Roof Depressurization for Total Extraction Mining Trials Collie Basin, Western Australia

By PETER J. DUNDON,[1] DAVID HUMPHREYS[2] and BRUCE HEBBLEWHITE[3]

Peter J Dundon, Managing Director, Australian Groundwater Consultants Pty Limited
David Humphreys, Senior Mining Engineer - Underground, Western Collieries Ltd
Bruce Hebblewhite, Divisional Manager, Mine Site Technology, Australian Coal Industry Research Laboratories Ltd

ABSTRACT

An experimental mining project has been carried out in the Collie Basin to demonstrate the safe operation of total extraction mining techniques in the underground mines of the basin. To achieve this, it was necessary to design and install a means of controlling or removing groundwater so that goafing of the overlying strata could be safely achieved as part of the mining operation.

The site chosen for the experiment was a triangular panel adjacent to Western No 6 (WD6) underground mine, which includes the 3 to 4 m thick Wyvern Seam beneath 130 to 180 m of overburden. The test area abuts a major fault on the downdip side.

The overburden and underburden sequences include several horizons of permeable sandstones which form major aquifers. Water problems have long been recognized in all underground mines in the Collie Basin, and have previously prevented the successful application of total extraction mining.

Following extensive hydrological investigations, dewatering and depressurization systems were designed to dewater the immediate roof aquifers and to depressurize aquifers higher in the sequence and in the floor. This would enable stable roof conditions to develop and controlled goafing to be achieved. The roof dewatering/depressurization procedure involved a combination of in-mine vertical roof drainage holes and conventional dewatering bores constructed from the ground surface above the mining trial area. The dewatering system was installed and operated for 29 months before the commencement of mining. Mining was eventually successfully completed in two trial panels using a retreat Wongawilli extraction system using bridge conveyors and continuous miners. Water inflow into the mine workings was channelled to a constructed sump area at the lowermost corner of the panel and pumped to the surface via vertical sump bores.

The dewatering and depressurization measures adopted were successful in permitting the first controlled and systematic total extraction recovery of coal from the Collie Basin. This trial mining exercise demonstrated the potential for increasing substantially the recovery of coal from the Collie Basin, where previously recovery rates of around 30 percent from underground mining were commonplace, using only bord and pillar methods.

INTRODUCTION

The Collie Basin (Figure 1) is a small basin of Permian sediments, some 230 km^2 in area, which contains all the operating coal mines in Western Australia. The basin is an eroded and downfaulted depression on the Western Australian Archaean Shield, and contains up to around 1 500 m of sediments which are predominantly sands and sandstones, with subordinate shales and coal seams, and a basal glacial tillite. The Permian sediments are overlain by up to 30 m of Cainozoic sands and lacustrine clays, with extensive lateritization at the surface.

The coal produced is used almost entirely for power generation in Western Australia. The coal reserves are limited due to the small size of the basin, and the resource is therefore valuable to the State and there is a need to achieve optimum coal recovery from the operating mines.

Coal is recovered from both open cut and underground mines. However, the underground recovery has been restricted to bord and pillar techniques, due to very weak roof and floor conditions. Geotechnical testing has shown the coal seams to be the strongest material in the sequence, with the sandstones and shales in the roof and floor exhibiting uniaxial compressive strength (UCS) values as low as 2 - 5 MPa[1].

Attempts to achieve higher coal production rates by pillar recovery have met with only limited success, and usually resulted in mine flooding and slurry inrushes. Consequently, typical coal recoveries were only 40 - 50% by plan, and 20 - 30% by volume.

The Collie Basin is recognized as a major groundwater basin, and the sands and sandstones within the Coal Measures sequence include major aquifers which have been developed on a large scale to provide 35 ML/day of cooling water to the nearby 1 200 MW Muja Power Station.

In 1979, Australian Coal Industry Research Laboratories Ltd, in conjunction with Western Collieries Ltd and the State Energy Commission of Western Australia, began an experimental mining project to demonstrate that the roof and floor sequences could be adequately dewatered or depressurized to allow safe mining by total extraction techniques. Australian Groundwater Consultants Pty Limited provided the hydrological input to this project. Funding for the project was provided by a National Energy Research Development and Demonstration Programme grant, and by financial contributions from Western Collieries Ltd and the State Energy Commission of WA.

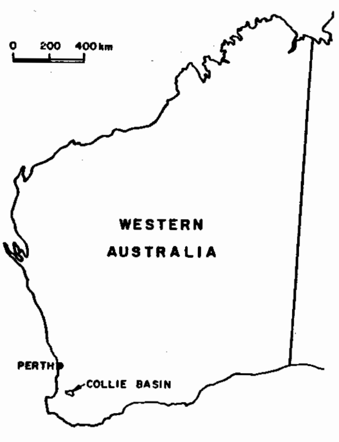

Figure 1 - Locality

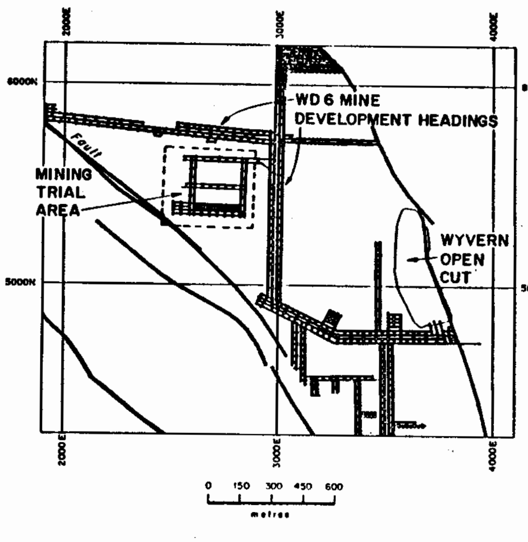

Figure 2 - Trial Mining Area

The project was completed in late 1987 with the successful extraction of two trial Wongawilli panels, after a period of extensive strata dewatering and depressurization. The success of the project has led to the adoption of more effective water control measures in the operating mines, and the acceptance of total extraction mining as a standard for future underground mine developments in the Collie Basin.

THE MINING TRIAL AREA

A triangular block of unmined coal adjacent to Western Collieries Ltd's WD6 mine was selected for the mining trial. This area (Figure 2) is bounded on two sides by development headings and on the third by a major (20 m throw) regional fault on the downdip side.

Within this block, the target Wyvern Seam is between 3 and 4 m thick, at between 130 and 200 m depth of cover, and dips to the south-west at around 10^0.

Access to the trial mine site was developed by dual headings from the main WD6 mine, and it was proposed to isolate the trial area from WD6 through the retention of an adequate width of barrier pillar (100 m minimum) and door seals on the two entry headings.

The proposed mining method for the trial was a modified Wongawilli method using road heading machines with a bridge conveyor and extendable belt for coal transport out of the mine[1].

The trial consisted of the consecutive mining of two total extraction panels, each 80 m x 200 m in size.

INITIAL HYDROLOGICAL INVESTIGATIONS

Hydrological investigations commenced in May 1980 with a drilling and test pumping programme. One test production bore (ACIRL 1) and an adjacent monitoring bore (ACIRL 2) were installed. The monitoring bore comprised a nest of multi-level piezometers at selected discrete levels in the sequence.

The following simplified sequence was revealed, with initial static water levels as measured in ACIRL 2 (see also Figure 3).

Aquifer	Depth Below Surface (m)	Height of Base Above Top of Wyvern Seam (m)	Static Water Level	
			m below ground level	m above top of Wyvern Seam
Aquifer 5	20 - 30	93	-	-
Aquifer 4	38 - 60	63	25	99
Aquifer 3	65 - 90	33	25	99
Aquifer 2½	93 -99	24	-	-
Aquifer 2	102 - 117	6	43	81
Aquifer 1	127 - 134	-11	35	88

Table 1 - Local Aquifer Sequence

A series of pumping tests were conducted over selected intervals in the pumping bore, to evaluate the hydraulic properties of the various aquifers identified. Pumping tests were conducted firstly on the total sequence, then on the upper aquifers separately after progressive backfilling of the lower part of the hole with cement grout. From these tests, transmissivities of 13, 5 and 14 m^2/d were determined for Aquifers 1, 2 and 3 (lower part only), respectively.

Aquifers 4 and 5, and the upper sections of Aquifer 3, were not test pumped at this time, but from drilling evidence were expected to be more permeable than the lower aquifers. Consequently, it was resolved to achieve depressurization of the upper aquifers primarily by pumped extraction from a few high-capacity pump wells constructed from the surface, while the lower aquifers (Aquifers 1 and 2) would be depressurized from a large number of low-capacity drainage points within the mine.

From consideration of the existing groundwater levels (Table 1), it was recognized that Aquifers 1 and 2 had already undergone some depressurization, which was believed to have resulted from natural drainage into the workings in the nearby WD2 mine. That mine had been in production for many years, producing from the Wyvern Seam, and had experienced a number of roof failures, both in areas of weak roof conditions and also where pillar-splitting had been attempted.

A geotechnical hole (ACIRL 3) was cored at a site adjacent to the trial mine site (Figure 4), to provide strength parameters for the various strata units.

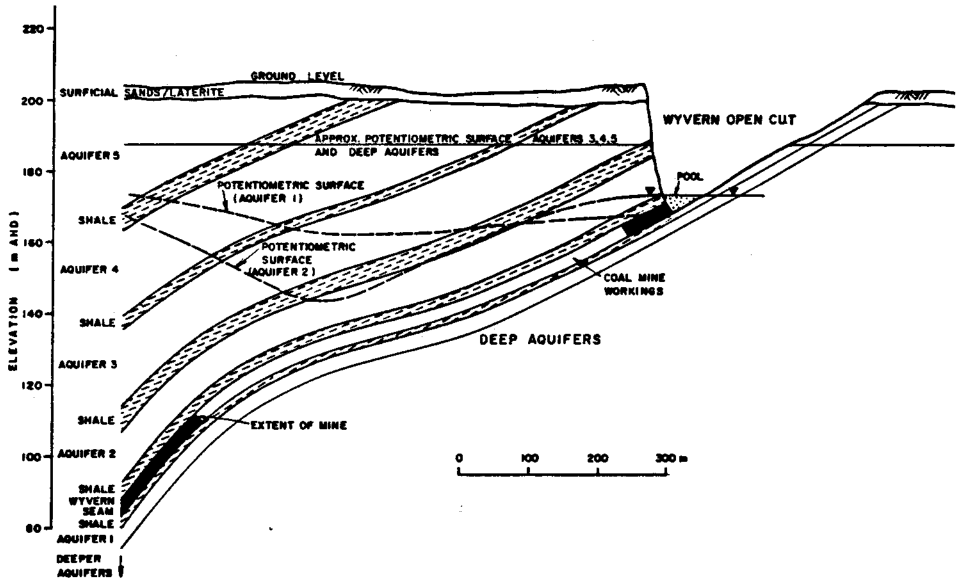

Figure 3 - Overburden Aquifers

ROOF DEPRESSURIZATION TRIALS

Conceptual studies and trials were undertaken to develop designs for the dewatering scheme to achieve adequate depressurization of the immediate roof aquifers. A two-dimensional finite difference numerical groundwater flow model, with a minimum cell size of 100 m^2, was used to simulate various dewatering/depressurizing approaches in order to predict the number and frequency of drainage and pumping holes required to meet the objectives. The requirements of each aquifer in the sequence were assessed separately.

Experience was gained in assessing various designs and construction techniques for the roof drainage holes, and on their effectiveness for depressurization, from a trial programme of roof-drilling in the development headings of the WD6 mine.

The predictive modelling had suggested the need for roof drainage holes through Aquifer 2 at approximately 30 m intervals in pairs as the headings advanced downdip. The holes were to be angled forward in the direction of the mining advance to encourage forward depressurization ahead of the advancing face. The drainage trial programme indicated that this frequency was close to optimum, and was ultimately extended throughout the mining trial area.

In the roof drilling trials, nineteen trial holes were drilled a distance of 10 - 20 m into the roof, extending substantially through Aquifer 2. Initially, a grouted standpipe was installed through the first 5 m or so of strata, to establish a stable collar. Then, the hole was extended upwards through the base of the standpipe to the desired depth. Water inflow was controlled during drilling by a stuffing box, and on completion with a gate valve permanently attached to the standpipe. An attachment for a pressure gauge was also fitted to the standpipe, to enable the shut-in pressure to be measured on a routine basis. Typical free draining discharge rates in the range 100 to 200 kL/day were obtained from each Aquifer 2 roof drainage hole.

In some areas, it was found necessary to first drill a series of short pressure relief holes to avoid roof fracturing during grouting of the standpipes.

The trial drilling programme proved successful, and in addition to its eventual extension through the trial mining area, it resulted in improved roof conditions and water inflow control generally in the WD6 development headings, and has been widely adopted in other mining areas as well.

Two trial holes were also drilled beyond Aquifer 2 into Aquifer 3 to evaluate the potential for in-mine drainage of Aquifer 3. Although two holes were successfully completed, the high inflow rates experienced (1 700 kL/day per hole) and high pressures (50 - 100 m) prevented the implementation of in-mine drainage of Aquifer 3 until later in the dewatering programme when the pressures had been reduced to a safe level.

Two trial holes were also drilled through the floor into Aquifer 1, producing modest flow rates of less than 100 kL/d.

SURFACE DEWATERING INSTALLATIONS

The computer simulation modelling had suggested that four pumping bores would be required to effectively depressurize the upper aquifers, Aquifers 3, 4 and 5. These were sited on the downdip western (ACIRL 5 and 7) and southern (ACIRL 8 and 10) sides of the trial mining panel (Figure 4). They were of conventional design, comprising 203 mm ID fibreglass reinforced plastic (FRP) casing, with in-line stainless steel screens adjacent to each of the main transmissive zones through Aquifers 3, 4 and 5. They ranged from 123 to 139 m in depth. The casing-screen string was centralized in a 380 mm hole, and the annulus filled with a graded gravel pack.

Four multi-level piezometer monitoring bores (ACIRL 6, 9, 14 and 15) were installed nearby. Up to five piezometers were installed in each bore, to monitor the drawdowns in Aquifers 2, 2½, 3, 4 and 5. The annulus was gravel-packed, with a cement grout seal placed between adjacent piezometers. ACIRL 14 was drilled on the opposite side of the south-western bounding fault. Several old coal exploration holes in the vicinity were also plugged to seal them from the Wyvern Seam workings, and where possible were completed with monitoring piezometers to add to the monitoring network. Finally, a number of the roof and floor drainage holes were used to monitor pressure heads in Aquifers 1, 2 and 3 from inside the mine.

The four dewatering bores were pumped at maximum rates to maintain pumping water levels as deep as possible. Initial design pumping rates ranged from 1 400 to 2 500 kL/d, for a total abstraction rate of 8 300 kL/d. Pumping commenced in June 1984, and continued till November 1986, during which time a total of 2.8×10^6 kL was discharged from Aquifers 3, 4 and 5.

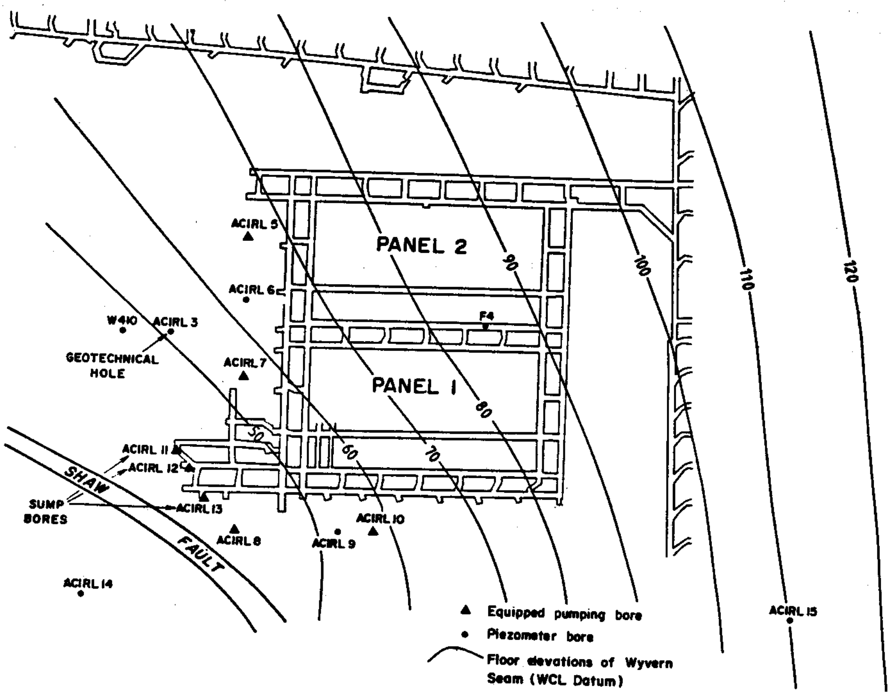

Figure 4 - Dewatering Bore Layout

The bores were equipped with all stainless steel electrosubmersible pumps with FRP rising mains. The groundwater was known to be highly corrosive, with low salinity at 200 - 300 mg/L total dissolved solids, but with pH in the range 5 - 6.5 and with typically high concentrations of dissolved gases (H_2S in particular).

UNDERGROUND DEWATERING INSTALLATIONS

Based on the experience gained during the trial roof drilling programme, an in-mine dewatering/depressurization system for Aquifer 2 was developed as follows -

- A series of roof depressurization holes would be drilled around the western and southern boundaries of the trial mining panel, as well as along the central roadways.
- Holes would be drilled in pairs and angled towards the central part of each panel area.
- Each hole would be fitted with a gate valve to control flow, and a coupling for gauges to monitor shut-in water pressures.
- A major sump area would be developed in the (downdip) south-western corner of the trial area, and sump bores would be constructed from the surface to enable collected water to be pumped out of the mine from the sump.

Twenty-eight roof drainage holes were installed from the development headings of the trial mining panel. These were located mostly on the downdip western and southern headings, and were initially installed only to Aquifer 2, 20 - 30 m above the roof (the first five holes on the western heading).

Subsequent holes were extended upwards into Aquifer 3, to hole lengths of around 60 m. By this stage (June 1985), the pressure heads in Aquifer 3 had been substantially lowered as a result of almost a year's pumping from the four surface dewatering bores.

Flow from the roof drainage bores gravitated to a sump at the south-western corner of the trial mining area (Figure 4). The water was pumped out of the mine from the sump via three vertical "sump" bores. These were drilled from the surface, through a coal pillar, to just below the Wyvern Seam (175 - 180 m below surface) then cased with 305 mm ID steel casing and grouted back to surface. Subsequently, the grouted casing was exposed underground by mining, to establish connection with the sump. These three bores were equipped with electrosubmersible pumps, with a total installed capacity of 6 200 kL/d. Additional pumping capacity of 1 500 kL/d was provided in the mine, through Flygt pumps capable of diverting up to 1 500 kL/d to other sumps in the WD6 mine.

The sump dewatering discharge was pumped directly to the nearby Muja Power Station as a supplementary, make-up cooling water supply. It is proposed to continue using the mining trial area as a major sump for the WD6 mine, after completion of the trial mining programme.

PROGRESS OF DEWATERING AND DEPRESSURIZATION

The rate of groundwater abstraction through the period leading up to the mining trial is shown on Figure 5.

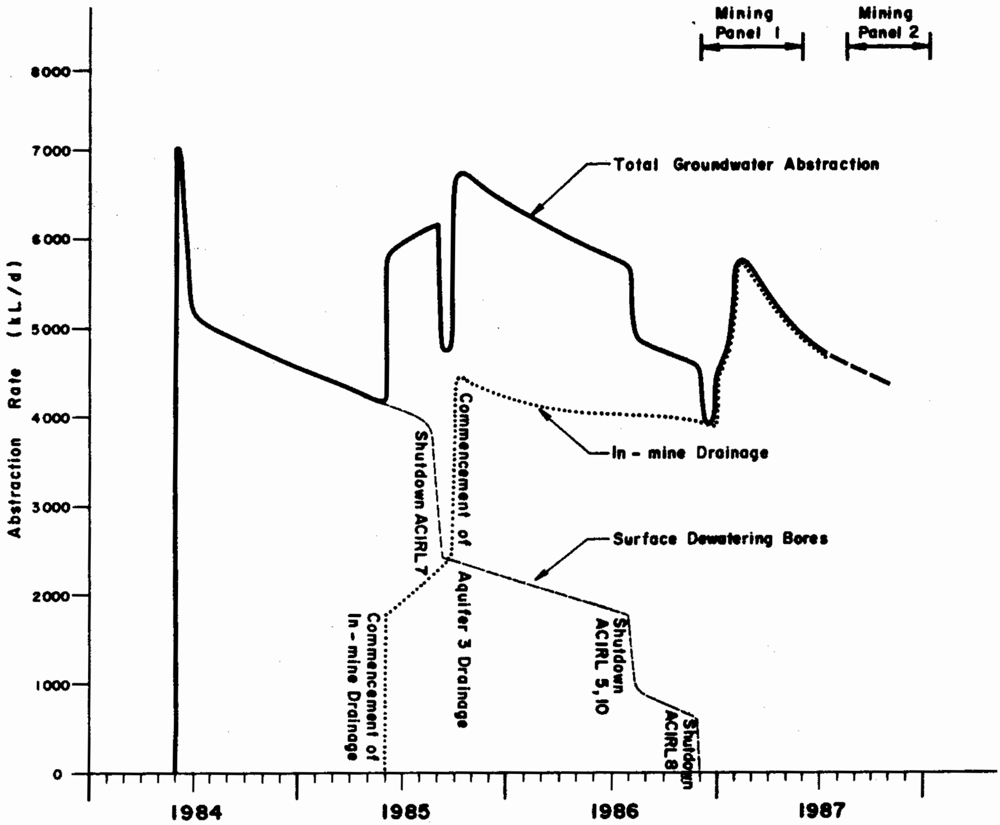

Figure 5 - Abstraction History

There were three distinct phases. Firstly, from June 1984 to May 1985, virtually all dewatering was achieved by the surface dewatering bores. (Minor additional quantities derived from natural roof and floor drainage were diverted to the WD6 mine.) In the second phase, dewatering by in-mine drainage from the roof holes commenced, and progressively took over in importance from surface pumping. In the third phase, when the mining trials took place, all dewatering discharges were derived from in-mine drainage.

Total abstraction rate peaked at around 6 700 kL/d in October 1985, coinciding with the commencement of extensive in-mine drainage from Aquifer 3. In-mine drainage stabilized at around 4 000 kL/d, before peaking at just below 6 000 kL/d in February 1987 during the mining of Trial Panel 1.

The progressive depressurization of Aquifers 2 and 3 is illustrated on Figures 6 and 7. Figure 6 shows the distribution of pressure heads in Aquifer 2 measured at three stages during the project -

- pre-mining (inferred from regional data),
- January 1985 (prior to the commencement of discharge from Aquifer 2 into the mining trial area), and
- May 1986 (by which time Aquifer 2 had been virtually fully dewatered).

Residual pressure heads at the south-western corner of Panel 1 were less than 10 m, or less than 4 m above the base of Aquifer 2. Discharge from Aquifer 2 had therefore ceased prior to commencement of mining in Panel 1 (December 1986).

Figure 7 shows the distribution of pressure heads in Aquifer 3, at three stages -

- pre-mining,
- May 1986, and
- December 1986 (at the commencement of mining of Panel 1).

At May 1986, a decision was taken to delay commencement of mining until pressure heads were further reduced in Aquifer 3. A ridge of residual high pressure had developed across the lower panel (Panel 1), which was interpreted to be a zone of lower permeability. This pressure ridge was reduced by the drilling of an additional pattern of close-spaced drainage holes from the central and southern roadways, angled across Panel 1. By December 1986, pressure heads had been sufficiently reduced to permit mining to commence. At this time, Aquifer 3 had been reduced to a saturated thickness of around 7 m at the north-western corner of Panel 1, and virtually fully depressurized over most of the panel.

Mining then proceeded through Panel 1, and shortly thereafter through Panel 2, with all mining successfully completed by the end of 1987. The mining phase was virtually free of water problems. Although there was a small increase in the total abstraction rate, there was never any significant presence of water at the face during goaf development.

The maintenance of a programme of regular monitoring played an essential part in the trial mining project[2], by providing the information needed for assessment of the residual groundwater heads above the panels, and to enable forward projections of the progess of dewatering and depressurization. As well as hydrological monitoring (groundwater levels or pressure heads, and discharge rates), subsidence monitoring was maintained at the surface above the trial area, as well as in-mine geomechanical monitoring based on a combination of stress change cells and strain change extensiometers strategically placed in a number of pillars and fenders within and around the panels.

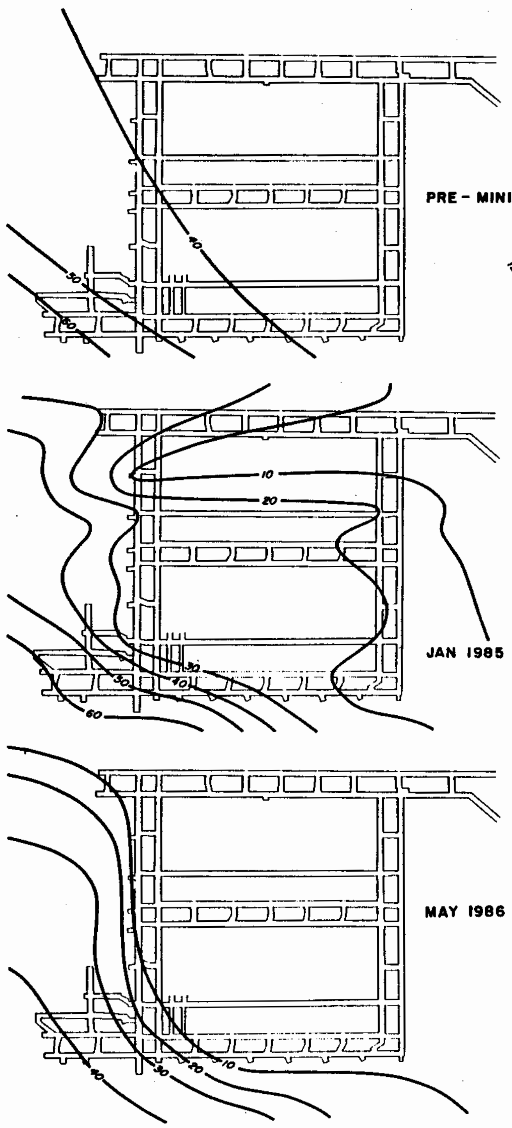

Figure 6 - Aquifer 2
Potentiometric Heads
(m above Wyvern Seam)

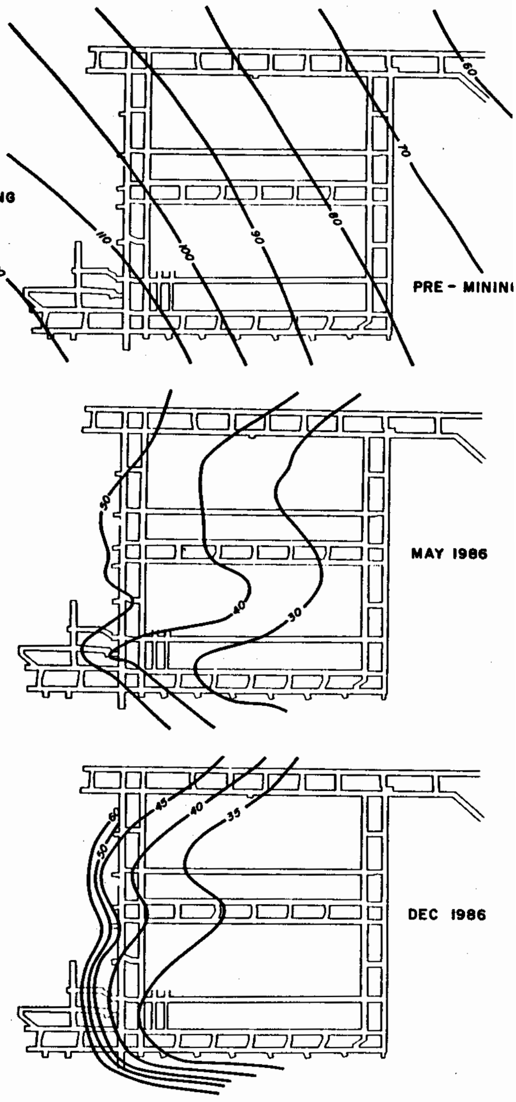

Figure 7 - Aquifer 3
Potentiometric Heads
(m above Wyvern Seam)

WIDER APPLICATION OF TOTAL EXTRACTION MINING

The experimental project has demonstrated that total extraction mining techniques can be safely and successfully applied to the coal resources of the Collie Basin. Although the dewatering/depressurization system installed was designed specifically for the trial mining project, the dewatering had a substantial regional impact on groundwater levels, indicating that an acceptable, cost-effective, pre-dewatering approach could be applied for mining developments on a larger scale.

Operational experience showed that the in-mine drainage approach is more cost-effective, more efficient and more reliable than the use of conventional surface dewatering bores. However, there is a need to reduce the pressure heads substantially prior to drilling roof drainage holes safely into areas of high pressure on a routine basis, hence there will remain a need for some high capacity pumping from conventional bores in the first instance.

The efficiency and cost-effectiveness of such large scale dewatering would be improved by the integration of dewatering needs with water supply needs, since the groundwater represents a valuable supply source for the region.

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