SOURCE OF GROUNDWATER ENTERING COLLIERIES BENEATH RESERVOIRS

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ABSTRACT

Some collieries in New South Wales, Australia, operate beneath reservoirs of the Sydney water supply. Special conditions are imposed upon mining beneath the reservoirs. Historically, entry of water into these collieries is minor. Dykes and faults normally have no effect. Groundwater systems are maintained even when major fractures appear on the surface over areas of full extraction. In one colliery investigations have been undertaken to prove or disprove that a reservoir is the source of a water inflow. Chemical analyses of the water have shown little change and are different from those of the reservoir. A tracer technique has involved the detection of algae in the mine water. An alternative source of algae is via the mine adit by piped water, the ventilation system and mine traffic. In another colliery a proposed extension of workings beneath a reservoir is under consideration. Accurate surveys of surface subsidence and monitoring of the behaviour of groundwater in bores have been undertaken. The monitoring to date shows that the reservoir is not suffering any loss to the groundwater regime or to the mine workings.

INTRODUCTION

Hydrological aspects of coal mining beneath stored waters were discussed by Williamson (1978). A public inquiry (Reynolds, 1977) had investigated the question of coal mining beneath the stored waters of five dams of the water supply for Sydney, New South Wales, Australia. Williamson concluded that it was practicable to mine beneath stored waters without causing undue leakage. Recommendations arising out of the inquiry included approval for extraction of coal with specified safeguards so as to maintain security of the stored waters. The recommendations were based on considerations of proportion of coal to be extracted from the deposit, depth and permeability of solid cover over the coal seams and minimal roof disturbance.

Since that time the New South Wales (NSW) Government established a Dams Safety Committee (DSC) with authority to specify conditions under which coal mining may be carried out beneath dams and their stored waters. About 400 Mt of coal resources lie within the area of its jurisdiction. The DSC's functions relate to the safety of dams and reservoirs. It is not concerned with the promotion of coal mining (Cantwell and Whitfield, 1984). At a public meeting in 1983, it presented criteria on which it would base considerations of mining proposals. Conflict between the desire of mining companies to extract coal and the DSC's desire to maintain integrity of the storages, each without detriment to the other, has been resolved only partially.

This paper deals with two cases on the NSW Southern Coalfield, namely Wongawilli and Bulli collieries (Figure 1). The stratigraphic sequence is illustrated in Figure 4 for Bulli colliery, where the Bulli coal seam is about 2.5 m thick. At Wongawilli colliery the Wongawilli coal seam is 10 m thick, of which the basal 3 m is mined, and is 30 m deeper than the Bulli seam. In both areas the strata are almost horizontal, but are intersected by faults and dykes. The dominant rock type of the overlying strata is sandstone having a permeability of about 10^{-8} cm per second.

Generally, the observed entry of water into underground mine workings of the Southern Coalfield is from the upper section of the Wongawilli coal seam, mostly in the form of roof drippers or seepages. Minor flows may be initiated by full extraction, but usually cease after a few weeks. Geological discontinuities provide barriers, rather than paths, for water flow. Faults and dykes are generally dry but, if wet, exhibit small seepages. At the time of the public inquiry, tests in vertical and inclined boreholes in areas of full extraction showed that strata that were disrupted sufficiently to allow drainage of water into mine workings were confined to the lower half of the strata above the workings. Above the disrupted zone, strata of low permeability were shown to provide such a retarding effect that the groundwater system was maintained. Since the overlying strata are known to be of low vertical permeability throughout, mining techniques can be adopted such that the relatively undisturbed strata prevent undue seepage losses from surface storages (Williamson, 1978).

THE WONGAWILLI CASE

General

An unusual flow of water into Wongawilli colliery occurred after the workings, 130 m deep, had extended approximately 100 m beyond the boundary of Avon Reservoir. Pillar extraction, laterally offset from the reservoir and its marginal zone, caused a sharp increase in the rate of flow in December 1982, initially fluctuating around 80 000 L/hour, reaching a peak of 100 000 L/hour, decreasing to 70 000 L/hour after a year and to 46 000 L/hour by March 1985. The proximity of its location to Avon Reservoir caused sufficient concern for the DSC to place restrictions upon future mining.

Because the Wongawilli seam can be wet and can readily transmit water as a result of goaf formation, the groundwater regime within the seam and adjacent strata has an irregular expression. Average entry, in the form of drips and small flows, is normally up to about 4 000 L/hour, although rates of 500 L/hour would be more common. Dykes and faults in this area normally do not transmit water. Figure 2 shows the position of the mine workings, particularly pillar extraction, and the position of Avon Reservoir. The major component of the flow occurred in Blue 2 Panel, in a much more confined area of pillar extraction than the minor component in Blue 3 and 4 Panels. The nature of this experience was typical, but the magnitude and sustained period of the flow were abnormal. A significant geological feature here, however, is the conversion of part of the seam section to cinder, associated with igneous intrusions in that part of the mine. The cinder is porous and permeable.

In Blue 2 Panel the flow declined to 27 000 L/hour by March 1985. The decline was not regular, but remained constant for limited periods after heavy rainfall. Since the Avon storage level remained relatively constant, the arrest of the decline of flow rate is attributed to a balance between recharge and draw-down of the groundwater system, associated with increased head of water in the superficial strata.

In Blue 3 and 4 Panels the flow rate declined to 19 000 L/hour by March 1985, but showed temporary increases in flow following heavy rainfall. This part of the mine workings therefore showed a sharper response to recharge than Blue 2 Panel, attributable to a greater area of pillar extraction in Blue 3 and 4 Panels. Because of its response to recharge from heavy rainfall, water entry in Blue 3 and 4 Panels is expected to continue indefinitely in varying degrees. Surveys on the surface showed subsidence over Blue 3 and 4 Panels, but not over Blue 2 Panel. No point in the reservoir bed had been allowed to subside.

The DSC stated that the coal mining industry must prove that leakage of the reservoir has not occurred, otherwise it will take a conservative attitude towards future applications for mining beneath reservoirs and their marginal zones. Technical investigations were instituted in an endeavour to prove the source of the mine water.

Technical Investigations

Alternative approaches have attempted to prove or disprove that Avon Reservoir is the source of mine water.

(i) Mathematical: A water balance of the mine and Avon Reservoir was considered, but the quantities were not sufficient to allow resolution. If the Wongawilli inflow were to be derived solely from the reservoir (an extreme and unlikely case), the level of the reservoir would drop 0.009 mm per hour, or 6.8 mm per month, which is much less than the evaporation rate of 70 mm per month. A loss of 100 000 L/hour is equivalent to 2% of Avon Reservoir's "safe draft", a term relating to the maximum rate at which the reservoir can be continuously depleted without emptying.

(ii) Water Quality: Chemical analyses of the mine water have shown little change for a period of over two years and have remained significantly different from those of Avon Reservoir. Consequently, flushing of natural groundwater from the coal seam and adjacent strata does not seem to have taken place. The persistent chemical differences refute a suggestion of fissured strata as a rapid flow path from the reservoir to the workings. Table 1 quotes typical analyses of the mine water and reservoir water.

If future chemical analyses show the saline contents of the mine water to remain more or less constant, groundwater would be confirmed as at least the dominant source.

(iii) Tracers: Radioisotopes or dyes are unacceptable media for testing a possible connection between the reservoir and the mine. Presence of algae has been attempted as an alternative tracer. Cheng (1984) sought further evidence (if any) of leakage of Avon Reservoir into Wongawilli colliery. He identified live and dead species of algae, bacteria and

Table 1. Chemical Analyses (in mg/L, except pH)

	Mine Water	Reservoir Water
pH	7.7	6.2
Cl	25	19
SO_4	<2	<2
Ca	24	1
Mg	11	1
Na + K	22	6
Alkalinity (as Ca CO_3)	135	5
Total dissolved solids	190	33

protozoa in the mine water and used this evidence to postulate passage of water through minute cracks and fissures in the rock strata between the reservoir and the colliery workings. Data from various sampling stations caused him to rate his correlation of mine water and reservoir water as weakly suggestive to strongly suggestive.

The case for algae as a tracer is based upon their mere presence in the mine water, but depends upon disruptions to normal fractures of the groundwater system to devise a flow path for their entry. The difficulty of avoiding contamination of the mine water before sampling weakens the case. Live algae or spores can be introduced into the mine from the adit in a number of ways, such as by piped water, traffic of men and materials and by the ventilation system.

All kinds of surface water can be assumed to contain algae. Jones (1984) prefers to explain presence of algae in mine water by dispersal from sources infecting the mine via its adits, recognising that a surface reservoir can be the original source for such introduced water. Once introduced, algae are able to find their way into water emitted from the strata. Longevity of algae in darkness is variable. An underground mine is likely to be less favourable than most habitats, light being the limiting factor. Algae species may be either slow-dying if suffering from lack of light, or may survive in the intermittent low intensity of light prevailing in the mine. Many cases exists where algae have actually grown with little or no light.

(iv) Hydrogeology: The Wongawilli seam would not normally be regarded as an aquifer. Nevertheless, in places it shows emission of water into mines. The main factor controlling movement of water through this seam into mine workings is fracture permeability. The caving of the upper part of the Wongawilli seam upon extraction of pillars allows significant fracture permeability to be superimposed on its original state of low permeability. In some cases pumping arrangements have been necessary, but documentation is seldom available since mining operations have not been interrupted for intolerable periods.

The rocks of the overlying strata have extremely low primary permeability, usually about 10^{-8} cm/second. Surface tensile fractures do not provide hydraulic connection to the workings, as has been shown in previous tests in surface bores drilled above mine workings. For example, in a case where surface subsidence was measured at 2.1 m at a height of 277 m above double seam extraction of supercritical width, and where substantial tension fractures were evident at the surface, the upper half of the strata effectively retained the groundwater system (Williamson, 1978).

No goaf in Blue Panels is sufficiently large to generate a high immediate zone of collapse above the workings, yet water inflow was initiated with goaf formation.

A crack 100 mm wide at its maximum development appeared on the surface above Blue 3 and 4 Panels, associated with a dyke 2 m wide at the edge of the goaf. The visible depth of the crack was 2.5 m. Such a crack is associated with lateral tensile strain in the subsided surface strata.

Measurements of zero surface subsidence above Blue 2 Panel indicate retention of the massive state of the strata. Over Blue 3 and 4 Panels, maximum measured subsidence is 220 mm. The area of this subsidence lies entirely outside the high water mark of Avon Reservoir.

Discharge from a groundwater source normally would be expected to decrease with time, unless in equilibrium with recharge. Such decrease has occurred. Progressive decline of rate of inflow was arrested twice after heavy rainfalls, indicating responses to recharge from the rain water, with a time lag of about two weeks.

The surface crack over Blue 3 and 4 Panels may well have facilitated entry of rain water into strata that had already relaxed as a result of subsidence. In this event, increase of the hydrostatic head proportionally affected the progressive decline in flow rate. Since there is no relationship between variation in head of water in Avon Reservoir and the pattern of decline of rate of inflow, any component from Avon Reservoir is regarded as minor.

Evaluation

Postulation that water may have gravitated rapidly from Avon Reservoir into the mine through the intervening strata is not supported by geological, hydrological and mining principles, or by chemical analysis. If the mine water flowed through natural fractures between the surface and the seam, there should be a relationship between the area exposed by mine workings and water-make. Since this is not the case, entry of surface water into the mine must rely upon mining-induced cracks for access, particularly if algae are valid tracers. Above Blue 2 Panel, the point of the major component of the inflow, surveys showed that the surface showed no vertical or lateral strain as a result of full extraction.

The strata have been measured to be practically impervious in the massive (or pre-mining) state. Fracturing as a result of mining need not necessarily be planar, but must provide a hydraulic connection between the surface and the mine. Williamson (1978) described areas where full extraction, up to supercritical width, caused tensile cracks to develop on the surface above the workings. In such cases, hydrological tests in bores showed that the surface fractures did not extend directly or indirectly to the workings and that no significant leakage would occur if a water storage were superimposed over the cracked surface. The groundwater system was maintained within the central zone of the overburden, due to the retarding effect of layers of low permeability. In no other cases in the region have surface fractures been shown to provide a hydraulic

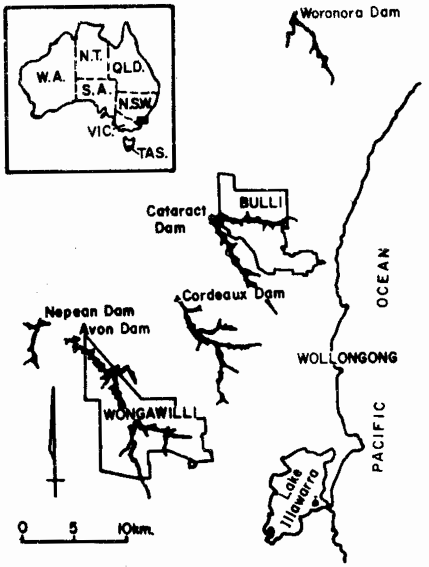

Fig. 1 Locality map. Part of coalfield showing reservoirs and Wongawilli and Bulli colliery holdings.

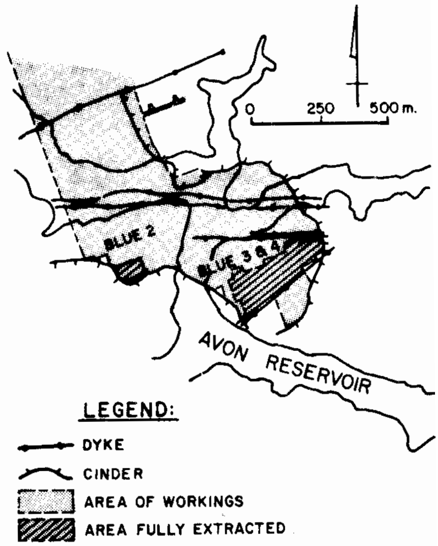

Fig. 2 Wongawilli colliery, underground workings of Wongawilli seam, and Avon reservoir.

connection to mine workings 120 m or more below the surface.

Algal analyses of the mine water can support the postulation of a surface connection. The postulation is contested because of the ability of algae to find their way into a mine by various media via the adit.

If the source is static, for example water-bearing strata in or about the Wongawilli seam, the flow should reduce and eventually cease. If the source is permanent, for example a reservoir, the flow should continue unabated. The variation in rates of flow in the past two years is consistent with the discharge from a natural groundwater system.

Blue 2, 3 and 4 Panels encountered cinder derived from a sill that had intruded the worked seam. A wide extent of porous and permeable cinder is sufficient to explain the experience of an unusually large and sustained water inflow. The results of the investigation therefore point to a groundwater system being the source of mine water, without the necessity to tap surface strata embracing the bed of Avon Reservoir.

THE BULLI CASE

General

Figure 3 shows the workings of the Bulli seam in Bulli colliery, wherein two panels have been fully extracted in the vicinity of Cataract Reservoir. This work was undertaken under conditions laid down by the DSC, which is now considering terms under which further mining should proceed. The DSC's considerations include the anticipated extent and nature of roof collapse and estimated rates of seepage of water in the vicinity of dykes or faults.

The Bulli seam is 300 m deep and is characteristically dry and dusty. Its roof strata consist of sandstone and shale, rather than coal and shale of the Wongawilli seam working roof. Geology of the overlying strata is uniform. No abnormal stress zone exists. Since no dyke, fault or joint in the history of Bulli colliery has been observed to allow transmission of water, and in this area dykes and faults are of a normal nature, any interruption to the groundwater regime by geological discontinuities is unlikely. However, the DSC is concerned that a precedent must be avoided. The proportion of extraction of coal and the geometry of existing and proposed panels and pillars were designed so as to limit surface vertical subsidence to a maximum of 100 mm, lateral strain to 0.3 - 0.5 mm/mm, and to avoid the development of a network of mining-induced cracks.

Extraction to date has been accompanied by tests of the hydrological environment around Cataract Reservoir. Vertical subsidence and lateral strain of the surface are being monitored by precise level and distance surveys. Bores were drilled at sites shown in Figure 3 in order to test the groundwater regime and to identify any changes caused by the mining operations. Such monitoring has been described by Cantwell and Wilson (1982), who are not aware of any similar monitoring of groundwater or subsidence in bores over a mining area elsewhere in the world.

Monitoring Programme

The purpose of groundwater bores at three sites was to provide a vertical two-dimensional pattern of the distribution of groundwater head. The presence or absence of aquifers was tested by placing a packer at progressive intervals of 18 m during the drilling, then testing by pumping techniques using pressures ranging from 50 to 450 kPa with increasing depth. The bores did not encounter recognisable aquifers. The water pressure tests showed very low permeabilities, the values being less than 10^{-5} cm per second in the upper strata and less than 10^{-8} in the central and lower strata. Nevertheless certain horizons were selected for placement of piezometers, not only to monitor existing heads but also to detect any subsequent mining-induced changes in the groundwater system. Each piezometer was placed in a 10 m bed of sand bounded by a column of cement. The assembly of the piezometer tubes incorporated ring magnets at 12 m intervals with the intention to monitor downhole differential subsidence during and after mining. The arrangement of the piezometers is shown in Figure 4 which also shows the stratigraphy.

Downhole monitoring has been carried out with the use of a special reel of a survey tape and electrical cable encapsulated in plastic.

Sites 1 and 2 have now been flanked by panels of full extraction. Depths of the magnets to denote subsidence settlement points show consistent readings. The surface has subsided by 40 mm, but no differential subsidence has been detected. The sequence of strata covered by the magnets is therefore subsiding massively, with no detectable bed separation.

Due to the low permeability of the strata, the artificial levels of water left in the bores took time to find their natural levels. Figure 5 shows the graphical representation of measurements of the water columns in relation to Australian Height Datum (AHD). For the sake of clarity, the results of monitoring at site 1 only have been shown.

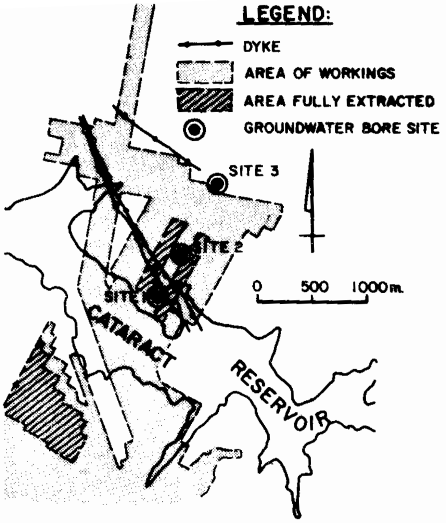

Fig. 3 Bulli colliery, underground workings of Bulli seam and Cataract Reservoir.

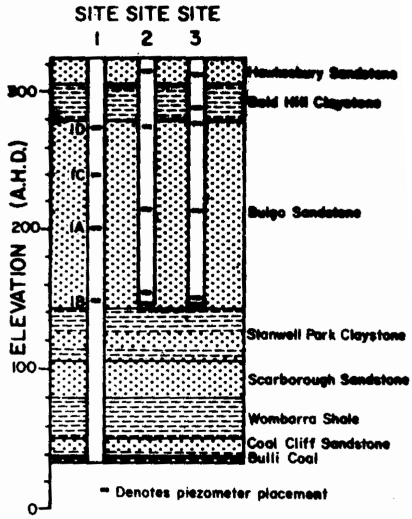

Fig. 4 Bulli groundwater bores, arrangement of piezometers and stratigraphic sequence (after Cantwell & Wilson, 1982).

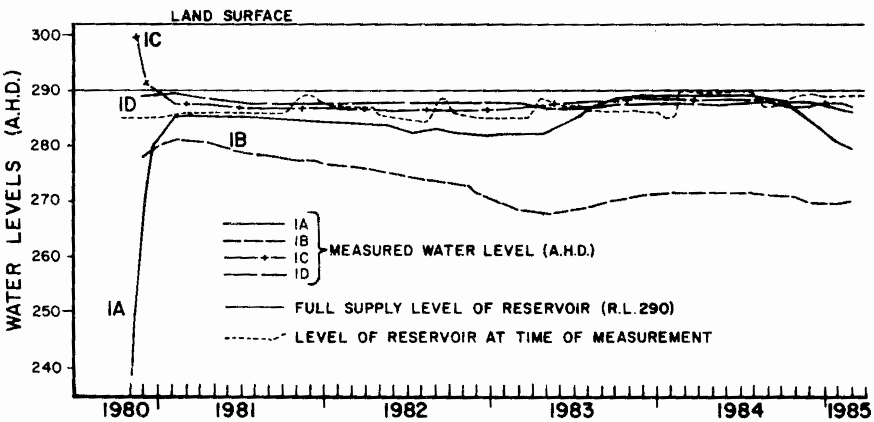

Fig. 5 Bulli groundwater bores, water levels monitored at Site 1.

The highest piezometers have shown some rises in water level at times, although not clear in Figure 5 because of its scale. The changes have been in sympathy with heavy rainfall, showing effects of topography and of recharge in the sandstone capping of the banks of Cataract Reservoir. The central strata have shown comparative stability.

Except for site 3, the lowest piezometers show the effects of mining. Reversal of the pore pressure gradient above the mine openings is reflected in a decrease in water level.

Evaluation

Groundwater levels in the lowest horizons are reflecting the changes in pore pressure gradient that are naturally brought about by the mine workings acting as a sink. The shallow piezometers show no such response, but have shown effects of recharge and discharge to the surface layer of sandstone. The groundwater system in this sandstone is topographically and climatically controlled and its groundwater heads are maintained above full reservoir levels.

The results of the monitoring thus lead to the conclusion that groundwater is not finding its way downward through the strata, but is contributing to the reservoir supply from the upper strata. The reservoir is not suffering any loss to the groundwater regime. Similarly no leakage occurs from the reservoir to the mine workings.

This conclusion is verified by the observed dryness of the mine workings. Thus, relaxation of the strata from the roof upwards, as indicated by decrease in hydrostatic head at the base of the Bulgo Sandstone, has not led to perceptible transfer of water into the mine.

Geological structures such as joints, dykes or faults have had no effect.

Williamson and Thorne (1984) concluded that available data were evidence of the effects of pore pressure reduction because of the "sink effect" of the mine workings, and there was no appreciable change in the degree of hydraulic connection between the zones monitored, or any loss from Cataract Reservoir.

Monitoring and underground observations will continue during subsequent extension of the full extracted areas beneath the reservoir.

ACKNOWLEDGMENTS

This paper is published with the approval of the Broken Hill Proprietary Company Limited. Inclusion of some material arising from personal communication with Mr. W.H. Williamson, in addition to use of cited references, is acknowledged.

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