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Artesian Dewatering Operations at Morwell Open Cut

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ABSTRACT

Morwell Open Cut is a brown coal project in the Latrobe Valley of South Eastern Australia. At the site, large scale dewatering of underlying aquifers is carried out to maintain the stability of the open cut floor. There are two extensive aquifers that contain groundwater under pressure and a continuous pumping program is required to lower the artesian pressures to safe levels. On a mass basis, the amount of artesian water pumped is about twice the coal won.

This paper briefly describes the hydrogeology of the situation, the requirements to prevent excessive floor heave, the dewatering operations, surveillance procedures, and pump and bore installations.

The problems and consequences of the dewatering operations are also reviewed. These include the dependence of the coal winning operations on the continuous dewatering of the aquifers and the extensive subsidence of the sediments of the Latrobe Valley resulting from the regional drawdown effects.

INTRODUCTION

Morwell Open Cut is a brown coal project located in the Latrobe Valley of Victoria, Australia (Figure 1). The brown coal is excavated to supply fuel to the Hazelwood Power Station (1600 MW) and Morwell Power Station (135 MW) which provide much of Victoria's base load electricity. Coal production from the open cut is currently running at about 16 million tonnes per annum.

Overburden at the site is generally less than 20 m deep and development is to the full depth of an upper coal seam ranging between 100 m and 120 m thickness within the open cut. Bucket wheel dredgers and one bucket ladder dredger operating on faces up to 25 m in height are used to supply coal via conveyors to bunkers of limited capacity. Overburden is transferred to an external dump. The dredgers move along parallel operating benches loading onto movable face conveyors. The open cut has been developed with multiple parallel operating faces to the west and is now going through a pivot operation to swing the development to the south-west.

The initial opening up of the site commenced in the 1950s. By 1960 bores were established in the open cut and dewatering of an underlying aquifer commenced, initially with free flow bores, but later with pumping bores as the depth of the excavation increased. It was required to lower the pressure of the artesian groundwater to maintain stability against excessive floor heave as done at the Neyveli lignite mine, India (Vogt (1)). However, by 1969 the development was approaching the base of the coal seam and floor heave together with uncontrolled flows of artesian water emerging through tension cracks in the base were experienced. Subsequent investigations revealed the significance of a deeper and more extensive aquifer. Since 1969 water has been extracted from both aquifers peaking for a short time in 1973 at 1350 l/s (refer appendix for units). Currently, the mass of artesian water pumped is about twice the mass of coal won.

It is postulated that, if the pressure of the artesian waters is not maintained at a safe level, excessive floor heave would result, flooding by water and sand slurry would occur and large batter movements could develop due to the loss of toe support.

This paper describes the artesian dewatering operations at Morwell Open Cut and discusses the methods used, the requirements for stability, and the problems associated with the dewatering program.

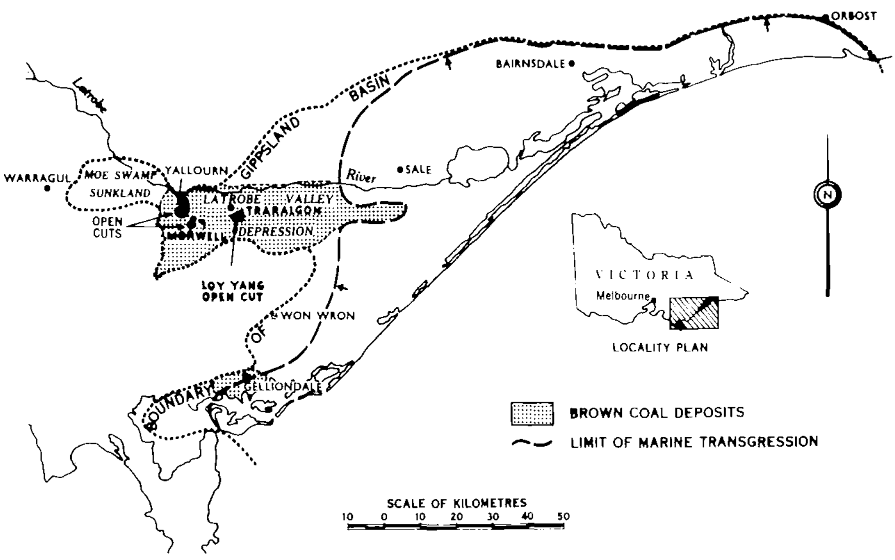

Figure 1 - Gippsland Basin and Locality Plan

GEOLOGY

The Latrobe Valley depression comprises up to 700 m of Tertiary sediments including thick brown coal seams at shallow depth, together with occasional basaltic flows. The depression exists at the western end of the Gippsland Basin (Figure 1) which is one of the coastal artesian basins of Australia. The stratigraphy and structure of the Latrobe Valley coal measures have been described by Gloe (2). The stratigraphy is complicated by numerous splits in the depositional sequence and later major structural events.

In the Morwell area, the Tertiary sequence lies unconformably on a Mesozoic basement. The sequence commences with the Hazelwood Formation which comprises up to 150 m of sediments interbedded with minor basalt flows. The sediments include clays and sands with up to 45 m of gravels towards the base.

The Hazelwood Formation is overlain by the Morwell Formation which includes two major coal seams separated by an interseam of clay and sand. The lower coal seam, named the Morwell 2 seam, is about 50 m thick in the area of the open cut. The upper coal seam (Morwell 1 seam) has a maximum thickness of 165 m just south of Morwell township, but, due partly to tilting and erosion, gradually thins to the south and west. It is this coal seam that is excavated by the Morwell Open Cut. The interseam separating the two coal seams has a thickness of approximately 30 m.

The sequence is terminated with the Haunted Hill Gravels. This deposit consists of sands and clays of Pliocene age that unconformably overlie the Morwell Group. It is less than 20 m thick in the area of the open cut. The stratigraphy of the site is shown in Figure 2.

The coal seams are strongly jointed with near vertical joints that fully penetrate the seams. The orientation of the joints clearly indicates their tectonic origin. They are often open and infilled with sand or clay.

HYDROGEOLOGY

Two major aquifer systems occur below the open cut as shown in Figure 2. The M1 aquifer is a near continuous sand layer of about 15 m thickness in the interseam separa-

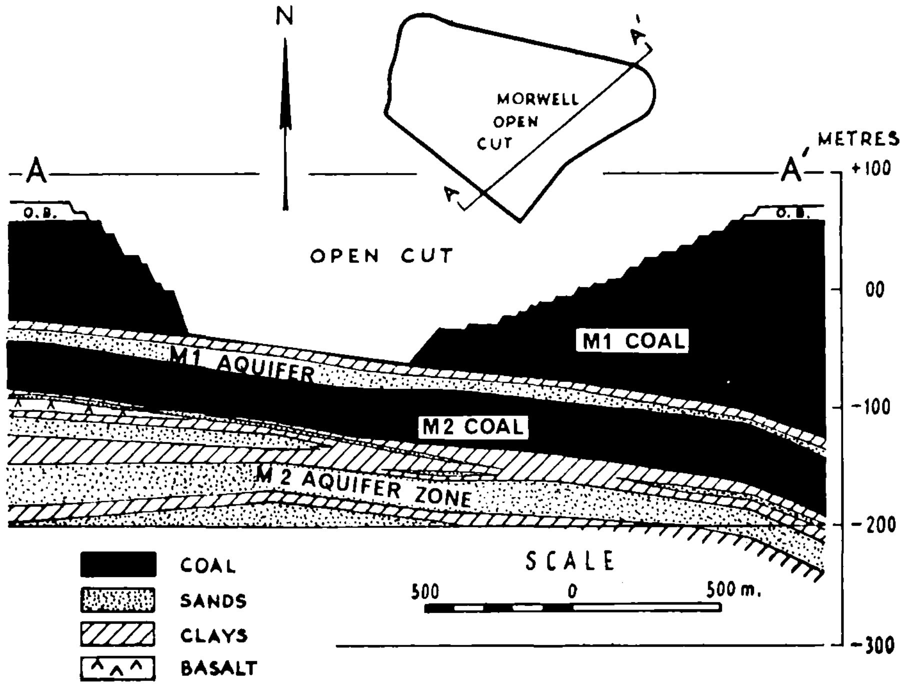

Figure 2 - Morwell Open Cut Section

ting the Morwell 1 and Morwell 2 coal seams. A clay layer separates the aquifer from the base of the Morwell 1 seam. The deeper M2 aquifer system occurs in the Hazelwood Formation as a series of lensoidal sand layers immediately below the Morwell 2 coal seam. The M1 aquifer extends up to 11 km to the western outcrop of the coal measures. To the north the interseam disappears at a distance of about 5 km whereas to the east it has not been traced due to rapid deepening of the strata. The M2 aquifer is less defined, but it is thought to be in hydraulic connection with the basal aquifers that exist as a complex leaky aquifer system throughout much of the Latrobe Valley.

Before open cut operations commenced the piezometric surface of the M1 aquifer was at about +60 m AHD which is very close to ground surface. In fact, it is on record that as early as 1913 artesian flows were obtained from deep bores in topographically low areas. This was possible as it has been found that the artesian pressures increase with depth.

The recharge source to both aquifers is not precisely known. However, indications are that they are both recharged from the hills at the western edge of the Latrobe Valley and possibly from the Moe Basin through the Haunted Hills. This inference is made from the relationship between piezometric surface and distance from centre of pumping shown in Figure 3. Carbon dating of the waters supports this boundary source and also suggests that the aquifers obtain leakage from deeper aquifers and drainage from consolidating aquitards.

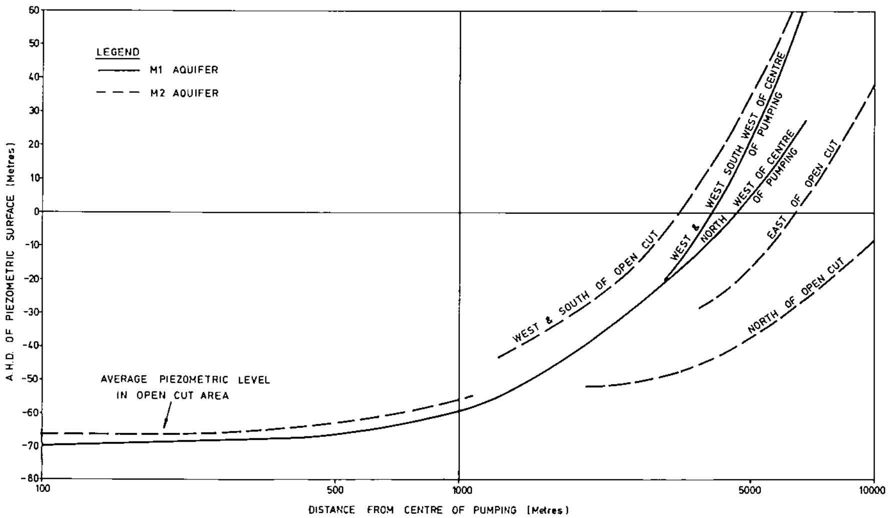

Figure 3 - Drawdown-Distance Relationships

The temperature of the artesian waters is high and the geothermal gradient is several times greater than world average. The average temperature of the water pumped from the M1 and M2 aquifers is $46^{\circ}C$ and $55^{\circ}C$ respectively. The waters are of reasonable quality with total dissolved solids averaging about 400 mg/l for both aquifers, but they can be highly corrosive to mild steel.

The M1 aquifer sands are reported by Barton (3) to be poorly sorted, positively skewed mature sediments with a mean particle size in the coarse sand range. The sands are predominantly clear, detrital quartz. Experience has shown the M2 aquifer sands to be of a similar nature. Pump tests done during the late 1960s indicated that the transmissivity of the M1 aquifer is 325 m^2/day and the storage coefficient is 1×10^{-3}. The average M2 aquifer parameters determined from a controlled recharge test in 1973 are transmissivity equal to 1700 m^2/day and storage coefficient equal to

3×10^{-4} (Golder, Brawner and Assoc (4)).

REQUIREMENTS FOR STABILITY

To prevent catastrophic floor heave, it is required that the water pressure in the aquifers below the open cut be less than the equilibrium pressure of the aquifer. The equilibrium pressure is that pressure which just balances the weight of the overlying sediments. Consequently, as the depth of the open cut is increased, the weight of overlying sediments is reduced, and the required amount of aquifer depressurisation is increased. It is assumed that the weight of the overlying sediments of clay and coal provide the reactive force required for stability as shown in Figure 4. The shear strength of the material separating the aquifer and open cut base cannot be relied upon for assistance because of the large floor area and the presence of near vertical joints that penetrate the full thickness of the coal seams.

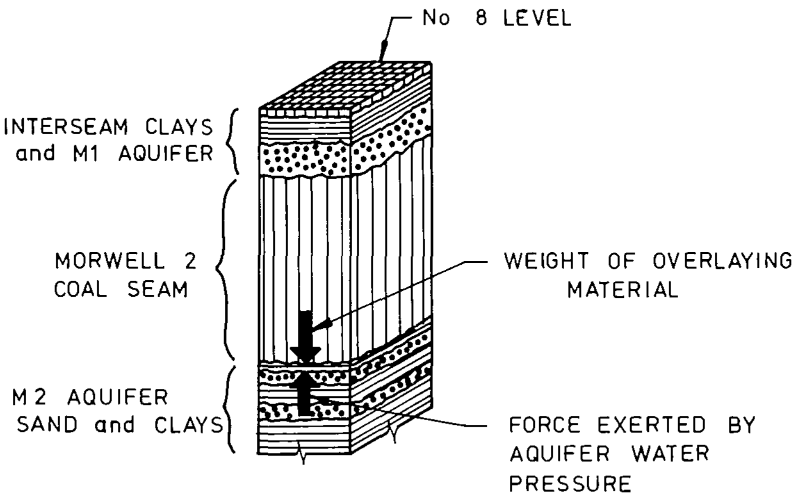

Figure 4 - Equilibrium Forces

To maintain stability, it is required that the artesian pressure at every location be lower than the corresponding equilibrium pressure. The critical location is where the weight of the overlying sediments is a minimum (deepest part of open cut) and aquifer depressurisation should be centred on that location to minimise pumping.

A factor of safety is applied to the determination of the equilibrium pressure to allow for uncertainty in the assessment of the forces involved. The factor of safety against floor heave is defined as -

$$\text{Factor of safety} = \frac{\text{Weight of material overlying aquifer}}{\text{Force exerted by aquifer water pressure}}$$

A system of "target", "security" and "emergency" piezometric pressures developed by Brown (5) and extended by Hutchings and Guest (6) is used to assist the operating staff in maintaining the stability of the current critical area and provide a code to the status of that stability. For each condition a different factor of safety is used which corresponds to a different probability of failure.

The following values are used:

Stability Condition	M1 Aquifer		M2 Aquifer	
	Factor of Safety	Probability of Failure	Factor of Safety	Probability of Failure
Target	2.0	0.005	1.30	0.005
Security	1.37	0.05	1.20	0.05
Emergency	1.16	0.20	1.06	0.20

The "target" piezometric levels are those below which it is aimed to maintain the aquifer piezometric levels during normal operations. These levels provide a buffer below the "security" levels to allow for pump outages. The "security" level is the highest level at which floor stability is deemed safe. If the "security" levels are exceeded, local emergency action is taken to reinstate pumps. Finally, if the "emergency" levels are exceeded then serious disruption to coal winning operations is likely and general emergency procedures are invoked to re-establish safe piezometric levels.

The "target" level for the M1 aquifer is simply selected as the lowest point in the open cut and the "target" factor of safety for the M2 aquifer is the optimum value determined with respect to cost of failure. The factors of safety for the "security" condition were selected so that the actual factor of safety would be unity if the uncertainty of measurement of the water pressure, the material thickness, and the material density were to take their worst case. The "emergency" factors of safety provide a probability of failure of approximately 20% (Hutchings and Guest (6)).

Under present conditions with the M2 aquifer at its "target" level and if all pumping ceased, it would take about 45 minutes to reach the "security" level and 10 hours to reach the "emergency" level. The times are estimated using the method suggested by Golder, Brawner and Assoc (4). For partial outages the times are significantly increased.

DEWATERING OPERATIONS

Before the project started, it was realised that the artesian pressure in the M1 aquifer would require lowering as the eventual base of the open cut was to be within 15 m of that aquifer. In 1960 the piezometric surface of the aquifer was more than 120 m above the base (-63 m AHD).

Artesian dewatering commenced in 1960 when four free-flow bores were drilled on No 1 coal level. By mid 1965 the piezometric surface had been reduced from +60 m AHD to about +15 m AHD by a succession of free flow bores as described by Gloe (7). The total flow from the aquifer peaked at 167 l/s in 1964. In 1965 the open cut was developed to No 4 level which is at about +10 m AHD.

During this initial period, widespread heaving, up to 2.5 m in places occurred in the floor. With the full development of No 4 level and a pilot opening to No 5 level in 1966 detailed surveys showed that an additional heave of 1.7 m occurred during the year (Gloe, et al (8)). Also, considerable uncontrolled flow of artesian water through the floor of the No 5 level opening indicated the possibility of further heaving. Four additional free flow bores were established on No 5 level and by the end of 1966 the piezometric surface was reduced to +5 m AHD. Nevertheless, at that time it was decided to advance the dewatering program with pumping bores and abandon the free flow concept in an endeavour to avoid further heave.

When the No 5 level and a temporary pump sump on No 6 level were developed in early 1967 the piezometric surface had been lowered by pumping, but the pressure was still too high and the first pilot bore drilled on No 6 level flowed and some heaving occurred. Pumping continued and by mid

1968 the piezometric surface below the open cut was at about -23 m AHD.

In mid 1968 development of No 7 level commenced with a pilot opening and similar conditions to those experienced on No 6 level were encountered. The elevation of the opening was -30 m AHD. As the opening was extended, uncontrolled flow of hot artesian water broke through a number of fissures and cracks in March 1969. The flow gradually increased to an estimated rate of 115 l/s with the total artesian flow being 340 l/s. At that time the piezometric level in the M1 aquifer was -35 m AHD.

Prior to the occurrence of uncontrolled flow on No 7 level, two attempts to dewater the M2 aquifer were unsuccessful because the bores encountered poor aquifer sands. However, by this stage the M1 aquifer dewatering operations had lowered the piezometric pressure of the M2 aquifer to approximately +25 m AHD by upward leakage. In November 1969 a bore drilled from No 7 level into the Morwell 2 coal seam produced a free flow of 45 l/s. The head in the bore was greater than that in the overlying M1 aquifer as was the water temperature. The water was derived from the M2 aquifer through cracks and fissures in the coal. A bore was immediately drilled from No 5 level into the M2 aquifer. Free flow from this bore quickly led to a lowering of pressures and the cessation of the uncontrolled flow on No 7 level by December 1969. During the period of uncontrolled flow, heave of the base amounted to 1.5 m.

In 1970/71 four additional free flow bores were established in the M2 aquifer from No 7 level. The total flow from the aquifer reached 265 l/s in early 1971 and the piezometric level was lowered by about 10 m in the vicinity of No 7 level. By this stage it was realised that much greater flows would be required from the M2 aquifer to establish a safe piezometric level prior to further deepening (Gloe, et al (8)).

The flow from the M2 aquifer was steadily increased by the introduction of pumping bores. In early 1973 the flow had reached 700 l/s but the piezometric surface had only been lowered to -30 m AHD. The dewatering program had called for a level of -48 m AHD before the No 8 level (bottom level) was opened up (Brown (5)).

After 1969 the piezometric surface of the M1 aquifer steadily declined along with the pumping rate. When the

No 8 level was opened up in mid 1973 the piezometric surface of the M1 aquifer was at about -61 m AHD and the flow rate was 200 l/s. In an endeavour to meet the target level set for the M2 aquifer the pumping rate from that aquifer was increased. By late 1973 the piezometric surface was slightly above that required and the flow averaged 1000 l/s with peaks in excess of 1100 l/s. Although the target level for the M2 aquifer was not quite achieved prior to the opening up, no major problems were experienced with the development of No 8 level.

The M1 aquifer flow and level continued to decline until 1976 when the flow rate was 130 l/s and the piezometric surface was at -62 m AHD. Since that time a relatively steady flow rate has been maintained and the level has continued to fall slowly. Over the same period the flow from the M2 aquifer was maintained at about 1000 l/s until 1975 when the piezometric level stood at -55 m AHD. Since then there has been a small, but steady, decline in pumping rate and a correspondingly small decline in aquifer pressure. The current pumping rate averages 860 l/s.

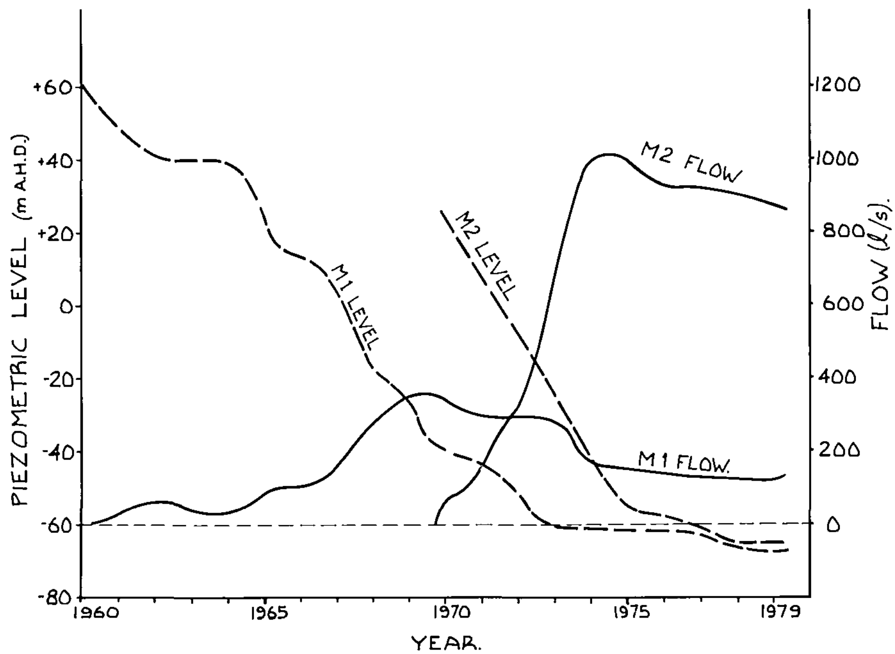

Figure 5 - Piezometric Levels and Flows

The history of piezometric levels and flows from the two aquifers is shown in Figure 5. Figure 6 shows the relationships between piezometric level and flow.

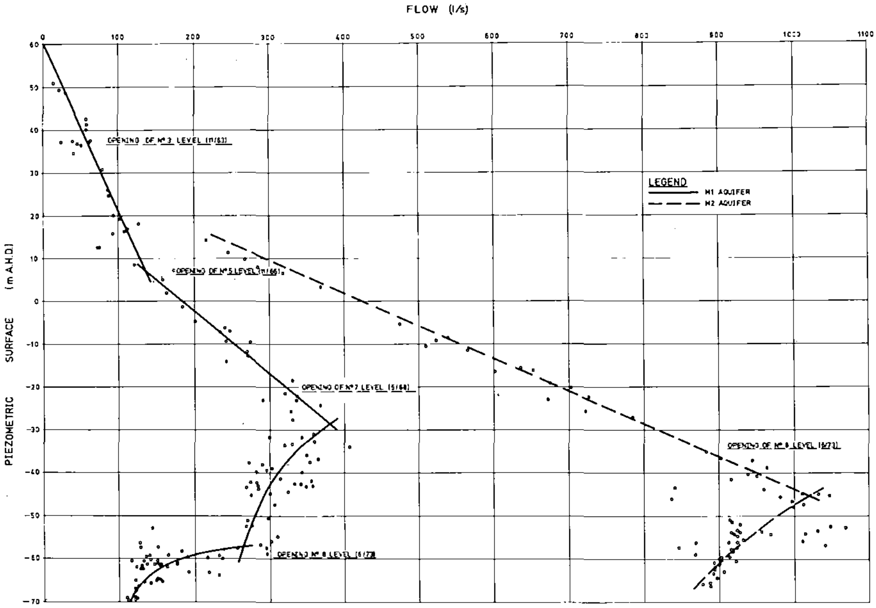

Figure 6 - Relationships Between Piezometric Level and Flow

From Figure 6 the four major episodes through which the dewatering operations have passed can be readily seen. The initial episode embraces the period of free flow from the M1 aquifer and shows a linear relationship between piezometric pressure and flow. The second episode also experienced a linear relationship and encompasses the period that pumping from only the M1 aquifer was carried out. The third episode commenced with the dewatering of the M2 aquifer and continued until stable conditions had been reached and the open cut was developed to its full depth. During this episode there was a slight reduction in flow from the M1 aquifer (less leakage from M2) and piezometric levels dropped. At the same time, there was a positive linear relationship for the M2 aquifer as with the M1 aquifer during the second episode. The final episode is one of consolidation of dewatering operations from both aquifers and it is characterised by reductions in pumping rates and stable equilibrium pressures being maintained.

PUMPS AND BORES

The free flow bores used during the early stages of the dewatering operations for both aquifers were mostly completed using 150 mm diameter steel casing open to the top of the aquifer. A valve at the surface discharged to a V-notch weir for control and measurement. With these bores, problems were often encountered with aquifer collapse due to sand removal.

When pumping bores were introduced, sand had to be excluded and there was experimentation with drilling and screening techniques. Resin bonded gravel screens of 400 mm diameter were used in the early stages along with welded steel bore casing.

After incidents of steel casing failures caused by the corrosive artesian waters, asbestos cement (AC) bore casing with a special coupling was developed in conjunction with a local manufacturer as reported by James Hardie and Co (9). Problems were also encountered during drilling. These included aquifer contamination by drilling mud, loss of circulation, and bore collapse. Consequently, the reverse circulation rotary drilling method was introduced in 1970. Difficulties were also encountered in developing sands through the resin bonded screens and some screen collapses occurred. Current bore construction methods make the use of resin bonded screens impractical and wire wound stainless steel screens are now used as standard (Scott (10)).

Currently, bores are constructed as shown in Figure 7. The procedure is to first drill a pilot hole of 125 to 150 mm diameter and obtain samples of the aquifer sands for screen design. The pilot hole is overdrilled by the reverse circulation method at 1000 mm diameter into the last clay above the aquifer sands. AC casing of 575 mm i.d. is then set into the clays and also supported from the surface. The space behind the casing is generally backfilled with gravel. Drilling is continued through the casing at 560 mm diameter to about 2 m below the last sand. The screen assembly consisting of 406 mm o.d. mild steel pipe with wire wound screens and centralisers is set into the aquifer.

Most bores are gravel packed behind the screens with 4-5 mm standard gravel. In such cases the screens have a 3 mm slot opening. Where natural packing is suitable, generally in the M1 aquifer, slot openings are 1-2 mm. The length of screens varies between 6 m and 14 m.

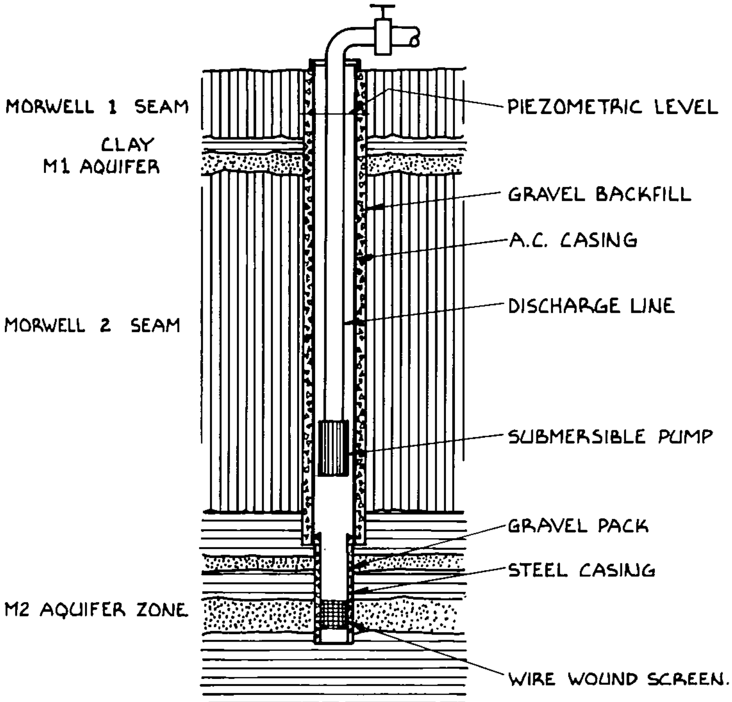

Figure 7 - M2 Aquifer Pumping Bore

Piezometric level observation bores are generally drilled at 150 mm diameter and a slotted 63 mm diameter galvanised iron pipe installed. Key observation bores in the M2 aquifer tap a thin sand seam near the top of the aquifer zone as this is the one that is important to stability.

Submersible motor pump combinations are used in the pumping bores. "Small" units have 70 or 90 kW motors with pumps rated at 75 l/s at 80 m head. "Large" units use 185 kW motors rated at 150 l/s at 85 m head. The pump units are very reliable, most outages being due to power supply problems. However, pump failures caused by sand ingestion or motor thrust bearing breakdown do occur. Currently, with good maintenance and bore construction practices, pump lives are in excess of 30 000 hours.

The submersible pumps deliver to a surface collection system leading to buffer tanks at the base of the open cut. Most bores deliver to the tanks via gravity pipelines, but a pressure pipeline is required from those bores at the lowest parts. The buffer tanks allow sand to settle and dissolved CO_2 to dissipate. Water in the tanks is pumped to the power station cooling pond or directly into the open cut fire protection network with high head centrifugal pumps.

The location of the pumping bores and the key observation bores operational in 1978 is shown in Figure 8. At that time there were four M1 aquifer pumping bores with only two in regular use. These bores were equipped with the "small" pumping units. The M2 aquifer had 13 operational pumping bores with eight in regular service. These were a mixture of "small" and "large" pumping units. The large number of pumping bores on standby is required to enable rapid reinstatement of the required flow whenever an outage occurs.

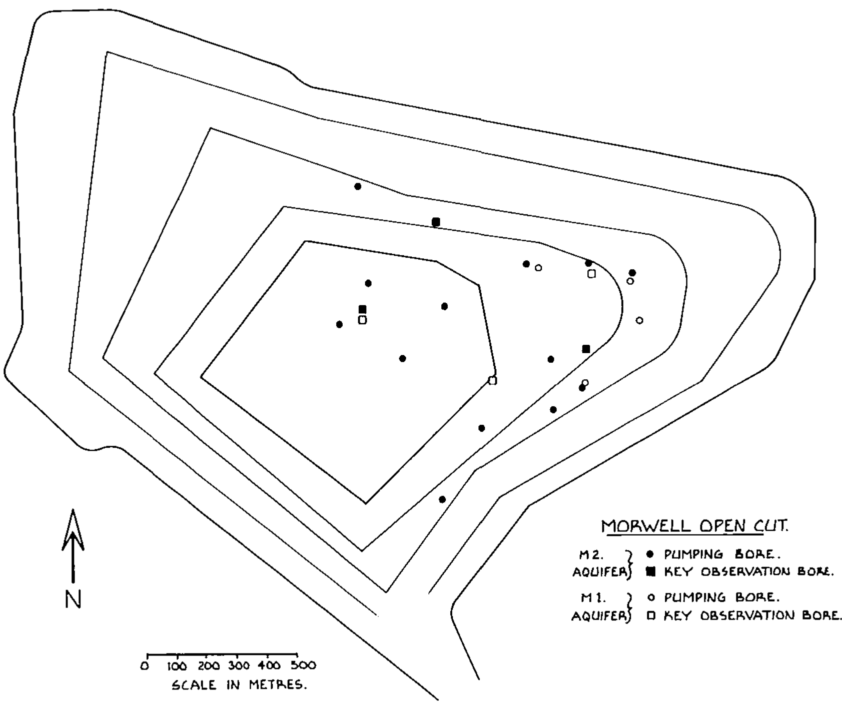

Figure 8 - Location of Bores

Each aquifer has three key observation bores to monitor the piezometric surfaces. The bores are carefully selected for location and response to changes in pumping rate. The average level from the key bores in each aquifer is used as a measure against the "target" piezometric level.

A large number of observation bores are located in and around the open cut. These are used for a variety of purposes, but mostly to provide back-up to the key bores and for studying the wider effects of the dewatering operation.

SURVEILLANCE

Monitoring of the dewatering operations is conducted on a routine basis. The piezometric level of the six key observation bores is monitored by continuous recorders. The pumping bores are inspected every shift and flows measured on a weekly basis. The piezometric level of several less important observation bores located within the open cut is also measured on a weekly basis and all other bores within the open cut on a two or three-monthly basis.

Outside the open cut, a network of regional observation bores is established. These tap either the M1 and M2 aquifer close to Morwell Open Cut, but beyond, where the stratigraphy changes, a variety of aquifers (mostly basal) are monitored. The frequency of readings on the regional bores is either two monthly or three monthly depending upon distance from the centre of pumping.

The target flows and levels are routinely adjusted every six months. This is done to take account of critical areas created by the advance of the working faces and the success in achieving previously set target levels.

Whenever an emergency condition arises, close monitoring is carried out until flows are re-established.

FACTORS ASSOCIATED WITH DEWATERING OPERATIONS

Pumping is required to be continuous to ensure that safe piezometric levels in the aquifers are maintained at all times. If interruptions occur, the piezometric levels in the aquifers rise rapidly. This could cause failure of the open cut floor if flows are not re-established rapidly. Outages due to pump failures, interruptions to the power supply and occasional bore failures make it difficult to maintain a constant pumping rate.

The State's generation system is arranged such that under a system emergency, Morwell Power Station, together with Morwell Open Cut and some other loads, are isolated completely from the rest of the State. This provides a secure overall power supply for the pumping bores as well as the many other important loads of the system.

The most common source of outage is in the open cut electrical distribution system where brief interruptions in the power supply cause the pump motors to stop. Most of these stoppages are of short duration and are overcome quickly. There are several such occurrences each month. If an outage is widespread many man-hours of work can be required to reinstate the pumping.

The worst such occasion was in November 1977 when a major coal fire in the open cut burnt power cables. During the fire, the flow rate from the M2 aquifer dropped to 230 l/s for more than one hour and was less than 50% of normal flow for more than 12 hours. It took about 27 hours to re-establish normal flow. During that time the piezometric level in the M2 aquifer rose by about 10 m. Fortunately, the levels were very low beforehand and the "security" level was not exceeded. It was estimated later that it would have taken three days to reach the "emergency" level under the prevailing conditions. The M1 aquifer bores were not greatly affected.

The work force responsible for the operation of the artesian system and rainfall and surface water pumping is usually six men with many others involved on a part-time basis and during emergencies.

Another factor associated with the dewatering operations is the regional subsidence caused by the widespread drawdown in the aquifers. The effect of open cut operations on large scale earth movements in the Latrobe Valley are fully discussed by Gloe (11) and Hutchings, et al (12). However, those caused by artesian dewatering are briefly discussed here.

A lowering of the piezometric pressure in the aquifers results in an increase in the effective stress in the strata. This in turn leads to consolidation of the coal seams and clayey interseams. The effects of drawdown in the basal aquifers can be seen to extend to the east of Traralgon (Figure 9). Survey data indicate that subsidence contours have a similar pattern with 0.2 m being recorded up to 15 km from the open cut and more than 1.6 m being recorded at Morwell township.

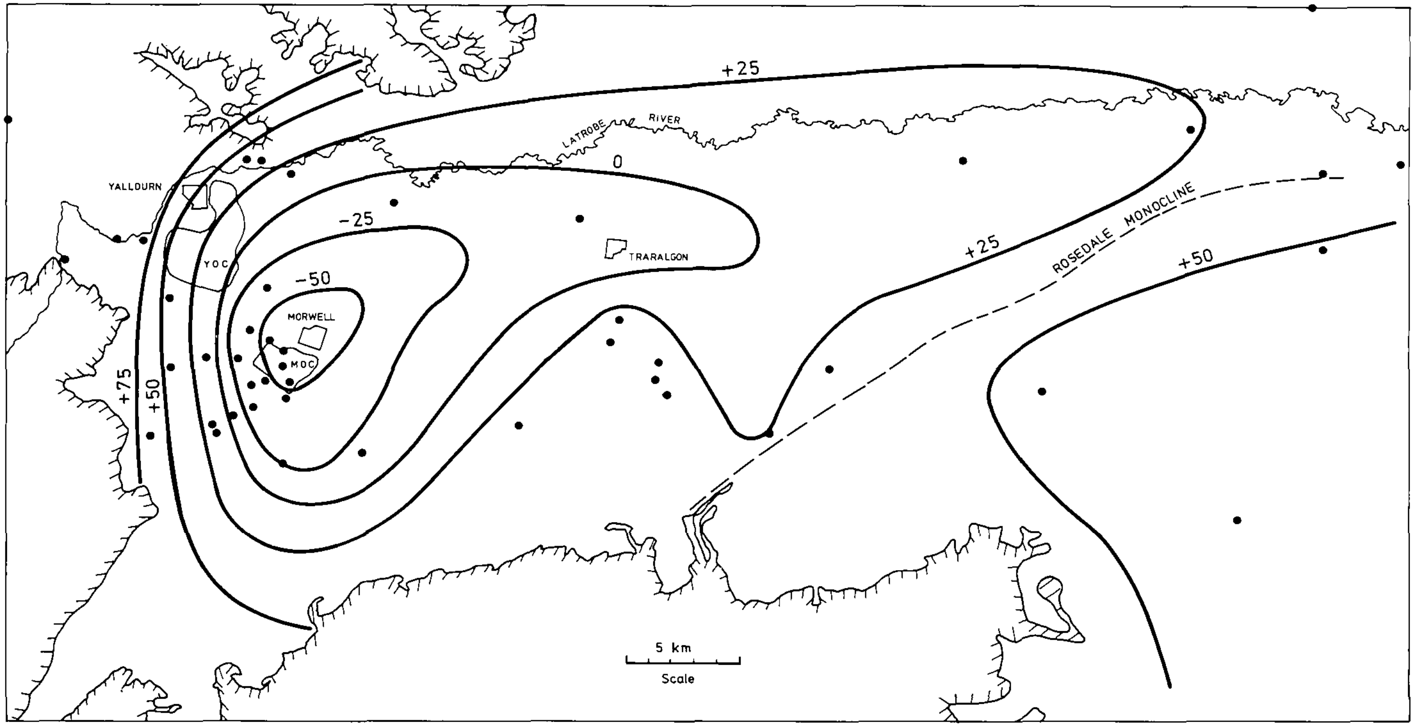

Figure 9 - Regional Piezometric Surface of Basal Aquifers

In order that the regional drawdowns are reduced to a minimum, an endeavour is made to keep the centre of pumping (centre of mass from operating bores) as close as possible to the critical area. This minimises the required flow. Currently, the working faces are passing through the deepest zone and the critical area is at the toe of the bottom cut. New pumping bores have been established on the floor as close as possible to the toe. By minimising the amount of pumping the rate of regional drawdown is reduced. This slows the rate of subsidence, keeps costs to a minimum, and helps to preserve the water as a resource.

CONCLUSIONS

Artesian dewatering is required at the Morwell Open Cut to ensure the stability of the floor against heave. Because of the hydrogeological situation and the importance of the open cut to the State's energy supply the dewatering operations are given special attention. A sophisticated system of pumping bores is operated on a continuous basis with operating personnel motivated to overcome all outages promptly. A large number of pumping bores are maintained on standby and a secure power supply is provided to assist in maintaining the required pumping rate.

Dewatering commenced in 1960, but large scale pumping did not start until 1970. It was not until 1975 that stable piezometric pressures were reached. Since then it has been possible to slightly reduce the pumping rate whilst maintaining stable piezometric levels. It is anticipated that this trend will continue even though the floor area of the open cut is steadily increasing.

The major problems associated with the artesian dewatering operations are those caused by the need for continuous pumping and the regional subsidence resulting from the dewatering.

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APPENDIX

AHD	=	level in metres relative to the Australian Height Datum which is mean sea level
1 m	=	3.281 ft
1 mm	=	0.04 inches
1 l/s	=	15.8 gpm (u.s.)
1 m^2/day	=	80.5 gal/day/ft (u.s.)
1 mg/l	=	1 ppm (approx)
1 kW	=	1.341 horsepower