 500sks/22MT		$57,500			
	351	Squeeze Cementing/Plug Back					
	352	Wireline Logging - none included					
	353	Coring					
	354	Casing Crews & Laydown Service				$ 15,000	
		Surface		$ 5,000			
		Intermediate		$10,000			
		Production - Not included					
	355	Coal Desorption Test & Mudlogs				$ 21,250	
		Mud Logging	15	$ 750			
		Desorption & Testing		$10,000			
	356	Drillstem Test *(Flow Test)*					
	360	Transportation - Trucking				$ 35,000	1.2%
		Misc. Trucking					
	361	Transportation - Dozer Assist					
	370	Directional Drilling - Day Rate - MWD/LWD/Motors, etc	44.50	Days	$ 15,000	$ 667,500	22.7%
	370	Directional Drilling - Stand By & reconditioning				$ 100,000	3.4%
	371	MWD/LWD Services					
	380	Tubular Inspection				$ 10,000	
	381	Tubular Repairs				$ 20,000	
	385	Plug & Abandonment Costs					
	390	Consultants *(Wellsite & Engineering)*	56.5	Days	$ 2,167	$ 122,447	4.2%
	391	Roustabout & Contract Labor				$ 5,000	
	394	Well Control Insurance					
	395	Contingencies (Budget Only) *20%*		20%		$ 489,691	16.7%
	398	Miscellaneous IDC					
	399	Overhead					
		TOTAL IDC				$2,938,144	
		TANGIBLE COSTS					
301	401	Casing 16"	$ 192	7		$ 1,344	
	401	Casing 10 3/4"	$ 120	120		$ 14,350	
	401	Casing 7 5/8"	$ 78	570		$ 44,433	
	401	4 1/2" Fiberglass Liner - Not included	$ 20	1000			
	402	Stock					
	403	Conductor Pipe - 20"					
	404	Line Pipe & Battery Fittings - Not included					
	406	Tubing - 2 7/8" - Not inculded	$ 21	570			
	407	Packer					
	410	Downhole Equip, Pumps & Rods - No Included					
	415	Wellhead Equipment - 10 3/4" X 7 5/8" X 2 7/8" - Larkin & fititngs				$ 20,000	
	420	Flowlines, Valves, Meters - Not included	$15	100			
	421	Water Disposal Lines					
	425	Valves - Oxygen Control					
	429	Water Treatment Facility					
	430	Electrical System - Not included					
	440	Pumping Units - Not included					
	445	Buildings					
	450	Wellsite Construction/Installation					
	451	Gas Compressor					
	460	Trucking					
	470	Other Tangible Equipment					
	471	Pipeline Installation					
	475	Heater/Treater & Separator - Not included					
	480	Tanks & Vessels - Not Included					
	490	Consulting - Construction					
		TOTAL TANGIBLE				$ 80,127	

Appendix 4: Draft Longitudinal Well Profiles

Appendix 4: Longitudinal Well Profile



DISCLAIMER: This map is designed to be an informational tool for the purpose of displaying design schematics, and is not intended to be used as a surveyed or engineered design plan. The information presented was provided by source(s) listed below and is believed to be accurate and suitable for modeling purposes, and is subject to the limitations stated above.

0 100 m 200 m 400 m

Drawing No.: GEOLOGIC MODEL

Paper Space View Name: DDWA 1	
Drawn By: CLMT	Date: 11/11/2010
Approved By: RCP	Date: 12/07/2010
Geology By: Linhua Mining Co., Ltd. Guizhou	Date: 08/2009
Current Revision No.: 1	Date: 11/11/2010
Revised By: CLMT	
Source: Linhua Mining Co., Ltd. Guizhou	

EXPLANATION

- TOPOGRAPHIC PROFILE
- GEOLOGIC UNIT PROFILE
- COAL SEAM
- MINE PANEL BOUNDARY
- BOREHOLE DDWA-91c
- BOREHOLE DDWA-41c
- BOREHOLE DDWA-51c

U.S. EPA Coalbed Methane Outreach Program

RAVEN RIDGE RESOURCES INCORPORATED
Exploration & Development Of Natural Resources
584 25 Road • Grand Junction, Colorado 81505
(970) 245-4088 • FAX (970) 245-2514

Global Methane Initiative

Client Name: US ENVIRONMENTAL PROTECTION AGENCY

Project Name: LINHUA COAL MINE CMM RECOVERY & USE PROJECT

Title: PROFILE OF DDWA-1C

BOREHOLES SHOWN INTERSECT COALS 4, 5 AND 9

Appendix 5: NIOSH Drainage Assessment Report

Assessment of Methane Drainage from In-Seam Boreholes and Methane Release from Mine Ventilation System in Lin Hua Coal Mine, Guizhou Province, China

Project owner: Raven Ridge Resources and U.S. EPA-Coalbed Methane Outreach Program

Dr. C. Özgen Karacan
NIOSH, Office of Mine Safety and Health, Pittsburgh
Dust Control, Ventilation and Toxic Substances Branch

April 5, 2010

Background:

NIOSH involvement:

NIOSH was approached by Raven Ridge Resources (RRR) with a supplementary request by EPA's Coalbed Methane Outreach Program (CMOP) for collaboration on the assessment of coalbed and coal mine methane recovery from Lin Hua Coal Mine, China, for safety of the mine. In particular, RRR requested assistance in using newly developed NIOSH Methane Control and Prediction (MCP) toolkit for this international project to analyze the situation existing at the LinHua Coal Mine, Guizhou Province China. The following memorandum was submitted to NIOSH by RRR:

" RRR, under our contract to CMOP, reached an agreement with the Lin Hua Mine to carry out the feasibility study. The mine is owned and operated by the Guizhou Nengfa Power Fuel Development Co., Ltd. (Nengfa) and has a designed capacity of 1.5 million tonnes per annum. The goal of this study is to provide the mine with guidance in developing an effective approach to gas drainage and cost effective use of CMM and VAM. This is done with the financial support and guidance of CMOP as it provides technical and analytical support to advance the aims of the Methane to Markets Partnership (M2M) and the US-China Strategic Economic Dialogue (SED). The state goals of CMOP's effort are to reduce greenhouse gas emissions and increase energy supply while having a positive impact on mine safety. The Lin Hua mine was chosen for the following reasons:

- *Mines of similar size are the norm for southwestern China;*
- *Coal is mined in southwest China in complex geology under difficult and gassy mining conditions*
- *The Guizhou Mine Safety Bureau helped choose this mine and endorsed our study with the hopes that we can recommend more effective alternatives to the gas drainage techniques that are presently being applied.*
- *The mine owner is the fifth largest power producer in China*
- *With the endorsement of the Mine Safety Bureau and participation of a large utility company the chance of replicating success is high; meaning recovery and use of CMM demonstrated by the Lin hua Mine will lead to emission reductions and safety benefits for many mines in the region.*

Hundreds of miners are killed in methane-related accidents in Chinese coal mines annually. Casualty figures were down in 2009 by 18 percent from the previous year, however, the Chinese government continues to spend over 240 million U.S. Dollars a year to try and improve the industry's dismal safety record, which is the worst in the world. Moreover, it is widely believed that the mining fatalities are significantly underestimated. These statistics probably do not represent the actual number of deaths in China coal mines, but only accounts for the larger state owned and private mines. Small private mines supplying coal to villages and counties are regulated, but not regularly inspected; so many miners perish in unreported accidents.

Development of the Lin Hua mine began in 2001 and continued until 2006 when the mine was idled. During this five year period, development roadways were driven and an inseam drilling campaign was conducted into the initial longwall panel. Inseam drilling was supplemented with intermittent cross measured boreholes. During development, the mine experienced 24 gas and rock outbursts, with the last episode in 2006 killing eight miners, which caused the mine to become idle until the gas situation could be managed. Each outburst averaged 85 tons of coal and over 12,000 cubic meters of methane.

According to the Chinese classification system, the Lin Hua mine is classified as a high-outburst mine. The mine was eventually purchased by Nengfa; Drainage borehole drilling resumed in May of 2009 and mining resumed in September. Although the mine is designed to produce approximately 1.5 million tons annually, progress remains slow due to continued gas influx into the mine workings. It is our believe that mining will not reach safe and sustained commercial production without implementing a integrated drainage program comprising pre-mine drainage (surface and in-mine) and gob drainage. Mine management has expressed their concerns to CMOP, and is the primary reason for their willingness to cooperate in the study. Raven Ridge became familiar with the NIOSH Methane Control Toolkit when Dr. Karacan asked us to peer review the software. During the review, we used real data to test the model that Raven Ridge acquired from another feasibility study we were conducting in China at the time. We believe our review comments resulted in several suggestions that were either considered or implemented by NIOSH. As the Lin Hua mine is only in the development stage, there is not much history in terms of methane emissions or drainage. As a result of recent discussions with Dr. Karacan, we believe that with Dr. Karacan's input and understanding of the model, he will be able to help us better understand the reservoir conditions of this specific mine site and aid us in the geometry and placement of pre-mine drainage boreholes and gob vent boreholes. Our recommended approach will be key in reducing the potential for outbursts; which will result in safer mining conditions. By increasing mine safety in the current mining environment the mine will then be able to produce high quality methane that can be safely used while reducing emissions, thus satisfying the primary goal of the CMOP program.
The benefits to NIOSH will be the availability of real data from a very gassy mine which can result in calibration of the model and eventual refinement of this model. NIOSH will get acknowledgement in the report, which once completed, will be translated into Chinese and both versions will be available on EPA's web-site. None of the results of the modeling will be proprietary which will allow both NIOSH and EPA representatives to present these findings at conferences and workshops. It is important to note that NIOSH and Raven Ridge's involvement in this project will not expose either organization to liability resulting from the findings and recommendations of this study. Dr. Franklin expressed her support and encouragement prior to taking a leave of absence, when Raven Ridge briefed her on this possible cooperative effort."

<u>Data provided by Raven Ridge Resources, Inc:</u>

RRR has provided the following information for implementation of this project on our end:

- Location map (Figure 1) and drainage map of panel 2093
- Production data from one of the boreholes
- Annual coal production starting from 2009 and projected coal productions until 2015.
- Monthly gas drainage and ventilation data for panel 2093.

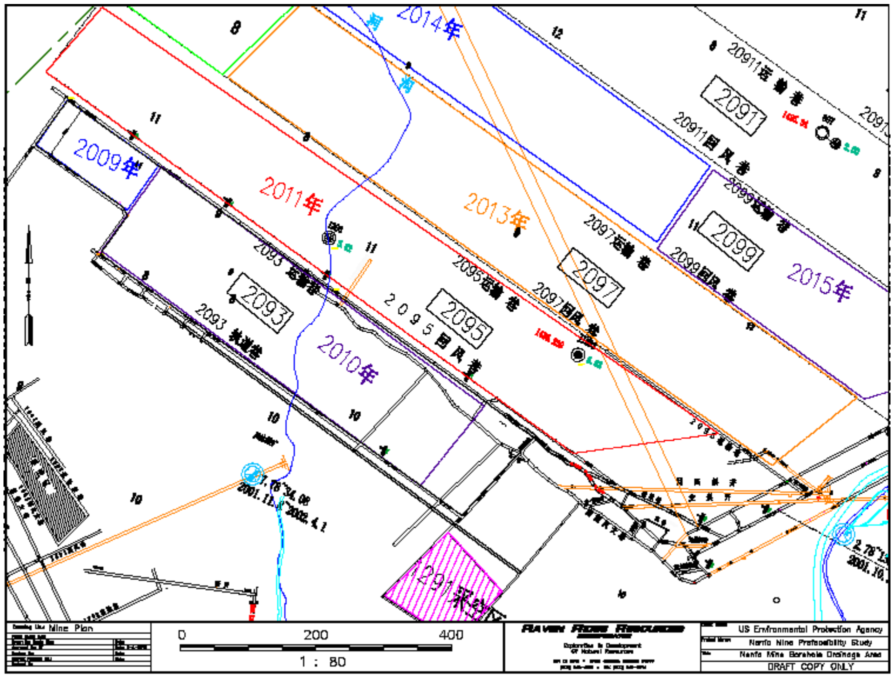
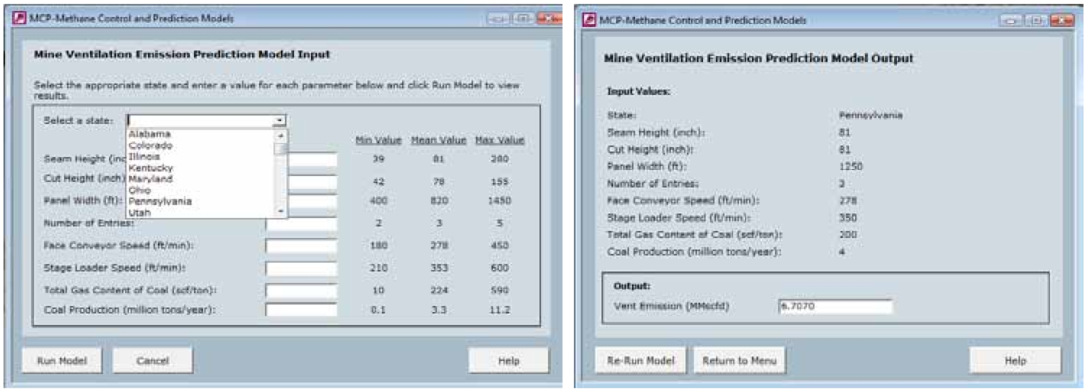


Figure 1. Location of panel 2093 in Lin Hua Coal Mine.

Technical work:

For a complete assessment of methane drainage characteristics and for designing an optimum degasification system for the mine in question, the data at hand missed unfortunately some of the critical information such as coal compositional properties, some of the coal seam reservoir properties, mine operational data, and overburden characteristics. The absence of this information also impaired readily use of MCP (version 1.2) as well with its current data needs and functionalities.

The current version of MCP can be downloaded free of charge from: http://www.cdc.gov/niosh/mining/products/product180.htm**.** The applicable modules in the current version of MCP for this study are the ventilation emission prediction model (Figure 2) and the degasification system selection model (Figure 3). These figures show the input and output screens for these two models. As seen from the screen captures of Figure 2 and 3, the models need a specific definition of the location (state) and a few parameters that are not existing (face conveyor speed etc.) in the available data.



Mine Ventilation Emission Prediction Model Input

Select the appropriate state and enter a value for each parameter below and click Run Model to view results.

Select a state:

Alabama
Colorado
Illinois
Kentucky
Maryland
Ohio
Pennsylvania
Utah

	Min Value	Mean Value	Max Value
Seam Height (inc	39	81	280
Cut Height (inch)	42	78	155
Panel Width (ft):	400	820	1450
Number of Entries:	2	3	5
Face Conveyor Speed (ft/min):	180	278	450
Stage Loader Speed (ft/min):	210	353	600
Total Gas Content of Coal (scf/ton):	10	224	590
Coal Production (million tons/year):	0.1	3.3	11.2

Mine Ventilation Emission Prediction Model Output

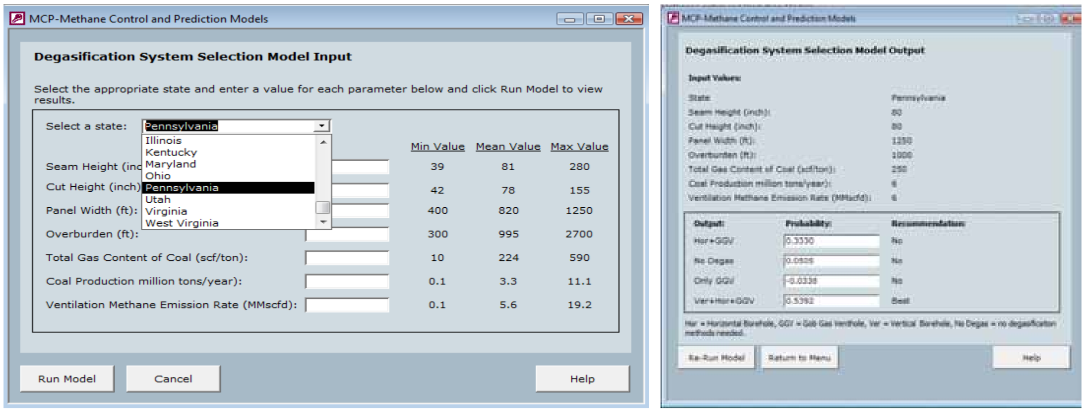
Input Values:

State:	Pennsylvania
Seam Height (inch):	81
Cut Height (inch):	81
Panel Width (ft):	1250
Number of Entries:	3
Face Conveyor Speed (ft/min):	278
Stage Loader Speed (ft/min):	350
Total Gas Content of Coal (scf/ton):	200
Coal Production (million tons/year):	4

Output:

Vent Emission (MMscfd) 6.7070

Figure 2. Input and output screens from the MCP "Mine ventilation emission and prediction" model.



Degasification System Selection Model Input

Select the appropriate state and enter a value for each parameter below and click Run Model to view results.

Select a state: Pennsylvania

Illinois
Kentucky
Maryland
Ohio
Pennsylvania
Utah
Virginia
West Virginia

	Min Value	Mean Value	Max Value
Seam Height (inc	39	81	280
Cut Height (inch)	42	78	155
Panel Width (ft):	400	820	1250
Overburden (ft):	300	995	2700
Total Gas Content of Coal (scf/ton):	10	224	590
Coal Production million tons/year):	0.1	3.3	11.1
Ventilation Methane Emission Rate (MMscfd):	0.1	5.6	19.2

Degasification System Selection Model Output

Input Values:

State:	Pennsylvania
Seam Height (inch):	80
Cut Height (inch):	80
Panel Width (ft):	1250
Overburden (ft):	1000
Total Gas Content of Coal (scf/ton):	250
Coal Production million tons/year):	6
Ventilation Methane Emission Rate (MMscfd):	6

Output:	Probability:	Recommendation:
Hor+GGV	0.3330	No
No Degas	0.0808	No
Only GGV	-0.0338	No
Ver+Hor+GGV	0.5392	Best

Hor = Horizontal Borehole, GGV = Gob Gas Venthole, Ver = Vertical Borehole, No Degas = no degasification methods needed.

Figure 3. Input and output screens from the MCP "Degasification system selection" model.

The modules presented in Figures 2 an 3 could have been used directly in this work with some assumptions on input parameters by using the similarities of the Lin Hua coal mine's basin to one of the basins in the listed states. However this might have led to over- or under-estimation of data. Therefore, an alternative and a more pragmatic approach was adapted to make the best use of the data at hand and to obtain results with minimal approximations.

The approach for this project consisted of:

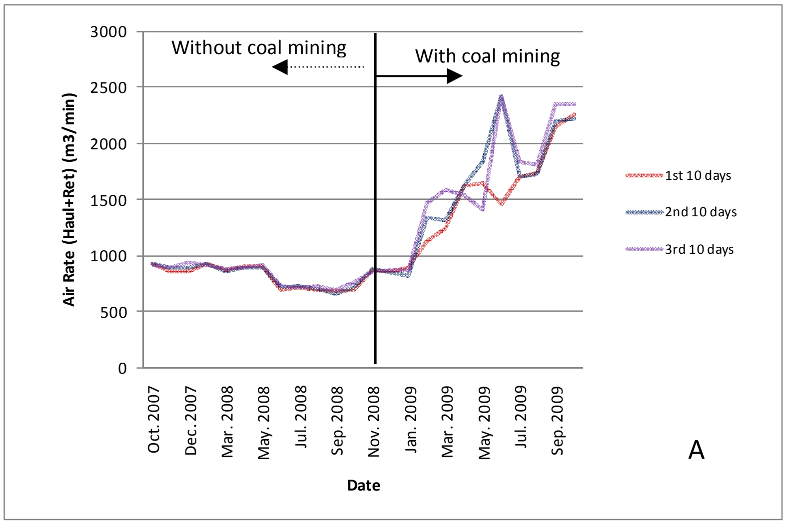
1) Compiling and evaluating the available data and extracting additional information from it,
2) Using some of the new predictive capacities (some of which have been developed, some still under development) that MCP's version 2.0 will have,
3) Development of predictive equations/stochastic techniques for VAM and methane drainage that can be used in this mine and other mines operating in the same area to improve the safety in the mines by capturing as much methane as possible.

These methods along with the data are described in the following sections.

Evaluation of mine (panel 2093) ventilation:

The ventilation air flow and methane percentage values measured in haulage and return entries from the mine, more specifically in panel 2093, were obtained as averages of 10 day intervals in each month. These data were plotted as a function of date, as shown in Figure 4 A and B. Measurements started in October 2007 and continued until the end of October 2009.

In this mine, mining of coal was delayed until 2009 due to excessive methane inflow into mine workings and associated coal bumps. Mining was resumed in 2009. Thus, the latest 12 months of the documented ventilation data likely belong to intrinsic emissions (emissions in the absence of mining) and emissions due to mining activities. These two periods in measured ventilation air amounts and in-mine methane percentages are shown in Figures 4-A and B. These data show that prior to end-of 2008, ventilation air provided to the mine was in the order of 900 m^3/min (31780 scfm) and the concentration of methane measured in the mine was 0.35-0.25%, with a declining trend possibly due to an aggressive methane drainage program implemented in the panel with a total of 375 cross-panel and cross-measure boreholes. After coal production with continuous miners and longwall operation had started at the end of 2008, and beginning in 2009 with a total coal output of 135150 tons (Table 2), methane percentages started to increase to 0.5-0.6% in the ventilation air, which demonstrated an ever increasing trend to 2300 m^3/min (81213 scfm) to keep the methane percentage low (0.1%). This level of methane was possible with a combination of ventilation controls and the existing drainage program of the mine in panel-2093.



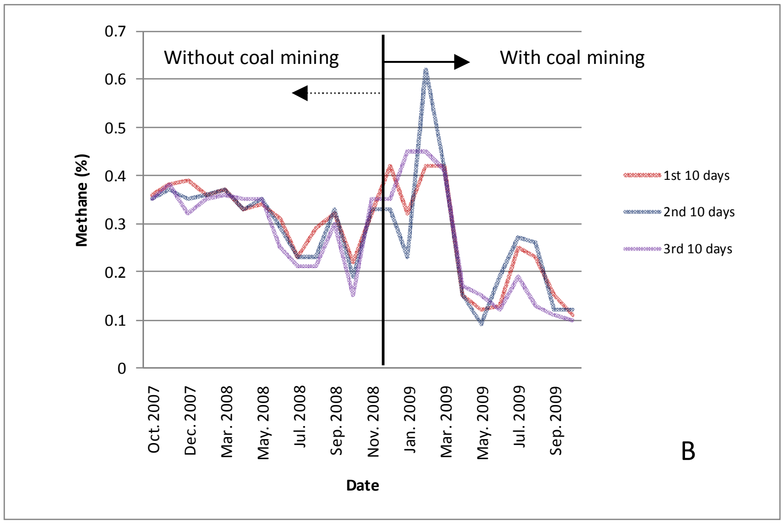
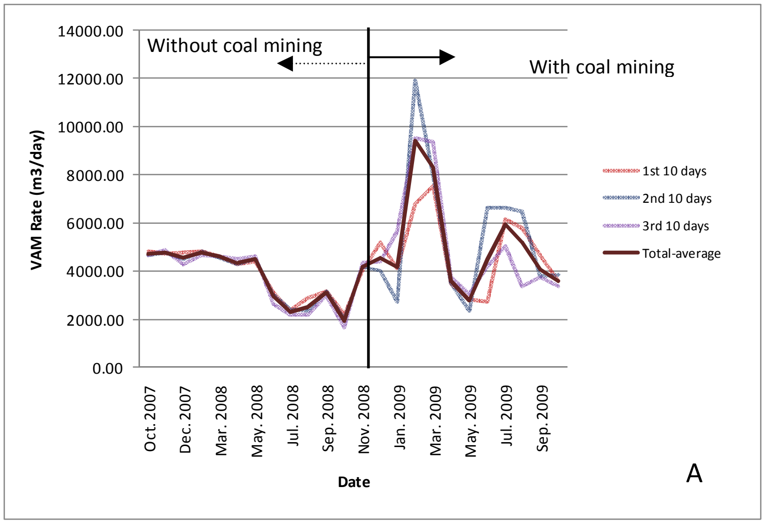


Figure 4. Ventilation air rate (A) and methane percentage measured (B) in mine air.



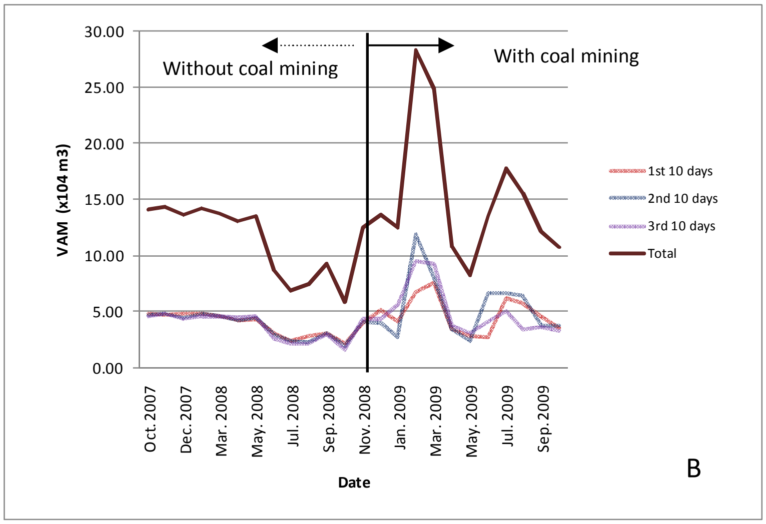


Figure 5. Ventilation Air Methane (VAM) rate (A) and monthly total amounts (B) estimated using the data given in Figure 4.

Using the ventilation air flow and methane percentage data presented in Figure 4, it is possible to estimate methane emissions from the ventilation system of the mine, which is commonly called VAM – Ventilation Air Methane. Figure 5 shows monthly VAM rates (A) and monthly total VAM amounts (B) calculated using ventilation data. These calculations show that prior to commencement of coal production VAM rate was around 4500 m^3/day (158895 scf/day), with a decline period to ~2250 m^3/day (79448 scf/day) as a result of methane removal from coal bed and a decrease in methane concentration in the ventilation air. In the same period, monthly total VAM that was expected from the panel was ~140000 m^3 (4.94 MMscf) initially and declined to ~75000 m^3 (2.64 MMscf).

Figures 5-A and 5-B shows that as coal was being mined, VAM rate increased to almost 10000 m^3/day (353.1 Mscf/day) between January 2009-April 2009, then increased again to 6000 m^3/day (211.9 Mscf/day) around July 2009. Monthly total VAM amounts corresponding to these dates were 280000 m^3 (9.88 MMscf) and 175000 m^3 (6.1 MMscf). Figure 6 gives the cumulative amount of VAM released from mine's ventilation system between October 2007 and October 2009 as 3100000 m^3 (109.5 MMscf).

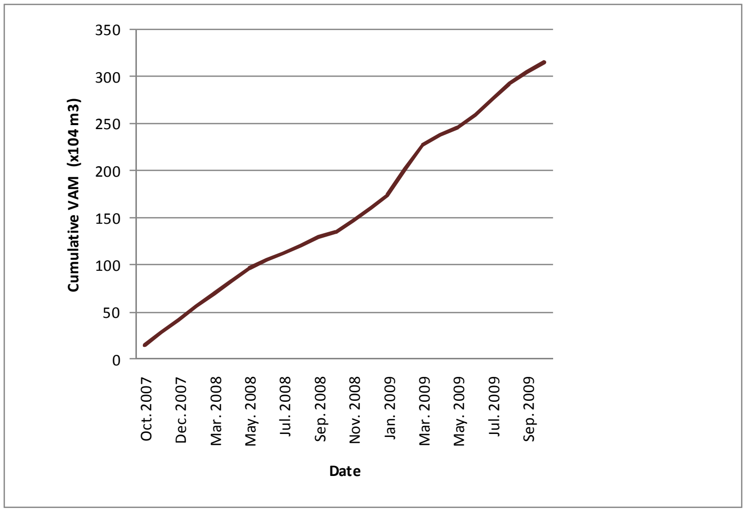
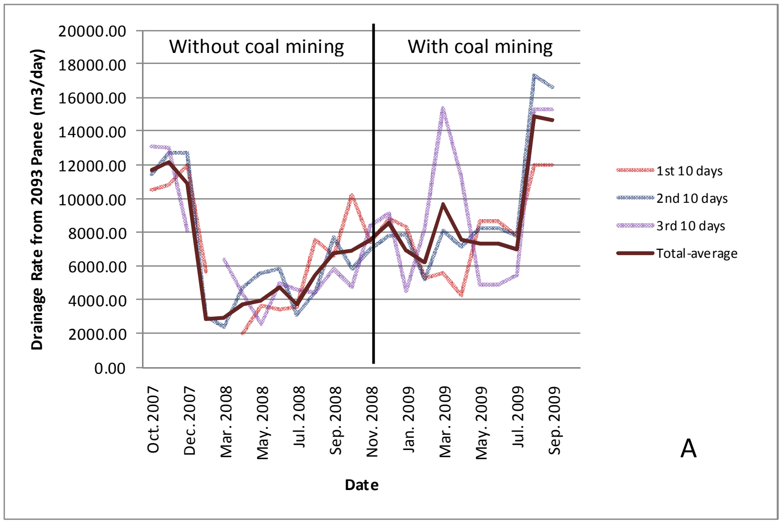


Figure 6. Cumulative VAM released from the mine between October 2007 and October 2009.

Evaluation of gas drainage from panel 2093:

Methane control by degasification in panel 2093 was achieved with a total of 375 in-seam cross-panel and cross-measure boreholes, whose total length was approximately 22274 m (73075 ft). These boreholes were drilled from headgate and tailgate entries with a spacing ranging from 2-5 m (6.56-16.4 ft) between the boreholes.

The methane drainage layout map and the direction of longwall mining indicate that the maximum lateral stresses are located in NW-SE direction and maximum permeability occurs in this direction as well. Considering the gassiness of the coal bed, prevailing stresses and the possible direction of higher permeability (face cleat, if they have developed), drilling cross-panel boreholes, as practiced in this panel by the mine, is a better option compared to drilling lateral boreholes along the entries or center of the panel. Also, considering the methane inflow to the mine and gassiness of the coal seam, vertical boreholes with or without fracturing do not seem to be a viable option. In addition, in the absence of overburden information, it is hard to judge gob gas ventholes and their drilling/completion details. Therefore, the rest of the presentation in this report will continue on evaluating the performance cross-panel in-seam boreholes based on the degasification data of the existing drainage system for better control of drainage and VAM emissions.



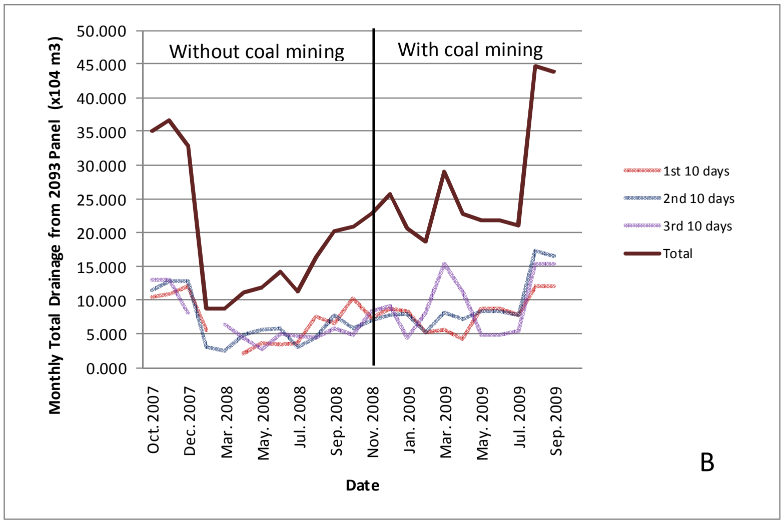


Figure 7. Ventilation Air Methane (VAM) rate (A) and monthly total amounts (B) estimated using the data given in Figure 4.

Figures 7-A and B present methane drainage rates and monthly total methane amounts captured from 2093 panel, respectively. These plots show that the drainage rate steadily increased after January-February 2007. This increase may be due to drilling more boreholes into the panel starting from these dates to capture a maximum amount of methane. The increase is in agreement with the decrease of methane concentration observed in ventilation air (Figure 4-B). The decrease in methane drainage rate and total methane captured in February 2009 (Figures 7-A and B) are also in agreement with increase in methane concentration (Figure 4-B) and VAM rates and amounts (Figure 5-A and B) around the same date. Thus, it is evident that methane drainage system and its performance have a significant effect on in-mine methane concentrations and VAM emissions from this mine.

Methane drained using in-seam boreholes at the mine level were produced at the surface from gathering wells equipped with pumps applying a negative suction pressure at the wellhead with values ranging from -37 to -48 KPa (-5.44 psi to -7.1 psi). Higher vacuums (-48 KPa) were present at the early months of drainage, which decreased to -37 KPa at the beginning of 2009. Using these values and production rates, the productivity index (PI) of the boreholes can be calculated.

Productivity index is a measure of the production performance capacity of any borehole under given flowing pressure conditions. In this work, average monthly PI's were calculated by dividing average production rates by the suction pressure. The plot of these data is given in Figure 8. Figure 8 shows that, the PI of the boreholes increased steadily despite the decrease in applied wellhead vacuum. This increase may be due to drilling new boreholes or redrilling the existing ones to extend them. As stated before, the total length of the final in-seam boreholes were around 22274 m (73075 ft) and the cumulative amount of methane drained by using this system, as of September 2009, was ~4000000 m3 (141.2 MMscf). The monthly change in cumulative methane drainage from this panel is given in Figure 9.

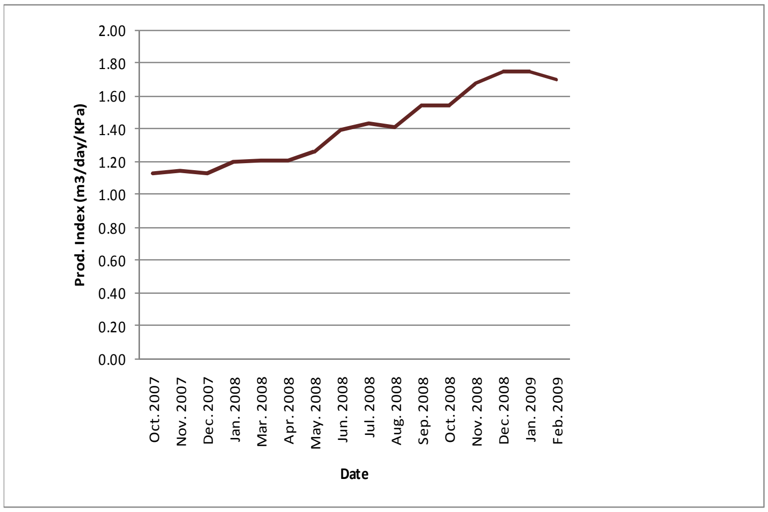


Figure 8. Monthly productivity index change of methane drainage system (boreholes)

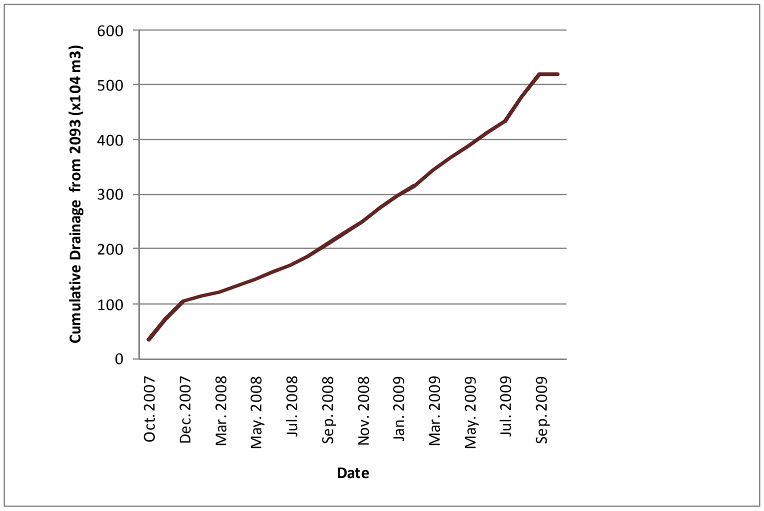


Figure 9. Monthly change in cumulative methane drainage using in-seam boreholes.

Table 1 gives the average methane drainage and VAM rates and amounts prior to 2009 (when no or minimal coal extraction occurred) and during 2009, when coal mining occurred as a summary of all data presented and discussed in this and the previous section.

Table 1. Average rates and total amounts of methane drainage and VAM emission before and during 2009.

Ave. VAM prior to 2009 (x10^4 m^3)	Ave. Drain prior to 2009 (x10^4 m^3)
11.239152	18.98075
Ave. VAM rate prior to 2009 (m^3/day)	Ave. Drain rate prior to 2009 (m^3/day)
3746.384	6326.917
Ave. VAM in 2009 (x10^4 m^3)	Ave. Drain in 2009 (x10^4 m^3)
15.052872	26.61745
Ave. VAM rate in 2009 (m^3/day)	Ave. Drain rate in 2009 (m^3/day)
5017.624	8872.485

Evaluation of coal production, gas content and specific emissions:

In the previous sections, it has been made clear that coal mining had a significant impact on the methane-make of this panel, and the drainage system had a significant influence on reducing methane concentrations in mine air. The question is, now, how these two processes influence each other. In order to be able to answer some of the questions related to optimizing methane drainage amount (and thus the system), coal production operation and VAM emission, gas content of the coal seam and specific emission as a result of coal mining should be known.

Table 2. Annual coal production in 2009 and projected productions until 2015.

Years	LW Coal Production (tons)	CM Coal Production (tons)	Total Coal Prod. (tons)
2009	**114000**	**21150**	**135150**
2010	493000	113744	606744
2011	720400	180000	900400
2012	742900	180000	922900
2013	1328000	180000	1508000
2014	1321300	180000	1501300
2015	1830700	216000	2046700

Table 2 gives actual coal production for 2009 and projected productions until 2015. The annual production for 2009 represents only one data point for the possible 12 month period that was productive. In order to estimate the monthly coal productions, specific emissions need to be determined. For this calculation, cumulative VAM that was released between October 2008-October 2009 was calculated and divided by total coal production of 2009. This calculation results in a specific emission of 13.365 m^3/ton of coal mined, which can later be used to determine monthly coal productions, approximately, by dividing each month's total VAM by the specific emission (13.365 m^3/ton). Average monthly coal productions so calculated from October 2008-October 2009 are given in graphical form in Figure 10. This data shows that monthly coal productions likely have changed between 5000-20000 tons.

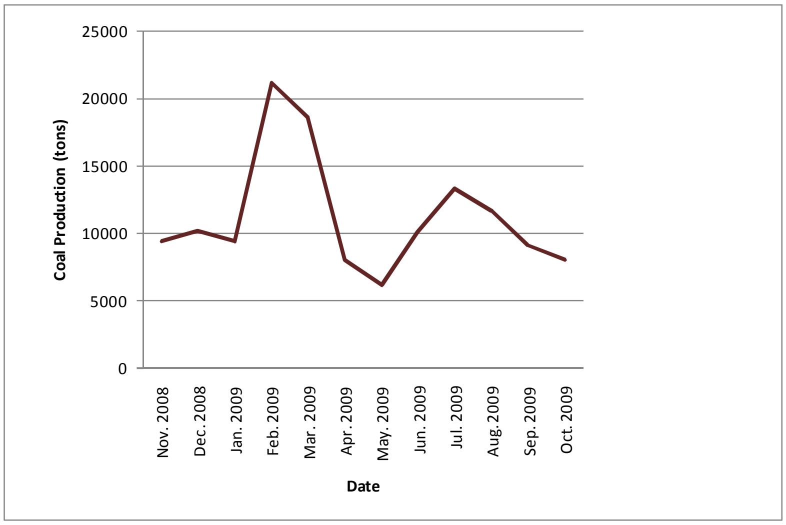


Figure 10. Average monthly coal productions for a period of 12 months that coal mining continued in the panel with CM and LW methods.

Coal gas content and its variation was determined using gas drained and VAM amounts and corresponding decreases in the methane content of the coal: coal operator reported gas volume in the 2093 panel area as 11415500 m^3 (405 MMscf), as well as remaining gas content of the coal for May-September 2009 period. In order to be able to construct a profile of coal-methane-gas-reduction and to find the gas content prior to degasification in 2007, monthly (between May-September 2009) total gas drainage and VAM quantities were determined and plotted against remaining gas content values (Figure 11). Five monthly data points that were plotted in Figure 11 showed a slightly exponential decrease as a function of drainage+VAM values. These data were fitted to an exponential equation and were extrapolated to "zero" methane drainage and emission. This technique establishes the initial gas content of the coal prior to start of drainage and mining. The initial gas content of this coal is 14.65 m^3/ton (517.3

scf/ton) (according to a linear fit) and 18.27 m^3/ton (645.1 scf/ton) from exponential equation. Since the exponential equation shown in Figure 11 fits the data better, its predictions will be used in subsequent sections to evaluate methane drainage system performance and VAM.

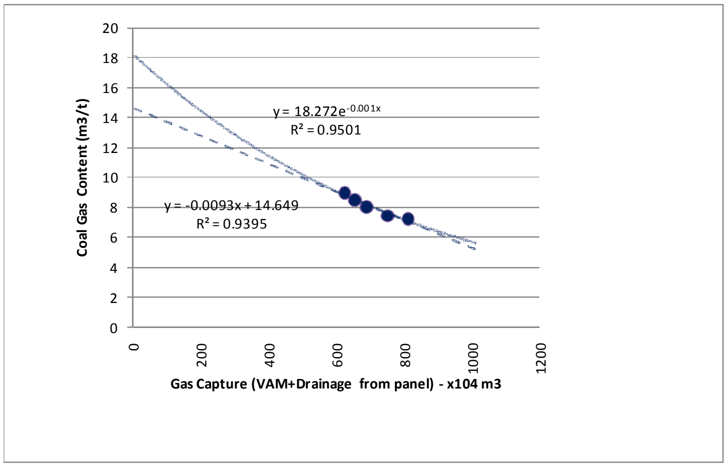


Figure 11. Prediction of coal's initial methane content and its decline as a result of mining and drainage.

Prediction of mine's methane drainage system's performance and VAM as a result of mining

In order to provide the Lin Hua coal mine's operators and their parent company with results and guidelines related to methane drainage and VAM of the mine, and to give them predictive methods that they and nearby mines can use in their drainage and VAM design for mine safety and methane capture, a technique that was developed using an ANFIS-based system (Adaptive Neuro-Fuzzy Inference System) was employed. This technique is developed for the mine ventilation emission module of MCP and will be included in its next version (MCP-version 2.0).

This method is based on generating a set of rules for emissions from a ventilation system depending on a set of different parameters related to mine operation and coal. Eventually, the data are split into various branches that the system is capable of differentiating depending on the inputs to generate a result. The node split rules are given for the general prediction system in Table 3 and its capability to predict methane emissions from mine's ventilation system is given in Figure 12.

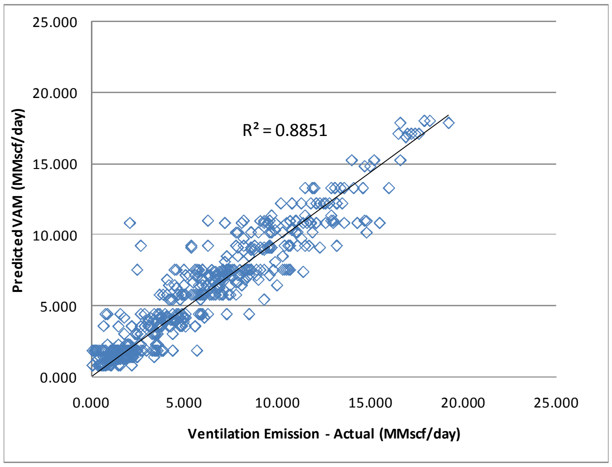


Figure 12. Actual and predicted methane emissions from mines as a result of a rule-based prediction system.

In order to implement this new technique to the current mine, its emissions, coal production and drainage data, the information generated and discussed in the previous sections were processed with the ANFIS-based module and were further analyzed to generate simple equations that will be applicable to the specific conditions of Lin Hua Mine and nearby mines.

Table 3. Split structure for the general VAM module of MCP-2.0 to predict ventilation methane emissions

Node	Level	Objects	%	Parent node	Sons	Split variable	Values
1	5.961	540	100.00%		2, 3		
2	3.517	431	79.81%	1	4, 5	Heat of Coal (BTU/lb)	[9400, 13615[
3	4.880	109	20.19%	1	72, 73	Heat of Coal (BTU/lb)	[13615, 14900[
4	2.454	369	68.33%	2	6, 7	Total Gas (scf/ton)	[9.6, 328[
5	1.403	62	11.48%	2	52, 53	Total Gas (scf/ton)	[328, 513.716[
6	0.345	221	40.93%	4	8, 9	Coal Prod (Mtons/day)	[0.274, 9.726[
7	1.866	148	27.41%	4	30, 31	Coal Prod (Mtons/day)	[9.726, 30.411[
8	0.410	152	28.15%	6	10, 11	Heat of Coal (BTU/lb)	[9400, 12900[
9	1.343	69	12.78%	6	18, 19	Heat of Coal (BTU/lb)	[12900, 13615[
10	0.214	141	26.11%	8	12, 13	Total Gas (scf/ton)	[9.6, 236.8[
11	0.559	11	2.04%	8		Total Gas (scf/ton)	[236.8, 328[
12	0.086	59	10.93%	10	14, 15	Heat of Coal (BTU/lb)	[9400, 11900[
13	0.336	82	15.19%	10	16, 17	Heat of Coal (BTU/lb)	[11900, 12900[
14	0.000	25	4.63%	12		Sulphur (%)	[0.4, 1.85[
15	0.000	34	6.30%	12		Sulphur (%)	[1.85, 3.4[
16	0.000	71	13.15%	13		Face Con Speed (ft/min)	[187, 300[
17	0.000	11	2.04%	13		Face Con Speed (ft/min)	[300, 357[
18	0.807	25	4.63%	9	20, 21	Sulphur (%)	[1.3, 1.935[
19	0.762	44	8.15%	9	24, 25	Sulphur (%)	[1.935, 3[
20	0.054	22	4.07%	18	22, 23	Panel Width (ft)	[465, 862.5[
21	0.201	3	0.56%	18		Panel Width (ft)	[862.5, 1100[
22	0.000	5	0.93%	20		Overburden (ft)	[350, 502.5[
23	0.000	17	3.15%	20		Overburden (ft)	[502.5, 2500[
24	0.406	20	3.70%	19	26, 27	Coal Prod (Mtons/day)	[0.274, 6.712[
25	1.597	24	4.44%	19	28, 29	Coal Prod (Mtons/day)	[6.712, 9.726[
26	0.000	12	2.22%	24		Stage Load Speed (ft/min)	[255, 337.5[
27	0.000	8	1.48%	24		Stage Load Speed (ft/min)	[337.5, 460[
28	0.000	2	0.37%	25		Stage Load Speed (ft/min)	[256, 268[
29	0.000	22	4.07%	25		Stage Load Speed (ft/min)	[268, 420[
30	2.090	102	18.89%	7	32, 33	Sulphur (%)	[0.55, 2.845[
31	2.388	46	8.52%	7	42, 43	Sulphur (%)	[2.845, 4.25[
32	3.183	19	3.52%	30	34, 35	Panel Width (ft)	[600, 775[
33	0.817	83	15.37%	30	36, 37	Panel Width (ft)	[775, 1100[
34	0.029	11	2.04%	32		Entries	[3, 3.5[
35	2.118	8	1.48%	32		Entries	[3.5, 4[
36	0.770	65	12.04%	33	38, 39	Coal Prod (Mtons/day)	[9.726, 22.329[
37	2.454	18	3.33%	33	40, 41	Coal Prod (Mtons/day)	[22.329, 30.411[
38	0.000	30	5.56%	36		Face Con Speed (ft/min)	[215, 291[
39	0.000	35	6.48%	36		Face Con Speed (ft/min)	[291, 357[
40	0.000	8	1.48%	37		Cut Height (in)	[66, 68.5[
41	0.000	10	1.85%	37		Cut Height (in)	[68.5, 71[
42	1.171	36	6.67%	31	44, 45	Coal Prod (Mtons/day)	[9.726, 16.027[
43	2.873	10	1.85%	31	48, 49	Coal Prod (Mtons/day)	[16.027, 30.411[
44	0.032	14	2.59%	42		Cut Depth (in)	[30, 35[
45	0.245	22	4.07%	42	46, 47	Cut Depth (in)	[35, 42[
46	0.000	12	2.22%	45		Coal Prod (Mtons/day)	[9.726, 12.603[
47	0.000	10	1.85%	45		Coal Prod (Mtons/day)	[12.603, 16.027[
48	0.931	8	1.48%	43	50, 51	Coal Prod (Mtons/day)	[16.027, 21.096[
49	0.000	2	0.37%	43		Coal Prod (Mtons/day)	[21.096, 30.411[
50	0.000	5	0.93%	48		Cut Height (in)	[63, 69[
51	0.000	3	0.56%	48		Cut Height (in)	[69, 86[
52	1.028	55	10.19%	5	54, 55	Panel Length (ft)	[1400, 8250[
53	2.180	7	1.30%	5	70, 71	Panel Length (ft)	[8250, 11000[
54	6.371	9	1.67%	52	56, 57	Stage Load Speed (ft/min)	[250, 297.5[
55	1.176	46	8.52%	52	62, 63	Stage Load Speed (ft/min)	[297.5, 468[
56	2.180	7	1.30%	54	58, 59	Seam Height (in)	[57, 174[
57	0.000	2	0.37%	54		Seam Height (in)	[174, 276[
58	0.761	3	0.56%	56		Cut Height (in)	[58, 69[
59	0.490	4	0.74%	56	60, 61	Cut Height (in)	[69, 72[
60	0.000	2	0.37%	59		Panel Length (ft)	[1400, 5750[

Table 3. Cont'd.

61	0.000	2	0.37%	59		Panel Length (ft)	[5750, 8250[
62	1.721	38	7.04%	55	64, 65	Panel Width (ft)	[560, 975[
63	2.286	8	1.48%	55		Panel Width (ft)	[975, 1000[
64	0.656	18	3.33%	62	66, 67	Coal Prod (Mtons/day)	[1.644, 4.521[
65	2.497	20	3.70%	62	68, 69	Coal Prod (Mtons/day)	[4.521, 19.452[
66	0.000	15	2.78%	64		Total Gas (scf/ton)	[328, 471.77[
67	0.000	3	0.56%	64		Total Gas (scf/ton)	[471.77, 513.716[
68	0.000	3	0.56%	65		Panel Length (ft)	[1400, 4675[
69	0.000	17	3.15%	65		Panel Length (ft)	[4675, 8250[
70	0.701	4	0.74%	53		Entries	[3, 3.5[
71	0.067	3	0.56%	53		Entries	[3.5, 4[
72	1.230	93	17.22%	3	74, 75	Ash (%)	[4, 21.5[
73	7.130	16	2.96%	3	96, 97	Ash (%)	[21.5, 28[
74	1.257	11	2.04%	72		Coal Prod (Mtons/day)	[1.37, 4.384[
75	1.865	82	15.19%	72	76, 77	Coal Prod (Mtons/day)	[4.384, 19.452[
76	1.269	39	7.22%	75	78, 79	Stage Load Speed (ft/min)	[290, 381.5[
77	1.112	43	7.96%	75	88, 89	Stage Load Speed (ft/min)	[381.5, 600[
78	4.450	12	2.22%	76	80, 81	Overburden (ft)	[575, 1200[
79	2.222	27	5.00%	76	84, 85	Overburden (ft)	[1200, 2300[
80	0.441	4	0.74%	78		Coal Prod (Mtons/day)	[4.384, 9.726[
81	0.035	8	1.48%	78	82, 83	Coal Prod (Mtons/day)	[9.726, 19.452[
82	0.000	5	0.93%	81		Coal Prod (Mtons/day)	[9.726, 12.603[
83	0.000	3	0.56%	81		Coal Prod (Mtons/day)	[12.603, 19.452[
84	0.290	23	4.26%	79	86, 87	Panel Length (ft)	[3850, 7100[
85	1.080	4	0.74%	79		Panel Length (ft)	[7100, 7500[
86	0.000	10	1.85%	84		Total Gas (scf/ton)	[387.2, 431.015[
87	0.000	13	2.41%	84		Total Gas (scf/ton)	[431.015, 513.716[
88	0.429	31	5.74%	77	90, 91	Cut Height (in)	[49, 78.5[
89	1.589	12	2.22%	77	94, 95	Cut Height (in)	[78.5, 111[
90	0.289	13	2.41%	88		Coal Prod (Mtons/day)	[4.384, 6.712[
91	0.604	18	3.33%	88	92, 93	Coal Prod (Mtons/day)	[6.712, 19.452[
92	0.000	11	2.04%	91		Cut Depth (in)	[28, 37[
93	0.000	7	1.30%	91		Cut Depth (in)	[37, 42[
94	0.446	9	1.67%	89		Panel Width (ft)	[850, 985[
95	0.000	3	0.56%	89		Panel Width (ft)	[985, 1040[
96	0.846	13	2.41%	73	98, 99	Panel Length (ft)	[3800, 9600[
97	0.000	3	0.56%	73		Panel Length (ft)	[9600, 12000[
98	0.000	2	0.37%	96		Panel Length (ft)	[3800, 4275[
99	0.056	11	2.04%	96	100, 101	Panel Length (ft)	[4275, 9600[
100	0.102	5	0.93%	99		Stage Load Speed (ft/min)	[320, 335[
101	0.257	6	1.11%	99	102, 103	Stage Load Speed (ft/min)	[335, 400[
102	0.006	4	0.74%	101	104, 105	Panel Width (ft)	[840, 882.5[
103	0.000	2	0.37%	101		Panel Width (ft)	[882.5, 890[
104	0.000	2	0.37%	102		Coal Prod (Mtons/day)	[6.301, 6.712[
105	0.000	2	0.37%	102		Coal Prod (Mtons/day)	[6.712, 7.123[

The predictive equations for Lin Hua Mine were generated to assess:

- drainage performance of the boreholes (rate/length of the borehole) and
- VAM rate from the mine

as a result of the information at hand. These two equations are in the form of linear and polynomial equations that can describe the data and input-output relations with reasonable accuracy. The equations in functional form are given as:

Prediction of VAM from Lin Hua Mine:

VAM Rate (m^3/day) = -5.50218***Time**+0.20518***Coal Production**-477.71650***Drainage Rate**-494.78386***Gas Content**+207.10941***Pump**+9673.17760***Methane in mine air**

In this equation:

- Time (in days): the number of days that passed since the start of degasification in the panel.
- Coal Production (tons per month): Average amount of coal that is mined monthly
- Drainage rate (in m^3/day/m-of-borehole): This is specific production rate of the borehole system. The value is given as stated.
- Gas content of coal (m^3/ton): Remaining gas content of the coal bed at "Time"
- Pump (neg. Kpa): Suction pressure of the wellhead pump in –Kpa
- Methane in mine air (in %): Methane percentage in mine air

Figures 13-A and –B show the application of this equation to Lin Hua Mine with the input data discussed in the previous sections. R^2 of the regression line between actual and predicted values is 0.98. Also, as seen in Figure 13, standardized residuals are within +/- 2, a good indicator of applicability of this linear formulation for prediction of VAM from Lin Hua Mine. The summary statistics of the input data that are used in generating this equation is given in Table 4.

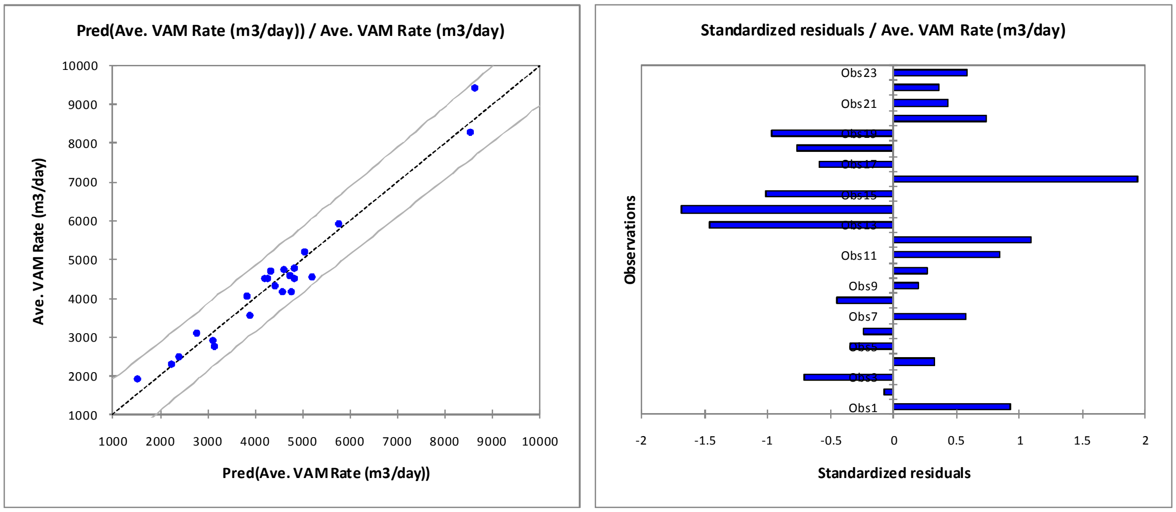


Figure 13. Actual and predicted VAMs using linear equation with the input parameters, the standardized residuals from predictions.

Table 4. Summary statistics of the input data that are used in ANFIS and to generate VAM-prediction equation

Variable	Minimum	Maximum	Mean	Std. deviation
Time	30.000	690.000	360.000	203.470
Coal Prod	0.000	21130.554	5525.130	6644.216
Drain Rate	0.130	0.668	0.339	0.154
Gas Content	8.005	17.396	12.499	2.712
Pump	37.000	48.000	42.488	3.385
Methane in mine air	0.120	0.497	0.291	0.100

Prediction of specific production rate of the drainage boreholes from Lin Hua Mine:

This model can be used to predict the methane drainage rate per length of the in-seam boreholes for a variety of conditions specific to Lin Hua Mine.

$$\mathbf{Borehole\ Prod.\ (m^3/day)/m)} = -148.35265+4.57160\times10^{-5}*\mathbf{Coal\ Prod}-7.86249*\mathbf{Gas\ Content} +13.76801*\mathbf{Pump}+1.93661\times10^{-3}*\mathbf{Time}-3.26621\times10^{-4}*\mathbf{VAM}-1.18589\times10^{-8}*\mathbf{Coal\ Prod^2}-+0.50858*\mathbf{Gas\ Content^2}-0.33393*\mathbf{Pump^2}+5.61450\times10^{-6}*\mathbf{Time^2}+1.15317\times10^{-7}*\mathbf{VAM^2} +6.79095\times10^{-13}*\mathbf{Coal\ Prod^3}-1.07707\times10^{-2}*\mathbf{Gas\ Content^3}+2.68635\times10^{-3}*\mathbf{Pump^3}-2.13836\times10^{-8}*\mathbf{Time^3}-1.146521\times10^{-11}*\mathbf{VAM^3}$$

In this equation:

- Time (in days): the number of days that passed since the start of degasification in the panel.
- Coal Production (tons per month): Average amount of coal that is mined monthly
- VAM (in m^3/day): Average daily VAM rate
- Gas content of coal (m^3/ton): Remaining gas content of the coal bed at “Time”
- Pump (neg. Kpa): Suction pressure of the wellhead pump in –Kpa

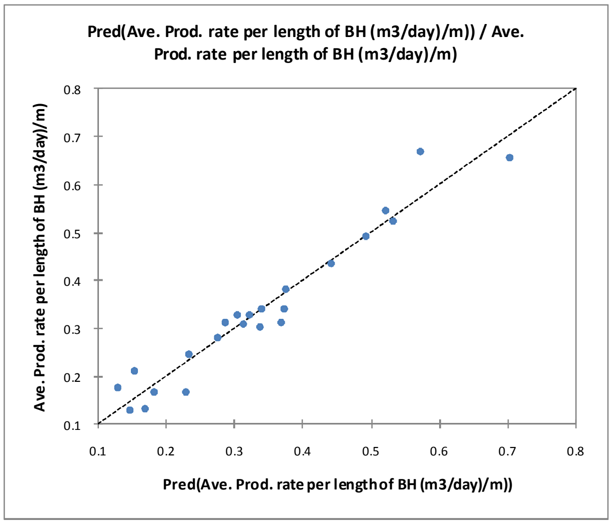


Figure 14. Actual and predicted specific drainage rates using the non-linear equation

Figures 14 shows the application of this non-linear equation to Lin Hua Mine with the input data discussed in the previous sections to predict specific drainage capacity (as rate/meter) of the boreholes. R^2 of the regression line between actual and predicted values is 0.94. The summary statistics of the input data that are used in generating this equation are given in Table 5.

Table 5. Summary statistics of the input data that are used in ANFIS and to generate specific borehole drainage-prediction equation

Variable	Minimum	Maximum	Mean	Std. deviation
Coal Prod	0.000	21130.554	5525.130	6644.216
Gas Content	8.005	17.396	12.499	2.712
Pump	37.000	48.000	42.488	3.385
Time	30.000	690.000	360.000	203.470
VAM	1940.160	9414.000	4416.169	1722.305

The use of both of the predictive equations should be easy enough and intuitive. However, may be the drainage rate equation needs a little bit more explanation for its use. This equation was designed to estimate how much a mine's drainage system can produce with given parameters of coal production, pump suction, time from the start of methane drainage, gas content of coal and at allowable VAM rate that mine's ventilation system can handle without overshooting the methane percentage levels. The result from this equation can be used to predict the total length of the boreholes that need to be in place and also their spacing. For instance, if one obtains 0.3 m^3/day/m specific rate as the result of this equation with given inputs, then the production from one cross-panel borehole is ~ 100*0.3= 30 m^3/day. For a given total drainage objective, the total length of the boreholes can be found using this number and the spacing can be arranged accordingly.

Example: if the drainage objective is 20000 m^3/day for safe mining, then total number of boreholes needed is 20000/300= ~67 boreholes. Knowing the length of the panel, the spacing between the boreholes can be calculated easily.

Stochastic method and results for 20, 50 and 80 percentiles of VAM and borehole drainage rates

The predictive equations given in the previous sections for VAM and specific borehole drainage rates can either be used as deterministic equations, or as stochastic method that can be built upon them to assess the risk associated with the uncertainity of input parameters. In this report, the prediction equations were used to build a stochastic model using Monte Carlo simulation. For the uncertainity in input parameters, truncated normal distributions were used with the min, max, mean and std. deviation data given in Tables 4 and 5. The stochastic equations for both VAM and borehole drainage were run 5000 times using a MC simulation routine. The results for mean, median and 20%, 50% and 80% percentiles for the inputs and results are given below:

For VAM rate prediction:

	Mean	Median	20%	50%	80%
Time (days)	359.9998	359.9986	210.7157	359.9986	509.17209
Coal Production (tons/month)	7692.362	7148.438	3152.947	7148.438	11942.665
Drain. Rate (m^3/day/m)	0.359315	0.352683	0.243147	0.352683	0.4709792
Gas Content of Coal (m3/ton)	12.56679	12.54289	10.51296	12.54289	14.60313
Pump (neg. pressure -Kpa)	42.4926	42.49075	40.00579	42.49075	44.976951
Methane % in mine air	0.29578	0.293964	0.217471	0.293964	0.372607
Ave. VAM Rate (m3/day)	**4869.793**	**4843.729**	**3160.887**	**4843.729**	**6576.9216**

For specific borehole drainage rate prediction:

	Mean	Median	20%	50%	80%
Coal Production (t/month)	7692.367	7147.454	3152.658	7147.454	11939.012
Gas content (m3/ton)	12.56679	12.54352	10.51246	12.54352	14.60271
Pump (neg. pressure -Kpa)	42.49261	42.49094	40.00586	42.49094	44.976608
Time (days)	359.9996	359.9676	210.6582	359.9676	509.16005
Ave. VAM Rate (m3/day)	4670.261	4573.951	3307.894	4573.951	5949.7378
Prod. Rate / length of BH	**0.304011**	**0.248192**	**-0.03730**	**0.248192**	**0.9957124**

Summary and conclusions:

In this report, ventilation and gas drainage data from Lin Hua mine for a period of 2 years were evaluated and interpreted. The analyses showed that coal production had a significant effect on VAM rates and the performance of methane drainage system influenced the in-mine methane percentages dramatically.

The raw data obtained from RRR were complied and processed using an ANFIS-based system, soon to be included to MCP and be released as MCP version 2.0. Processed data were used to generate predictive equations to estimate VAM rate and specific drainage rate from the boreholes based on a few parameters. These equations can be used by Lin Hua mine and the mines operating in the same area under the same conditions. These equations are promising approaches to control methane Lin Hua Mine for safety and productivity.