

The Effect of Coal Mining on the Hydrogeological Regime of the Southern Coalfield, New South Wales

L.M. WHITFIELD
Geologist, N.S.W. Geological Survey

SUMMARY Extensive monitoring of groundwater levels over panel and pillar mining at Bulli Colliery indicated a direct relationship between panel extraction and water movement. In seam water monitoring suggested that dykes were not necessarily a barrier to water movement. At Wongawilli Mine, a small area of pillar removal resulted in a large water ingress which investigations suggested was partly from a surface source.

1. INTRODUCTION

Coal mining under water storages has been a contentious issue since the turn of the century when the first of the Sydney Water Board's major dams was built. A Judicial Inquiry attempted to resolve the matter and laid down guidelines under which bord and pillar and panel and pillar mining could be undertaken (Reynolds 1977).

The NSW Dams Safety Committee, although set up to maintain a surveillance of prescribed dams and ensure their continuing integrity, was also charged with the task of assessing and making recommendations on coal mining activity under such dams. It adopted the recommendations of the Reynolds Inquiry in respect of coal pillar sizes and cover thicknesses.

Its general policy allows total extraction outside a Marginal Zone equivalent to an angle of draw of 35° from Full Supply Level but only bord and pillar mining within this zone or under the storage. However, experimental panel and pillar mining was allowed at Bulli Colliery within this zone. Mining is not allowed under major dam structures.

It has always been the concern of the Sydney Water Board that mining could induce or enhance fractures within the overlying strata which would allow loss of stored water - despite substantial evidence during the Reynolds Inquiry to the contrary.

Little information is available on the hydrogeology of the Triassic strata overlying the Permian Coal Measures of the Southern Coalfield. Most mines are not adversely affected by water inflows and therefore hydrogeological investigation is considered unwarranted.

The general stratigraphy of the Bulli-1 area is shown in Figure 2. The Hawkesbury Sandstone is a massively bedded sandstone with thin lenticular shale and siltstone beds. It is underlain by mud rocks of the Newport Formation and chocolate shales of the Bald Hill Claystone. The Bulgo Sandstone is a massively bedded lithic sandstone, often conglomeratic, with thin mudstone bands. The Scarborough and Coalcliff Sandstones are of similar composition to the Bulgo. The Stanwell Park Claystone and Wombarra Shale are green-grey claystones with interbedded sandstones. The Wongawilli seam is separated from the Bulli seam by 30 m of interbedded sandstone and shale. This full sequence is found in the Bulli area but in the

south, around Avon dam, the Stanwell Park Claystone and Wombarra Shale are thin or unrecognisable.

2. BULLI MINE - CATARACT RESERVOIR

Development in the Bulli seam under the Sydney Water Board's Cataract Storage commenced in 1978 with extraction of three NE-SW panels from April 1983 to March 1986. Each panel was approximately 80 m wide, separated by 65 m pillars and varied in length from 400 m to 730 m. Minimum depth of cover was 230 m under the storage, increasing northwards to 300 m (Figure 1).

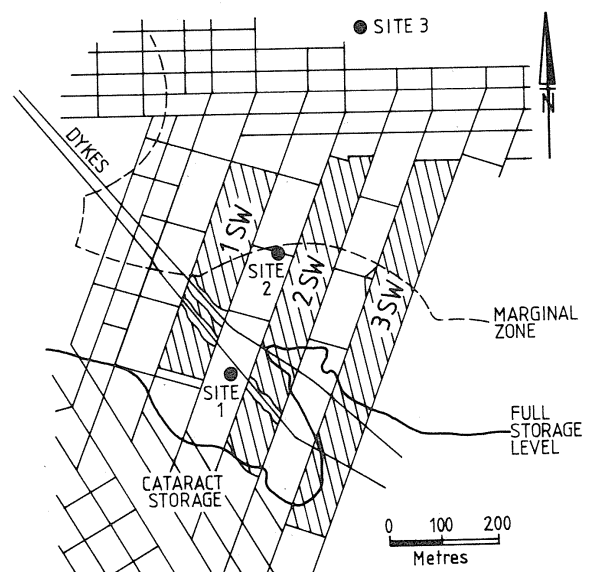


Figure 1 Layout of mining: Bulli-1

The DSC considered the mining to be critical as not only was it within the 35° Marginal Zone and under the storage but it was transected by a major dyke zone, delineated on the surface by a major lineament.

To evaluate the influence of mining on the dykes, overall strata movement and permeability, a comprehensive investigation was initiated. This comprised installation of piezometers to measure water levels, ring magnets to allow measurement of

vertical strains, surface subsidence and horizontal strain surveys, surface and seam level geological mapping and monitoring of water movement within the mine workings. This latter comprised weekly measurement of coal moisture, intake and return air moisture and all pumped or flowing water.

Piezometers 2E and 3E, located in the topmost strata, the Hawkesbury Sandstone, showed no response to mining. They are above the Full Supply Level of Cataract Reservoir and their response was characteristic of a perched aquifer governed by climatic and topographic controls.

Thirteen, 1 m long Casagrande type porous pot piezometers in a 10 m sand filter, were installed in individual boreholes grouped at three sites. Sites 1 and 2 were located over the coal pillar between 1SW and 2SW panels whereas Site 3 was located outside the area of mining to act as a control (Figure 1). The location of each piezometer within the stratigraphic section is shown in Figure 2. Maximum depth of monitoring is 215 m, to the base of the Bulgo Sandstone, approximately 100 m above the Bulli seam.

The influence of the first workings was evident in the response of the deepest piezometers at Sites 1 and 2. These showed a decline in level corresponding to a pore pressure reduction due to the sink effect of the development headings.

At Site 1 all four piezometers, located in the Bulgo Sandstone, showed small water level rises as the extraction of 1SW panel passed the site. Extraction of 2SW panel and the initiation of tensional conditions occasioned falls in water

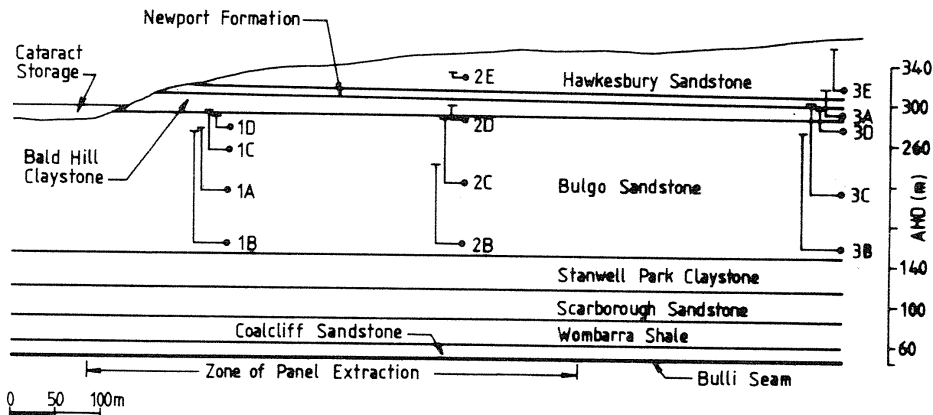


Figure 2 Stratigraphic section and location of piezometers

Groundwater levels and the position of ring magnets (fixed at 12 m intervals to ABS tubing in the deepest hole at each site) were measured monthly, increasing to fortnightly during extraction of each panel. Although extraction ceased in March 1986, monitoring will continue, to ascertain the post mining regime.

level. These effects were greater in the deeper piezometers, reducing in amplitude and increasing in time lag at higher stratigraphic levels.

Groundwater level measurements showed that the piezometer response could be divided into three groups. The behaviour of selected piezometers is shown in Figure 3. Detailed discussion of this aspect is contained in Williamson and Whitfield (1987) but is summarized below.

Similar effects were measured at Site 2 although the response of piezometers 2B and 2C to the extraction of 1SW panel was muted, the main response occurring during extraction of 2SW and 3SW panels.

The water levels in piezometers 2D and 3D consistently remained above Cataract Reservoir Full Supply Level, indicating an hydraulic gradient towards the storage from the very upper part of the Bulgo Sandstone.

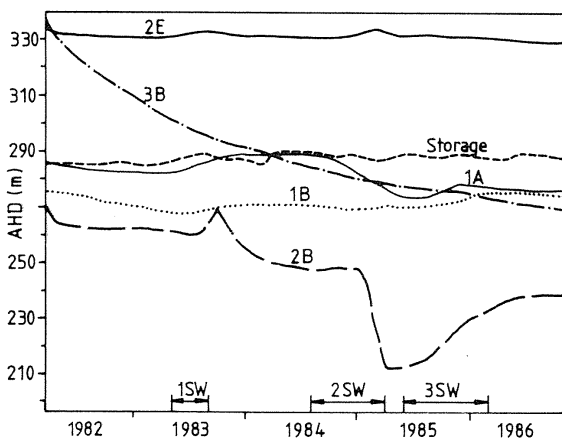


Figure 3 Groundwater Levels: Bulli-1

At the deeper stratigraphic levels, groundwater levels at Sites 1 and 2 declined during first workings and on commencement of panel extraction and development of tensional effects in the overlying strata, compression resulted in a rise in water level. Such changes were not reflected in water levels at Site 3 which was located away from the extracted panels. Levels in the deeper piezometers, 3B and 3C, are still stabilising after five years of monitoring, thereby indicating the very slow rate of water movement through the strata.

Workings in the Bulli seam have generally been dry and monitoring of water movement within this area of Bulli mine confirmed that situation. Although some water make was measured during extraction of the three panels this did not exceed 1120 l/hr and as such was not noticeable within the mine. There is some evidence to suggest that throughout development and extraction water make was

associated with drivage through the dyke zones. Water losses (less water exiting the workings than entering) of up to 1900 l/hr were recorded during extraction of 2SW and 3SW panels. This was possibly due to disruption of seam floor and underlying strata resulting in downward movement of water which it was not possible to record. Water levels in the deepest piezometers remained within the Bulgo Sandstone. There are two thick shale/claystone horizons between the Bulgo Sandstone and the Coal Measures which are effectively aquicludes (Figure 2). This suggests that any water make into the mine was probably localised groundwater from the immediately overlying Coalcliff Sandstone. It would appear that disruption to the strata from panel extraction has not been of sufficient magnitude to evoke any significant change in the hydraulic connection between the surface storage and the mine workings.

Extensive measurement of surface subsidence and horizontal strain confirmed the prediction of minimal surface disruption. Maximum subsidence was 114 mm and tensile strains were generally less than 1 mm/m, although 2.5 mm/m was measured in the vicinity of the dyke/lineament. These figures compare well with predicted values of 92 mm and 0.3 mm/m (Kapp 1982) and 150 mm and 0.9 mm/m (Holla 1986).

Measurement of vertical movement indicated tensile strains up to 0.58 mm/m at the base of borehole 2B during extraction of each panel, with negligible movements in the upper part of the strata. Borehole 1B closed off, some 60 m below the surface during extraction of 3SW panel, presumably along a claystone horizon within the Bulgo Sandstone, a common occurrence in boreholes in the Southern Coalfield. The results of monitoring indicate that the majority of movement has taken place in the intervening 100 m of strata below the base of the boreholes.

Measurements of strata movement in boreholes over longwall extraction in the Southern and Northern Coalfields have indicated that major caving and bed separation only extends above the seam for a height of about 10 to 13 times the extracted thickness (Holla and Armstrong 1986). Tensile strains in this zone were measured at between 40 and 135 mm/m. They suggested a criterion for rock fracture to be where more than 2.5 mm/m tensile strain occurs. Strata undergoing less strain would therefore retain their structural integrity, even following undermining.

Mathematical modelling of the extracted panels and the dyke zone was undertaken using a variety of insitu stress regimes, rock mass parameters, joint and defect parameters and location and inclination of defects. All results suggested that mining effects would only extend upwards approximately 50 m to the base of the Scarborough Sandstone and that a continuous defect would remain closed over most of its length.

3. WONGAWILLI MINE - AVON STORAGE

The Dams Safety Committee recommended that bord and pillar first workings be allowed in the Wongawilli seam under the storage and within the 35° Marginal Zone of Avon Reservoir, with pillar removal outside the 35° Zone. Depth of cover varied from 90 m under the storage to 140 m at the Marginal Zone. The Wongawilli seam is 9 m thick but only the lower 3 m is extracted. The mining was restricted by extensive silling within the seam section (Figure 4).

The Wongawilli seam is notably wetter than other seams in the Southern Coalfield and could be considered to be a discontinuous aquifer with a vertical permeability of approximately 6×10^{-7} cm/sec. (Whitfield 1986) For this reason a system of comprehensive measurement of water movement in

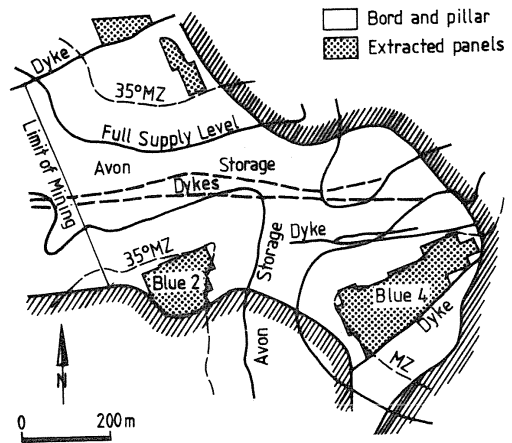


Figure 4 Layout of mining: Wongawilli-1

the mine workings was implemented similar to that at Bulli Mine. However, as water make in the seam was expected to be considerable, several V-notch weirs were installed to measure flow along the seam floor.

Mine water monitoring indicated that the moisture content of coal and air remained constant as did the amount of water piped into the area, less than 2000 l/hr (Figure 5). The only variable was the amount of water flowing out of the workings.

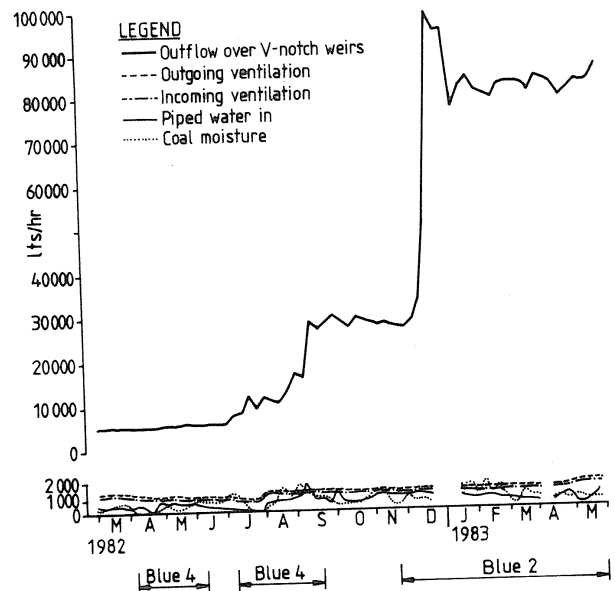


Figure 5 Water Monitoring: Wongawilli-1

Development of first workings was undertaken without problems. With the commencement of pillar extraction in Blue-4 panel adjacent to a 2 m thick dyke an increase in water make from 6000 to 12,000 l/hr occurred in July 1982 and a further increase to 29,000 l/hr on completion of this extraction in

September 1982. In mid December 1982, during extraction of Blue-2 pillars adjacent to the sill, inflow rose dramatically to 100,000 l/hr before stabilising at approximately 80,000 l/hr (Figure 5). This sudden inrush damaged track and belt roads before being contained behind a breeze block dam and piped from the area. It resulted in reduction and eventual curtailment of mining in this area of Wongawilli Colliery.

Three possible sources of the water were: flooded old workings 400 to 800 m updip of Blue panels on the southern side of the sill; groundwater in the seam and surrounding strata; and surface water from the Avon Reservoir. Chemical and Tritium analyses ruled out the old workings as a source and suggested that the inflow contained components of both surface and groundwater.

Investigation was limited by the nature of the terrain. The area comprises four arms of the Avon Storage in deeply dissected valleys. In addition, there is a 24 hour pumping station supplying the City of Wollongong. These aspects precluded use of most tracers and also of thermometric analysis (the determination of leakage points by analysis of the thermal profile of the storage). Borehole drilling and High Resolution Seismic Reflection geophysics were rejected as not being cost-effective. The investigation therefore concentrated on algal analysis of the various waters in an attempt to define the source.

Analysis of water samples from Blue-2 and Blue-4 panels, goaf, drippers and floor water confirmed the presence of algae of species consanguinous with those known to occur in Avon Storage. As algae require sunlight to be viable it is improbable that they could be found naturally either in a mine environment or in a confined rock sequence.

One theory proposed that they were introduced into the workings through the intake air system or through the transport of men and materials (Jones 1984). Studies by the DSC to elucidate the problem confirmed that algae die out rapidly when introduced to an alien mine environment (Cheng 1986). Samples of Avon Reservoir water and sterile mine water were left in separate cutthroughs off a track road in Wongawilli Mine. The Avon algae died within a few weeks. Whilst a number of organisms were able to establish themselves and grow in the sterile water, algae were not amongst them. This finding does not support the theory that algae are prevalent throughout a mine. Similarly analysis of waters from elsewhere in Wongawilli Mine and from other mines in the Southern, Western and Northern Coalfields showed an absence of algae.

Both the numbers and species of algae declined with the decrease in water inflow, suggesting either that the source is finite or that the conduits are being gradually blocked.

Consideration of the response of water flow from Blue-2 and Blue-4 panels has shown their hydrogeological regimes to be very different. The water inflow from Blue-2 panel has been steadily decreasing with time, suggesting that the dominant control is that of a confined aquifer draining to a sink. The water inflow via Blue-4 panel, although gradually decreasing, has responded to rainfall events with a time lag of only a few days, suggesting that its source is a groundwater system being rapidly recharged by rainfall (Williamson 1984). Detailed discussion can be found in Anderson (1986).

The different responses reflect differences in strata behaviour, both inherent and induced, under a similar set of mining conditions. The method of mining, first workings followed by pillar removal, is exactly the same. The topographic setting is the same - steep, narrow ridges bounded by arms of the Avon Storage. Only the geological setting is different. Blue-2 area is bounded by a sill in the upper part of the seam. Blue-4, as well as being bounded by the sill is transected by a major dyke. Total extraction has taken place on one side of the dyke only (Figure 4).

Negligible subsidence has been recorded over Blue-2 panel but a maximum of 231 mm subsidence and 1.94 mm/m tensile strain has been measured over Blue-4 panel and the dyke. Predictions prior to mining suggested a maximum subsidence of 2 m and tensile strain up to 4 mm/m. The magnitude of subsidence and strain actually measured should not have been sufficient, considering the relatively low depth of cover and subcritical area of extraction, to cause strata disruption such as that suggested by the nature of the water inflow.

It would appear that the strata have been more severely affected than the subsidence data indicate. The increase in water inflow during extraction of Blue-4 panel suggests that the dyke was acting as a conduit for water, either directly or indirectly, from the Avon Storage. This is at variance with previous experience in the Southern Coalfield which suggested that faults and dykes do not transmit water to mine workings in any quantity (Wilson 1985; Doyle and Poole 1986). The possibility that a dyke played a part in the inflow suggests that some other stress factor, such as a localised high horizontal stress field or a highly fractured subsurface zone, may be involved. A topographic effect and the possibility of valley bulging effects increasing permeability at depth should also not be disregarded (Whitfield 1986).

4. DISCUSSION

In its natural state the hydrogeological environment of the Southern Coalfields has a series of groundwater heads at progressively lower levels. This is due to the layered strata, massive sandstones interbedded with claystone or shale horizons. Most flow is horizontal and confined within the particular bed. Inherent primary vertical and horizontal permeability are very low, less than 10^{-7} cm/sec. The major control of groundwater movement is secondary, due to fracture permeability.

It is generally believed that mining only substantially affects the lower third of the overlying strata. Although subsidence effects are measurable at the surface, a central zone will be left undisturbed, forming a barrier to downward water percolation. Mathematical modelling of a number of mine layouts has also suggested this to be the case. Modelling has also borne out the premise (from underground experience) that dykes and faults do not transmit water but in effect act as a barrier to water movement.

Borehole investigation of strata permeability and the extent of strata disturbance has also shown that strata disruption sufficient to increase permeability only occurs in the lower third of the strata and that surface fractures, even over areas of multiseam extraction, do not extend from the surface either directly or indirectly to the mine workings (Reynolds 1977).

In the case of the Wongawilli and Bulli seam extractions these premises have been shown to be incorrect. Groundwater monitoring over Bulli seam panel and pillar extraction showed that disruption to the hydrogeological regime extended over at least half of the overlying strata. The fact that this did not result in substantial water ingress is due to the low permeability of the strata, resulting in only slow movement of very small quantities of water. Similarly, although the dyke zones did not result in major water ingress there is evidence to suggest that they did allow the transmission of small quantities of water.

Some increase in water make was expected at Wongawilli Mine because of the nature of the seam. Inflow of surface water, however, was not anticipated because pillar extraction took place outside the 35° Marginal Zone. In addition it was considered that the goaf area was not large enough to generate a high collapse zone (Wilson 1985). However, there are a number of unfavourable conditions in the area which help to explain the inflows. The strata between seam and storage is principally massive sandstones, the main claystone horizons being thin or absent. Therefore, in the absence of a major aquiclude, downward drainage would be unimpeded.

The overall structure of the area is that of a NW trending syncline with a major fault, the Wongawilli fault, along its axis. It is probable that the area of panel extraction is therefore located in a zone of previously induced tensile strain. The dyke in Blue-4 panel, being orthogonal to the structural axis would be predisposed to tensional dilation and this, combined with the effects of total extraction on one side, could lead to the development of openings, as evidenced by the formation of a parallel surface fracture, 80 mm wide and 80 m long. The high porosity cindered coal around the sill has emitted water, although like the seam itself, this has been of an irregular and discontinuous nature. However, in appropriate circumstances an extensive cindered zone could provide a large water storage.

5. CONCLUSION

The predicted effect of mining on the hydrogeological regime of layered strata has been shown to be incorrect in the case of panel and pillar mining at Bulli Colliery and pillar removal at Wongawilli Colliery.

Subcritical panel extraction at Bulli Mine affected the distribution of groundwater levels over a greater thickness of strata than previously assumed. Although the effect was restricted laterally this might not be the case with more extensive mining. As substantial aquicludes were present the vertical extent of groundwater was limited. Water make in the mine is believed to be from local aquifers.

At Wongawilli Mine potential aquicludes were either thin or absent. The thin cover and combination of geological, structural and topographic setting resulted in major ingress of water, both from groundwater and a surface storage, the magnitude and duration of which was not predicted.

In both the Wongawilli and Bulli cases it is suggested that water makes were associated with dykes contrary to the belief that dykes provide a barrier to the transmission of water both vertically and horizontally. At Bulli, water make was associated with drivage through dykes. At Wongawilli, it appears that the dyke may have provided, at least in part, a conduit for water ingress both from the storage and rainfall.

The above investigations of water movement associated with mining have highlighted the necessity for careful consideration to be given to the effect of mining on the hydrogeological regime. In addition it has been shown that in some circumstances, long held premises are not necessarily valid.

6. ACKNOWLEDGEMENTS

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