Dewatering and Depressurization of a Multi-Aquifer Groundwater System at Loy Yang Open Cut, Victoria, Australia

By P. WOOD,[1] J. SOMERVILLE[1] and I. GIBSON[1]

ABSTRACT

Three main confined aquifers occur in interseam sediments beneath the planned excavation for the Loy Yang Brown Coal Open Cut. Sub-artesian groundwater pressures occur in all aquifers necessitating dewatering to prevent excessive seepage and depressurisation to prevent heaving of the open cut floor and batter instability. Reduction of water pressures in coal joints is also required to maintain coal face stability.

This paper describes the depressurization and dewatering strategies, investigation for and installation of pump bores and groundwater observation bores. Approximately 5000m of drilling is carried out annually for dewatering at Loy Yang and both cable tool and rotary flush drilling methods are utilized. The cabletool method is used to obtain accurate samples for laboratory analysis, whereas rotary flush methods are used for speed and for installation of the larger diameter pumping bores. A method of re-establishing pump bores after partial excavation during mine development has been successfully developed with large cost savings. Trials are also being conducted with pre-collaring of deep bores with rotary methods then sampling the aquifer strata with a cable tool rig.

INTRODUCTION

The Loy Yang Open Cut, from which coal extraction for power generation commenced during 1983, is designed to provide up to 32Mt of brown coal per year during the nominal 30 year design life of the project.(1) This open cut has predicted reserves of more than 1000Mt of brown coal, occurring in four main seams ranging from 15m to 100m thickness.

The coal seams dip gently to the north and are separated by interseam sediments comprising mostly fine-grained sands, clay, silt and inferior coal. The sands represent a series of ill-defined, low-yield, confined aquifers which display considerable and often rapid lateral and vertical variation in thickness, grainsize and continuity. The sedimentary sequence continues at depth below the proposed mining limit of 170m.(2)

In order to provide stable operating levels and batter conditions, an extensive aquifer dewatering and depressurisation system capable of achieving drawdowns of up to 80m is being implemented. The technical approaches taken to determine depressurisation requirements are described, along with the methods of drilling and bore installation under conditions often adversely affected by sub-artesian or artesian water pressures and by significant fluid circulation losses within the jointed coal mass.

The difficulties of establishing and maintaining adequate operational pumping capacity and monitoring systems within the developing open cut must be overcome, and the various techniques undertaken to permit re-establishment of existing pump and monitoring installations at deeper levels are described. Future technical needs relating to achieving maximum efficiency from pump bore installations, modelling of time-drawdown effects of proposed pumping systems, and modelling potential recharge sources and volumes, are identified.

MINE DEVELOPMENT

The 1000Mt of brown coal required for the nominal 30 year mine life, which will necessitate coal extraction over an area of more than ten square kilometres (Figure 1), will be achieved through a three stage mine development (1).

1 In Block 1 (current) the open cut is extending in depth and to the north, with two bucket wheel excavators following cyclic pivot operations arcing repeatedly across the open cut. By late 1989 excavation will proceed on parallel stepped levels progressing northwards.

2 In Block 2 the excavators will firstly undergo a major pivot to the east, then proceed at full depth, with the final eastern boundary dependent on future coal demands.

3 In Block 3 excavation will be completed back to the south in an up-dip direction, with tapering of the extracted coal wedge matched to retirement of power station units.

HYDROGEOLOGY

The geology of the Loy Yang area is described in detail by Bolger and Brumley (2) in the Proceedings of this Conference. At Loy Yang the Tertiary coal measure sequence includes the Morwell Formation overlying the Traralgon Formation. Mining will be carried out in the M1A, M1B, M2A and M2B seams of the Morwell Formation (Figure 2). Deeper unmined coal seams include the M2C and Traralgon (T). Interseam sedimentary sequences are identified by the overlying coal seam; for example the M2B interseam underlies the M2B coal seam. Aquifers within interseam sequences are similarly named.

Within proposed mining areas the coal measures dip to the north at between $5^{\circ}$and 10°. This sequence is unconformably overlain by overburden of the Haunted Hills Formation, a flat lying unit, 6m to 40m thick, comprising mainly clay and sandy clay. The overburden contains no known aquifers.

Aquifers mostly comprise the sand and silt units within the interseam sediments. Fractured coal seams also contain significant free water, especially when joints and minor faults open up through stress relief due to the mining operation.

Upper interseam members of the Morwell Formation Aquifer System (MFAS), including the M1A, M1B and M2A interseams, will require no depressurisation during Block 1 development due to the general absence of sand lithologies.

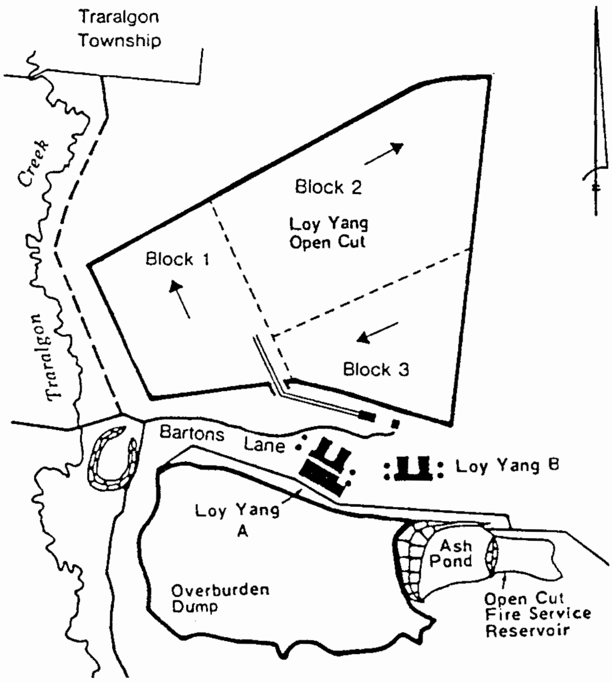

Figure 1: Loy Yang Mine Development

At Loy Yang Open Cut major depressurisation will be concentrated on aquifers occurring beneath the open cut floor. These include the M2B interseam of the MFAS and the deeper aquifers of the Traralgon Formation Aquifer System (TFAS) including the M2C and T. The most significant hydrogeological features of the M2B and M2C aquifers are the vertical and lateral variability in grain sizes and the scarcity of medium to coarse grained sand units. Transmissivities in the order of 10m/day are normal. The Traralgon aquifers are generally coarser and thicker with transmissivities ranging up to 1000m/day.

The use of measured aquifer parameters to determine local depressurisation strategy has proven difficult due to the extreme variability of the aquifers. Nevertheless, preliminary mathematical modelling results indicate that discharge rates of the order of 50 000Ml/year, or 850l/sec will be required by the year 2010 [Bolger (3) and Evans (4)]. These rates will be required to achieve the necessary drawdowns for open cut stability. Based on currently available geological data and proposed mine development plans, the estimated drawdowns which must ultimately be obtained are:

<u>MFAS</u> -	M1A, M1B, M2A members	No depressurisation
	M2B	RL +45m to -82m
<u>TFAS</u> -	M2C	RL +20m to -76m
	T	RL +15m to -73m

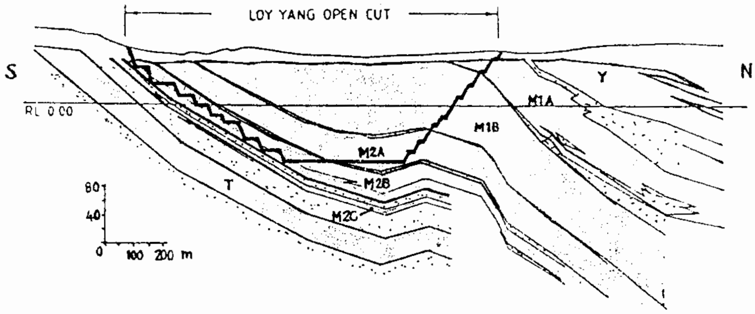

Figure 2: Geological Cross-Section of Loy Yang Open Cut

Fundamental to an assessment of required aquifer yields is the determination of sources and volumes of recharge. At Loy Yang Open Cut, potential sources of recharge include:

- lateral aquifer flow from recharge sources in surrounding hills;
- leaky aquitards, including the adjacent coal seams;
- infiltration from nearby water courses and water retention ponds;
- infiltration from surface runoff water.

Within the open cut the major recharge in the upper aquifers is from surface water feeding into the aquifers via destressed coal joints. Sources of surface water include:

- infiltration from rainfall (800mm per annum);
- fire prevention sprays;
- discharges from horizontal drains and pumping bores; and
- general open cut drainage works.

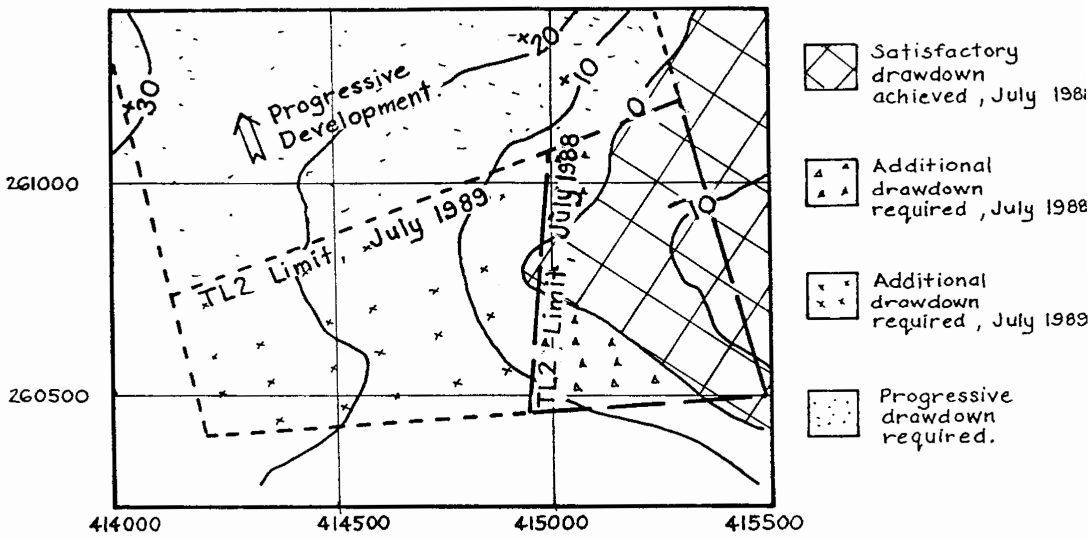

Figure 3: Loy Yang Open Cut, Block 1.
Aquifer Pressure Target Plot for M2B Aquifer and TL2 Mine Grading

WATER IN COAL JOINTS

The coal mass contains prominent sub-vertical jointing which, based on routine joint data surveys, display relatively consistent northerly strike,easterly and westerly dips of 70°to 90°and 10m to 15m lateral spacing. Maintenance of satisfactory hydrostatic pressures in the jointed coal mass is fundamental to stability of permanent and semi-permanent coal batters. Reduction of these pressures is achieved by a network of sub-horizontal drainholes.(5) These are placed routinely as access to batters becomes available. Although these drains may only flow intermittently, as after prolonged rains, their importance should not be underestimated. Firstly, the absence of water emanating from the face cannot be taken as indicating an absence of pressures in the slope, especially as the low permeability of the large unjointed blocks of coal inhibits dissipation of pressures by any but artificial means, and secondly, the low mass of the brown coal (1.1 tonnes/m^3) tends to maximise the effect on batter stability of any water pressures in the slope.

EFFECTS OF AQUIFER PRESSURES

Aquifer depressurisation is required where the weight of overlying coal and interseam sediments is exceeded by the uplift hydrostatic pressure in a confined aquifer.(6)

At Loy Yang Open Cut minimal depressurisation was required for initial mining. However, as progressively deeper mine levels are approached it is becoming necessary to achieve a progressive increase in drawdown which is, at a minimum, proportional to the mass of material removed in developing from one level to the next.

In the event that uplift pressures do exceed the weight of overlying material the potential magnitude of floor heave and seepage rates must be quantified to evaluate the effects on mining activities. Wet digging and trafficking conditions and conveyor misalignments could result. For the low-yield aquifers occurring in the MFAS at Loy Yang Open Cut it can be demonstrated that, even under moderately excessive pressure heads, the consequences would be operationally manageable.

This assessment is based on the observation that stress relief of the coal due to mining would, in conjunction with aquifer initiated heave, cause increased hydraulic connection between the aquifer and overlying coal, resulting in an essentially unconfined aquifer situation. While this would not be seen as an operational aim, it may arise from operational necessity. For the higher yield TFAS aquifers the hydraulic interconnection is likely to be less efficient. Consequently, excessive pressure heads would lead to substantial heave and, possibly, significant flooding.

At Loy Yang Open Cut the determination of depressurisation needs is achieved through comparison of proposed mine grading levels with observed aquifer pressures and inferred piezometric surfaces. Application of known average densities for coal and interseam, and of an appropriate factor of safety, enable the status of depressurisation to be most simply expressed as a "Target Plot" (Figure 3).

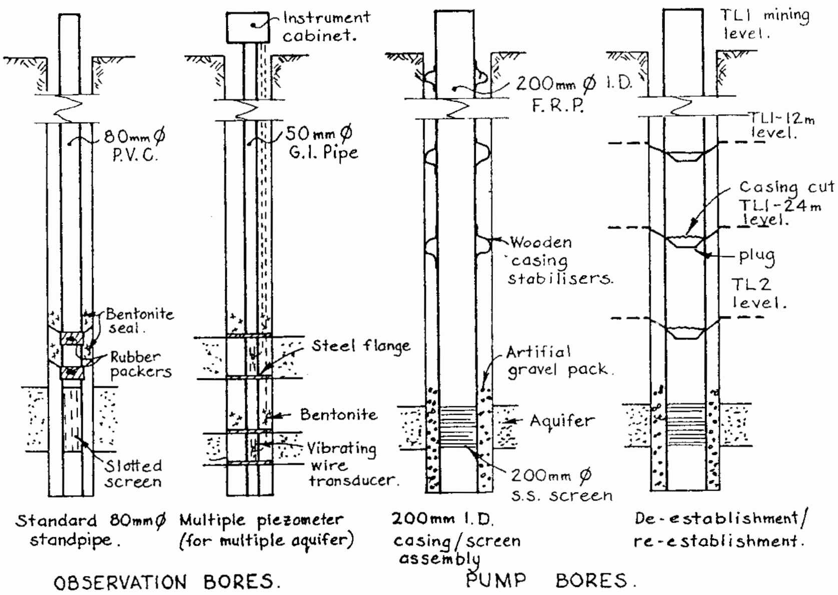

Figure 4: Typical Observation and Pump Bore Designs

Although calculations are initially effected for a completed mine grading level, manipulation of progressive mine development plans enables identification of a theoretical boundary separating those areas which are below or above defined "target" pressures. The accuracy, and interpretation, of this system rests heavily on the sensible locating of monitoring bores.

AQUIFER YIELDS AND DEPRESSURISATION STRATEGY

Actual aquifer yields from pumping depend on aquifer properties and pump bore design. Aquifer materials at Loy Yang Open Cut are fine grained sand sizes consisting dominantly of quartz, but also containing platey mica and feldspar. The latter minerals have the potential under stress of pumping to move through or clog a screen system.

In the generally fine grained aquifers at Loy Yang, pump bore design is critical. Screen slot size and artificial pack size must be accurately matched to grain size distributions in the aquifers. It is equally important to locate bore sites where aquifer thickness is adequate. Typical bore design is given in Figure 4.

Electric submersible bore pumps are currently used in all pumping installations. The pumps are placed just above the screen and are connected to the surface via a flexible riser main. The corrosion potential and moderate temperature of aquifer waters has led to the use of fibreglass bore casing and stainless steel screens and pump components.

Aquifer yields to date have varied from 0.5 l/sec/m for the M2B Aquifer to 1.8 l/sec/m for the M2C Aquifer for 200mm Ø bores. The application of vacuum pumping to the extraction system is to be trialled to improve pumping efficiency. Total continuous flows of 25 to 30 l/sec from approximately nine bores have been achieved from the M2B Aquifer to date. Continuous pumping will commence from the M2C Aquifer later in 1988.

Drawdown at the open cut margins matches that predicted from earlier pumping tests. However, within the central part of the open cut, aquifer recharge from surface water and leaky aquitards, exceeds achievable pumping flows. Depressurisation of the M2B Aquifer in this area will be achieved by relatively closely spaced relief wells, effectively altering the aquifer to an unconfined state.

Computer modelling of proposed pumping bore and relief well layouts is required to permit assessment of overlapping cones of depression. Given the stratigraphic complexity at Loy Yang further development of this capability is necessary for calculation of both volumes of water extraction and time taken to achieve a required drawdown. The latter is particularly critical for the low yield aquifers where pumping may be required over a considerable time period to achieve drawdown over a significant area.

TYPES OF DRILLING

Both cabletool and rotary drilling techniques are used to drill bores in the following three categories:

- Investigation Bores
- Pumping Bores
- Drainage Bores (horizontal)

Investigation bores are drilled to obtained detailed information on stratigraphy and aquifer material properties. Where suitable aquifer materials are found, bores may be established as observation bores or converted to pumping bores. If no suitable aquifer materials are found these bores are grouted and plugged. The bores range in depth up to 400 metres.

Pumping bores to date have been installed with 200mm internal diameter fibreglass casing with inline 200mm diameter stainless steel screen assemblies. These bores are gravel packed as the aquifer materials are often laminated with layers of very fine or fine-medium sands. The bores are drilled at a diameter of 400mm which allows placement of 100mm of gravel pack material around the screen. The maximum depth of pump bores drilled to date is approximately 200m but generally the depth is 50m to 100m.

Coal dewatering is carried out using 115mm diameter sub-horizontal drainage bores drilled at varying angles form $0^{o}$to $+10^{o}$elevation to lengths up to 350m.

Drilling with cabletool rigs requires running of up to three strings of casing (generally 125mm, 152mm and 200mm AWW casing) in order to drill and accurately sample each aquifer. Major drilling problems are rarely encountered. However, as the depth of the bore increases so does the need for additional casing and therefore drilling costs rise significantly.

Rotary flush drilling techniques are regularly used for general investigation work. Partial or full loss of drilling fluid return is common and, therefore, much emphasis is placed on geophysical logging for strata definition. Loss of circulation in fractured coal is a major problem where representative samples are required or when drilling large diameter (400mm) pumping bores. Circulation can be regained by casing off fractured zones but it is a slow and costly operation.

INVESTIGATION BORES

Rotary Method

The SECV operate two rotary table type rigs (Gardner Denver 1500 and a Bourne 1000R) and one hydraulic top drive rig (Atlas Copco B40L).

Circulation fluids include either bentonite or polymer based systems depending on the purpose of the bore. Biodegradable polymer muds are preferred in bores that are intended for establishment as observation or pilot bores.

Sampling from cutting returns is carried out if there is drilling fluid return. However, loss of circulation and contamination of cuttings in the return fluid preclude the use of this method for accurate strata definition. Consequently all bores are geophysically logged. Local knowledge of drillability of various clay, coal and sand materials, together with the geophysical log, usually enable accurate screen placements. HQ wireline or convential coring has occasionally been used for detailed sampling of interseam lithologies.

Most observation bores consist of either PVC casing/screen assemblies or single piezometer installations (either pneumatic or vibrating wire). Multiple piezometer systems have also been installed in a number of bores to monitor groundwater pressure variations throughout the stratigraphic sequence.

PVC casing/screen assemblies are run into a conditioned mud filled hole. A rubber borehole packer is placed above the screen and rock dust and bentonite pellets are used to isolate the aquifer being monitored. Development of the bore is commenced by gentle bailing and continued until the mud is removed and hydraulic connection is established with the aquifer. Surging or air lifting techniques may also be used to speed up final development.

Where piezometers are installed they are usually placed into a short length of slotted pipe which is lowered to the bottom of the hole with the drill rods. A left hand thread is incorporated at the top of the slotted pipe to facilitate backing off of the pipe. A rubber flare is located on the top of the slotted pipe to enable the piezometer to be sealed into the chosen aquifer. As no development process is possible biodegradable muds are always used with piezometer type installation.

Rotary mud drilling is the most rapid and cost effective method of installing observation bores. However, a disadvantage of this method is that good samples of aquifer materials are rarely recovered.

Cabletool (Percussion) Method

The SECV operates four cabletool drilling rigs, including Bourne C500 and C2000 machines, a Rustin Bucyrus 22RL and a Hydromaster 500.

The bores are advanced using a combination of drilling tools (earth socket, sand pump and rock bits) depending on type of formation and conditions encountered. Multiple strings of casing are required in deeper bores to enable the lower M2C and Traralgon aquifers to be accurately sampled. To enable drilling to depths up to 300m a driller must maintain a very straight hole, keeping each string of casing as free as possible to enable maximum advancement with each casing string used.

Sampling of aquifer sands is usually carried out at 0.5m intervals using a bailer of SPT spoon. The combined use of casing and these methods ensures that accurate samples are obtained, especially where the aquifer is laminated with fine and coarser materials.

The installation of piezometers and development of sandpipes is carried out in a similar manner to that used for rotary drilling. The main difference is that all installations are usually placed inside cased holes and the casing then pulled back to expose the screen or piezometer to the aquifer.

The main advantages of installing in a cased cabletool drilled bore are as follows:

- Standpipes require less developing as there is no drilling mud to remove;
- Piezometer readings can be relied on sooner than those installed by rotary drilling;
- There is no risk of installations being hung up in the hole during installation, requiring costly redrills.

Combined Rotary/Cabletool

This method involves placing pre-collar casing in the top portion of the bore with a rotary drilling rig and completing the bore, including detailed sampling, with a cabletool rig. The advantage of this technique is that on deep investigation bores requiring accurate sampling at depth, the top 80-90% of the bore can be advanced rapidly and cased with either 152mm or 203mm casing. The cabletool rig can then be used to carry out accurate aquifer sampling and place groundwater monitor equipment if required.

Major care has to be taken during rotary pre-collaring to ensure that the bore is vertical prior to casing placement. Any significant deviation from vertical will make cabletool drilling very difficult, if not impossible. This method has the potential to be very cost effective providing the pre-collaring work is carried out properly. As the average depth of investigation bores increases with open cut development, the method will be used more routinely than at present. Driller skill and knowledge is vital to the economic success of this method.

PUMPING BORES

Drilling and Installation of Bores

A Gardner Denver 1500 rotary drill rig with 5" x 8" Duplex mud pump is used to drill and install M2B and M2C aquifer pump bores. Although working at the limit of rig capability approximately 20 bores up to 200m depth have been installed successfully and economically to date.

Drilling is carried out using the conventional rotary flush method. The drill string includes a 400m Ø bit and a stabilized drill collar attached to 2-7/8" FE drill pipe. Polymer type drilling muds are used. Viscosifying liquid polymers are used at top of bore in coal materials and biodegradable polymers are used for drilling and stabilising the aquifers.

Loss of fluid circulation in overburden and fractured M1A coal can be a problem when drilling bores from grass level and 450mm Ø casing is run into the top of the bore if circulation cannot be controlled. Bores drilled from the base of the open cut usually proceed without circulation problems as the piezometric levels in the coal and aquifers are relatively high.

The inline 200mm Ø casing/screen assemblies are installed into an open hole stabilized with drilling fluids. The screen and bore casing are centralised with wooden stabilizers at approximately 20m intervals. A gravel pack is then poured into the annulus with a constant flow of fresh water to fill the annulus around the screen and displace drilling fluid into the bore casing. When gravel packing is complete the bore is bailed to take some head off the aquifer and ensure hydraulic connection is made. The mud is then flushed out of the casing and developing commenced.

Bore development is carried out by a combination of jetting, airlifting and backwashing. Satisfactory development, based on airlift flow and volume of fines removed, is achieved in approximately three to five days with several cycles of jetting and airlifting.

Pumping Bore Re-establishment

As pumping bores are required in advance of developing coal mining areas of the open cut, bores must be cut and plugged at a lower design level and then re-established once coal is excavated.

Cutting of the fibreglass casing is achieved using either an air driven cutter, when the cut is above the water table, or explosives when the cut is below. A plug, with spring loaded lugs and a rubber flare, is installed in the bore at the level of the cut prior to removing the severed upper length of casing. Following excavation of the coal the bore is relocated by survey, the plug removed and the pump reinstalled into the bore.

HORIZONTAL DRAINAGE BORES

These bores are drilled into permanent coal batters with either a Longyear 36 or Longyear 38 drilling rig. Both rigs are skid mounted and fitted with hydraulic swivel heads and hydraulic chucks which maximise drilling efficiency.

The rig is set up approximately 6m from the batter and at a bearing roughly perpendicular to major joints. The rod string is supported at the batter face by a rod roller support fixed to the batter with steel spikes. The rod string consists of a 115mm step face blade bit attached to a 6m length of HQ pipe stabilized at either end with spiral reamers of approximately 114mm diameter. This stabilized unit is driven by BQ rods.

Bores are flush drilled, using water as a circulating fluid, at an elevation of $+3^{o}$to $+10^{o}$to the horizontal. This angle is checked using a single shot Eastman borehole camera. Practice has shown that a faster drilling rate will tend to increase bore elevation and a slower rate will cause the angle of elevation to fall.

When target depth (usually 180m) has been reached and drilling rods are withdrawn, a short length of 90mm PVC pipe is placed into the bore to identify it and ensure that is does not become blocked with coal debris falling from the batter face.

CONCLUSIONS

Dewatering and depressurisation of both coal and interseam aquifers are essential for the stability of Loy Yang Open Cut. Required extraction rates are predicted to increase from 25 l/sec at present to 850 l/sec in the year 2010.

The fine grained sands in the upper aquifers are difficult to dewater due to lateral and vertical lithology changes and low transmissivities and yields. Relief wells are used to supplement conventional pumping bores at this stage. Substantial aquifer recharge is also inhibiting dewatering of the upper aquifers.

Both rotary and cabletool drilling techniques are successfully being used. The rotary flush method has the advantage of speed whereas cabletool methods are necessary for sampling of aquifer materials.

A method of re-establishing pumping bores after partial excavation during mine development has been successfully developed with large cost savings. Trials are also being conducted with pre-collaring of deep bores with rotary methods then sampling the aquifer strata with a cabletool rig.

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