The Role of Algae in the Investigation of Water Inflow into a Coal Mine

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ABSTRACT

Investigation of a water inflow into Wongawilli Mine in the Southern Coalfield of New South Wales included algal analysis. The determination of algae in the water suggested an external water source. An alternative hypothesis proposed that algae are inherent in a coal mine environment. Investigations to determine the validity of these hypotheses and provide information on the viability and longevity of algae under adverse conditions were conducted in the mine and the laboratory. Results indicated that a mine environment is not natural to algae and is not conducive to their growth. These findings support the hypothesis of introduction of surface water to the mine workings. They indicate that, in the absence of other available techniques, algae can be an effective tracer for use in the determination of a water source.

INTRODUCTION

The use of algae as a tracer in the determination of the source of seepage water in coal mines was proposed by the Metropolitan Water Sewerage and Drainage Board during the Inquiry into Mining under Stored Water [1]. Preliminary analyses suggested that a proportion of seepage water in Huntley Colliery had originated from the overlying Avon reservoir.

The use of algae in the identification of specific waters when mixed with water of a different origin is recognised by the World Health Organisation [2]. However, Jones [3] believes that although algae can be satisfactory tracers when comparing different types of water, their use is limited in the comparison of adjacent waters. The situation at Wongawilli Colliery, with different environments, surface and underground, can however be deemed analogous to the comparison of different waters. There are a number of constraints, however, in that the range of algal species and the number of individuals found in coal mine water is much smaller than that of the surface source.

BACKGROUND

Under the Coal Mining Act (1973) (as amended), the Dams Safety Committee has the task of assessing and making recommendations on coal mining activities under the structure and storage of prescribed dams. The Reynolds Inquiry [1] recommended depths of cover at which various types of mining should be allowed and the required dimensions of bords and pillars and panels and pillars. These recommendations have generally been used as the basis for the determination of types and extent of mining. In general, only bord and pillar mining has been allowed under the storage and within a Marginal Zone around the storage. This zone is defined by an angle of draw of 35° from FSL (a plan distance of 0.7 times depth of cover to the worked seam). Total extraction, either by longwall, shortwall or pillar removal is allowed outside this zone.

At Wongawilli Colliery, in the Southern Coalfield, bord and pillar development of the Wongawilli seam took place under Avon storage with pillar removal outside the Marginal Zone.

The Wongawilli seam is 9 m thick but only the lower 3 m is extracted. Depth of cover varies from 90 m under the storage to 140 m at the Marginal Zone. The overlying stratigraphic sequence consists of 30 m of interbedded sandstone and shale to the 2.5 m thick Bulli Seam, overlain by the Triassic Narrabeen Group comprising massively bedded Bulgo Sandstone with minor shale beds. The strata dips 2° to 5° to the northwest. Extraction was restricted by silling within the seam section. This, in conjunction with a number of major dykes, limited pillar removal to two main areas, designated Blue 2 and Blue 3/4 panels.

As the Wongawilli seam has always had an ability to emit water and some water make was therefore expected during pillar extraction, a number of V-notch weirs were installed to measure flow along the seam floor. Associated monitoring consisted of the measurement of coal moisture, intake and return ventilation moisture and water piped into the area. Throughout development and extraction, these latter sources of moisture remained relatively constant, generally less than 2,000 l/hr.

WATER INFLOW

Monitoring of water movement commenced whilst first workings were being developed under Avon storage. At this stage, water flow over the V-notch weirs averaged 6,000 l/hr. This increased to 12,000 l/hr during extraction of Blue 3/4 panel and 29,000 l/hr on completion of this extraction. In mid December, 1982, during pillar removal in Blue 2 panel adjacent to a sill, the water make rose dramatically to 100,000 l/hr. This inflow resulted in the reduction and eventual curtailment of mining in this area of Wongawilli Colliery. Measurement of the water inflow continued with gradually reducing frequency. After the initial inrush, the water make stabilised at 80,000 l/hr. It has gradually declined and is now approximately 30,000 l/hr.

A number of accounts of the events leading up to and following the inflow including considerations of the water source and potential investigation methods have been compiled [4], [5], [6], [7].

INVESTIGATION

Three possible sources of water were considered; old workings 400 - 800 m updip of Blue panels on the southern side of the sill, surface water from the Avon reservoir and ground water in the coal seam and surrounding strata.

Initial investigations focussed on algal, chemical and tritium analyses of the possible sources. Chemical and tritium analyses ruled out the old workings but suggested that the inflow contained components of both surface water and groundwater (Tables 1 and 2).

Table 1

Analysis of Tritium Content

Sample	Range (Tritium units)
Avon Storage	4.7 ± 0.4 to 5.5 ± 0.4
Mine Water Inflow	3.4 ∓ 0.4 to 4.6 ∓ 0.4
Old Workings	7.7 ∓ 0.4 to 8.4 ∓ 0.4

A number of methods were considered for further investigation but ruled out because of socio-economic factors and the nature of the terrain. The area comprises deeply dissected valleys containing four arms of the upper reaches of Avon storage. In addition, there is a 24 hour pumping station supplying water to the City of Wollongong. These factors negated the use of various tracers such as fluorescein, sodium chloride and potassium sulphate. Similarly, thermometric

TABLE 2 Chemical Analyses (mg/l)

Sample Location	Date	pH	Cl	SO_4	Ca	Mg	Na	K	Fe	Zn
Blue 2 inflow	24.12.82	7.6	32	< 2	24	14	26*		<0.1	
	21.4.83	7.8	24	< 2	56.9	18.4	48.1	5.6	<0.02	0.05
	29.3.84	7.5	25	< 2	16.8	7.7	15.5	2.5		
	18.3.85	7.0	18	3	76	18	28	2		
	12.3.86	7.5	16	< 2	20	10	1.0	20		
Cindered coal	21.4.83	7.5	26	< 2	18.6	20.5	129	5.4	0.08	<0.05
Blue 3/4	21.4.83	7.4	22	< 2	29.3	18.3	30.1	4.2		0.05
	29.3.84	7.9	26	< 2	37.2	17.1	21.3	3.8		
	12.3.86	7.8	19	8	38	21	24	2		
Bolt hole	10.10.84	7.1	26	< 2	37.6	19.6	34	3.6		
2 West panel	30.5.85	7.3	16	6	34	12	327	7		
Avon storage	Feb 1983	6.85	15	1.5	1.7	1.85	8.0	0.83	0.20	
	29.3.84	6.2	20	< 2	1.3	0.8	4.5			

* Na + K

TABLE 3 Algal Analyses (Cells/100ml)

Sample Location	Date	Melosira	Cryptomonas	Peridinium	Navicula	Cyclotella	Synedra	Dactylococcopsis	Trachelomonas	Staurastrum	Rhizosolenia
		Species									
Blue 2 inflow	18.1.83	24	42	1	0.4	0.8	0.4			0.4	
	16.2.83	1.2	7.6	1.2							
	7.3.83	1	31			1					
	20.5.83		10		1	1		3.5	1	1	
	17.5.84	3	1		1						
	20.5.85	1						2			
	28.5.86	No algae									
Blue 3/4	20.5.83		1		1	1					
	21.7.83	11					1				
Avon storage	5.1.83					31000					16700
	20.7.83		2800			12100		18850		1750	
	17.5.84		1000			1100		3100		12000	800
	3.10.84					60600		4900			127000

analysis, the location of possible leakage points by determination and analysis of the thermal profile of the storage, was precluded by the presence of the pumping station. Drilling of boreholes and high resolution seismic reflection were rejected as not being cost effective.

ALGAL ANALYSIS

Because of the aforementioned constraints, the eventual method of investigation pursued was algal analysis. Water samples continued to be taken for chemical analysis but their composition varied little with time (Table 2).

Initial Investigation

Samples from a number of locations in Blue 2 and Blue 3/4 panels were taken at intervals between January, 1983 and May, 1986. Algae were found throughout the panels, both in seepage from the sill/seam contact, in water from roof bolt holes and drippers and in flowing water. Algal species common to the overlying Avon storage were found albeit in much reduced numbers. Table 3 allows a comparison of algal species although the listing is not exhaustive and other species were found in the inflow water. Similarly, the analyses of Avon reservoir record only the commonest species.

Although the low concentrations of algae in the inflow water continued to decrease, algae were still being found in May, 1985, some 2 1/2 years after the initial inflow, by which time it had reduced to approximately 41,000 l/hr. The majority of algal cells found were dead and in various stages of degradation and disintegration. From the comparison of Avon algae and mine water algae and the state of a number of apparently live cells of Cryptomonas found in May, 1983, it was concluded that a surface to seam connection existed and that the travel time from surface to seam could be as low as four days [8].

The company disputed this conclusion, claiming that the water was normal seam groundwater and that algae could be brought into a mine environment by other means such as mine ventilation, transport of men and materials or in water from surface dams used for dust suppression purposes [3].

A series of investigations and experiments were therefore conducted to determine the viability and longevity of algae in a mine environment and to check the validity of the two conflicting hypotheses.

Further Investigations

The potential of photosynthetic organisms to survive in the absence of light is not known but it is possible for some algal species to revive after exposure to long periods of darkness [3]. In order to determine whether a coal mine, with only weak and sporadic lighting, would be a suitable environment for habitation by algae, water samples were taken from mines in the Southern, Western, Newcastle and

Hunter Valley Coalfields. Other areas of Wongawilli Mine were also sampled. Apart from Pikes Gully-Foybrook Mine where the low cover depth, 60 m, has resulted in water inflow from overlying creeks and opencut water storages, no algae were found. These findings suggest that algae are not inherent in a mine environment and therefore that algae found in the water inflow at Wongawilli Mine have been introduced from a surface storage as a highly localised occurrence. It was, however, agreed that further investigation of the mine environment and its ability to support algae was warranted.

Samples of filtered and gamma irradiated mine water from Blue 2 panel were placed in a cutthrough next to the main track road, a short distance outbye of a working face at Wongawilli Mine. The location ensured the regular passage of men and materials as well as a supply of fresh ventilation. Light was the only limiting factor. Samples were analysed with decreasing frequency over a period of nine months from June, 1986 to March, 1987. Although amoebae and fungal spores colonised the water after two weeks and bacteria after approximately three months, no evidence of algae was found [8].

At the same time, samples of untreated Avon reservoir water were placed in a similar location, one cutthrough inbye of the irradiated mine water samples so as to avoid contamination. Analysis of samples at similar intervals showed that algal species started to decrease in numbers within two to twelve days of placement in the mine and that the majority of algal species had completely died out within forty-two days. Only flagellates, ciliates and amoebae continued to survive [8].

A concern was then raised as to the ability of filtered, irradiated mine water to support an algal population under even the most advantageous of circumstances. To test this, filtered and irradiated mine water to which was added Avon reservoir water containing algae, was kept in the laboratory under simulated reservoir conditions, temperature of 20°C and alternating twelve hours of light and darkness. The algal population increased approximately 1,500 times but analysis showed this to be mainly due to a vast increase in Chlorella after a period of sixty days, to the detriment of the majority of other algal species. Some species such as Arthrodesmus, Cyclotella, Closteria, Cosmarium and Staurastrum retained their viability whereas the majority reduced in numbers and died off within fifty days, at which point Chlorella took over [8]. The results indicated that mine water does contain sufficient nutrients to enable and promote algal growth. Therefore, the absence of algae in a mine environment is due to the nature of that environment, in particular the absence of light, and that algae found in such an environment must be introduced from a surface source.

DISCUSSION

The above investigations confirm that algae are not normally found in a coal mine and that such an environment is not conducive to their longevity or viability. The presence of algal species under such conditions strongly suggests introduction from an external source. The proximity of Avon reservoir, the absence of other surface water bodies in the vicinity, and the commonality of algal species between the mine water inflow and the Avon reservoir also suggest a surface to seam connection.

The mechanics of such a connection are imperfectly understood but there are a number of factors which should be considered.

The depth of cover is low, approximately 90 m under the storage increasing to 140 m over the areas of pillar removal. Although surface subsidence and tensile strains are low, approximately 231 mm and 1.94 mm/m respectively, a surface fracture 80 m long, 0.8 m wide and up to 2 m deep, occurred over the goaf edge of Blue 3/4 panel, paralleling a seam level dyke and a surface lineament. This suggests that strata disruption has been more severe than would be expected from the small area of extraction.

The regional stress field in the Southern Coalfield is 3:1 (horizontal : vertical) with stress concentrations occurring at the base of valleys. The topography is also conducive to the generation of valley bulging effects which may result in increased permeability at depth [6], [9].

Evidence for open fractures at depth is given by Snow [10]. He tested 5,500 specimens of fractured rocks including sandstone and found that in the upper 10 m natural fracture openings ranged from 400 to 75 microns. These openings decreased to 100 to 50 microns in the lower 15 to 60 m.

Extracted thickness of the Wongawilli Seam is 3 m. The expected extent of strata disruption above seam level could therefore be up to 30 m.

The range of algal species found in the water inflow is related to the point in the reservoir at which the water enters the strata and the size of the rock fractures. Estimates based on the largest algae found in the mine water suggest a crack width of 50 microns.

On this basis, the maximum inflow of 100,000 l/hr could be sustained by a fracture 50 microns wide and 600 m long.

It is acknowledged that more water has entered the mine at a sustained rate via Blue panels than the goaf is capable of producing just due to the normal volume of roof caving [7].

Analysis of the individual flow rates from Blue 2 and Blue 3/4 panels has shown that their characteristics are different. The behaviour of Blue 2 inflow is now seen as that of a virtually confined groundwater system draining to a sink. Although a surface water component may originally have been substantial, as testified by the presence of algae, this is now minor and masked by the dominant groundwater. Blue 3/4 inflow is similarly now dominantly sourced by groundwater. However, in this case, since February, 1984, the inflow has responded to periods of heavy rainfall, with a time lag of only a few days, evidence of an hydraulic connection with the surface [11].

Chemical analysis did not provide any clues as to the source of the inflow. As can be seen from Table 2, the water quality varies considerably throughout Wongawilli Mine. It bears some limited similarity to Avon reservoir water, the differences, higher Ca, Mg and K being due to passage through marine sediments.

CONCLUSION

The determination of Avon reservoir as the source of some of the water inflow was initially based on the similarity of the algal species and the fact that some found, notably Cryptomonas, which was later shown to die within 7 days in the absence of light, were still relatively fresh.

As algae are photosynthetic plants which require light to grow and multiply, their presence in the mine water led to the conclusion that mining had resulted in the initiation or enlargement of strata fractures resulting in water movement from the overlying surface storage to the mine.

Subsequent investigations have shown that new or enlarged fractures are not necessarily required to enable such water flow. Natural fractures of sufficient width may be present up to 60 m below the surface. If the extent of strata disruption from mining were then to intercept these fractures and the normal groundwater system, the mine would act as a sink and water would flow into the workings [11]. The groundwater system would be in connection with the reservoir, enabling algae to travel to the mine in a relatively short time.

The investigation of the water inflow into Wongawilli Mine has resulted in a great deal of information on the behaviour of algal species, their variable response to the absence of light and their viability and longevity in a hostile environment. It has shown that algae are not inherent in coal mines and are most unlikely to be introduced by means of ventilation or human access. Algae can only be introduced via their natural growth medium, water, and as such are useful tracers in determining the source of such water.

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