HYDROGEOLOGICAL INVESTIGATION OF THE GELLIONDALE LIGNITE DEPOSITS VICTORIA, AUSTRALIA

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ABSTRACT

The Gelliondale Coalfield in south eastern Australia has large reserves of lignite in virtually a single seam of Tertiary age. The basin is structurally and hydrogeologically complex and includes areas of high pressure and highly transmissive aquifers in both the overburden and underburden. Hydrogeological investigations have been intergrated with coal reserve evaluation programs using a wide variety of investigation techniques to achieve a progressively advancing understanding and evaluation of the hydrological controls for mining, and their implications for project feasibility.

The hydrogeology program has approached the evaluation on a representative site basis using geophysically derived analogs to extend hydrological parameters rationally basin wide. The program approach has achieved substantial cost savings without significant loss of reliability in the results.

1. INTRODUCTION

Hydrogeological investigations of coal prospects are usually carried out in conjunction with the coal resources evaluation programs. As a consequence, the hydrogeological investigation is often a secondary consideration in terms of program logistics, and is often fettered by data gathering programs designed specifically for resource evaluation, with hydrogeological evaluation provided as a spin-off.

Hydrogeological programs, particularly those aspects related to bore siting and bore design, closely follow a systematic gridded approach which often restricts the potential to optimize the information gained from the hydrogeological investigation.

At Gelliondale, in S.E. Australia, groundwater factors related to dewatering and depressurization, were recognized at an early stage of exploration as important potential determinants of mining feasibility in terms of both economics and engineering. A major hydrogeological investigation program was carried out at Gelliondale by various lease holders between 1977 and 1982, and was characterized by a methodology aimed initially at determining the general condition and then focusing on investigation of key problem situations using integrated techniques, re-evaluation of detailed information thus obtained, and repetition of the investigative cycle.

The adoption of the exploration methodology was instrumental in maximizing the information returned for minimum economic costs. The hydrogeological investigation drew on a large armoury of data collection and evaluation techniques, and normal approaches to interpretation were employed to draw as much hydrogeological and geological understanding from the program as possible.

This paper describes the principal techniques used during the hydrogeological investigation to date, and compares the benefits with more conventional hydrogeological exploration programs.

1.1 History of Investigation

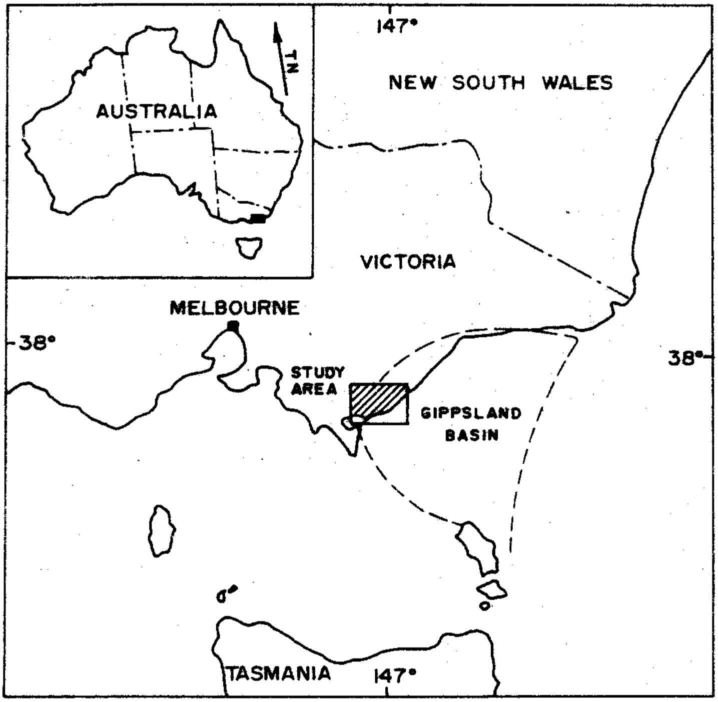

FIGURE 1 - LOCALITY PLAN

The Gelliondale lignite deposits occur as part of the Tertiary (Eocene to Pliocene) lignite deposits of the Gippsland Basin at the south eastern corner of the Australian continent (Figure 1). Together with the lignite of the Latrobe Valley and the hydrocarbon resources of Bass Strait. they form part of one of the largest natural energy resource accumulations on earth. (Lignite reserves, at a 0.5:1 overburden to coal strip ratio are greater than 116 x 10^9 tonnes; crude oil/condensate 280 GL; Liquid Petroleum Gas 65 GL; Dry Gas 190 Gm^3).

The lignite resources at Gelliondale have been known since the 1890's but were not exploited until early this century (Thomas & Baragwanath, 1950). Mining continued in a small open pit near Hedley (Figure 2) until 1920's and then closed. At the outset of the investigation the inferred lignite reserves were 5,600 Mt at a 0.5:1 strip ratio. This reserve excluded any coal horizon with a top below 90 m or bottom below 200 m (Bowen, 1982). The indicated reserves are now set at 1,700 Mt and the inferred reserves at 3,500 Mt (Greer & Smith, 1982).

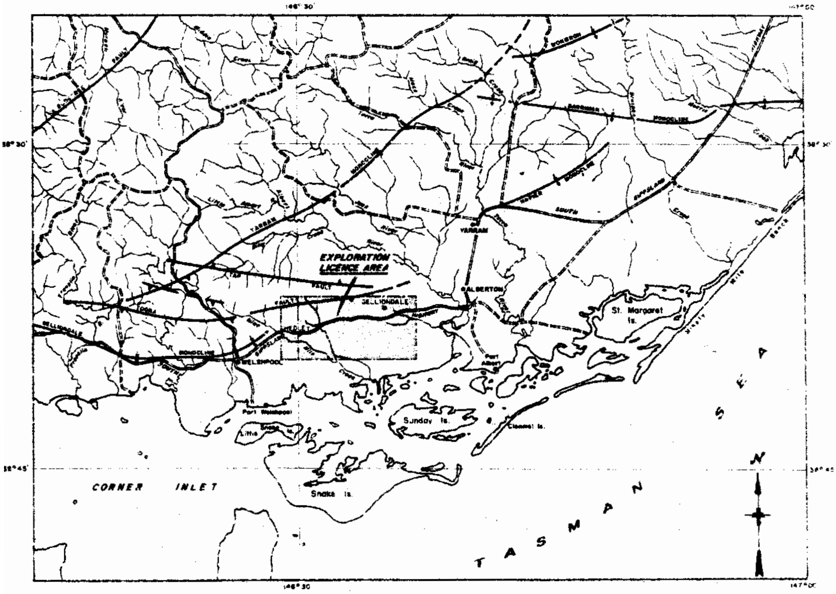

FIGURE 2 - GELLIONDALE PROJECT LOCATION

The large size of these coal reserves has attracted much attention. Since the 1930's, first the Victorian State government, then various private organizations, have undertaken exploration and development drilling to confirm the magnitude of the mineable lignite resource and to identify a use for these resources.

Australian Groundwater Consultants Pty. Ltd. was responsible for design and management of the hydrogeological investigation for the years of active resource evaluation between 1977 and 1982 and undertook most of the supervision of the overall coal basin evaluation conducted during that period.

1.2 Regional Geology

At Gelliondale, the Tertiary age lignite deposits, with overburden and innerburden sands, occur on a down faulted bedrock platform of Lower Cretaceous mudstone faulting which occurred at a slow rate and contemporaneously with the period of the lignite sequence deposition. Figure 3 shows the structural geology of the coalfield. The lignites have been stressed and fractured by the contemporaneous faulting and form apparent monoclines. Marked thickening of the lignite sequence occurs to the east of the bedrock fault lineation (The Alberton Monocline) shown in Figure 4, and the overburden shows a distinct facies change with argillaceous and fine sediments predominating to the west and arenaceous material to the east.

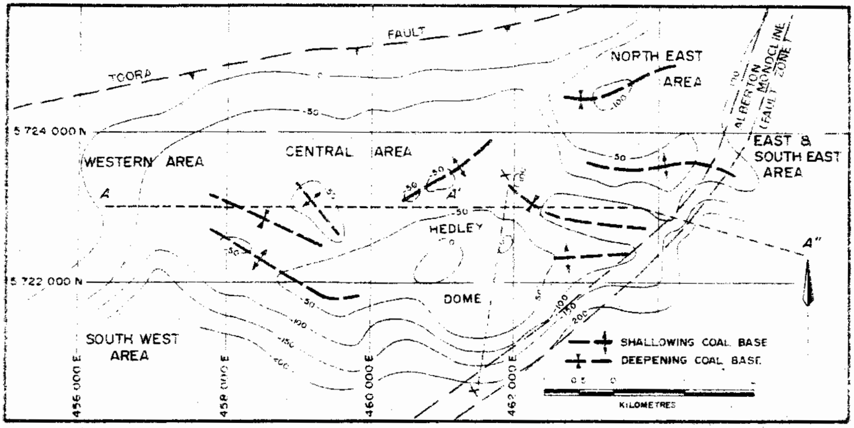

FIGURE 3 - STRUCTURE GEOLOGY GELLIONDALE COAL FIELD

The stratigraphic sequence in the area is set out in Table 1.

Unlike the Latrobe Valley Group in the Latrobe Valley to the north, the lignite sequence at Gelliondale is not lithologically broken by aquifer sands or clays. Only one persistent innerburden sand bed occurs, and this is near the base of the sequence and is of minor significance in hydrogeological terms.

A significant feature of the Gelliondale Coal field is the Hedley Dome. This buried structural feature is believed to have been an island block on the bedrock platform throughout the period of deposition of the Tertiary sequence. Lignite is absent on the Hedley Dome, and was probably never deposited over the feature. Alternatively, the lignite was eroded during marine transgression prior to the deposition of the Jemmys Point Formation, or during the various marine transgressions of the Quaternary Period.

1.3 Coalfield Condition

The Gelliondale coalfield is consistant with many other deposits having a simple sequence of overburden, coal and underburden.

1.3.1 Overburden

The overburden consists of a sequence of Quaternary to Pliocene arenaceous and argillaceous sediments of variable thickness but generally in the range of 15 to 30 m thick, except to the east where the thickness increases markedly. The overburden disconformably overlies the lignite sequence. The lowermost sequence of the overburden probably consists of a lateral equivalent to the upper layers of the lignite. This has been interpreted as relating to a beach barrier paludal facies (Thompson 1982) which occurs 10 km east. Coarse sands and gravels representing more active fluvial locations occur through the overburden, especially to the east of the Alberton Monocline.

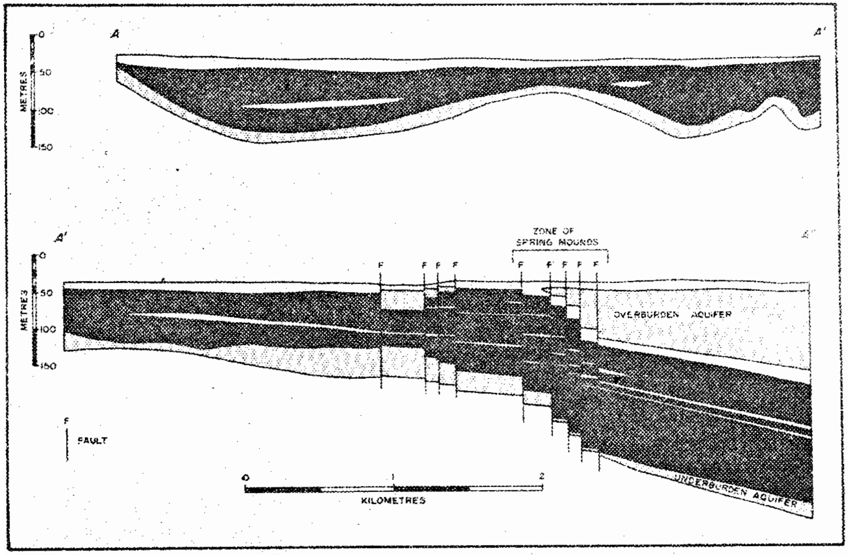

FIGURE 4 - CROSS SECTION GELLIONDALE COAL FIELD

1.3.2 Lignite

The lignite sequence consists of several units of coal and carbonaceous sediments of varying lithotypes, up to 170 m thick, with occasional breaks of sand and clay in lenses.

1.3.3 Underburden

The underburden sequence appears to be conformable below the coals but varies in thickness, dependent upon bedrock depth, structure and lateral thinning of the coal.

The underburden is composed of a variable sequence of well sorted sands, gravels and ligneous clays of fluviatile and/or lacustrine origin.

The sands in the sequence appear to increase in coarseness with depth within any one layer and in general are coarser to the east and finer and more laminated to the west.

2. INVESTIGATION METHODOLOGY

2.1 Hydrogeological Framework

The nature of, and relationships between, the overburden and the lignite desposits, dictate that any mining of the lignite would be by open cast techniques. Mining would necessitate the desaturation of the overburden to produce stable and economic batter angles, and depressurization of the underburden aquifers to avoid block shifts around and in the pit, floor heave and flooding problems. Finally innerburden layers would have to be depressurized and ultimately, desaturated, either by face drainage or by other techniques.

Early in the lignite reserve evaluation it was recognized that the existance of unconsolidated and pressure aquifers in both the underburden and overburden were a critical parameter of the coal basin and one which would have a significant impact on the feasibility and economics of any coal mining operation to be conducted at this site. It was decided that the evaluation of the coal reserves must advance parallel with hydrogeological investigations.

Initial drilling data and site inspections showed that high artesian pressures (15 m + above ground surface) existed towards the east end of the coalfield. Several irrigation wells existed tapping the underburden aquifer. Geomorphic interpretation of the area also revealed mound springs and spring seeps aligned north east/south west across the coalfield. Towards the west, where hydraulic heads were lower, no irrigation wells had been constructed, nor was there any evidence of springs. Some brackish stock water supply wells existed.

The approach to establishing proven, indicated and inferred reserves was essentially a statistical exercise involving the establishment of sufficient reliable coal grade data for reliable correlation across the coalfield.

While the coal evaluation approach gave some semi quantitative data of value in establishing the hydrogeology of the area, the hydrogeological evaluations aimed at;

- characterizing the coalfield quickly to determine whether the groundwater problems were of the magnitude of importance to the feasibility that was imagined.
- evaluating the critical areas with respect to potential coal mining, and
- identifying contingent problems which could be involved in the management of the groundwaters around the site (environmental problems subsidence etc.).

For these reasons an integrated approach was selected using a variety of regional and site specific evaluation techniques. Repeated evaluation and re-evaluation was undertaken as the data base expanded to give progressively more reliable input to the continuing overall economic assessment of the project.

Investigations and evaluations carried out by Australian Groundwater Consultants Pty. Ltd. were directed to obtaining a definition of the overburden and underburden hydrological systems and their interaction. The principal hydrogeological features of the area were seen as being:

- the Alberton Monocline (Fault) to the east (then unknown),
- the Hedley Dome (defined by gravity surveys in 1931),
- the underburden aquifer distribution across the area,
- the overburden aquifer extent,
- the hydrological characteristics of the lignite.

An integrated investigation programme was carried out which included:

- drilling using rotary mud, twin tube reverse circulation, coring and augering,
- wireline logging,
- electrical resistivity surveying, and
- hydraulic testing by flow and protracted pumping.

2.2 Drilling

Drilling is an expensive operation at Gelliondale where artesian conditions are expected, since surface casing must be cemented in place. Lignite, overburden and underburden coring was undertaken using clean water at minimal rates to avoid sample contamination and washing. Stationary inner tube core barrels were used and while lignite core recoveries were high (generally greater than 90%). sand and gravel core recoveries were frequently less than 70% due to the occurrence sulphide nodules, especially in the underburden.

In some cases, boreholes in suspected artesian areas were drilled utilizing a system capable of shutting the holes in with the rods in the hole. Where artesian flows occurred, the holes were mudded up under pressure with a weighted mud including high yield bentonite, organic polymer and barite. The main drilling technique in such areas was to drill to the base of the coal, and then to proceed with weighted drilling mud. Mud weight and condition was carefully monitored during these stages.

Prior to these precautions being taken, several small diameter geological exploration holes had flowed uncontrolled at a rates in excess of 60 L/s. Sealing such high flowing wells had proven difficult and expensive.

Sample handling of the lignite and sands was found to be critical to obtain reliable assessment of lithological type and moisture content. Some moisture uptake is suspected to have occurred in several cases. as gas released on core withdrawal.

Dual tube. reverse circulation, continuous core drilling was attempted for a trial period, but this resulted in broken and mixed core arriving in the catcher trays, and the technique was abandoned after two holes.

Coring of the overburden strata was seldom attempted, and cuttings samples only were collected from mud drilled holes. Size analyses were performed on the samples for screen aperture determination but otherwise no quantitative use was made of the samples.

In the Hedley Dome area, artesian pressures did not exist and stratigraphic and core drilling did not require cemented surface casing. Water was used for hole flushing.

The density of drilling data finally established across the coal basin was 5.8 holes/km^2 for coal geology and 0.5 wells/km^2 for hydrogeological data. However, some of the holes drilled for coal reserve evaluations were extended to bedrock and wireline logging of these boreholes gave data on aquifer thickness and nature.

2.3 Wireline Logging

Every hole drilled, irrespective of its purpose, was geophysically logged. The sondes run included where possible:

- electric logs - spontaneous potential and point resistivity,
- gamma radiation,
- gamma gamma density,
- caliper,
- neutron.

These logs were used to provide a basis for detailed correlation from hole to hole, as well as for identifying possible variations in coal type, ash content, innerburden lenses and for identifying aquifers in the overburden and underburden. The results were used to select representative samples for coal assay.

From a hydrogeological viewpoint the most valuable logs were the electrical and gamma ray logs. These permitted aquifer correlation and a reasonably accurate aquifer thickness and hydrological index (of hydraulic conductivity) to be established. Since hydraulic testing of the aquifers was necessarily limited, this data allowed mapping, or zoning, of hydrological characteristics for later modelling.

2.4 Electrical Resistivity Surveying

Geo-electric surveys were undertaken as a means of identifying lateral variations in facies or continuity and depth to bedrock. A total of 52 km of survey were carried out including 108 vertical electrical soundings.

The geophysical surveys were applied to achieve:

- A quick and inexpensive mapping of the overburden material particularly to identify lateral changes in formation resistivity (apparent resistivity). A modified Wenner electrode array was used with a current electrode separation of 60 m for traversing. The electrode separation was determined from interpretation of

Vertical electrical soundings (VES) undertaken at 1 km spacing along the traverse lines and was considered to appropriately identify the coal/overburden interface.

The V.E.S. data was also used to delineate changes in bedrock depth and/or type by extending their depth of penetration by increasing the current electrode separation.

Current electrode separations were extended out mostly to 650 m but in the deeper area 950 m was required. For the deepest soundings high power A.C. transmitters were used with output voltage up to 900 V at over 6 amps. Interpretations of the V.E.S. used standard curves or the auxiliary curve method and were interpreted on site to ensure that definition of the bedrock depth was achieved. This was taken to be near infinite resistivity for the bottom layer. Most interpretations were for four to five layer cases. The use of computer programs greatly expedited site evaluations.

The results were compared with earlier gravity surveys of the area and were calibrated against the existing borehole data. The results were used to site hydrogeological investigation holes on a representative target basis, rather than simply on a grid basis.

Several stages of electrical resistivity surveys were carried out as the needs of the program and assessment demanded.

The data obtained from electrical resistivity surveying was shown by correlation with drilling to have been helpful in:

(i) defining the Hedley Dome and the bedrock types which comprise it,

(ii) identifying variations in the lithology of the overburden sequence, especially as clays were replaced by sandy sequences towards the east in the Gellionde Trough, and

(iii) identifying major variations in the configuration of the base of the coal, relating to the structural features in the area.

The resistivity data were plotted as contours of apparent resistivity and as geological sections which were correlated from V.E.S. to V.E.S., through existing borehole data. From these data, initial isopach and structure contour plans were produced to act as a guide for future drilling. These plans were then progressively refined as further stratigraphic, coal core and hydrogeological drilling data were collected. In essence, the geophysical data established an early, but inexpensive, first assessment of the area, at a time when only a small amount of reliable drilling data existed.

Estimates of underburden sequence thickness derived from V.E.S. data alone proved to be excessive. This over estimation was due to the occurrence of a thick sequence of relatively low resistivity weathered bedrock profile which was initially interpreted as being underburden.

Figure 5 shows a cross section of the Hedley Dome compiled from V.E.S., auger and diamond drilling data.

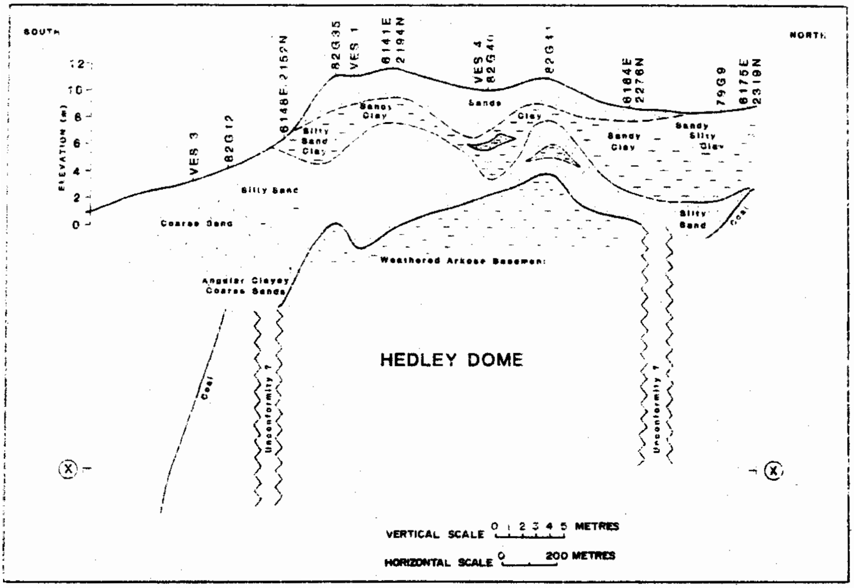

FIGURE 5 - CROSS SECTION X - X ACROSS THE HEDLEY DOME INTERPRETED FROM V.E.S., AUGER AND HALL HOLE DATA

2.5 Hydraulic Testing

Testing to evaluate aquifer hydraulic parameters were carried out using a number of different methods. Three extended period pumping tests were carried out, there being two on the underburden aquifers and one on the overburden aquifer. Artesian flow recession tests were carried out on eight observation wells, all of which were conducted in the underburden aquifers. Falling head tests were conducted on observation wells at twenty five sites, of which ten were within the underburden, seven on the Hedley Dome and the remainder in sub-artesian, underburden observation wells.

The maximum length of the pumping tests was 28 days with water level records being collected at observation wells tapping both the overburden and underburden aquifers. Flow recession tests were of only a few hours duration, but flow reduction and pressure variation were monitored by pressure transducers with a data logger sampling and recording the results at high frequency (up to 15 times/minute). This provided highly reliable data, even of highly transmissive aquifers. Flow measurements were obtained using central, sharp edged, end orifice plates in conjunction with a piezometer. Manual confirmation of pressure head variations up to 15 m were achieved using mercury manometers.

Falling head tests were conducted on small diameter wells drilled using water only. These were generally shallow observation wells. Volumes between 20 and 200 L of water were rapidly introduced into the wells by a large diameter sluice valve. Measurement of the recession of head in the well to original state condition was recorded and the results evaluated in terms of hydraulic conductivity using the method of Ferris & Knowles (1963).

The results of the falling head tests were generally considered to give a reliable indication of the order of magnitude of the hydraulic conductivity in close proximity to the bore. However, a significant number of tests undertaken, especially in lower permeability sediments, showed that a reasonable correlation emerged against lithology.

In some wells hydrostatic head recovery tests were conducted by measuring the recovery of water level after a bailer or a large volume object was removed "instantaneously" from below water level (for example a cable tool percussion rig sinker bar). This test was successful only where water level was shallow and the time to remove the object from the well was short. Otherwise too much early time data was lost.

The objectives of pump testing were commonly two fold, these being to evaluate the aquifer characteristics, as well as to determine the impact of structure on the hydrogeology.

Though the aquifers were apparently confined, the analyses of pumping test results, especially in the underburden, were seldom straight-forward due to the presence of hydraulic barriers and leakage. The longer duration pumping tests were carried out to improve analytical certainty.

Up to nine observation wells were monitored simultaneously on occasions covering both the overburden and underburden aquifers in order to evaluate the effects of pumping. Often excellent results were obtained close to the pumping bore, but several equally valid interpretations could be derived from the results at a distance.

The ranges of hydraulic parameters evaluated in the pumping tests was from less than 10 m^2/d to over 500 m^2/d.

During an early stage in the program a relationship was sought between formation true resistivity (from V.E.S.) and transmissivity. An apparent relation was struck (Figure 6), on a limited data base, and this was used in early aquifer modelling to determine possible levels of depressurization of pumping.

2.6 Aquifer Modelling

The results of aquifer modelling based on results from the representative aquifer tests then available, and on the allocation of hydraulic parameters using true resistivity and electrical log characteristics, gave a result which indicated that the quantities of pumpage from the underburden at least, was not likely to be so large as to render the project infeasible. This conclusion helped the project developers, at prefeasibility stage, to determine their future expenditure allocations in relation to the coalfield, which by then had been subdivided into four identifiable subdivisions in mining terms.

On the basis of the early computer modelling the estimated quantities to be pumped are as set out in Table 2. These indicated underburden aquifer pumping requirements of 1.2 ML/d for the central section of the lower permeability Western and Central areas, not including rainfall recharge. Subsequent more detailed modelling for mining a similar portion of the area, showed that the depressurization pumpage from the underburden would range from 7.2 ML/d at start up, to less than 1.1 ML/d after five years. (Average of 1.8 ML/d over 5 years). These results show that the early estimates were reasonable given the limited data base at that time.

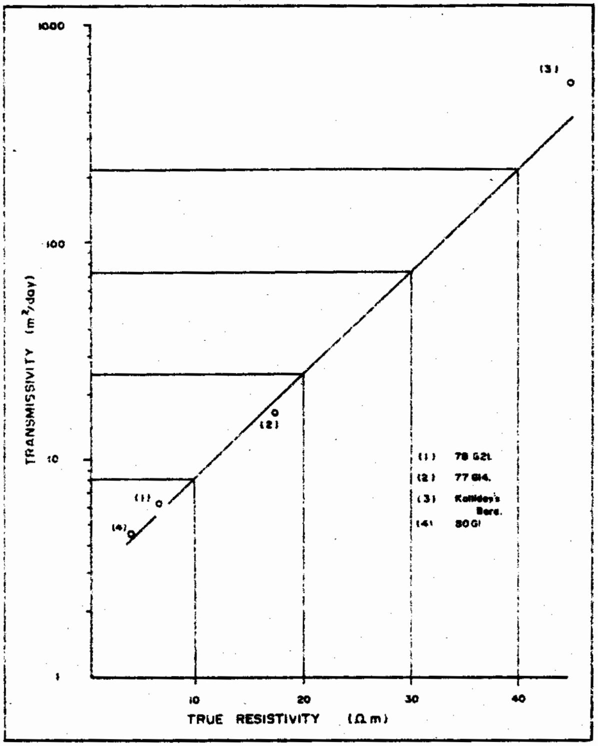

FIGURE 6 - EMPIRICAL RELATION BETWEEN TRUE RESISTIVITY AND TRANSMISSIVITY

Early modelling of overburden and underburden dewatering east of the Alberton Monocline indicated that pumpage would need to be in excess of 200 ML/d and it was decided that unless such quantities of water were required by other aspects of the project, mining would not be considered in these areas.

3. DISCUSSION

Quantitative estimates of the cost benefits to the approach used at Gelliondale have not been made. However, some aspects can be highlighted where economic savings over more conventional techniques were clearly made.

The principal costs for an hydrogeological evaluation at the scale warranted at Gelliondale, would normally be incurred by drilling and test

TABLES

AGE	GROUP OR FORMATION NAME	DESCRIPTION	THICKNESS	COALFIELD TERMINOLOGY
QUATERNARY Recent PLEISTOCENE	BOISDALE FM	dune sands	0 - 3 m	

&	NORTH EASTERN	SOUTH EASTERN	SOUTH WESTERN
^{6}	8.1×10^{6}	1.65×10^{7}	1.14×10^{7}
	6×10^{-4}	6×10^{-4}	6×10^{-4}
	94.4	116.0	8.6
	128.9	183.6	2.6
	70.8	157.0	110.0
	12.2	53.1	35.7
	77.6	171.0	112.6
	38	140	11.2

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pumping. Clearly, in any program substantial savings can be made if these two elements can be reduced. The approach at Gelliondale was to use existing bores and geological data as much as possible and to compare the conditions with a minimum number of specifically sited hydraulic evaluation points. In this way a progressively more detailed understanding of the aquifer conditions and potential reactions to mining and dewatering could be obtained.

In the placement and interpretation of pumping tests, not only was it possible to achieve hydrological evaluations, but also interpretations resolved geological uncertainties. For example, in the pumping tests close to the Alberton Monocline, it was reaction in observation wells tapping the overburden aquifer, when the underburden aquifer was being pumped, which revealed that the lignite sequence was vertically cleaved and fractured. The lack of reaction in more distant underburden observation bores further demonstrated the level of faulted discontinuity applying. These interpretations significantly altered the modelling basis in this area and also demonstrated the inadequacy of simply correlating beds bore to bore. The Alberton Monocline has been shown to be a fault.

The electrical resistivity surveying was a major contributor to reducing groundwater exploration costs. Initial comparison of resistivity interpretation and drilling data indicated good correlation, and that the resistivity techniques portrayed the subsurface conditions with sufficient accuracy to define the vertical and areal extent of aquifer systems in the basin. Furthermore, the geophysical prospecting provided information of a much greater cross sectional area of aquifer than that attainable from bores, which sampled only a very small area by comparison.

Geophysical logging of existing and new bores was carried out in order to reduce the normal costs involved with hydrogeologic data gathering techniques and to reduce the subjectivity of much lithological logging. The costs of hydrological evaluations not only derive from the cost and analysis of the aquifer tests themselves, but also from the bore construction, which has to be specifically designed for aquifer testing. Quantitative comparison of the geophysical logs with the litholog and correlation with bores on which aquifer tests had been performed, showed that the relationships were strong and that the technique could be used to substantially reduce the number of aquifer tests required.

The most critical contribution made by the hydrogeological investigation to the overall project feasibility was in defining the margins of easily mined coal by hydrogeological modelling. In this case the margin was not dependant upon coal grade or coal to overburden stripping ratios, but to dewatering and depressurization costs and problems.

The definition of the margin permitted the concentration of project feasibility evaluation expenditure to be made on the most economic coal resources. Without the use of the integrated and representative area approach, the cost savings inherant in the setting of these margins would not have been achieved.

4. CONCLUSIONS

The definition of the geology and hydrogeology of the Gelliondale Coalfield is yet to be completed, but the integrated use of drilling, geophysical techniques and hydraulic evaluations with continuous assessment of their composite indications, has permitted the exploration and evaluation programs to be targeted sharply upon the areas of greatest importance to the feasibility study.

Further, the use of relatively low cost testing techniques has been a feature of the hydrogeological program, and even though the number of hydrologically evaluated sites remains few, a large population of reasonably reliable assessments has emerged.

Vast resources of lignite are available in the Latrobe Valley Coal Measures, but the development of the Gelliondale Coalfield may be many years away due to external factors. In the interim, data collection and collation is continuing from observation wells already established. This and the information obtained so far will stand to measurably assist developers in the future.

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