Design and Operation of the Dewatering System for the Lochiel Trial Pit

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ABSTRACT AND INTRODUCTION

The Lochiel coal deposit, a large Tertiary soft brown coal deposit in the mid north of South Australia, is currently being investigated by the Electricity Trust of South Australia (ETSA) as a potential source of fuel for a base load power station. Feasibility studies indicated that the proposed dragline method of overburden removal was viable but economically sensitive to both highwall and dump batter angles. The unusual properties of the unconsolidated overburden sediments and the groundwater regime posed a number of intimately related hydrogeological and geotechnical questions which were addressed before and during the excavation of a trial pit.

All strata at Lochiel are of soil strength, and artesian aquifers occur above and below the coal. From the initial evaluation of the deposit a number of hydrogeological questions were defined. These related to the rate at which the pore pressure in the silts is reduced by dewatering, the extent of the reduction in pore pressure due to prestripping, and the feasibility of dewatering and depressurising carbonaceous silty sand sequences.

The site of the trial pit was selected to answer these and other questions from the basis of a detailed geological, hydrogeological and geotechnical understanding.

The trial pit dewatering system simulated a full scale mine dewatering system and included ten pumped wells, twenty drainage wells, and nearly 400 monitoring instruments. It operated from September 1986 to June 1987. The excavation was carried out between February and May 1987.

Performance of the system was most satisfactory and with the

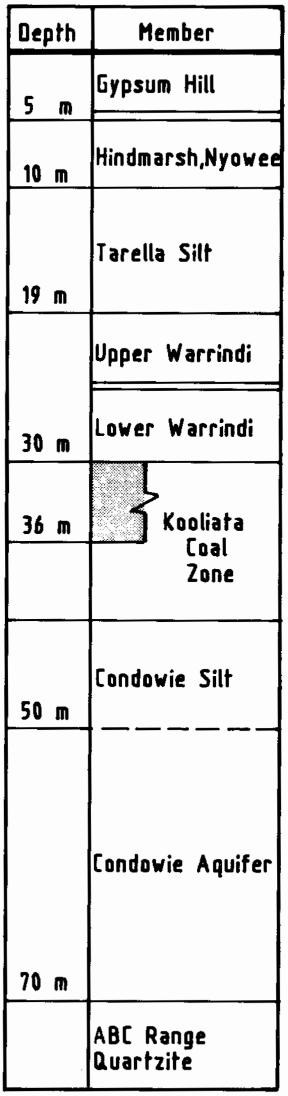
application of vacuum to the pumping bores, dewatering and depressurisation to predicted levels was achieved in the time allowed.

In May 1988 the project was awarded the 1987 Engineering Award by the Institution of Engineers (SA Division).

STRATIGRAPHY AND HYDROGEOLOGY

All materials above the Precambrian basement are of Tertiary age and are of soil strength and saturated with saline groundwater. The main units in the informally named sequence are the ABC Range Quartzite, Bumbunga Sand, Condowie Silt, Kooliata Coal Zone, Warrindi Silt, Tarella Silt, Hindmarsh Clay and the surficial Gypsum Hill Beds.

The aquifer system at the trial pit site consists of



1. a minor unconfined aquifer at the base of the Gypsum Hill Beds, recharged directly by rainfall.
2. the Upper Warrindi aquifer (WA2 and WA5), a 4 m interbedded sequence of clayey silt, silt, fine sand and carbonaceous sand and silt comprising 1.9 to 3.0 m of clean non-clayey and non-carbonaceous material. WA2 and WA1 are separated by a 2 to 3 m thick bed of clayey silt.
3. the Lower Warrindi aquifer (WA1), an interbedded sequence of fine to medium grained clean sand and carbonaceous sand beds, containing 2.9 to 4.0 m of clean sand. Hydrogeologically, this unit is one with the FG Interburden, which contains 0.5 to 1.0 m of clean fine to medium grained sand in a 1.5 m interval. WA1 and FG Interburden are separated by a 1.5 m thick bed of carbonaceous sand.
4. the Condowie Silt (CN), which consists of a total of 1.0 to 4.3 m of clean, fine to medium grained sand within an overall sequence averaging 16 m thick. The clean sand occurs in discrete layers 0.3 to 2.5 m thick interbedded with carbonaceous sand. At the trial pit site in the south-eastern part of the deposit, the Condowie Silt member is sandy and the Bumbunga Sand is not present. However, to the north the Condowie aquifer is hydraulically connected with the main Bumbunga sand aquifer.
5. the fractured rock ABC Range Quartzite basement aquifer, which is recharged through rainfall on outcrops to the west, and from which all other aquifers (except the Gypsum Hill aquifer) are recharged by upward percolation.

Within the trial pit area, all confined aquifers are artesian or nearly so. Artesian heads of up to 20 m are recorded elsewhere.

PIT DESIGN

The trial pit and spoilpile were designed to simulate as far as possible the full scale dragline mining situation. The principal features of this design were: total depth 36 m including 6 m of coal for combustion testing; batter angles 42.5° except on the east wall, which was excavated at 60° in order to induce a slope failure for back analysis; a 10 m wide ramp at 10% grade leading to the top of coal and overall dimensions of 100 m x 370 m including the ramp. (See Figure 1).

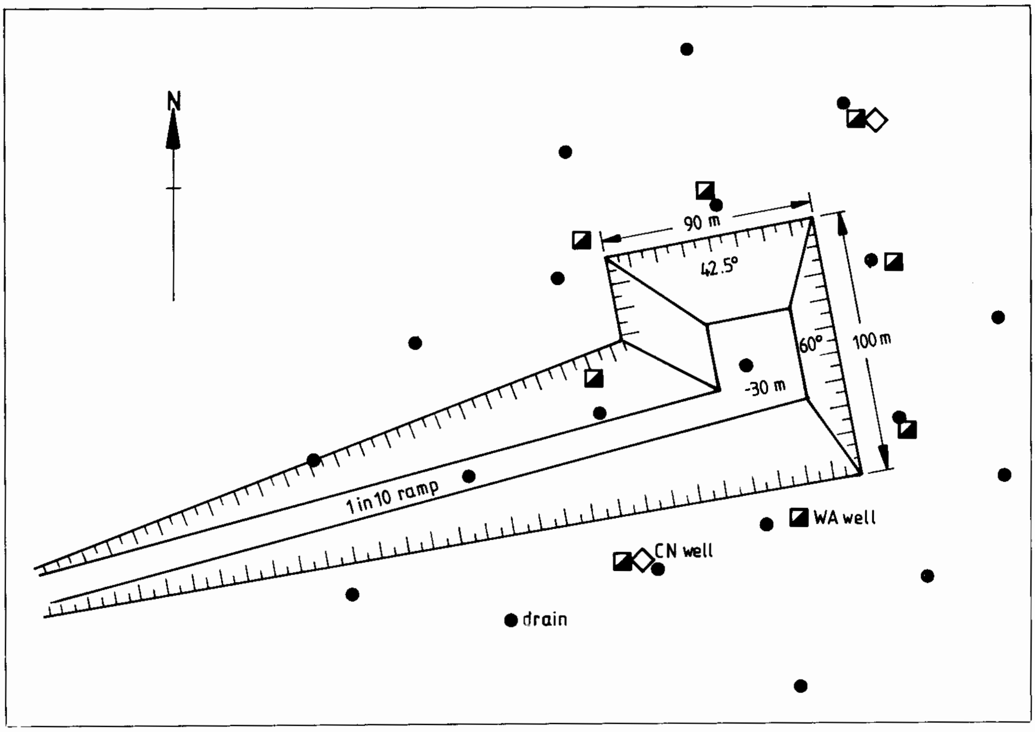


Figure 1. Pit design and well location plan

DEWATERING SYSTEM DESIGN

The design of the trial pit dewatering system had three principal aims.

1. to depressurise the subcoal Condowie aquifer to prevent floor heave,
2. to dewater the Warrindi and FG aquifers above the coal to facilitate excavation and to permit vertical drainage from the fine grained units above and below the aquifer, and
3. to depressurise the fine grained units, in particular the Tarella Silt.

The design phase examined the design of the dewatering and depressurisation system, the hydrogeological monitoring system, the regional effects of dewatering and the water balance following abandonment (Coffey and Partners 1986).

Analytical transient well programs were used to study the interference effects of multiple well drawdown, and finite element models to analyse the regional transient groundwater behaviour.

The computer models used for the trial pit dewatering studies were based on the Theiss equation for radial flow to a well pumping at constant rate and penetrating an infinite confined aquifer. These analyses determined the drawdown versus time characteristics at specified locations for multiple wells pumping at various rates from an aquifer. Aquifer boundaries and variations in aquifer thickness were also included in the analyses.

The modelling was developed in several stages. Firstly, a preliminary assessment was made of separate Warrindi and Condowie aquifer models to examine the sensitivity of drawdown to well numbers and spacing. These results were used to formulate a series of more detailed models analysing the interaction between wells and drains in the configuration and numbers under consideration for actual pit dewatering.

To assess the spacings and pumping requirements of the well field, three design criteria were defined.

1. The Warrindi aquifers were to be drawn down to the top of the Lower Warrindi (WA1) and the Condowie aquifer to just below the bottom of the coal zone. This was necessary to ensure that the fine grained layers, in particular the Tarella Silt, were subjected to significant depressurisation stress.
2. These drawdowns should develop fast enough to allow time for the subsequent depressurisation of the fine grained units to take place, ideally in 90 to 180 days.
3. The area to which such drawdowns and timing would apply was set at an 80 m radius from the centre of the excavation.

<u>Drain and well layout studies</u>

Three dewatering configurations were considered in the computer based modelling studies.

- In Case 1, various numbers of wells in each of the Warrindi and Condowie aquifers were pumped, and in several models were supplemented by vertical free flowing drains connecting all aquifers. The primary objective was to drain water from the Warrindi aquifer into the Condowie aquifer below, to enable faster dewatering of the Warrindi with the Condowie acting as the sump. These drains were located at approximately 60 m centres.
- Case 2 was similar to Case 1 except that the vertical drains did not interconnect the Warrindi and Condowie aquifers. The major pumping effort was concentrated on the Warrindi aquifer with the vertical drains connecting the Warrindi with several minor aquifers between the surface and 45 m depth. The Condowie aquifer was partially depressurised in a separate pumping operation.
- Case 3 was as for Case 2 but with the addition of eductor pumps in each of the drains to reduce pumping rates from the main wells.

For the first two configurations the influence of recharge and low flow boundaries was also examined. The fourteen different models which were analysed are described in Table 1.

Table 1

Summary of computer models for well and drain layout studies

Model No.	Number of Wells Warrindi	Number of Wells Condowie	Number of Drains	Inclusion of Boundaries	Warrindi properties $T(m^2/d)$	Warrindi properties S
CASE 1 - No drains or fully penetrating drains						
1	4	4	0	No	29.0	0.00014
2	4	4	20	No	29.0	0.00014
3	4	4	20	No	29.5	0.00060
4	8	8	0	No	29.0	0.00014
5	8	8	20	No	29.0	0.00014
6	4	8	20	No	29.0	0.00014
7	8	8	0	Yes	29.0	0.00014
CASE 2 - Partially penetrating drains						
8	8	2	20	No	29.0	0.00150
9	8	2	20	Yes	29.0	0.00150
10	8	2	20	Yes	29.0	0.00200
11	6	2	20	Yes	29.0	0.00150
CASE 3 - Partially penetrating, pumped drains						
12	0	2	20	No	29.0	0.00150
13	4	2	20	No	29.0	0.00150
14	0	2	20	No	29.0	0.00150

Note: Condowie aquifer properties used throughout were: $T = 4.5\ m^2/d$, $S = 0.0002$

The storage coefficients used for the Warrindi aquifer were based on values obtained from pump testing, modified to include an allowance for the contribution to storage coefficient from the drainage of the fine grained silt layers.

For all models, several variations were run using different well and drain locations. Sensitivity studies were carried out on the effects of variations in the storage coefficient.

Recommended dewatering method

Table 2 lists the satisfactory models in decreasing order of performance. To be considered satisfactory, model drawdowns had to exceed 25 m in the Warrindi and 38 m in the Condowie. Also shown in Table 2 is the ratio of dewatering rate to drawdown, which quantifies the efficiency of each configuration but does not demonstrate the adequacy of pit centre drawdowns.

Table 2

Listing of satisfactory models in decreasing order of performance

Model No.	Net dewatering rate (m^3/d)		Pit Centre drawdown 180 days		Ratio dewatering rate to drawdown ($m^3/d/m$)	
	WA	CN	WA	CN	WA	CN
14	1720	302	34.7	38.0	49.6	7.9
6	1088	304	28.9	42.0	37.4	7.3
5	1064	352	28.5	48.1	37.6	7.2
7	544	488	27.8	68.0	19.6	7.2
9	824	302	26.5	38.0	31.5	7.9
10	880	302	26.3	38.0	33.5	7.9
13	1280	302	25.6	38.0	50.0	7.9

Of the successful models, models 5, 6 and 7 were discarded because the storage coefficient used for the Warrindi aquifer was considered to be unrealistically low, and models 13 and 14 were discarded because of the reliance on the extensive use of eductor pumps. The recommended dewatering strategy was thus based on models 9 and 10 and comprised

- eight wells pumping from the base of the Warrindi aquifer at an average 90 day rate of about 110 cubic metres per day per well,
- twenty vertical drains on a 60 m triangular grid interconnecting all aquifers between the surface and 45 m depth, so constructed as to permit the later addition of eductor pumps if necessary, and
- two wells pumping from the Condowie aquifer at a depth of 64 m below surface at a 90 day rate of 151 cubic metres per day each to achieve depressurisation in 180 days.

The design of the wells and the manner in which they interact are shown in Figure 2, and their locations in Figure 1. The Warrindi and Condowie wells were drilled 300 mm diameter and fitted with 205 mm casing and screens and 100 mm diameter pumps and column. The drainage wells were drilled 600 mm diameter and sandpacked around a 150 mm slotted PVC pipe down the middle.

Modelling of regional groundwater behaviour

To assess the regional effects of dewatering associated with the trial pit and to provide a better assessment of the effects of the boundaries on dewatering rates calculated from the analytical modelling, finite element computer modelling was carried out. The above and below coal aquifers were modelled separately as two-dimensional plan models. Each model represents a grouping of aquifers of similar stratigraphic levels with an allowance for leakage from the overlying and underlying fine grained sediments where appropriate. For 270 days of pumping, the drawdown in the Condowie aquifer 1.5 km from the pit ranged from 0 to 3.5 m, and for the Warrindi from 0.8 to 10 m. The environmental impact of such drawdowns was considered to be negligible, as virtually no use is made of the aquifers in the Lochiel area.

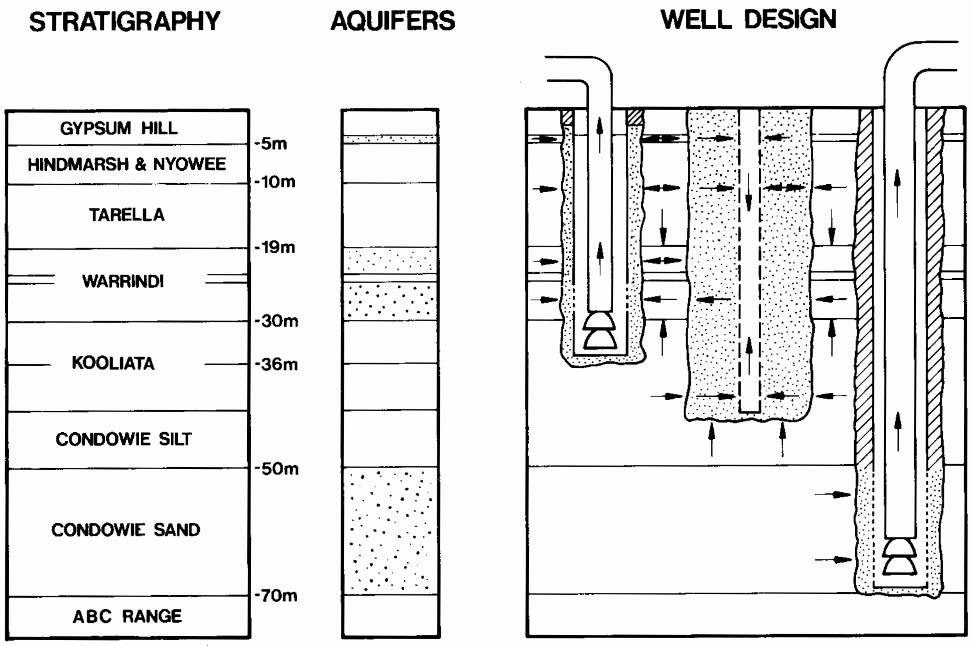


Figure 2. Design and interaction of water wells

Trial pit water balance following abandonment

As part of the environmental assessment, estimates were required of the level to which water would rise in the trial pit on abandonment. Inflows included catchment runoff, aquifer inflow, overburden seepage and rainfall, while losses included evaporation and possible overflows. Calculations showed that depending on the assumed initial total inflow from the Warrindi aquifer, equilibrium would be achieved with the water level close to the top of the pit in about three years. The actual recovery in the fifteen months since the pit was completed has been in line with these projections.

Pumping system

The tender specification called for corrosion resistant pumps capable of flow rates of 0.5 to 5.0 l/sec against total heads of 30 m (Warrindi) and 70 m (Condowie).

Shaft-driven turbine pumps were selected in preference to electro-submersible pumps because of their lower cost and their ability to handle very low flow rates. The same make and model pumps were used for both applications, four stage turbines being used in the Warrindi wells and seven stages in the Condowie wells. All pumps were connected to a common ring main discharging to a nearby salt lake.

Hydrogeological and geotechnical instrumentation

The objectives of monitoring the performance of the dewatering system included an assessment of the following.

1. the characterisation of the undisturbed groundwater pressure profile with depth
2. radial and vertical depressurisation effects within fine grained units between drains and wells, including arching effects
3. the effects on pore water pressures of unloading (prestripping).
4. regional influences of the dewatering system.
5. the extent of drainage in major aquifer units
6. the effectiveness and efficiency of the well and drain design.

Nearly 400 instruments were installed to meet these requirements.

1. 95 pneumatic, 28 vibrating wire, and 101 standpipe piezometers to measure groundwater pressures and levels.
2. 6 multiple rod extensometers, 38 slip indicators, 10 slope indicators, 30 settlement stations and 12 survey bench marks to measure vertical and horizontal ground movements.
3. 12 slope alarms to warn personnel of impending slope failures, 5 earth pressure cells in the spoilpile, and over 50 instruments to monitor pump performance.

Throughout most of the project, approximately 350 instrument readings were taken each day. Instrument data was keyed directly into an Epson PX4 handheld computer, which sorted the data according to instrument number and automatically recorded time and date of reading. Data from the PX4 was dumped directly into an Olivetti M24 PC, which was used (with Lotus 123) to prepare drawdown curves for piezometers, to plot trends for other instruments, and to plot simultaneous data from groups of instruments to present vertical and horizontal profiles. This data was used firstly to monitor the progress of dewatering and secondly to analyse the behaviour of the hydrogeological system for inclusion in design of a full-scale mine dewatering system for use in feasibility studies. This analytical work is described elsewhere (Coffey and Partners, 1988).

PERFORMANCE OF DEWATERING SYSTEM

In general, the dewatering system performed according to design. The Warrindi aquifer was sufficiently dewatered to enable mopping up operations to be carried out with only a single row of vacuum well-points, the drawdown achieved in the Condowie aquifer was adequate to prevent floor heave, and the depressurisation of the fine grained units exceeded expectations.

Pump performance

All downhole problems resulted from corrosion (probably electrolytic) of the driveshaft couplings or the pump column. During the nine months duration of the project, all pump columns had to be replaced at least once despite being epoxy lined. Parts of the pump column were covered with waterproof adhesive tape, which appeared to inhibit corrosion. Wear and corrosion of the pumps themselves was insignificant. Flow rate control was excellent.

Drain Performance

The performance of the drains depended largely on the quality of the interface between the insitu soil and the sandpack.

The drains were drilled by reverse circulation methods to ensure stability during drilling. To minimise caking on the wall of the hole only brine was used as a drilling fluid.

Blinding of the sandpack by infiltration of the silt was considered a strong possibility, but examination of the three drains in the pit area showed this did not occur. The drains operated with a high efficiency throughout.

Instrumentation

The performance of the buried instrumentation was most satisfactory. Great care was taken with installation of all instruments, and it quickly became clear that installation is the key to performance. The instruments with which ETSA had previous experience (piezometers and slip indicators) were correctly installed and produced reliable data throughout. The excavation provided a rare opportunity to recover piezometers in the pit and to confirm that they had been installed according to design (see Figure 3). The slope indicators were not installed deep enough, making data difficult to interprete, and the rod extensometers were installed with insufficient tension, which produced some unreliable data until rectified.

Figure 3. Pneumatic piezometer exposed in excavation

Depressurisation

Figure 4 shows vertical pressure profiles in the various units with time. Examination of Figure 4 shows an excellent correlation between predicted and actual values. The dewatering of the upper aquifers was somewhat slower than predicted from the modelling, but the depressurisation of the fine grained units, in particular the Tarella Silt, exceeded expectations. Both of these factors are attributed to the presence of previously undetected large-scale vertical joints which permitted much free vertical drainage of the Tarella and overlying strata into the Warrindi aquifer.

Depressurisation due to unloading was also monitored. It was shown that the depressurisation that does occur is not, as previously postulated, directly related to the total overburden stress reduction but to the change in bulk stress at any point. The transferral of horizontal stresses to the base of the excavation results in smaller pore pressure reductions.

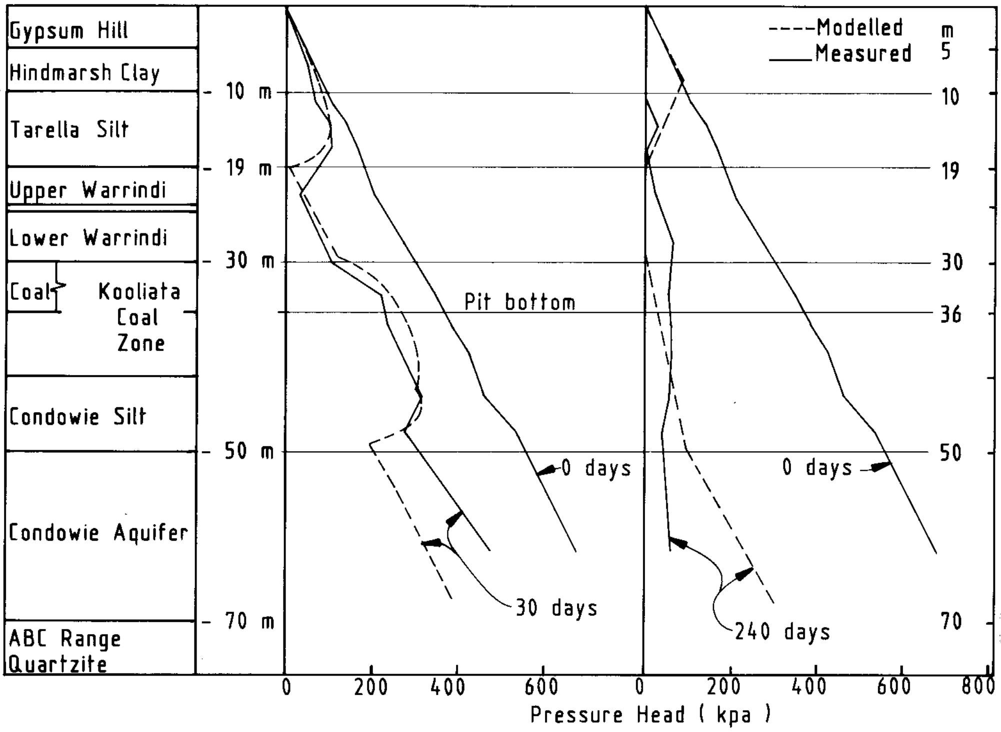


Figure 4. Actual versus predicted drawdown at centre of pit

Vacuum assisted pumping

After approximately 90 days pumping, it was apparent that the dewatering of the Warrindi aquifer was not proceeding fast enough to permit excavation to commence as planned after 120 days. This was largely because of the difficulty of modelling a system in which the condition of the aquifers changed from confined to unconfined, and because of the presence of the hitherto unknown vertical joints referred to above.

Several options were considered for accelerating the dewatering, including pumping from the drainge wells, installing additional water wells, or fitting vacuum pumps to the existing wells. The last appeared to offer the cheapest and simplest solution. After some preliminary tests, all wells were connected via a ring main to a 16 cubic metre per hour vacuum pump, which evacuated the annulus between the casing and the pump column (all wells had been constructed with collar seals with this eventuality in mind). A vacuum of 90 kPa was quickly achieved, raising the water level in each well by approximately 9 m. The flowrate in each well was then increased until the water level fell to the limits of the nett positive suction head requirements of the pump. The flowrate of the eight Warrindi wells was initially increased by 40% to 50%, and the drawdown accelerated. The Condowie wells were subsequently connected to the vacuum system. This dramatic increase in the ouput of all ten wells was achieved at less than a quarter of the cost of one additional well. (O'Brien, 1987).

Vacuum well pointing

Predictive models of the dewatering system showed that both the Upper and Lower Warrindi aquifers were likely to contain substantial quantities of water even though essentially dewatered. It was planned initially to install up to 3 rings of vacuum well-points to permit excavation to proceed, but in the event only one ring was needed to mop up the lower 4 m of the lower Warrindi aquifer. It was necessary to operate this well-point system for only one week while the aquifer was excavated and the underlying coal removed.

SUMMARY

The hydrogeology of the Lochiel Trial Pit is complex, consisting of a series of leaking confined aquifers separated by fine grained soils of low permeability. Based on results from field trials, a system was designed to dewater the aquifers and depressurise the fine grained soils. The dewatering system performed very much according to design, confirming the accuracy of the predictive modelling. The analysis of its performance has provided the basis for the design of the dewatering system to be included in a major mining feasibility study. The effectiveness of applied vacuum in increasing the flow from the pumped wells was clearly demonstrated.

ACKNOWLEDGEMENTS

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