CHAPTER 9

Methane drainage

Introduction

1. Knowledge and understanding of the basic principles of methane gas control is fundamental to a mine's ability to design effective controls and safe systems.

2. This chapter describes the hazard of methane in underground coal mines and summarises and assesses Pike's knowledge of its gas reservoir and its approach to managing methane.

Overview of best practice approach to methane drainage

Introduction

3. Methane gas occurs naturally in coal mines and is a natural by-product of mining. In the history of coal mining methane explosions have caused more loss of life than any other factor.[1]

4. Increasing coal extraction rates often result in higher rates of methane emissions. However in modern mining, sustainable coal production should not be limited by a mine's inability to prevent gas concentrations from exceeding statutory safe limits, nor compromised by uncontrolled gas-related incidents that endanger life. Investment in effective gas drainage can ensure that mines meet production targets legally and safely.

5. Neither New Zealand's mining legislation nor MinEx Health and Safety Council (MinEx) guidelines specifically address the practice of methane drainage.

6. In February 2010 the United Nations Economic Commission for Europe published a best practice guidance on methane drainage,[2] and the following overview is sourced primarily from this.

Methane gas

7. Coal seam gases typically consist of 80 to 95% methane, with lower proportions of other gases, including carbon dioxide and nitrogen. Bag samples of gas tested by Pike in 2009 and 2010 showed the seam gas composition at levels between 95% and 99% methane.

8. Methane forms in coal seams as the result of chemical reactions taking place when the coal was buried at depth. Methane occurs in much higher concentrations in coal than other rock types because of the 'adsorption' process, which enables methane molecules to be packed into the coal interstices (gaps or spaces) to a density almost resembling that of a liquid. In a vertical sequence of coal seams like those at Pike River, the methane content of coal often increases systematically with depth and rank (maturity).

9. Methane and other gases stored in the coal seam and the surrounding strata can be released if they are disturbed by mining activity. The amount of gas and the rate of release or emission depend upon several factors, including the initial gas content of the coal, the distribution and thickness of the coal seams, the strength of the surrounding strata, the geometry of the mine workings, the rate of coal production and the permeability of the seam. The total gas flow varies proportionally to how much mining activity disturbs the strata and coal seam.

10. Coal seam gases become flammable and potentially explosive only when mixed with air. Methane is flammable when mixed with oxygen in a wide range of concentrations, but generally between 5 to 15% methane in air by volume. Gas released from mining activity inevitably mixes with the mine's ventilation air, is diluted and passes

through the flammable range. It is therefore critical that methane concentrations in the flammable range are limited in time and location as much as possible, to reduce the potential for exposure to ignition sources and the risk of explosion.

11. Methane is buoyant and rises in air, and layering of methane can occur in poorly ventilated areas underground. Concentrated methane tends:

> *to collect in roof cavities and to layer along the roofs of airways or working faces. In level and ascentionally ventilated airways with inadequate airflow, the layer will stream along the roof in the direction of airflow, increasing in thickness and decreasing in concentration as it proceeds. Multiple feeders of gas will, of course, tend to maintain the concentration at a high level close to the roof.*[3]

12. Layering extends the area within which an ignition of methane can occur, and 'acts very effectively as a fuse along which the flame can propagate',[4] with a risk of ignition of much larger accumulations of gas in roof cavities or goaf areas.

13. It is critical to reduce explosion risk by preventing occurrences of explosive mixtures wherever possible, and ensuring separation from potential ignition sources. It is essential to dilute high-purity methane by ventilation air to safe general body concentrations at the points of gas emission. This requires a well-designed ventilation system and knowledge of the seam's gas emission characteristics. Capturing high-purity gas in drainage boreholes at its source, before it can enter mine airways, and removing it from the mine, is another way of minimising the risks.

Gas emission characteristics

14. Peak flows of gas occur in a mine's return airways during the coal face cutting cycle and following roof caving. This is particularly the case with hydro mining, which is designed to quickly extract large quantities of coal from thick seams.

15. The volume of gas released from any coal disturbed by mining decreases over time, while continued mining activity adds new gas sources. When mining activity stops, gas continues to desorb from the coal seam and flow from rider seams and surrounding strata, but at a declining rate. Coal seams above and below the working seam may release methane that will migrate through the relaxed strata into the goaf.[5] Unless methane drainage is carried out, this methane will also be emitted into the mine ventilation system.

16. When assessing gas flows and ventilation requirements, mine operators assume steady state coal production and uniform predictable gas emission characteristics. Although this approach suits most planning needs, other factors such as outburst and sudden emissions of gas from the floor create safety hazards and are not easily predicted, although the geological and mining factors indicating the risk of such events can often be identified.

17. Outburst is the sudden ejection of gas, coal and sometimes rock from a solid coal face into mine workings. Outburst hazards include asphyxiation, burial and impact injuries, and damage to mine equipment and systems. Outburst is a risk in certain mining situations where coal seams have a high gas content and low permeability. Structures in the coal seam, such as faulting, may increase the potential for outburst where they change gas migration or the gas drainage characteristics of the coal. Assessing the outburst risk for a coal seam requires collection, testing and analysis of gas data from core samples, and relating the results to other coal seams where outbursts have occurred. The use of such data for safety planning cannot be overstated. Management of the hazard typically involves pre-draining the coal, before mining begins, to reduce its methane content to below an identified critical gas content amount (m^3/tonne).[6]

Pre-drainage

18. Pre-drainage of gas ahead of mining is done by drilling boreholes into the coal seam. Drilling can occur from the surface or within the seam from underground drill rigs.

19. Horizontal in-seam drilling for pre-drainage involves the drilling of boreholes from underground roadways into future mining areas. Moderate to high natural coal seam permeability is required to ensure significant decay of gas content over a reasonable period of time. A standpipe is installed at the collar of the borehole and connected to a

pipeline that removes the captured gas from the area. Problems with this method can include high water emissions pressurising the pipeline, borehole instability and directional control of drilling. Additional hazards are created if actively draining boreholes are later intersected by mining operations.

20. Coal permeability directly affects the time needed to drain gas to the required average gas content value. The lower the coal's permeability, the more time is necessary. The ultimate feasibility of pre-drainage depends on the available time for degassing the coal before mining and the cost of the drilling operation.

21. Modern directional in-seam drilling techniques and patterns can maximise the amount of gas removed from the seam. Patterns designed for pre-drainage purposes typically involve multiple boreholes about 20–30m apart drilled from one location in a fan, or parallel, orientation, and in a formation to ensure minimal intersection by future mine workings. Boreholes are designed to target the gas and drain the coal, with a sufficient lead time, typically more than six months, before there is intersection by mining.[7]

22. The flow rate of gas from a gas drainage borehole will vary with time. High initial flow occurs from the expansion and desorption of gas in the immediate vicinity of the hole. This may diminish fairly rapidly but then increase again as the surrounding strata are dewatered, which increases the relative permeability of the coal and also the flow of gas. This in turn is followed by further decay as the area of influence is depleted of gas.[8] Structures in the surrounding strata, including faulting, can also affect gas emission and flow rates.

23. From a strictly regulatory perspective, only enough gas needs to be captured to ensure that a mine's ventilation system can adequately dilute the methane to a level below the permitted maximum. However, methane drainage also affects productivity, since the capacity of the ventilation system and the efficiency of a mine's methane drainage system will determine the maximum rate of coal extraction that can be safely achieved from a gassy coal face.

24. Introducing a gas drainage system, or increasing its effectiveness, is often cheaper than increasing ventilation air volumes. Investment in 'good practice' gas drainage systems therefore results in less downtime from gas emission problems, safer mining environments and the opportunity to reduce emissions and use more gas, which may have financial benefits under emissions trading schemes.

The need for gas data

25. Pre-planning of methane drainage is critical, and the design of gas drainage and ventilation systems to ensure safe mining requires knowledge of the amount of gas adsorbed in the coal (the gas content). Coal seam methane contents typically range from trace levels up to around $30m^3/t$.

26. To assess gas content (which should not be confused with specific emissions),[9] core samples are taken from the coal seam, sealed in canisters in as fresh a state as possible, and maintained at near reservoir temperature while gas is allowed to desorb. The measured release rate allows estimation of the quantity of gas lost before sampling, and the gas remaining in the coal is also measured, by crushing the coal and measuring the amount released. An overall gas content assessment can then be made. The composition of the gas can also be established by chemical analysis.

Design of a gas drainage system

27. The design of a methane drainage system should reflect the maximum expected gas flows from all sources in the mine. The system must ensure that gas in the drainage pipeline is not diluted to less than 30% methane in air, safely above the explosive range. That requires quality borehole sealing, including proper installation of standpipes, the systematic regulation of individual boreholes and suction pressure from the surface to assist with the flow of gas from the holes and through the pipeline, if assistance is required. Water also needs to be controlled in the system to prevent pressure build-ups.

28. Underground drainage pipe systems are vulnerable to damage from mining equipment, blasting activities, strata movement and roof collapse. The drainage system should be designed to minimise these risks.

Monitoring of drainage systems

29. Gas drainage systems require continuous monitoring and management to determine effectiveness and performance. Mixture, gas flow and concentration, gauge pressure and temperature should all be monitored, with measurements made of individual boreholes, the gas drainage pipework and at the surface. Changes in barometric pressure affect gas flows and should also be recorded to assist in standardisation of flow data. The data obtained from monitoring these parameters is essential for safety planning.

30. Modelling of gas emissions can provide predictive information on the effects of increased coal production rates on gas flows. Modelling can also forecast the maximum controllable gas flow and the associated maximum coal production rate, depending upon methane limits and ventilation quantities.[10]

The need for pre-drainage at Pike River

Methane content of the seam

31. When Japanese company Mitsui Mining Engineering Co. Ltd carried out drilling at Pike River in 1993, methane was 'bubbling out' of drillholes close to the fault,[11] and reports from a series of consultants between 2000 and 2010 described Pike River's gas content levels as moderate to high.[12] Pike technical services co-ordinator Gregory Borichevsky described the mine as 'very gassy' because areas being mined were bounded by faults that had isolated blocks of coal. In these areas the coal had not been exposed to atmospheric pressure and gas remained adsorbed within the seam until intersected by mining activity.[13] In Masaoki Nishioka's experience, high methane emission was generally to be expected near faulting in coal seams.[14]

32. The company's knowledge of the gas content levels within the coal seams was limited because of the relatively small number and wide spacing of vertical drillholes from the surface. Core sampling of vertical drillholes for gas content analysis began in 1999, and gas content results were available from 18 of the 33 surface holes drilled before the explosion (PRDH8 to PRDH40). These showed methane gas content levels varying from 1 m^3/t to 10 m^3/t, with the higher levels recorded close to the Hawera Fault.[15]

33. The company's knowledge did not improve to any significant degree once in-seam drilling began, as discussed further below. Few of the horizontal in-seam boreholes had core samples taken for gas content testing.[16] The day before the explosion Pike received gas content results from sampling of its most recent borehole, GBH019,[17] ranging between 2.80m^3/t to 5.32m^3/t.[18] After the explosion Pike advised Queensland's Safety in Mines Testing and Research Station (SIMTARS) that the mine's coal seam gas content before drainage was approximately 8m^3/t.[19]

Advice on the need for pre-drainage

34. In 2006 Pike was informed that the high (but variable) permeability and porosity of the Brunner seam meant gas control 'will not be able to be accomplished by ventilation means alone.'[20] Minarco Asia Pacific Pty Ltd recommended pre-drainage in areas of the mine, particularly to the north and for the initial development inbye from the stone drive.[21] Minarco also recommended flanking boreholes in advance of development, and suggested the extent of pre-drainage required should be confirmed by further modelling of the gas reservoir. Investigation into likely emission rates was 'essential', and regular gas surveys were necessary particularly during the first period of development.[22]

Pike's intended approach

35. Pike intended to use pre-drainage to reduce methane gas content in the Brunner seam before mining. General manager Peter Whittall described Pike's intended approach in a paper presented to a coal operators' conference in 2006:

> *Recent sampling has determined a seam gas content of 7.0-7.5 m^3/t at the proposed seam entry location. This is at a depth of 85 m. This gas content is considered to be difficult to control by ventilation means alone and in seam gas capture (pre-drainage) will be used as part of the roadway development process. PRCL*

will aim to reduce seam gas to <3m^3/t prior to mining, however where insufficient lead-time is possible, a maximum content of 6.5 m^3/t will be sought so as not to pollute the intake airways with rib emissions. In thick seam mining a more significant impact is content per square metre as the whole seam is removed during hydraulic extraction and the gas is liberated to the return airways.[23]

In-seam drilling at Pike River

Purpose

36. Pike intended to supplement its limited geological knowledge from surface drillholes by the use of in-seam directional drilling for geological exploration.[24]

37. The delays that plagued the initial development of the mine infrastructure, and the resulting pressures to produce coal, meant that all the in-seam boreholes drilled up to the time of the explosion were designed for exploration of the seam, rather than for the systematic reduction of methane gas content.[25]

38. Some long boreholes, over 2000m with multiple branches, were drilled to delineate the seam. Although these holes would have provided some reduction in seam gas content in the areas drilled,[26] coverage was neither wide nor systematic and methane drainage was incidental. The boreholes did not serve to reduce methane gas content in the hydro panel down to Pike's planned < 3m^3/t levels.

Valley Longwall International

39. In 2008 Pike contracted VLI Drilling Pty Ltd (VLI) to provide in-seam drilling services. The contract required VLI to drill directional in-seam boreholes with branches to the roof and floor of the coal seam to Pike's specifications, take core samples from the boreholes when requested, provide and maintain the specialist equipment and provide trained drillers and fitters/offsiders.[27] The contract was managed by geologist Jimmy Cory from Pike's technical services department.

40. VLI's crews generally comprised an experienced driller and at least one offsider. VLI had its own health and safety management documentation system relating to the contracted tasks, which it provided to Pike.[28] Site-specific documents were also created and VLI staff participated with Pike staff in a risk assessment on 14 November 2008 into the hazards arising from the drilling operations.[29]

The drilling method used at Pike River

41. The directional drilling equipment used by VLI comprised an electro-hydraulic drill rig and a drill string, consisting of a down-hole motor and rotating drill bit, drill rods and an electronic drill guidance system.[30] The drill rig, shown below, was fitted with a gas monitor that alarmed at 1% methane and cut power to the rig when the sensor detected 1.25% methane.

Figure 9.1: Track-mounted Boart Longyear LMC75 drill rig[31]

42. The drilling method involved orientation of the down-hole motor (a 3m rod) to aim the slight bend in the tool towards the desired drilling direction. The down-hole motor (driven by a supply of water intensified by a pump on the rig) was fed in and out of the hole and rotated (to change orientation) using the rig's hydraulics. The electronic guidance survey tool (also approximately 3m long) relayed information back to a receiver unit with the driller, and was separated from steel rods by a copper rod to ensure no magnetic interference. The driller operated the drill rig, spinning rods onto the drill string and using a rotation unit to push the rods, the survey tool, the down-hole motor and the resulting hole to the required distance.[32]

43. The photographs below show the drill bit, down-hole motor and assembly, and a close up of the rotating drill bit with high-pressure water forced through the assembly to provide rotation and torque to the bit.

Figure 9.2: Bit, down-hole motor and assembly[33]

Figure 9.3: Rotating drill bit with high-pressure water[34]

44. At Pike River, roof touches or coal seam roof intersections (branches) were drilled as a hole proceeded forward, normally at 40m intervals depending upon structural complexity in the area. When the borehole reached the planned limit, the drill string was progressively withdrawn and branches drilled down to the floor of the coal seam.[35]

45. The directional guidance system controlled the borehole trajectory, which was pre-planned using 3D modelling software, guided by the geological model of the seam. Real-time survey information was obtained at 6m intervals and combined with logs kept by the drillers, enabling accurate mapping of the coal seam.[36]

Installation of gas riser and pipeline

46. A risk assessment into in-seam drilling involving VLI and Pike staff and held in November 2008, before drilling began, identified the need for a 'gas discharge solution'. Three options were assessed,[37] and Pike adopted the second, installing a gas drainage system during December 2008 and January 2009.[38]

47. Pike installed a 6" gas riser into an existing cased vertical drillhole, PRDH36, which was located close to the first VLI drill stub. A 4" fire-resistant anti-static (FRAS) pipeline (range) was connected to the three standpipes in place in the drill stub. Pike installed a flame arrestor on the surface for safety reasons,[39] but no pump or suction arrangement to assist with gas flow through the range.

48. Mr Cory prepared a memorandum to staff on the procedures required for underground connection of the gas drainage line and the necessity for water traps to be drained regularly. He also suggested that the engineering department start a maintenance schedule for the surface flame arrestor.[40] Many of these procedures were not followed consistently.[41]

Management of gas at the drill face

49. VLI established a gas management system at its drill sites in accordance with its own standard procedures, which included:

    - drilling through a standpipe – a gland driven into the wall face and grouted into position as a permanent access point to the borehole;
    - using valves connected to the standpipe to divert the flow of water and/or gas while drilling, and contain or divert the water and/or gas after drilling;
    - using a stuffing box, which prevents gas or water from the borehole from entering the mine's atmosphere, enabling it to be diverted to a gas/water separator; and
    - using a gas/water separator to assist with managing the flow of gas from the borehole and directing it through a T-piece into the mine's gas drainage line, or free venting the gas into the return ventilation system, in accordance with Pike's instructions.[42]

Initial in-seam boreholes

50. Boreholes were assigned individual identifiers, from GBH (geological borehole) 001 up to GBH019 by the time of the explosion.

51. In-seam drilling began at Pike River in December 2008 from a drill stub in pit bottom, aimed at development around that area. The second in-seam borehole intersected the large stone graben (a down-thrust block of strata bordered by parallel faults), estimated at up to 220m wide in places, the significance of which Pike was unaware from its earlier geological exploration. By the time Pike got through the graben the focus was on roadway development and the ability to pre-drain the coal seam was limited.[43]

52. No core samples for coal seam gas desorption testing could be taken from the first few in-seam boreholes, as the drilling method and the size of the graben meant samples would have a 'coal to canister' time exceeding one hour, giving unreliable results.[44]

The slimline shaft

53. The collapse of the ventilation shaft on 2 February 2009 severely limited mine ventilation. To recover air capacity, Pike drilled the slimline shaft from the same surface drill pad location it had recently used to install the gas drainage system. Figure 9.4 below shows the gas riser (yellow) with flame arrestors, and the brown pipe is connected to the top of the slimline fresh air shaft.

Figure 9.4: Gas riser and slimline shaft[45]

54. The bottom of the 6″ riser is shown below connected to the 4″ gas drainage line labelled in yellow, at the entrance to what became the fresh air base (FAB) in mid-2010.[46]

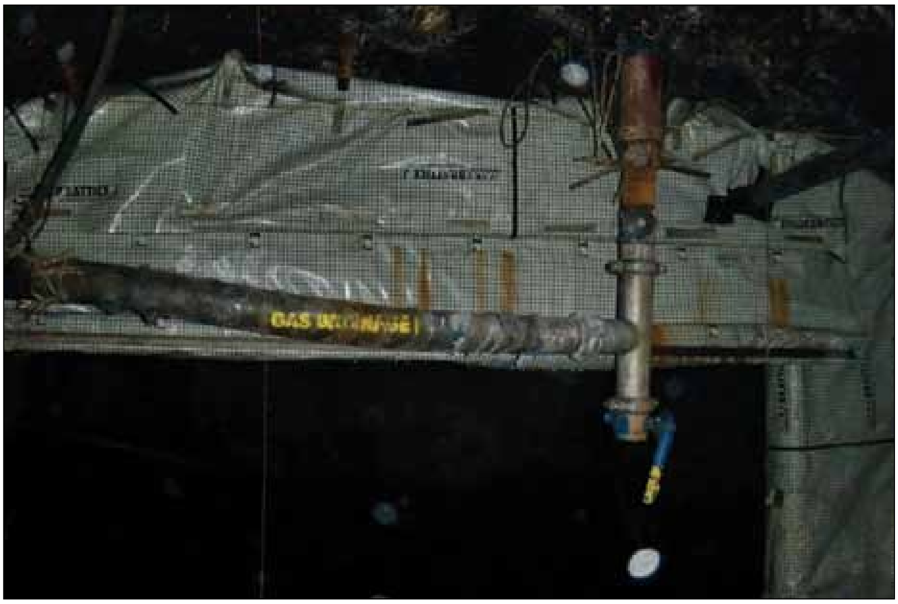

Figure 9.5: Bottom of gas riser at entrance to the FAB

55. To drill the slimline shaft the flame arrestors at the surface had to be disassembled and removed and the gas drainage line temporarily decommissioned, which resulted in suspension of the drilling programme. VLI's crews left Pike and returned to Australia.

56. The three active boreholes were temporarily closed at the collar, and boreholes GBH001 and GBH002 were soon intersected by development and became inactive for gas flow monitoring.[47]

Recommencement of drilling and extension of the drainage pipeline

57. VLI returned to Pike River in May 2009 and continued the drilling programme, completing GBH003 and drilling six more holes by the end of 2009.[48]

58. Very limited gas flow data was obtained from these boreholes. Three were quickly intersected by roadway development and only initial flow measurements were taken,[49] and no gas flow measurements could be taken from the other three.[50] Nor were core samples obtained during the drilling of any of these holes to permit gas content analysis.

59. In October 2009 the gas drainage range was modified and extended by the installation of a 4″ Victaulic pipeline dedicated to the in-seam drilling programme, and installation of a water trap at the riser.[51] The pipeline continued to extend as new borehole drilling locations were established.[52]

60. Four more boreholes were drilled between December 2009 and March 2010 and connected to the gas drainage line.[53] All had initial high gas and water makes, but subsequent gas flow measurement was hampered by those factors and by poor management of the drainage line.

Problems with Pike River's gas drainage system

System at full capacity

61. By April 2010 the gas drainage line was at full capacity. High water capture in recent boreholes, and ineffective dewatering of the drainage line and at the drill rig,[54] resulted in resistance and regular flooding of the line, impeding the drainage of gas from the holes and making the system ineffective and highly pressurised. Accurate measurement of gas flows was impossible.

Warnings from workers

62. On eight occasions in March 2010 Pike deputies completed statutory reports noting their concerns with the overpressurised gas drainage system.[55] VLI's drilling co-ordinator Gary Campbell also voiced his concern that the gas drainage system was inadequate for the gas make, which was affecting their ability to continue drilling some holes.[56]

63. On 11 April 2010 Brian Wishart, an experienced underviewer, sent this email to Mr Cory:

Attention Jimmy Cory

General Concerns Methane drainage system PRCL. 11/4/2010

I would like to bring to your attention again the inadequacy of our Methane Drainage system.

1 – The running of a gas drainage system in intake airways is of concern to me as any trouble that we have with water traps, which is very regularly causes methane to vent into our intake roadways this scenario would not happen in NSW or QLD as this kind of arrangement would not get past a risk assessment process and would not be allowed, we should also not allow this practice.

2 – The positioning of this system in 3ct also leaves it venerable to damage from jugos ect.

3 - We now also have a fresh air base with a methane riser in the middle of it.

4 – Over the weekend we had to reposition a water trap at the FAB as it was installed in such a way that the FAB door could not be dropped down in an emergency?

5 – On numerous occasions I have found methane free venting in the old drill stub, while we are drilling there is so much pressure in the line that this stub does not actually discharge any methane into the system.

6 – Water traps are continuously filling with water at a rate faster that they can be drained.

7 –The first trap in the line is that inundated with water while drilling that the trap tube is by bull hose draining straight into the flumes which also surges gas into the return.

8 – "There is a definite problem when we are pushing water up the riser".

9 – This is all due to the line being too small for the sheer volume of methane we are trying to force downhill then up the riser.

10 – My list goes on… but by now I'm sure you get the picture.

It is my opinion that the VLW drill program should be suspended until the line is renewed with larger pipes installed out of the intake. I am well aware of the pressures we are under as a company but this should not be the pressure that possibly one day causes us a serious incident.

Last night the surges in the system were so violent that I was concerned it could blow of the rubber pipe which connects to the trap in the 3/B intake position. This would be very dangerous, if this happened with nobody in the vicinity to close the valve at macdow cribo which is not easily accessible we would have full flow methane directly into the intake and in turn across macdow headings I'm sure with that flow the methane would be in the 5 – 15% range with plenty of Oxy not a nice scenario.

Just to bring to your attention the suspected findings of the American pit that recently exploded was centered around an inadequate methane drainage system.

History has shown us in the mining industry that methane when given the write environment will show us no mercy. It is my opinion that it is time we took our methane drainage here at PRCL more seriously and redesigned our entire system.

Regards

Brian Wishart

Figure 9.6: Email from Brian Wishart to Jimmy Cory[57]

64. Some issues with the system were already known,[58] but this email provoked an immediate response.[59] Mr Cory showed it to Pieter van Rooyen, who took it to the next production meeting where 'various actions' were discussed.[60] Short-term remedies were implemented, and Pike engaged an Australian gas drainage consultant, Miles Brown of Drive Mining Pty Ltd.[61]

Insufficient planning and design

65. At the time it was installed Mr Whittall 'fully expected' that the 4" pipeline would eventually become inadequate, but the small diameter pipeline was chosen because 'it was easiest to start with'.[62]

66. In these circumstances, close management of the pipeline and monitoring of gas concentrations, pressure and flow was essential. Yet no manual measurement or monitoring processes were established when the system was installed, and commonly used sensors (measuring real-time flow and pressure and reporting to the control room) were not installed on the system.[63]

67. Pike's gas drainage system was designed with insufficient information on gas flows or the mine's future drainage requirements. David Reece considered that the gas drainage system was clearly inadequate for the methane levels predicted and experienced.[64]

Location of pipework and gas riser

68. Gas drainage pipelines carrying high-purity methane under pressure should be located in a mine's return airway to minimise the risk of damage from blasting and mining equipment.

69. At the time of the explosion, the whole pipeline ran downhill to the riser, working against the natural inclination of methane to rise.[65] Significant pressure was required to force the gas along the 4" pipeline and to the top of the riser, and the pressure peaked at the highest point on the pipeline, at the drill stub. This led to difficulties for the drilling crews in managing water and gas from boreholes.[66]

70. The pipeline was installed primarily in the return airways leading from connected boreholes outbye to the riser (as shown below in green), but it also ran for about 100m in the intake airway (shown in pink) from the overcast near the underground fan through Spaghetti Junction before turning left and then right to the gas riser located at the entrance to the slimline shaft/FAB. This created a significant hazard.

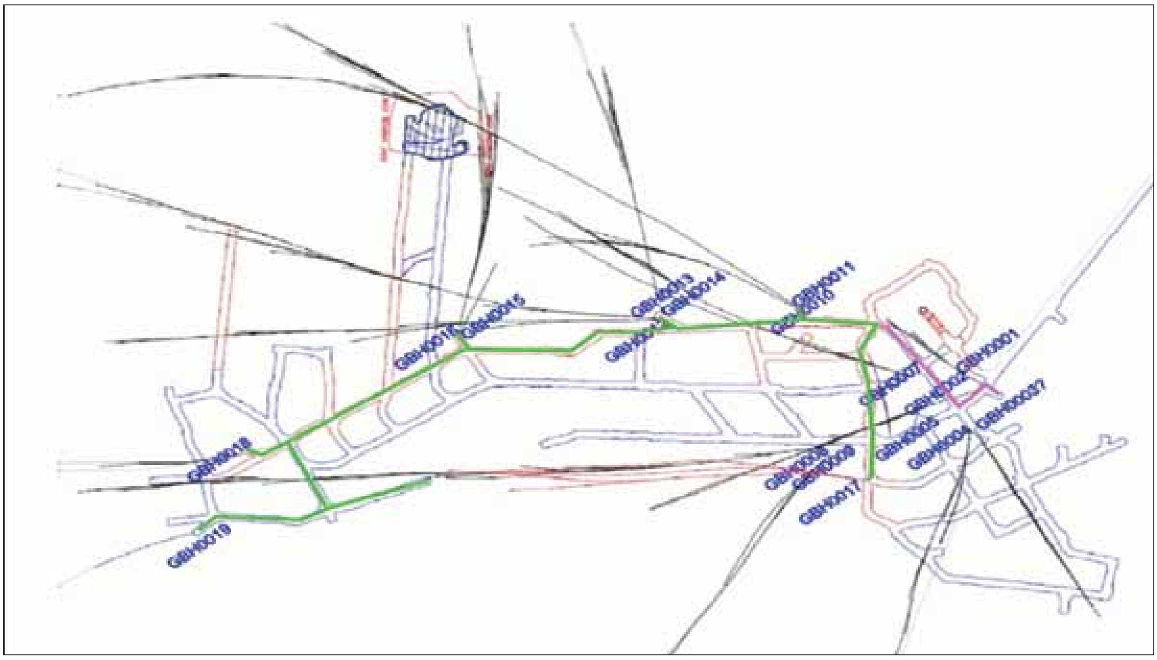

Figure 9.7: Gas drainage line and in-seam boreholes[67]

71. During a risk assessment into the operation of the ventilation fans held on 14 October 2010, an action plan recorded the need to move the methane drainage lines into a better area, away from the methane sensor at the main fan motor.[68] This had not occurred by 19 November 2010.

72. Staff from the technical services department disagreed with the decision to establish an FAB near the gas drainage line and riser, but the design decision was not theirs.[69] Mr Reece also criticised the decision:

> *you wouldn't have something of a hazardous nature like that in that sort of a location, you'd want to keep them significantly separated. … A different roadway, you wouldn't have them anywhere near each other.*[70]

The intersection of boreholes

73. Also not ideal was the frequent intersection of boreholes by the mining process. Intersections create a risk of frictional ignitions and the potential for release of large volumes of gas at the face. Intersections also reduce the effectiveness of gas drainage since boreholes must have a pipe connection to the drainage line to remain useful for that purpose.[71]

74. A safe operating procedure for borehole intersection was in place,[72] but it appears the procedures were not necessarily followed.[73] Pike commissioned a review and received expert advice in July 2010 on changes required to its safe operating procedure.[74]

75. A more structured approach to advising operational crews about upcoming intersections, via borehole warning zones marked on permits to mine,[75] was implemented but crews sometimes remained unaware of imminent intersections with gas boreholes. An example occurred in August 2010 when the ABM crew mined 3m past the indicated 'stop' point in the permit to mine for the intake in panel 1, intersecting in-seam boreholes and with the roof strata unsupported.[76]

76. Intersections with boreholes sometimes occurred shortly after the holes were drilled.[77] This meant little time for reduction of methane levels in the area drilled, and did not allow the technical services department to obtain gas flow and content data from the holes for planning purposes.

77. Pike's accident and incident reports show gas drainage issues were reported by workers. For example in August 2010 a butterfly valve was found partially open, which allowed flammable gas to enter the fresh air intake. In July 2010 a worker found a borehole hose that was incorrectly connected. In February 2010 there was back pressure in the gas drainage range. In August 2009 there was a report that:

> *The gas drainage holes in C/2-1 stub are all in floor & branching into multiple holes. This is making it very dangerous & hard to try & plug these holes which are producing large amounts of methane. To try & plug these holes requires people to be working in an explosive/very high CH_4 atmosph [sic]. Tech Services need to plan these holes & intersecting points better to avoid repeats of this situation.*[78]

78. Vehicle collisions were sometimes reported. For example in July 2009 a buried gas pipe was hit by mistake, puncturing it and releasing methane into the workings. Also in July 2009 a worker was:

> *using the roadheader to trim corner for vale fan the head caught some rib mesh pulling it down along with the gas drainage hose cutting it, releasing gas and water from the drainage line, 3-4% CH_4.*[79]

79. Causes identified in the reports include not following procedure, lack of knowledge and training, lack of skill or experience, congestion and substandard work practices.[80]

Expert advice on gas drainage

Drive Mining Pty Ltd

80. New South Wales mining engineer Miles Brown,[81] engaged to advise Pike on its gas drainage system,[82] conducted three site visits in 2010, each involving underground inspections and consultation with staff from the technical

services department. He gave Mr Cory training, including on gas flow measurement, and provided lengthy technical reports supplemented by email advice when required.

81. Mr Brown requested information on Pike's gas reservoir before he arrived. No gas content data was available as up until then Pike had not taken any core samples during its in-seam drilling programme.[83]

Miles Brown's first site visit

82. When Mr Brown visited Pike River on 28–29 April 2010 he found Pike's drainage system under significant pressure and inadequate for the gas flows experienced from the thick Brunner seam. There was inadequate maintenance of the pipeline and no method for measuring gas flows. Mr Brown recommended the VLI drillers not to force any further gas into the pressurised pipeline, to reduce the risk of gas emissions around their drill site.

83. Mr Brown suggested the design of flanking drainage holes as a minimum for all development headings, including the proposed hydro bridging panels, and gas content core sampling at 200m spacing. A lack of data meant he was unable to properly design a gas drainage system and had to make assumptions about the gas reservoir. He provided a gas drainage schedule for Pike, noting:

> *This schedule highlights the fact that draining such a thick seam without a large lead time or enough data to quantify an accurate delay curve leads to the conclusion that if there is 8 m^3/t of gas then development rates will be affected. The solution will be to gain more knowledge quickly and if high levels of gas are found introduce a smaller spacing of drainage holes. This will increase costs, however will assist with increasing development rates.*[84]

84. Mr Brown advised Pike to improve its gas drainage system by:

- installing a new gas riser inbye of current development within three months, with a minimum 10″ internal diameter to service the current and future drainage needs; and
- upgrading all current and future underground drainage pipes to 10″ pipes to lower frictional resistance and pipeline pressure, increase drainage capacity and water control, and improve the ability to maintain the system.

85. Mr Brown also urged an assessment of the outburst risk of the Brunner seam, and cautioned that if the gas content was 'confirmed above 8m^3/t or a GeoGas DRI of 900, then development should be stopped until a risk assessment for continuation has occurred.'[85] The DRI900 method has been universally accepted by the mining industry for determining outburst threshold limit values.[86]

86. Mr Brown described the need for data collection over the next three months as a 'key' recommendation:

> *Gas Content Cores must be taken to not only allow the assessment of an area but to determine the drainage parameters. These core results also determine if the coal seam is liable to Outbursts. … Hole flow data assists in the determination of pipeline and riser design. This flow data along with virgin core results help create the decay curve for drainage which is the backbone of a drainage model. This allows for the development of hole spacing requirements.*[87]

87. Pike accepted that recommendation, noting 'no historical gas-flow data has ever been collected from in-seam drill-holes and the gas reservoir content is therefore unknown.'[88] Collection of gas flow data and information on the gas reservoir began in mid-June 2010 when Mr Cory began recording some weekly gas data measurements.[89] Pike took one core sample on completion of in-seam borehole GBH014,[90] but the sample was compromised and no gas desorption testing or analysis was possible.[91] From August 2010 Mr Cory began to measure and monitor essential flow data from all individual holes, after measuring sets were installed at the borehole standpipes and at the bottom of the 6″ riser.[92]

Outburst management plan

88. Pike created a draft outburst management plan in July 2009, although no signed or final version was available to the commission.[93] It aimed to reduce and minimise the risks associated with outbursts in development panels by

draining in-seam gas content to below agreed threshold limits, and by implementing a system of measurement and risk assessment before authorisation of mining, via the permit to work process.[94]

89. Parts of the plan reflected Australian documents,[95] and had no relevance to Pike River.[96] Other parts were simply not followed or ignored in practice, for example:

> *Prediction, in the form of comprehensive data acquisition and extensive inseam drilling, and prevention by way of effective gas drainage coupled with gas flow monitoring, and regular core sampling so that the Mine Manager is always aware of the seam gas and structure environment into which the Mine is about to develop or extract, are the two prime components of The Plan. These form the input into the Authority to Mine process which, upon completion, will determine the mining methodology to be used to develop each roadway or sequence of roadways and extraction panels.*[97]

90. The plan also stated, as a basic operating principle, 'that no mining will take place when the gas content of the coal is above the established Outburst Threshold Level.'[98] A risk assessment into ventilation and gas monitoring on 7 September 2010 also recorded 'propensity testing' as an existing control of the outburst risk.[99]

91. The outburst threshold level for the Brunner seam was still unknown at the time of the explosion.

Miles Brown's second site visit and Pike's decision to free vent methane

92. Mr Brown returned to Pike River from 28 June to 1 July 2010. During his underground inspection he became concerned about the imminent uncontrolled intersection of GBH012, a highly pressurised borehole, by a development mining machine. After discussion, Douglas White made an operational decision to 'free vent' the borehole into the main return, by releasing gas directly into the mine atmosphere via a valve on the borehole standpipe. Free venting occurred over several days in a controlled manner and methane levels were kept within a target maximum of 1% in the main return. GBH012 was then intersected on 7 July 2010 with reduced gas make and limited impact on mining.[100]

93. Free venting released large quantities of methane and allowed Pike to 'make full use of the existing dilution capacity in the main returns to relieve this pressure on the gas drainage line and to actively manage gas from the Panel 1 area in advance of mining.'[101] This was a more attractive alternative than relying on an inadequate drainage system. In early July 2010 Pike decided to free vent all three boreholes in the hydro panel to the return before they were intersected by development of the panel headings, to avoid 'possibly days of lost development' while the holes were depressurised at the face.[102] Large quantities of methane were free vented from these holes,[103] and methane levels were closely monitored.[104]

94. Free venting became part of a new gas management strategy, although no formal procedure existed. In July 2010 the technical services department prepared a draft gas drainage management plan,[105] and issued operational advisory notices setting out the strategy.[106] Deputies, underviewers and surface controllers were to manage the process so the level of methane at the main fan remained below a maximum of 1.25%, with a target level of 1% in the return. Intersected boreholes required installation of standpipes and hosing into the return.

95. Mr Brown's second report, finalised on 22 July 2010 after discussions with Pike, recorded the continuing struggle to maintain the gas drainage system. Gas make was greater than the system's capacity, and the pressure at the bottom of the riser was considerably greater than the flow of gas up the riser.[107] Overall the system was highly restrictive.[108] Mr Brown made a number of short-term suggestions and advised Pike to plan for a suction unit on the upgraded system.

96. Mr Brown stated that beginning hydro extraction before the underground fan was commissioned would increase methane levels in the return and have a negative effect on the available ventilation. He doubted the desired extraction rates were achievable without an upgraded gas drainage line.[109]

97. Mr Brown calculated production scenarios, but noted a number of assumptions,[110] including the unknown effects of the surrounding strata on gas emission calculations for panel 1, and increased methane levels from the ABM20 development miner. Although his calculations indicated a more manageable situation once the main underground

fan was commissioned, he had 'major' concerns about predicted methane levels in the hydro panel return and advised that additional air would be required for panel 1.[111]

98. Mr Brown suggested replacing the 4" pipeline with a 12" diameter line, and that Pike use the slimline fresh air shaft as the gas riser until a new 12" riser could be drilled and installed inbye.[112] He urged Pike to start 'vital' weekly gas flow and emission measurements, and create a database to inform future gas flow estimations and for emissions trading legislative requirements.[113]

99. By this time three core samples had been taken from GBH16,[114] a borehole flanking the hydro panel. One worrying gas content result of 8.29m^3/t fell just below the outburst threshold limit of 9m^3/t identified for the Bulli coal seam in Australia. Mr Brown repeated his advice that additional gas cores must be taken from new boreholes drilled ahead of development, and cautioned:

> *If ever the DRI900 limit is exceeded then development must not mine this area until drainage has occurred and a new core sample has been taken and found to be below this value. As Pike River is approaching outburst threshold limits additional drilling should be conducted to both drain the coal of gas but to [sic] understand the gas reservoir.*[115]

100. There was no additional in-seam drilling to reduce the gas content levels in panel 1, although one of Mr Brown's assumptions was pre-drainage down to 3m^3/t in that area.

Mechanical Technology Ltd

101. Pike also engaged mechanical engineer Chris Mann, of Mechanical Technology Ltd in Auckland, to report on gas utilisation options and to address Mr Brown's recommendations for upgrading the drainage line.[116] In his multi-purpose report to Pike in August 2010,[117] Mr Mann agreed that Pike's gas drainage system was inadequate for the gas levels experienced and required upgrading. He described Pike's gas flow measurements as 'rudimentary' and dismissed the mine's historic predictions of gas drainage flows of 300l/s, estimating peak flows of up to 1400l/s for the next 10 years as multiple panels were drained.[118]

102. The system's borehole pressure was high and Mr Mann suggested that, before the pipeline upgrade, Pike should install a temporary blower at the top of the gas riser to provide suction on the system. He estimated this would approximately double the flow of gas from the boreholes and through the pipes.[119] Mr Mann agreed that Pike should upgrade the current pipeline to a 12" diameter range, pre-drain the seam to a methane content of 2–3m^3/t and install a temporary flare to flare gas out of the drainage system if that could be achieved safely.[120] He, too, suggested Pike consider using the slimline fresh air shaft as a temporary gas riser.

Miles Brown's third site visit

103. Mr Brown made a third visit to Pike River from 13 to 17 September 2010. Panel 1 roadways were completed, equipment was being installed for the monitor panel and Pike was about to begin hydro extraction. There had been no upgrade of the gas drainage infrastructure, the underground fan had not been commissioned and free venting was still occurring. Lack of certainty in mine planning and the fact that inadequate gas data had not been obtained for a sufficient period of time meant Mr Brown could not provide a drilling design for pre-drainage. His third report dealt primarily with short-term tasks.[121]

104. Mr Brown found improved control of the gas drainage holes and no water in the pipeline as a result of Pike's better management of the system, although only three non-critical holes were connected and only approximately 40l/s of gas was flowing up the riser.[122]

105. Mr Cory was continuing with weekly gas drainage measurements and spreadsheets had been set up for recording data from each borehole.[123] Pike also planned, but had not yet begun, weekly gas emission measurements to identify where gas was being emitted and its effects on production.[124]

106. Mr Brown also suggested the VLI drilling crews required greater direction to manage the gas at their stubs in a more regimented way, as their next drill site was at the highest elevation yet and at the end of the pipeline range, so

would be the most pressurised. He suggested continued free venting to the ventilation system with connection to the pipe range once a hole was completed.

107. An outburst threshold value had still not been estimated. Mr Brown described core sampling as 'the single most important task' that needed to be regimented, as results were vital for estimating an outburst threshold rating, estimating gas hole flows and for the creation of a decay curve for the Brunner seam. This in turn would assist Pike in estimating pipeline and riser requirements for the future. He suggested 'all efforts' should be made to obtain a DRI900 level for safe mining.[125]

108. The evidence of further borehole core sampling provided to the commission is of samples taken from boreholes GBH018 in September 2010 and GBH019 in November 2010,[126] both located in the south-west corner of the workings as shown in Figure 9.7. Pike received results of gas desorption testing from those samples just before the explosion on 19 November, but no outburst threshold limit had been established.

Pike's approach to methane management

Insufficient pre-drainage of panel 1

109. The following diagrams show the proposed production area of the hydro panel, and the expected gas emission area for gas flows from the surrounding strata.[127] Long in-seam boreholes intersect the panel,[128] and faulting to the east of the panel is shown.

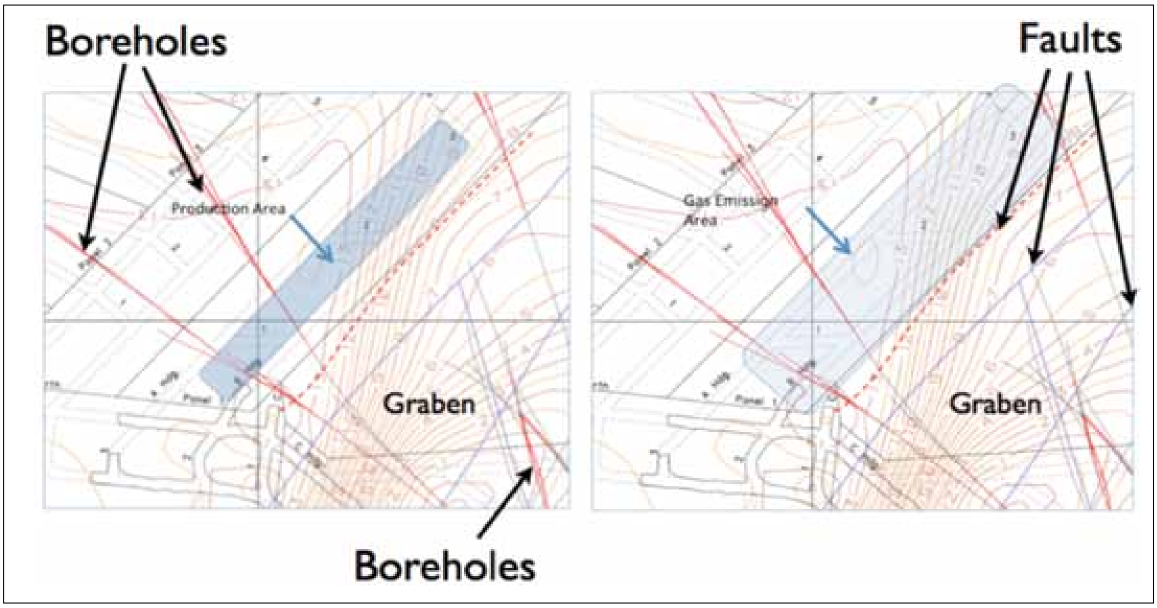

Figure 9.8: Panel 1 production area and panel 1 area of interest for gas emissions[129]

110. Borehole GBH016 was subsequently drilled 'flanking' the eastern boundary of panel 1, but no drainage holes were drilled within or to the west of the panel. GBH016 and the intersected boreholes were designed primarily for exploration of the seam, not for systematic pre-drainage of methane from the panel before mining.[130]

111. The gas content core sample result of 8.29m^3/t from GBH016 underlined the need for further drainage of the area, particularly given the use of an untried hydro-extraction method in a thick seam with the likelihood of high methane release. However, coal extraction from panel 1 began without pre-draining the seam down to safer gas levels.

The hazard of free venting

112. Free venting created an additional hazard by increasing the level of methane within the mine's return, removing (up to) a 1% buffer and putting pressure on the ventilation system. It required close monitoring and effective management.

113. In practice, free venting involved staff opening a borehole until gas levels in the return got to around 1%, which allowed sufficient capacity for 'little peaks' to go up to a maximum of 1.25%, 'with the idea being that they could go, always go and turn it back down again if they needed to.'[131]

114. Mr Borichevsky monitored gas levels and trends and reported these to the daily production meetings until the new production manager, Stephen Ellis, took over running the meetings about mid-September 2010. Messrs Borichevsky and Ellis gave conflicting evidence about the change of focus in the production meetings, but the daily review and reconciliation of gas levels and trends did not occur regularly from that point on.[132]

115. Although more air was available to the mine from October 2010, when the main underground fan came online, the ventilation system was almost immediately at capacity and at times struggled to cope with the high methane levels experienced from hydro and development mining.

116. Expert evidence before the commission was that the practice of free venting is only a 'stop-gap' measure and no longer a common or preferred practice for dealing with problem amounts of methane. Mr Reece described reliance on free venting as 'not done these days.'[133]

117. Pike had initially described free venting as an interim measure when dilution capacity in the return permitted,[134] until the (then imminent) drainage system upgrade. Given anticipated high methane levels, it was not expected to continue once hydro panel extraction began.[135] But the practice did continue up to the time of the explosion.

Deferral of the system upgrade

118. Mr Mann had investigated the scope and cost of upgrading the drainage system, and budgetary approval had been given to install a bigger pipeline and riser.

119. The technical services department considered it was impractical to upgrade the current 4" pipeline or the 6" riser in the existing locations. It also rejected the suggestion that the larger slimline fresh air shaft be used as a temporary gas riser, given the stub was, by then, designated as the FAB. Instead a location inbye to the north-west was identified as suitable for installation of a new larger gas riser, which would then be connected to a new 12" pipeline installed from that location to the active drill stubs. Roadway development to this location was estimated to be three months away.[136]

120. Mr van Rooyen explained that his department was concentrating on finding a longer term solution to Pike's problems, and installing a new larger capacity gas drainage system was part of that plan. Otherwise, 'trying just to solve a short term problem creates other problems that's not always foreseen when you try and solve the problem.'[137] Mr van Rooyen estimated installation of the new gas drainage infrastructure would have taken a further six months from the time he left Pike in early November 2010.[138] A temporary blower/pump arrangement on the surface to increase the flow of gas from the boreholes and through the pipes was not installed. Pike continued to extend the 4" pipeline to newly drilled in-seam boreholes.[139]

Failure to assess the risks

121. The free venting programme successfully reduced the hazard created by the overpressurised drainage line. Yet the effect was the release of large quantities of methane into the mine's returns, extending the duration and location of potentially explosive mixtures underground. High methane levels continued, particularly after panel 1 extraction began, but there is no evidence of a risk assessment of the free venting practice.

122. In August 2010 both Hawcroft Consulting International and Zurich Financial Services Australia Ltd,[140] during annual insurance assessments, noted the need for Pike to conduct a risk assessment of the methane hazard in the mine. Hawcroft recommended Pike should 'expedite' a risk assessment into gas and ventilation, and 'implement suitable measures to ensure the methane in the underground workings remains at management, risk free levels.'[141]

123. The 7 September 2010 risk assessment report into ventilation and gas monitoring assessed the hazard of 'gas drainage',[142] but made no mention of free venting. Some controls did not exist, or were ineffective in addressing the actual hazard. For example, the existence of a safe operating procedure for gas drainage was listed as an existing

control, although it was not finalised until 5 November 2010.[143] The risk of high methane levels from exploration holes in development headings referred to the 'specification of new drainage system' as an existing control,[144] but it did not exist. The assessment did not recognise the use of pre-drainage as a control measure to reduce in situ gas content to safer levels. Nor did it identify Pike's limited knowledge of the characteristics of its gas reservoir as a hazard in itself.

Lack of oversight by the Department of Labour

124. Kevin Poynter, the DOL mines inspector dealing with the company in 2010, was unaware that Pike's gas drainage system was inadequate for the gas levels encountered. He did not know of the reliance on free venting or the lack of gas data, and he did not audit the systems Pike used to measure and monitor gas flow and emission rates. He acknowledged that the department did not know whether Pike's methane drainage system met health and safety standards.[145] The location of the gas riser at the FAB should also have been an issue of concern to the regulator.[146]

The gas drainage system at November 2010

125. A few weeks before the explosion, VLI had begun drilling GBH019, and several in-seam boreholes were free venting to the mine's atmosphere. Problems with management of the gas drainage system continued with gas flow from borehole GBH018 backing up and restricted by the 4" pipe.[147] Les Tredinnick, McConnell Dowell's underground superintendent, advised Pike staff in October of a 'whistling' standpipe and methane being emitted through the stone floor in A heading in pit bottom north. This had not been addressed by 19 November 2010.[148]

126. The following graph prepared by the joint investigation expert panel[149] summarises the total daily methane volumes (m^3/day) for the drainage system gas from July 2010 until the explosion. The red line depicts the volume of methane measured at the bottom of the gas riser, which decreases from the beginning of July when the practice of free venting began with GBH012 disconnected from the range. The blue line shows the volume of methane free vented to the mine's atmosphere for dilution by ventilation; and the grey line shows the total methane flow from all boreholes. These measurements began on 20 August 2010, the start of gas flow measurement from individual boreholes. The green line shows the total methane volume flowing into the range from September 2010 when weekly gas drainage measurements commenced.

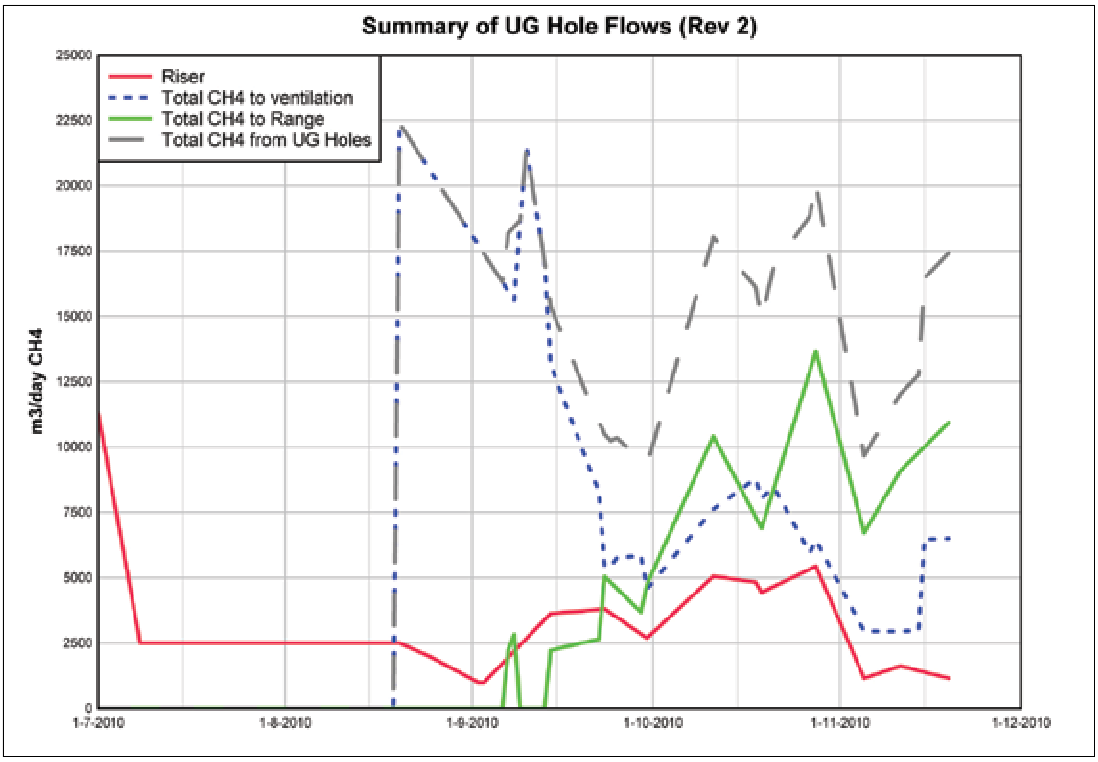

Figure 9.9: Graph summarising total daily drainage system gas flow measurements[150]

127. The noteworthy features are the high volume of methane free vented when compared to the volume of gas entering the range, and the difference between the volumes entering the range and reaching the bottom of the riser. For example, on the day of the explosion the measured gas flow into the range was 126.4l/s but only 13.3 l/s was measured at the gas riser. Such discrepancies dated back to the beginning of October. Various explanations for the difference have been suggested including leakage, methane back-feeding into other areas, a blockage in the range or incorrect measurements at the gas riser.[151]

128. As late as 27 October 2010, there was no accurate recording of methane emissions and no comprehensive system in place to capture, record and store all data permanently.[152]

129. The expert panel criticised Pike's gas management approach:

> *Significantly, there was a lack of specific gas drilling design and implementation for adequate in situ gas reduction; a particularly inadequate gas drainage system with substandard pipeline dimensions and lack of evacuation (pumping); and little determination of in situ gas content (cores) linked with an authority to mine.*[153]

Conclusions

130. The following key features marked the management of methane drainage at Pike River:

- In-seam drilling undertaken from December 2008 was designed to explore and delineate the coal seam. Pre-drainage of the coal seam was a secondary purpose of the drilling and was often prevented by intersection of boreholes before gas levels could decay.
- A limited gas drainage system was installed in 2009 which, by early 2010, was inadequate to service the gas flows experienced from in-seam boreholes and was poorly managed. Management of the system improved, but the system capacity was not upgraded.
- Free venting of methane into the mine return began in July 2010 to relieve pressure on the range in the interim, and continued to the time of the explosion.
- Adequate gas data was not gathered until August 2010. Knowledge of the gas reservoir remained limited.
- Gas management continued to be a problem into November 2010 even after the main fan improved the ventilation capacity.

ENDNOTES

1 Malcolm J. McPherson, Subsurface Ventilation Engineering, CAC0158/389, ch. 12.1.

2 United Nations, Economic Commission for Europe, Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines (ECE Energy Series No. 31), 2010, http://www.unece.org/fileadmin/DAM/energy/se/pdfs/cmm/pub/BestPractGuide_MethDrain_es31.pdf

3 Malcolm J. McPherson, Subsurface Ventilation Engineering, CAC0158/412, ch. 12.4.2.

4 Ibid.

5 Ibid., CAC0158/410, ch.12.4.1. The author suggests a range of methane migration from some 200m above to 100m below the working horizon.

6 Volume of gas contained per mass of coal substance in situ.

7 David Reece, transcript, pp. 4502–03.

8 Malcolm J. McPherson, Subsurface Ventilation Engineering, CAC0158/421, ch. 12.5.1.

9 Specific emissions represent the total volume of gas emitted per tonne of coal mined over any given period. Gas from all sources is measured, i.e. not just from the coal that is being extracted, but all the strata that is disturbed and becomes relaxed as the void left by the mining process collapses.

10 Modelling requires adequate data collection that includes seam gas contents, mechanical properties of the rock and coal strata, mining geometry and coal production rates.

11 Masaoki Nishioka, transcript, p. 3481.

12 AMC Resource Consultants Pty Ltd, Pike River Coal Company Final Feasibility Study – Project Summary, 23 June 2000, NZOG0007/10, 18; Minarco Asia Pacific Pty Ltd, Pike River Coal Company – Ventilation Report, June 2006, DAO.001.04505/5; Hawcroft Consulting International, Pike River Coal Limited, Pike River Mine – Risk Survey – Underground, CPP & Surface Operations: Final Report, July 2010, DAO.003.08710/60; Zurich Financial Services Australia Ltd, Pike River Coal Ltd – Risk Assessment and Improvement Report, 18 August 2010, INV.04.00868/15.

13 Gregory Borichevsky, Police/DOL interview, 26 April 2011, INV.03.18954/7–8; Gregory Borichevsky, witness statement, 26 June 2012, BOR0001/9, para. 57.

14 Masaoki Nishioka, transcript, p. 3481.

15 Pike River Coal Ltd, Summary Tables of Drillhole Gas Measurements, June

2008, DAO.025.42433; CRL Energy Ltd, CSG Canister Desorption Results (PRDH037), 2009, DAO.025.36396.

[16] Pike River Coal Ltd, Monitor and Report on In-seam Gas Levels and Flow Rates from the In-seam Holes, 14 October 2010, DAO.025.44571/3.

[17] Shown in Figure 9.7.

[18] For example: CRL Energy Ltd, CSG Canister Desorption Results, 18 November 2010, DAO.025.34092, DAO.025.34090 and DAO.025.34094.

[19] Safety in Mines Testing and Research Station, Review of Gas Data Following Pike River Explosion on 19 November 2010 for New Zealand Police, 7 April 2011, SOE.001.00004/8.

[20] Minarco Asia Pacific Pty Ltd, Ventilation Report, June 2006, DAO.001.04505/27.

[21] Ibid., DAO.001.04505/27, 6,18. However as discussed below no pre-drainage of the area between the stone drive and the connection to the shaft occurred – Peter Whittall, transcript, pp. 878–79.

[22] Minarco Asia Pacific Pty Ltd, Ventilation Report, June 2006, DAO.001.04505/6, 15.

[23] P. Whittall, 'Pike River Coal – Hydraulic Mine Design on New Zealand's West Coast', in N. Aziz (Ed.), Coal 2006: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2006, pp. 161.

[24] Petrus (Pieter) van Rooyen, witness statement, 27 January 2012, PVR001/39, para. 230.

[25] Ibid., PVR001/43, para. 253; P. Whittall and J.J. Cory, 'In-seam Directional Drilling at Pike River Coal Mine – An Essential Planning Tool', in AusIMM New Zealand Branch Annual Conference 2009, CAV0001/705.

[26] David Reece, witness statement, 2 February 2012, DOL3000150001/21, para. 92.

[27] David Carter, witness statement, 9 August 2011, VLI0001/4, paras 8–10.

[28] The documentation included risk assessments, critical work procedures, JSEAs and work method statements on its directional drilling procedures and for coring and gas testing from underground exploratory drillholes: Valley Longwall International Pty Ltd, Standard Work Method Statement, 15 August 2008, DAO.032.03294.

[29] Pike River Coal Ltd, Risk Assessment Report – In-seam Directional Drilling Provided by Valley Longwall Drilling, 14 November 2008, DAO.032.00244.

[30] P. Whittall and J.J. Cory, 'In-seam Directional Drilling at Pike River Coal Mine', CAV0001/710.

[31] Peter Whittall and Jimmy Cory, In-seam Directional Drilling at Pike River Coal Mine: An Essential Planning Tool – AusIMM conference – Queenstown, August 2009, DAO.007.25198/6.

[32] David Carter, witness statement, 9 August 2011, VLI0001/5, paras 16–22.

[33] Peter Whittall and Jimmy Cory, In-seam Directional Drilling at Pike River Coal Mine, DAO.007.25198/4.

[34] P. Whittall and J.J. Cory, 'In-seam Directional Drilling at Pike River Coal Mine', CAV0001/709.

[35] Ibid., CAV0001/710.

[36] Ibid.

[37] Pike River Coal Ltd, Risk Assessment Report, DAO.032.00244/11–12. The first option was to 'utilise existing gas drainage pipeline', which was (described as a 4" polypipe non-FRAS pipe) installed as a control measure when Pike mined through the Hawera Fault. Further details of this pipeline are unknown from documentation filed with the commission.

[38] Memorandum, Jimmy Cory to Peter Whittall, 29 January 2009, DAO.003.16304; Memorandum, Jimmy Cory to Kobus Louw, 12 February 2009, DAO.003.16311.

[39] Petrus (Pieter) van Rooyen, transcript, p. 5229.

[40] Memorandum, Jimmy Cory to Kobus Louw, 12 February 2009, DAO.025.53172.

[41] John (Jimmy) Cory, witness statement, 18 June 2012, COR0001/12–13, paras 53–60.

[42] David Carter, witness statement, 9 August 2011, VLI0001/7, para. 33.

[43] Peter Whittall, transcript, p. 879.

[44] Pike River Coal Ltd, Monitor and Report on In-seam Gas Levels and Flow Rates from the Inseam Holes, 14 October 2010, DAO.025.44571/3.

[45] Photograph sourced from Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report, 22 July 2010, DAO.001.04909/5.

[46] Mechanical Technology Ltd, Pike River Coal – Methane Gas Drainage and Utilisation Concept Design Report, August 2010, MED0010070099/22.

[47] Pike River Coal Ltd, Monitor and Report, 14 October 2010, DAO.025.44571/5.

[48] Ibid., DAO.025.44571/6. Boreholes GBH04-05 and 07-10. There was no borehole labelled GBH006.

[49] Ibid. GBH003 (greater than 50l/s), GBH004 (greater than 50l/s), and GBH008 (135l/s)

[50] Ibid. No measurements could be taken from GBH005 (as the borehole was abandoned as the area was required for development), GBH007 (due to a recovery operation for drilling rods lost down the borehole), or GBH009 (which was grouted on completion to allow a drill and blast crew to develop a heading through stone).

[51] Memorandum, Jimmy Cory to Pieter van Rooyen, 21 October 2009, DAO.003.16400/2; Pike River Coal Ltd, Operations Report, 16 November 2009, DAO.019.00568/6; Petrus (Pieter) van Rooyen, witness statement, 27 January 2012, PVR001/43, para. 257.

[52] Ibid., PVR001/40, para. 236.

[53] GBH010 to GBH013: Pike River Coal Ltd, Monitor and Report, 14 October 2010, DAO.025.44571/6–7.

[54] Ibid., DAO.025.44571/4.

[55] Simon Donaldson on 5 March (DAO.003.15146) and 6 March (DAO.003.15150), Stephen Wylie on 13 March (DAO.003.15197), Simon Donaldson on 14 March (DAO.003.15199), Boyd Molloy on 18 March (DAO.003.15215), Simon Donaldson on 22 March (DAO.003.15252), Russell Smith on 24 March (DAO.003.15261) and Simon Donaldson on 30 March (DAO.003.15304).

[56] Gary Campbell, Police/DOL interview, 13 January 2011, INV.03.08182/12–18.

[57] Email, Brian Wishart to Jimmy Cory, 11 April 2010, DAO.025.32975/1.

[58] Emails between Jimmy Cory and Lunagas Pty Ltd, 26 March 2010, INV.03.29639/3; John (Jimmy) Cory, witness statement, 18 June 2012, COR0001/20, para. 102.

[59] Ibid., COR0001/20, paras 97–100.

[60] Petrus (Pieter) van Rooyen, transcript, p. 5230.

[61] Pike River Coal Ltd, Operations Report, 19 April 2010, DAO.019.00616/7; Petrus (Pieter) van Rooyen, witness statement, 27 January 2012, PVR001/44, paras 260–62.

[62] Peter Whittall, transcript, pp. 913, 910.

[63] David Reece, transcript, p. 4537.

[64] Ibid., p. 4536.

[65] Department of Labour, Pike River Mine Tragedy 19 November, 2010: Investigation Report, [2011], DOL3000130010/93, para. 3.5.1.

[66] Drive Mining Pty Ltd, Pike River Coal Ltd – Gas Drainage Assessment, 15 May 2010, DAO.001.04811/9.

[67] Department of Labour, diagrams, DOL3000150025/1. (Diagram modified by the commission)

[68] Pike River Coal Ltd, Main and Standby Fans Operation and Control: Risk Assessment V2 (Draft Document), 14 October 2010, SOE.024.00333/11.

[69] Petrus (Pieter) van Rooyen, witness statement, 27 January 2012, PVR001/40–41, paras 239–42.

[70] David Reece, transcript, pp. 4542–43.

[71] David Reece, witness statement, 2 February 2012, DOL3000150001/21, para. 93.

[72] Pike River Coal Ltd, Mining Towards Boreholes not Fully Cemented: Safe Operating Procedure (Final Document), 6 January 2010, DAO.001.04188.

[73] Department of Labour, Investigation Report, DOL3000130010/90, para. 3.4.17.

[74] Memorandum, Jimmy Cory and Gregory Borichevsky to Peter Whittall, Pieter van Rooyen, Douglas White and Michael Lerch, 2 June 2010, DAO.003.16495/5; Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report, 22 July 2010, DAO.001.04909/21–22.

[75] Memorandum, James Wimbridge to Bernard Lambley, Brian Wishart, Lance McKenzie, Martin Palmer, Dean Jamieson, Jan Joubert and Peter O'Neil, 19 July 2010, DAO.003.16345; Pike River Coal Ltd, Risk Assessment – Intersection of In-seam Borehole GBH0008 along 1West CT AB6, 29 October 2010, DAO.025.34614.

[76] Memorandum, James Wimbridge to Douglas White, Bernard Lambley and Grant MacLean, 17 August 2010, DAO.025.41497.
[77] Gary Campbell, Police/DOL interview, 13 January 2011, INV.03.08182/18–19.
[78] Simon Donaldson, Incident/Accident Form, 30 August 2009, DAO.002.09069/2.
[79] D. Murphy, Incident/Accident Form, 31 July 2009, DAO.002.08933/2.
[80] Royal Commission on the Pike River Coal Mine Tragedy (Katherine Ivory), Summary of the Reports of Certain Incidents and Accidents at the Pike River Coal Mine, November 2011, CAC 0115/10-20.
[81] Mr Brown was interviewed during the joint investigation by DOL and the police, and also by counsel assisting the commission in 2011, but subsequently declined to sign a witness statement for the commission.
[82] Email, Jimmy Cory to Miles Brown, 13 April 2010, DAO.001.05060/1.
[83] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Drainage Assessment, 15 May 2010, DAO.001.04811/16.
[84] Ibid., DAO.001.04811/8.
[85] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Drainage Assessment, 15 May 2010, DAO.001.04811/17. GeoGAS DRI 900 is a method developed by GeoGAS Pty Ltd to define outburst threshold limits for coal seams other than the New South Wales Bulli seam. The method requires measuring the volume of gas emitted from a coal core sample after crushing for 30 seconds. The result is related to the total gas content of the full core sample in order to calculate a figure which, if above 900, indicates there is a risk of an outburst of coal and gas if a geological structure (such as faulting) is present.
[86] D. Black, N. Aziz, M. Jurak and R. Florentin, 'Outburst Threshold Limits – Are They Appropriate?', in N. Aziz (ed.), Coal 2009: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2009, pp. 185–92.
[87] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Drainage Assessment, 15 May 2010, DAO.001.04811/17.
[88] Memorandum, Jimmy Cory to Gregory Borichevsky, 24 May 2010, DAO.003.16501/2.
[89] Email, Jimmy Cory to Miles Brown, 20 June 2010, DAO.001.05096/1.
[90] Pike River Coal Ltd, Operations Meeting Minutes, 16 June 2010, DAO.002.14622/4.
[91] Pike River Coal Ltd, Operations Meeting Minutes, 30 June 2010, DAO.002.14672/3.
[92] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report #2, 20 September 2010, DAO.012.02524/13; Pike River Coal Ltd, Monitor and Report on In-seam Gas Levels and Flow Rates from the In-seam Holes, 14 October 2010, DAO.025.44571.
[93] Pike River Coal Ltd, Outburst Management Plan: Management Plan (Draft Document), 7 July 2009, DAO.003.06920.
[94] Ibid., DAO.003.06920/4, 8.
[95] For example see University of Wollongong's website on outburst hazards: http://www.uow.edu.au/pdfs/OMP.pdf
[96] For example, the plan states that 'PRCL has a long history of mining the Bulli Seam' – a coal seam in New South Wales: DAO.003.06920/9,11, 37.
[97] Ibid., DAO.003.06920/13.
[98] Ibid., DAO.003.06920/12.
[99] Pike River Coal Ltd, Formal Risk Assessment – Ventilation and Gas Monitoring, 7 September 2010, DAO.011.00025/4.
[100] Memorandum, Gregory Borichevsky and Jimmy Cory to Pieter van Rooyen, 5 July 2010, DAO.001.04572/1–2.
[101] Ibid., DAO.001.04572/1.
[102] Ibid.
[103] When the target level of 1% methane was achieved in the main return, daily methane volumes peaked at 67,514m^3 with typical daily volumes of 62,000 to 63,000m^3 from GBH012 and GBH013: Pike River Coal Ltd, Operational Advisory – Gas Drainage Management Plan – Panel 1 Degassing and Borehole Intersections, 27 July 2010, DAO.001.04566.
[104] Gregory Borichevsky, notes, July 2010, INV.03.29202/9–18.
[105] Pike River Coal Ltd, Gas Drainage Management Plan (Draft Document), undated, DAO.002.03631.
[106] Memorandum – Operational Advisory, Gregory Borichevsky to Pike River operational staff, 8 July 2010, DAO.001.04569; Memorandum – Operational Advisory, Gregory Borichevsky to Pike River operational staff, 27 July 2010, DAO.001.04566.
[107] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report, 22 July 2010, DAO.001.04909/4.
[108] Ibid., DAO.001.04909/8: The drainage system showed a flow of approximately 135l/s of methane, and the flame arrestors at the surface of the gas riser were highly resistant due to coal fines and water emitted through the drainage pipelines.
[109] Ibid., DAO.001.04909/10–11.
[110] Ibid., DAO.001.04909/10. Including a 20m-wide extraction panel and pre-drainage of the area down to a level of 3m^3/t of methane, shown in a table.
[111] Ibid., DAO.001.04909/10–11.
[112] Ibid., DAO.001.04909/12.
[113] Ibid., DAO.001.04909/23.
[114] Pike River Coal Ltd, Q1 Sheet – GBH0016, 19 July 2010, DAO.025.34058; VLI Drilling Pty Ltd, Inseam Drillhole Report – GBH0016, 30 July 2010, DAO.025.45024/23.
[115] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report, 22 July 2010, DAO.001.04909/28.
[116] Emails between Chris Mann, Gregory Borichevsky, Miles Brown and James Cory, 1–15 July 2010, DAO.001.05008.
[117] Pike was interested in reducing its liability under New Zealand's Emissions Trading Scheme by capturing methane and converting it to carbon dioxide using a flare, and in future options for the generation of electricity. Mr Mann's report also addressed these options.
[118] Based upon known flows from boreholes and an assumed decay curve prepared by Miles Brown: Mechanical Technology Ltd, Pike River Coal – Methane Gas Drainage and Utilisation: Concept Design Report, August 2010, MED0010070099/17–18.
[119] Ibid., MED0010070099/23: He suggested the blower could be installed on the concrete pad at the current gas riser site subject to addressing safety issues with the flame arrestor.
[120] Ibid., MED0010070099/16–25.
[121] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report #2, 20 September 2010, DAO.012.02524/3.
[122] Ibid., DAO.012.02524/4: Mr Brown was concerned that connected borehole GBH008 appeared to be blocked at the intersection point, meaning the gas flow make may only have been from a newly drilled hole.
[123] Ibid., DAO.012.02524/6.
[124] Mr Brown suggested these should be taken from the same locations at which a ventilation survey had been recently conducted with Pike's ventilation consultant John Rowland.
[125] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report #2, 20 September 2010, DAO.012.02524/7, 11.
[126] Pike River Coal Ltd, Q1 Sheet – GBH0018, 27 September 2010, DAO.025.34088; Q1 Lost Gas Desorption Sheets – GBH0019, 8–10 November 2010, DAO.025.34782/2–4.
[127] The Rider and Paparoa seams above and below the hydro panel may also contribute to the gas emissions.
[128] Some of the in-seam boreholes are marked in red and black, used to represent drilling through coal and stone respectively.
[129] Drive Mining Pty Ltd, Pike River Coal Limited – Gas Management Primary Report, 22 July 2010, DAO.001.04909/10. (Labels added by the commission)
[130] Petrus (Pieter) van Rooyen, witness statement, 27 January 2012, PVR001/42, para. 253.
[131] Gregory Borichevsky, Police/DOL interview, 7 June 2011, INV.03.20410/73.
[132] Gregory Borichevsky, witness statement, 26 June 2012, BOR0001/37, para. 257; Douglas White, transcript, pp. 4917–21; Petrus (Pieter) van Rooyen, transcript, p. 5215; Stephen Ellis, witness statement, 14 March 2012, DAO.041.00042/3–4.
[133] David Reece, transcript, p. 4541.
[134] Memorandum, Gregory Borichevsky and Jimmy Cory to Pieter van Rooyen, 5 July 2010, DAO.001.04572/1.
[135] Pike River Coal Ltd, Gas Drainage Management Plan (draft document), DAO.002.03631/4. Although undated or signed off, it must have been created in early July 2010. See also: Hawcroft Consulting International, Pike River Mine

– Risk Survey, DAO.003.08710/57.

[136] Petrus (Pieter) van Rooyen, witness statement, 27 January 2012, PVR001/46, 50, paras 271, 294. Subsequently a design review based upon further geological information resulted in a change of direction and development to the west (towards the proposed location of the second intake, return and egress), and another location for the new riser was identified.

[137] Petrus (Pieter) van Rooyen, transcript, p. 5235.

[138] Ibid., pp. 5233–35.

[139] Gregory Borichevsky, notes, 3 August 2010, INV.03.29202/19; Gregory Borichevsky, witness statement, 26 June 2012, BOR0001/35, para. 240.

[140] Zurich Financial Services Australia Ltd, Pike River Coal Ltd – Risk Assessment and Improvement Report, 18 August 2010, INV.04.00868/9.

[141] Hawcroft Consulting International, Pike River Mine – Risk Survey, DAO.003.08710/58.

[142] Pike River Coal Ltd, Formal Risk Assessment – Ventilation and Gas Monitoring, 7 September 2010, DAO.011.00025/11.

[143] Pike River Coal Ltd, Management of the Gas Drainage Line: Safe Operating Procedure (Draft), 5 November 2010, DAO.025.34471/3.

[144] Pike River Coal Ltd, Formal Risk Assessment – Ventilation and Gas Monitoring, 7 September 2010, DAO.011.00025/5.

[145] Kevin Poynter, transcript, pp. 3095–96.

[146] David Reece, transcript, p. 4543.

[147] Emails, Jimmy Cory to Miles Brown, 9 November 2010, DAO.001.05057/1.

[148] Leslie Tredinnick, Police/DOL interview, 15 December 2010, INV.03.03263/19–29, and map INV.03.03382.

[149] Keith Stewart, witness statement, 16 August 2012, MBIE3000010012; Email, Tim Harvey to Jane Birdsall, David Reece and Keith Stewart, 16 August 2012, MBIE3000010016.

[150] Graph, 16 August 2012, MBIE3000010017/1.

[151] David Cliff, David Bell, Tim Harvey, Anthony Reczek and David Reece, Pike River Coal Mine Explosion: Investigation for Nature and Cause (DOL Investigation Report, Appendix 6), October 2011, DOL3000130007/43, para. 9.3.

[152] Email, Gregory Borichevsky to Danie du Preez, Pieter van Rooyen and Jimmy Cory, 27 October 2010, INV.04.01375/1.

[153] David Cliff et al., Investigation for Nature and Cause, DOL3000130007/12, para. 6.1.