LONGWALL MINING UNDER THE CATARACT RESERVOIR

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ABSTRACT

Coal mining below the ocean floor and under water impoundments has been successfully carried out by caving methods in many parts of the world. In Australia, mining of vast amounts of coal reserves under dams and stored water is administered by the Dams Safety Act of 1978 and permission to mine such reserves has to be obtained from the Dams Safety Committee. Until recently, mining overlain by stored bodies of water has been carried out by partial extraction systems only. This paper describes a scheme where longwall mining has been carried out in the Bulli coal seam some 250 m below the Cataract Reservoir. So far, 13 longwall blocks have been extracted without any increase in water influx to the mine and a plan exists for extracting another 4 longwall panels. Mining under Cataract Reservoir is now considered to be a benchmark throughout the industry which will encourage opening up new underwater coal reserves for safe and economically sound extraction.

INTRODUCTION

Mining has been carried out quite successfully under reservoirs of water, aquifers, rivers and under the sea in various parts of the world. The problems associated with structural stability, safety and that of mining operations have been adequately dealt with as part of mining under these water bodies. When mining underground there is always the potential risk of water entering the workings from both surface and ground water sources. However, when mining is carried out under large bodies of stored water, there is increased risk of water entering the mine due the continued presence of the source of water and the presence of induced water conduits. Once an inflow is established, it is difficult to control the large quantities of water entering the mine and carrying out mining operations with economy and safety. However, many underground mines overseas have successfully been able to avert water away from the workings to prevent the problems associated with water in mines through adequate mine design and monitoring. Adequate thickness and petrography of protective barriers and their integrity is one such method that has been used to prevent water entering the mine or to minimise the flow (Singh, 1982; Whittaker, Singh and Neat 1983).

In Australia, sizeable coal resources in the Southern Coalfield of NSW are overlain by bodies of water where mining has been restricted to first workings only (Mining Act; 1992). In this coal field, Cordeaux, Cataract, Avon and Nepean Dams store water for domestic supply to the surrounding areas by the Sydney Water Corporation. Despite the cover between underground mining operations and the dams, which exceeds 250 m, the major limits have been imposed on the extraction of coal by the Dams Safety Committee (DSC, 1978) to minimise any subsidence that may occur during the mining operations. This paper describes a case history of longwall mining of the coal reserves overlain by a dam and stored water with minimal disruption to surface structures.

WORLDWIDE EXPERIENCE IN WORKING IN THE VICINITY OF LARGE WATER RESERVOIRS

Coal mining operations below the sea utilising total caving systems have been carried out successfully in the U.K. Canada, Japan, Chile, and the former Soviet Union (Kapp and William, 1972; Singh, 1982 and 1994). Total extraction of coal has also been carried out beneath rivers and estuaries in Druisburgh, Germany, under the Tyne River and the Lougher River (Singh and Kendorski, 1981). A brief account of some of these experiences is presented in this section.

Under Sea Workings in the U. K.

The extraction of coal from workings under the sea in the North East of England has been successful in many instances (Watson, 1979). In 1984, under sea coal production came from 10 small to medium capacity coal mines producing 1500 t/d to 5000 t/d. Large quantities of water have been associated with these workings but the coal has been of good quality and some 210 million litres /day of mine water have been pumped out to obtain 8 million tonnes/y of coal from 6 coal seams. This represents some 9.3 tonnes of water per tonne of coal extracted in comparison to the national average of 2.5 tonnes for the whole of the U.K (Singh, 1994). The entry of water into longwall workings under bodies of water occurred due to combinations of factors which include mining in close proximity to old abandoned water logged workings in adjoining collieries, aquifer located in the Coal Measures and on aquifer outcropping on the surface which could act as a water source. Subsidence caused by mining creates a destressed zone around the excavation which can allow the water to flow into the mine workings due to formation of flow conduits. Protective layers and barriers are one of the main methods that have been used to prevent water from entering the mines or to minimise the flow. These mines have also coped with the presence of faults, dykes and joints which act as water conduits by leaving an appropriate thickness of coal pillars against the geological structures and by changing the direction of mining to minimise the inflow. The design of all under sea workings in the U. K is carried out in accordance with the NCB Production Department Instructions (NCB; 1971, Singh and Atkins, 1982)

The depth of mining under the sea floor in North East of England varied from approximately 125 m to 410 m. The limit of cover between the sea bed and the site of extraction within the mine determines the selection of mining method. The deeper mines in this area use longwall method of mining. Face length ranges from 120 m to 260 m with the exception of one mine where the face length was 64 m. Mines with shallow cover have been forced to adopt room and pillar mining to reduce the potential for water inflow or inrush. The majority of mines use a combination of Dosco dint header and Dosco road headers or continuous miners for development. The deeper collieries sometimes use the drill and blast method for development. Some 70% of all output from under sea workings is derived from the longwall method of mining and 30% from the room and pillar mining. One of the major design factors taken into consideration for using the longwall system of mining is to select the width of extraction and longwall pillars in such a way so as to control the subsidence strains to < 10 mm per metre at the sea bed or at the bottom of aquifer, thus reducing the fissures developed resulting from this strain. Mudstone and seatearth strata layers were also utilised where possible to reduce the flow of water as these strata are aquicludes and aquitards and were located between the workings and the source of water and can act as water barriers. The experience of under sea workings in England has indicated no record of inrush into workings by sea water (Whittaker and Aston, 1982). It has been noted that water inrush has occurred from Permian aquifers and Coal Measure aquifers above the coal seam being extracted. In many occasions, these inflows followed the main and periodic roof falls in the goaf behind longwall workings (Singh, 1986 and 1989). In general some 51% of under sea mine workings in NE England experienced wet conditions. The rate of inflow of water to under sea workings gradually increased frm 9 tonnes to 14 tonnes of water per tonne of coal extracted which forced closure of all under sea mines between 1990-to 1994 (Singh, 1994).

Nova Scotia - Canada

In Canada coal mining has been carried out in Cape Breton Island in the State of Nova Scotia under the ocean floor since 1720 (Maclean, 1982). The annual coal production for three underground coal mines averaged 11,000 tonnes per day amounting to some 3 millions tonnes per annum. Four major coal seams have been extracted namely, Bonnar Seam which is 3m thick, Hub Seam which is 2.7 m thick, Harbor Seam whose thickness varies between 2.1 to 4.2 m and the bottom most Phalen Seam 1.5 m to 2.1 m thick. Under Canadian Mining legislation, these mines are designed with a minimum thickness of protective barrier between the ocean floor and the top of the coal seam as 97 m per metre thickness of coal extracted. One of the important requirements of under sea workings is that the overlying protective barrier above the coal seam must contain beds of shale or other impervious materials.

In No. 6 Colliery, coal was produced by two advancing longwall faces with face lengths of 212 m using 225 kW ranging drum shearers and 300 tonne shield supports. The gate end development was carried out using a Dosco Road Header in the main gate and using drilling and blasting, and loading with Eimco Loader in the tail gate. The average depth of this mine was 760 m below the sea bed. The annual production from this mine was some 1.0 million tonnes per year, employing 1200 workers and achieving overall Output per Man-Shift (OMS) of 3.0 tonnes. In this mine, the average distance of the coal face from the mine portal was some 10 km.

In Lingal Colliery the annual production of 1.4 million tonnes was achieved from three 212 m wide advancing longwall faces at a depth of 485 m below the sea bed. The gate-roadway development work was done using Dosco Mark II road headers. The Output per Man -Shift achieved from these workings was 6.3 tonnes. In Prince Colliery, workings were carried out in the Hub seam some 163 m below the ocean floor from a longwall retreating face. The face was equipped with 300 tonne, 4-legged chock shields and a double-ended ranging drum shearer. The heading development in this mine was carried out using a Dosco Dintheader and a Lee Norse continuous miner. The average distance of the coal face from the mine portal was 4 km. The mine employed some 400 people and produced an output of 2000 tonnes /day achieving the OMS of 5.0 tonnes.

Chile

Longwall mining operations were carried out in under sea workings at great depth at Lota, near Conception where three coal seams have been extracted. The minimum permissible thickness of protective barrier for under sea workings was 140 m and special precautions were taken near geological faults and mine boundaries by providing safety barriers of sufficient thickness. (Kapp and Williams, 1972).

Japan

In Japan coal has been mined under the sea by the longwall method from a 4.2 m thick seam at an average depth of 330 m below the ocean floor. The main legislative precaution against inundation was to require drilling of advance precautionary bore holes ahead of the longwall workings.

UTILISATION OF MINERAL RESOURCES UNDER STORED WATER

There are coal seams under reservoirs and dams within New South Wales that are economically viable. Mining under stored bodies of water is possible without serious consequences to the supply of water and with safe extraction of mineral resources if mining is properly undertaken in a planned and controlled manner. There are, however, risks and it is because of these risks that restrictions are applied to mining operations. These risks concern the mining operation, the community and the environment, especially the loss of water from the storage body. Therefore, in NSW, Australia restrictions are applied to mining operations to minimise these risks through the Mining Act 1992 and the Dams Safety Act 1978. These procedures are discussed in the following sub-section.

Marginal zone and lease under the Mining Act 1992

Determination of marginal zones

Before the public inquiry by the Reynolds Commission 1974, no mining was permitted under stored bodies of water. Figure 1 indicates a marginal zone around stored water as determined by an angle of draw of 35° taken from the boundary of the stored water at full storage level.

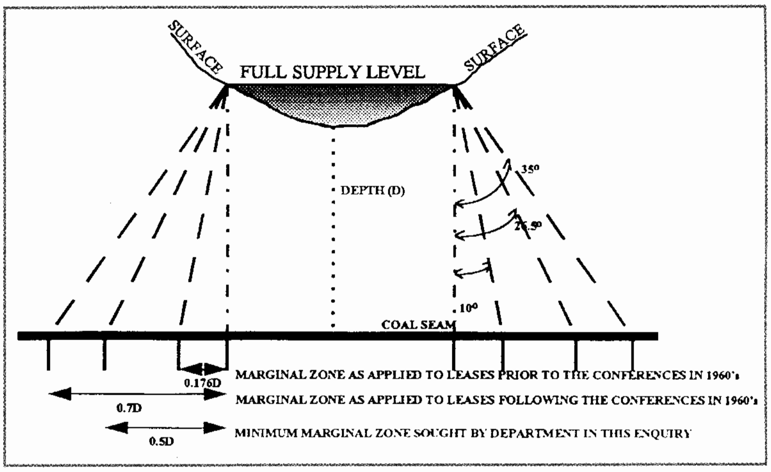

Figure 1. Effect of angle of draw on the marginal zone (After Loveday et al 1983).

Formation of restricted or notification zones

The Dam Safety Committee has defined a restricted zone as the area on the surface as determined by the angle of draw of 35° plus an additional width of 0.5 x depth of the coal seam. Under the Dam Safety Acts 1978 the restricted area below a water reservoir can be classified safe area outside which mining can be carried out in a normal manner and inside the restricted zone where mining can only be carried out with the permission of the Dams Safety Committee. Figure 2 shows the notification area required from the Dams Safety Committee in the Southern Coal Field.

Procedure for mining under stored water

In New South Wales, the issue of mining leases is administered by the Department of Mineral Resources under the Mining Act 1992. Before inviting tenders for a mining lease in respect of land within the notification area the Minister must inform the Dams Safety Committee. According to the Section 80 of the Mining Act 1992, the committee may recommend to the Minister that the mining lease for coal be amended by the variation of, or addition to the conditions of the lease so as to prevent or mitigate any damage to a prescribed dam.

The Dams Safety Committee comprises 8 members drawn from the regulatory authority, Water Board, Pacific Power as well as mining groups (Dams Safety Act, 1978). This committee has adopted a view that each application for permission to mine under dams and water reservoirs should be evaluated by the committee on the individual merits. In order to

Seam	Cataract (Mt)		Cordeau (Mt)		Woronora (Mt)		Total Reserves(Mt)	
	10°	35°	10°	35°	0°	35°	10°	35°
Bulli	20.67	50.19	6.89	14.76	9.84	46.25	59.84	164.85
Balgownie	5.91	19.68	7.38	16.73	6.89	30.51	20.18	66.95
Wongawilli	22.62	69.88	30.51	75.78	–	–	77.25	202.74
						Total	157.27	434.54

Table 1 Reserves of coal in marginal area in the Southern Coalfields (Reynolds, 1976).

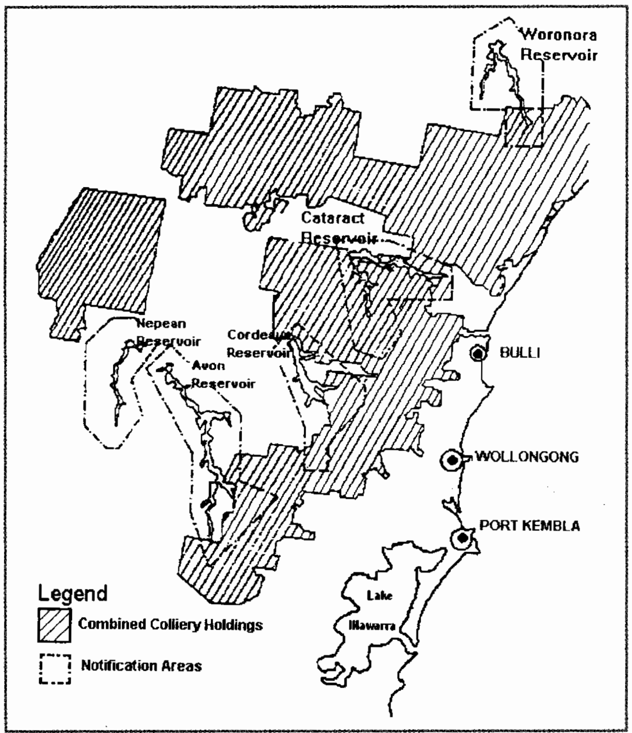

Figure 2. Notification area under stored water in the Southern Coalfields.

allow a meaningful assessment an applicant is required to submit supportive material as follows:

i) The proposed mining method with an action plan.
ii) Details of local geology in the area including stratigraphy, faults, dykes, surface topography and joints and their orientation and spacing.
iii) Prediction of surface subsidence and strains at key stages of mining.

The Dams Safety Committee considers the application along with the supportive material and makes its recommendations to the Minister of Minerals Resources for approval, conditional approval or rejection.

The conditions are usually related to a monitoring surface subsidence, identification of geological structure acting as conduit of water and ground water inflow, and then to verify the predictions. Typical conditions included in the permission are:

i) Production of regular mining plans identifying the progress and plotting the geological structures encountered.
ii) Observation of water inflows including seepage and their sediment contents.
iii) Measurement of surface subsidence and strain.
iv) Water balance study of the mining operations with special reference to the restriction zone.
v) Monitoring of the piezometric levels in the borehole overlying the production district showing the fluctuation of ground water pressure level as a consequence of mining.

Statutory limitations to coal mining under a reservoir

Inside the restricted zone mining can be carried out within the following rules but with the explicit permission from the Dams Safety Committee.

i) No mining in areas of 60 m or less cover,
ii) Bord and pillar mining is allowed at depths greater than 60 m. The bords may have a maximum width of 5.5 m and pillars may have a maximum width of 15 x the extracted seam height or 1/10 the depth of cover, whichever is greater.
iii) Panel and pillar mining is allowed at a depth greater than 120 m. The panel sizes are to be not greater than 1/3 x the depth of cover. The pillar sizes are not to be of a length co-extensive with that of the panel extracted and a width not less than 1/5 x the depth of cover, or 15 x the height of extraction, whichever is greater. Panel and pillar mining is now allowed with widely spaced cross-cuts to enable underground development.
iv) The marginal zone around the stored water should be determined by an angle of draw of 35° taken down from the boundary of the stored water at full storage level.
v) There should not be any mining or driving of access roads beneath a dam structure within a coal pillar at a point 200 m away from the edge of the structure and an angle of draw of 35°.
vi) The depth used in the panel calculations is taken as the least solid cover and for the pillar width calculations, the greatest solid cover is used.

Factors Used for the Design of Mine Workings Under Stored Water

The main objective of mining under bodies of water is to safely extract as much coal as possible without disturbing the overlying strata to a degree so that water inflow to the mine workings becomes out of control. There are two main possibilities in relation to the inflow of water. The first is the possibility of water ingress through pre-existing arrays of discontinuities or geological structures such as dykes and faults. The second possibility is that the water enters the mine through tensile zone created by the sub-surface subsidence associated with longwall mining. These factors have been considered in detail in previous publications (Whittaker, Singh and Neate, 1979; Singh and Aktins, 1982; Singh and Kendorski, 1981; Singh, 1986 and 1989). The main conclusions of the above work is to incorporate the following considerations into the design of mine workings under bodies of water:

i) Geometry of workings causing destressed zone between mine workings and the water reservoir,
ii) Sufficient thickness of barrier between the reservoir and the workings,
iii) Nature of rock material in the barrier (mudstone, shale and claystone)
iv) Strain at the bottom of the water accumulation,
v) Presence of geological features forming conduits of water such as faults, dykes and joints.

LONGWALL MINING AT BELLAMBI WEST COLLIERY

Site location

Bellambi West Colliery is situated in the Southern Coalfields of NSW some 14 km west of Wollongong. The mine is over 100 years old and has produced some 60 million tonnes of coal since its inception and provides jobs to some 315 people in the local community. The colliery also indirectly boosts about 1000 other jobs in the area due to the continuous operation of the mine. Some $A 52 millions per annum were injected to the local economy through employees wages, direct and indirect taxes and the purchase of goods and services. In the late 1980s good quality coal started to become depleted in the western district of the colliery and the quality requirements of an international customer could not be met. At that time the best quality reserves were locked up under the Cataract Reservoir as a coal reserve in the restricted zone. As a consequence, the management applied to the Dams Safety Committee for permission to mine coal reserves under the Cataract Reservoir in 1990. In May 1991, the Minister of Mineral Resources consented based on the recommendations of the Dams Safety Committee, allowing extraction of the first seven panels and the development of the eighth panel. The Chief Inspector of Coal Mines subsequently approved the extraction of the first seven panels by the longwall system of mining. The development of roadways in the Cataract district commenced in March 1992 and by March 1993 the development of first longwall panel was completed. The mining in the Western district ceased completely in June 1993 and panel LW 501 in the Cataract district commenced production concurrently. At present, the entire production of the colliery comes from the Cataract district (Jakeman, 1996 Australian Longwalls, 1999).

Stage 1 approval and conditions Imposed

A mining proposal based on the statutory requirement developed by the Reynolds Commission and presented in subsection 3.3 was submitted to the Dams Safety Committee and the Chief Inspector of Coal Mines for approval. Table 2 shows the major mine design parameters including the minimum and maximum depth below the surface. It may be noted that the minimum depth below the surface was used to calculate the panel width and the maximum depth of the panel was used to calculate the width of the rib pillar with widely spaced cut throughs.

In an initial plan of the first 8 faces, a 105 m wide face was developed with 70 m wide rib pillars. In the subsequent design, a face width of 115 m with 65 m x 100 m wide rib pillars was incorporated in the mine plan.

Approval conditions

Mining under the Cataract Reservoir was authorised by the Minister of Mineral Resources, NSW subject to the following conditions:

- Underground seam mapping was to be carried out to extrapolate the known geological features which may influence the stability of the strata below the reservoir.
- An in seam seismic survey using boreholes within the seam to identify any structures that may lie within but not revealed by previous extraction from areas around the reservoir.
- A detailed surface subsidence grid to accurately measure subsidence around the perimeter of the reservoir.
- Mine water monitoring to measure the water inflow into the mine by means of water balance studies of underground operations.
- This was carried out by measuring the quantity of water used for dust suppression and drinking. The quantity of water pumped out of the mine during normal operation of the mine was also measured. Any increase in this imbalance could be attributed to inflow from the reservoir to the mine through arrays of mining induced fractures.
- Insitu strain measurement was carried out on the dam structure using strain gauges capable of measuring strain in 0.1 mm per metre.
- Ground water monitoring using piezometers to measure variation in water pressures contained within the strata above the area to be extracted.

Panel	Depth (m)	Panel width (m)	Pillar width (m)	Width and depth ratio as % Panel W/d Pillar W/d	
501	325-445	110	66	25 to 33 %	14 to 20%
502	325-410	110	66	33 to 25%	16 to 20%
503	330-430	110	66	25 to 33%	14 to 20%
504	335-445	110	66	25 to 33%	14 to 20%
505	340-440	110	66	25 to 33%	14 to 20%
506	325-445	110	66	25 to 33%	16 to 20%
507	295-415	100	60	25 to 33%	14 to 20%
508	325-445	100	60	22 to 33%	14 to 20%

Table 2 Longwall design parameters for mine workings under Cataract Reservoir.

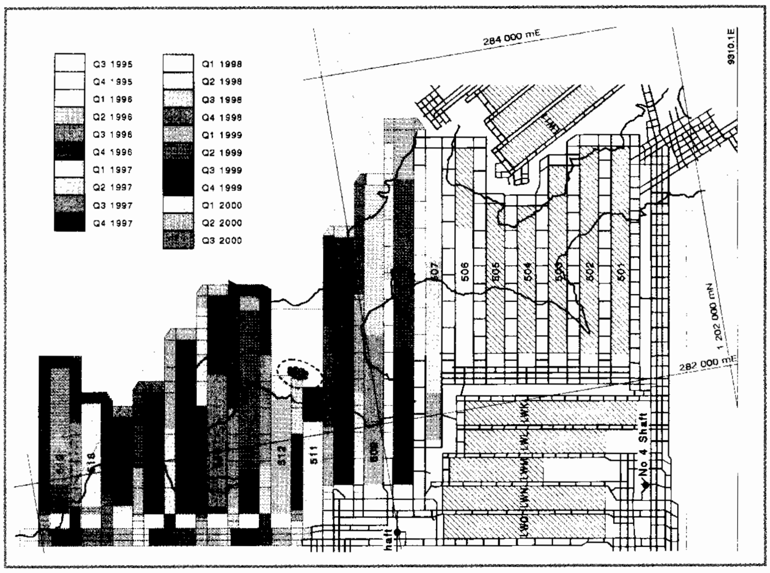

Figure 3. Mine plan of longwall faces in the Cataract District at Bellambi West Colliery.

- Pillar loading and deformation using gauges within the chain pillar remaining after longwall extraction to measure deformation resulting from the extraction process.

Developments

Development of the first longwall face LW 501 was carried out between March 1992 and March 1993. Since then some 60 km of gate roadways have been developed. The development machinery used in the mine are as follows

- 1 x Joy 12CM20 Continuous Miner
- 1x Joy 14CM14 Continuous Miner
- 2 Long Airdox Un-a - haulers
- 5 Joy 15C Shuttle cars
- 12 Wombat 1100 LP portable bolters
- 1 Fletcher dual head bolter

Mining method

The first two longwall faces were 110 m in width and the lengths of the mining blocks were 880 m and 1040 m respectively. The face was equipped with a Mitsui Mikke-type MCLE 101 double ended ranging drum shearer. Both maingate and tailgate drums were 1.6m in diameter and the cutting height was 2.5 to 2.7 m using bi-di cutting method. Total installed power of the face was 500 kVA. The roof supports were manufactured by Joy Mining Machinery, 4 legged chock shields, 76 in number with 680 tonnes yield load and working and range of 1.6 to 2.8 m using MS control system. The armoured face conveyor was 940 mm wide with a 30 mm twin in-board chain using 250 kw drive motor manufactured by Joy Mining Machinery. The chain speed was 1.26 m/s. The stage loader was a 150 kW beam type manufactured by Joy Mining Machinery.

Mining extraction

Mining to date has consisted of extracting all Stage I panels from LW 501 to LW 508 and subsequently Stage II panel from LW 509 to LW 514. The panel LW 514 was completed at the end of March 1999 and currently longwall LW 515 is being equipped. A total of 5.5 million tonnes of raw coal from Cataract District has been obtained and some 60 km of gate roadways have been developed. It is hoped that mining will

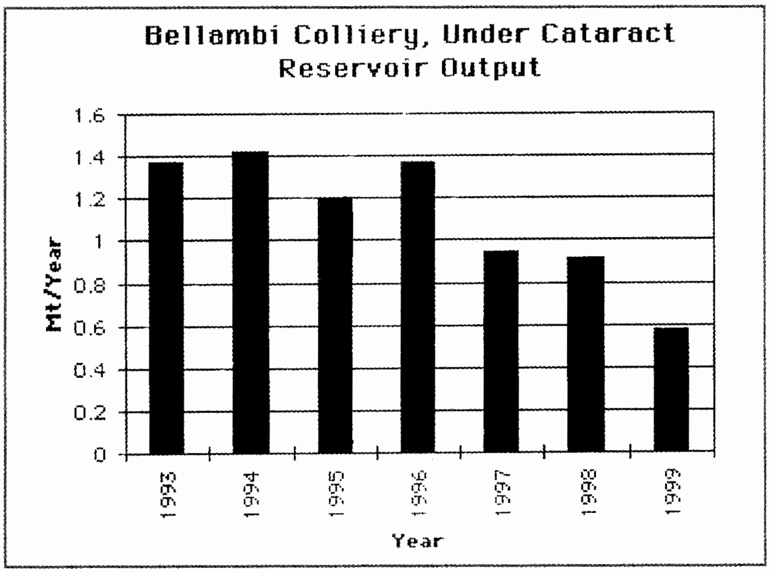

Figure 4. Output from longwall panels under Cataract Reservoir.

continue until panel LW 519 is extracted. Figure 4 shows the coal output from the longwall panels under the Cataract Reservoir from 1993 to May 1999.

MONITORING, INVESTIGATION PROGRAMS AND RESULTS

An extensive programme of monitoring has been carried out to delineate geological structures and to verify and confirm the actual parameters for stress, strain and subsidence against theoretical modelling predictions. These include:

- Surface geological mapping
- Underground geological mapping
- Geophysical surveys
- In-seam longhole drilling
- Surface subsidence measurements
- Strain measurements
- Piezometric studies in boreholes
- Water balance study in underground operations
- Pillar stress and stability monitoring

The sub-surface geological program indicated the presence of dykes in panel LW 510. As a consequence panel LW 510 was not mined.

A number of additional analyses and tests were completed to improve the understanding of seam and overburden characteristics. These included geotechnical testing of samples, drilling in-seam longholes, aerial magnetic survey to locate major geological structures and surface exploration boreholes. The details of the monitoring programs are described elsewhere (Singh, Chowdhury and Jakeman, 1999). Figure 5 shows the groundwater pressure monitoring programme on a section above LW 501 and LW 502. The results of the piezometric survey in the boreholes indicated that the caving zone extended up to 40 m and the zone of linked fractures extended up to 85 m above the Bulli Seam. It is considered that there was no disturbance in the Mid-Bulgo sandstone level as a consequence of mining. Above Bulgo sandstone and upto the Hawkesbury sandstone level, there was a horizon of flexed strata without

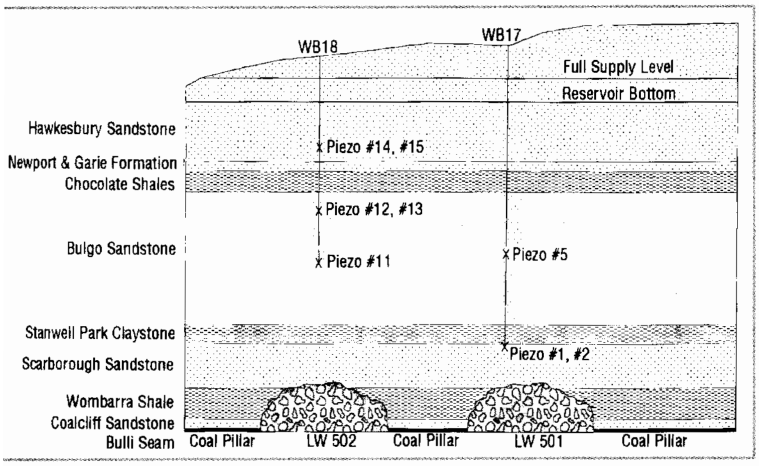

Figure 5. Piezometric survey above LW 501 and LW 502 panels.

formation of bed-separation cavities. At this level and above very little strata disturbance has taken place in response to longwall mining and the Stanwell Park claystone is considered to form an aquiclude layer.

The subsidence monitoring results above LW 501 and LW 502 panels are shown in Table 3.

Survey	Subsidence	Strain Compressive	Tensile Strain
Line A-A	173 mm	0.3 mm/m	0.5 mm/m
Line B-B	56 mm	0.2 mm/m	< 0.1 mm/m
Line C-C	158 mm	0.2 mm/m	< 0.1 mm/m
Line D-D	18 mm	0.2 mm/m	< 0.1 mm/m

Table 3.

The above results indicate that the measured subsidence were less than the predicted subsidence of 200 mm and the strain values were some 60% of that predicted by modelling. The results from all above programs confirmed that the strata response to mining operations has been very small, which is close to original expectations (Jakeman, 1996).

A water balance study carried out in the Cataract district showed that the water pumped out of the mine was 38% of the water supplied to the mine, the rest of the water was lost in dust supression and evaporation. No drippers of water were visible on the roof strata and the amount of water emanating from the goaf was too small to measure. The results from all monitoring programs confirmed that the strata response to the extraction of LW 501 and LW 502 panels has been very small as expected.

CONCLUSIONS AND RECOMMENDATIONS

Over a period of three years from 1990 to 1992, the management of Bellambi West Colliery worked with the Dams Safety Committee to gain approval for mining the restricted zone below the Cataract Reservoir. This was the first real test of the Raynold Commission's recommendations outlined in Section 3.3. Thus far, 13 longwall panels have been successfully extracted below the Cataract Reservoir providing an average export revenue of some $A 52 millions per year. It is expected that the production from the Cataract District will continue for the next two or three years.

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