INSTITUTE of
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WINTINNA COALFIELD, AUSTRALIA

REVIEW OF HYDROGEOLOGICAL STUDY

Report prepared for Sir Alexander Gibb and Partners
by Institute of Hydrology, Wallingford.

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WINTINNA COALFIELD, SOUTH AUSTRALIA
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PROPOSED MINING DEVELOPMENT

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A. GENERAL

A feasibility study was carried out by Coffey and Partners in 1983 for Meekatharra Minerals Ltd to evaluate a proposed mine site in the Wintinna Coalfield. Their report was presented in December 1983 (ref. Z1/1 - AN).

The objectives of the groundwater study, made in conjunction with a geotechnical investigation programme, were:

> "to provide an assessment of groundwater occurrence, aquifer hydraulics and other hydrogeolgical criteria of the site, specifically the evaluation of the hydrogeological aspects of the proposed mining operations"

We were requested by Sir Alexander Gibb and Partners to review and comment upon the hydrogeological study. It was agreed that an independent check of the predicted volumes to be removed by dewatering could not be made since these were based on a digital model. Our comments relate therefore to the hydrogeological interpretation.

Summary of Report

The Wintinna Coalfield is situated in the north central section of the Arckaringa Basin, a partially connected sub-basin at the western edge of the Great Artesian Basin. The area receives about 130 mm/year rainfall. The topography consists of low ridges with broad outwash channels at an elevation of 130-150 m above sea level.

The geology of the area is known in some detail from earlier coal exploration boreholes. It is underlain by a thick sequence of relatively flat (5°) and undisturbed Permian to Cretaceous sediments on a horst/graben structure of Pre-Cambrian to Devonian basement. The four main lithostratigraphic units are:

Recent deposits:	alluvium and aeolian deposits	0 = 9 m
Bulldog Shale:	siltstone-mudstone with minor sandstones	50 - 90 m

Cadna - Owie: and Algebuckina Sandstones:	fining upwards sequence of poorly consolidated, mainly uncemented sandstones to siltstones	65 - 105 m
Upper Mt Toondina: Formation:	coal sequence with sandstones and siltstones	80 m

The coal could be mined by either the open cut or underground mining methods.

The Mesozoic sandstones (Cadna-Owie and Algebuckina) form a single major aquifer of high transmissivity. They are confined by the Bulldog Shale, which contains shallow perched aquifers, and underlain by the Permian coal sequence (UMT) of mainly low permeability. Water quality throughout the sequence is generally poor.

The regional hydrogeology was established from a general reconnaissance which included an inventory of some 40 boreholes together with information from several groundwater studies carried out in the region by others. However, there were no previous groundwater studies related specifically to the Arckaringa Basin.

Site investigations were undertaken to evaluate the relevant aspects of the groundwater system relating to the dewatering requirements of an open cut mine or inflows to an underground mine.

These investigations included the following:

1. Drilling ten boreholes at three locations (one of these sites is in the adjacent licence area to the south). Four of the boreholes were cored.

2. Detailed geophysical logging at 8 boreholes.

3. Three packer tests in the UMT

4. Twelve sieve analyses, but including only one in the Cadna-Owie Formation and two in the Algebuckina Sandstone.

5. Field pH, temperature and EC measurements at 20 boreholes. Only three chemical analyses in or near the mine area for major cations and anions.

6. Aquifer tests for 24 hours at two locations (MPT, BPT) at rates of up to 1160 m^2/d (13.4 l/s), using arrays of three piezometers with screens placed at different levels. All in the Mesozoic sandstones.

The Mesozoic sandstones were shown to form a major aquifer with a high transmissivity and, as such, could contribute large flows into an open cut or underground mine. A numerical model was developed to represent the groundwater system in a simplified form to predict the volumes that would have to be abstracted to allowing mining. These predictions and choice of appropriate dewatering schemes may be summarised as follows:

(i) Open Cut Mine:

Dewatering of the Mesozoic sandstones and partially of the coal measure sequence will be required. The model study used an average transmissivity, measured storage coefficient and assumed specific yield with the water level drawn down rapidly to near the base of the Mesozoic sandstones.

(a) First stage (2 km x 2 km mine). Abstraction initially 600 Ml/d for 1 year. However, a constant 360 Ml/d for one year decreasing to 160 Ml/d would be a more likely dewatering regime.

(b) Second stage (2 km x 3.2 km mine). Increase abstraction to 280 Ml/d for one year subsequently decreasing to 180 Ml/d.

These predictions do not include inflow from the UMT and allow a saturated zone of 10-15 m at the base of the Mesozoic sandstones.

The dewatering scheme would involve 40 boreholes at a spacing of 200 m around the mine perimeter with screens placed over the lower half of the Mesozoic sandstones. Well yields would initially be 120 l/s decreasing to 40-50 l/s. Seepage from the UMT would be collected in drains and sumps.

(ii) Underground Mine

The development of an underground mine in the unusual geological environment (by Australian precedent) at Wintinna is somewhat unique.

Assuming a mine of 0.8 x 3.5 km some 43 boreholes would be required for the same total abstraction as for the open cut mining option. Individual well abstraction rates initially would be 100 - 110 l/s subsequently decreasing to 40 - 50 l/s.

It was assumed that there is no major interconnection between the Mesozoic sandstones and the UMT and thus an inflow of 3 - 10 Ml/d from the UMT could be disposed of by conventional underground pumping.

Disposal of the water could be used partly at the mine but due to the poor quality is unsuitable for irrigation use. It is suggested that the water is piped 20 km away to the west and re-injected into the Mesozoic sandstones.

Further hydrogeological investigations were recommended:

- a large-scale pumping test to assess storage changes
- detailed modelling to examine regional effects
- a large-scale re-injection test for recharge wellfield design

B. REVIEW AND COMMENTS

Geological Framework

The geology of the area scheduled for mine development has been well defined. With this geological understanding the report presents a consistent and acceptable conceptual model of the aquifer system, which is briefly tabulated below:

AQUICLUDE 50-89 m thick	BULLDOG SHALE	Mudstones Siltstones Minor sandstones	
AQUIFER 65 - 105 m thick	CADNA-OWIE FORMATION) ALGEBUCKINA SANSTONE.	fining upward sequence	siltstones sands gravels
AQUICLUDE 80 m thick	UPPER MOUNT TOONDINA) FORMATION)	Mudstones Siltstones Shales Coal	

The main water-bearing formations are identified as the Cadna-Owie Formation and Algebuckina Sandstone, which on a regional scale are considered to behave as a single aquifer unit.

This aquifer is confined above by the Bulldog Shale. Minor sandstones within this sequence carry some water and perched aquifers are known to exist but the shales can be considered as non-water bearing on a regional scale. Boreholes which abstract from this sequence generally yield less than 0.4 m^3/hour.

Forming a lower aquiclude is the Upper Mount Toondina Formation. Packer tests within the formation have been used to demonstrate low permeability and show the sequence to be of little importance as a water-bearing unit.

Within the Cadna-Owie/Algebuckina sandstone aquifer itself the report uses lithological logs and grain size analyses to show that permeability is likely to increase with depth in response to increasing grain size and decreasing clay content. Figures 6 and 7 of the December 1983 report, showing grain size and lithological features, are used to highlight this feature.

The layered distribution of permeability and storage is also picked out by the gamma logs of project boreholes, although these are not specifically referred to in the text of the report. Our figure 1 and 2 show the three zones of permeability present within the aquifer at the two pump test sites. These zones have been defined using the gamma logs reproduced in the September 1983 report, where lower API values have been taken to represent lower clay content and by inference higher permeability and storage. Correlation between these zones and lithology is good.

In geological terms, therefore, we feel that the aquifer system is well defined and a consistent and logical pattern seems to emerge.

Aquifer Parameters

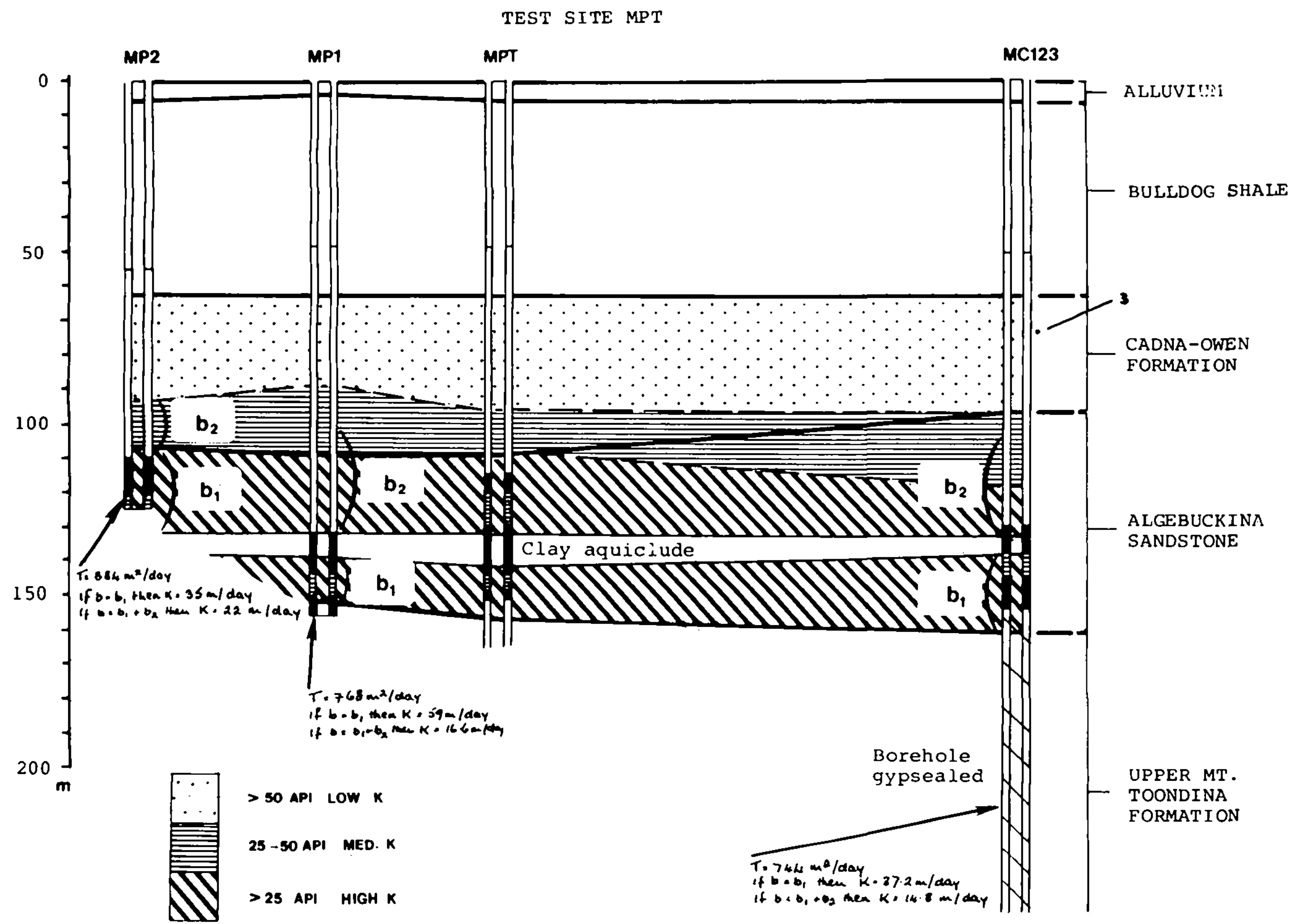
To establish values of aquifer parameters reliance has been placed entirely on the results of two pumping tests, one at site MPT within the mine area and a second at site BPT in the licence area to the south. The only other work done in this direction was the packer testing undertaken in the Upper Mount Toondina Formation, already mentioned. By placing reliance on so few sites the report implicitly assumes that aquifer parameters do not vary significantly in the lateral sense over the area of investigation. Given the granular and non-fissured nature of the aquifer and the fact that the lithology appears to be fairly uniform, we accept that this is a reasonable assumption to make.

The pumping tests at MPT and BPT were carried out competently with accepted techniques being used to analyse the data. Values of transmissivity and storage subsequently derived are accurate within the limitations of the analytical techniques. We feel, however, that the permeability values derived directly from transmissivity are open to some debate.

In order to discuss this point we propose to examine the interpretation of each test in turn.

(a) Pumping Test at MPT

The geological situation at this site is complicated by the presence of a 10m thick clay horizon within the higher permeability zone of the



TEST SITE MPT
MP2
MP1
MPT
MC123
0
50
100
150
200
m
ALLUVIUM
BULLDOG SHALE
3
CADNA-OWEN FORMATION
ALGEBUCKINA SANDSTONE
UPPER MT. TOONDINA FORMATION
b2
b1
Clay aquiclude
T = 884 m²/day
if b = b1 then K = 35 m/day
if b = b1 + b2 then K = 22 m/day
T = 768 m²/day
if b = b1 then K = 59 m/day
if b = b1 + b2 then K = 16.6 m/day
Borehole gypsealed
T = 744 m²/day
if b = b1 then K = 37.2 m/day
if b = b1 + b2 then K = 14.8 m/day
> 50 API LOW K
25 - 50 API MED. K
> 25 API HIGH K

Figure 1

sandstone (Figure 1). This effectively creates 2 aquifers, at least locally, since the clay is 500 m from the test site. In an attempt to overcome the problem the pumped well was installed with two lengths of screen, one above and one below the clay horizon. But, as we will demonstrate, by doing this a degree of uncertainty is introduced in interpretation of the data.

At this site three observation wells were installed, all situated at a sufficient distance from the pumped well to avoid problems of partial penetration. Two were screened below the clay and one above (Fig. 1).

For the purposes of interpretation the report has assumed 2/3 of discharge enters through the upper screen of the pumped well and 1/3 enters through the lower screen. Under the circumstances this is a reasonable assumption which we have no reason to question. By making this assumption it is implied that drawdown in boreholes screened below the clay are a function of 1/3 of the total discharge, whereas in boreholes screened above the clay they are a function of 2/3 of the total discharge.

Based on this asumption, transmissivity values of 768 and 744 m^2/day are derived for boreholes MP1 and MC 123, both of which are screened below the clay. Again these results are acceptable provided we recognize the transmissivity to apply specifically to the thickness of aquifer beneath the clay, since only flow moving through this section of aquifer has been used to calculate the transmissivity value. Hence to obtain permeability this transmissivity should be divided by the thickness of aquifer below the clay, which at sites MP1 and MC 123 is 13 m and 21 m respectively; by doing this values of 59 and 37 m/d are obtained.

Unaccountably, however, the report appears to have derived permeability by dividing by the full thickness of the 'clean sand' aquifer both above and below the clay. The thicknesses adopted are 46 m and 50 m at MP1 and MC123 respectively and result in permeabilities of 16.6 and 14.8 m/d (Fig. 1).

At observations well MP2, which is screened above the clay we also feel that flow is assumed to be taking place over too large a thickness. The reports assigns an aquifer thickness of 40 m at this point to obtain a permeability of 22m/d. We feel, however, that there is a case for suggesting that flow is restricted mainly to the high permeability zone at this site (Fig 1). This is 25 m thick and results in a permeability of 35 m/d.

(b) Pumping Test at BPT

Once again the problem here centres about which thickness to take in order to derive an average permeability. Figure 2 is a section across the test site. Two of the observation wells are screened in the high permeability zone, as recognized from geophysical logs, while a third is screened against the medium permeability zone.

For the boreholes screened against the high permeability zone the report assumes flow is taking place throughout the entire thickness of both high and medium zones. This results in permeabilities of 10.4 and 9.9 m/d for sites BC 38 and BP1 respectively.

There is however a strong possibility that most of the groundwater flow to the pumped well will tend to move through the high permeability zone, this being the zone of least resistance to flow. As a result the permeability should be obtained by dividing transmissivity by the thickness of this layer rather than including other zones. Under these circumstances permeabilities of 26.7 and 19.8 m/d are derived for sites BC38 and BP1 respectively.

Support for the proposition that most flow is confined to the high permeability zone is provided by the very high transmissivity derived for borehole BP2 which is screened against the medium zone of permeability. At this point the calculated transmissivity value of 958 m^2/day is almost double that of the other two sites.

Our interpretation of this is that because less flow is taking place through the medium permeability layer less drawdown is incurred in the borehole. The high transmissivity derived by the report results because the low drawdown is taken to be a function of total discharge rather than only a small part of it.

Results of the pumping tests can be summarised as follows:

1. The results of the test re-inforce the concept of an aquifer divided into three strongly contrasting zones of permebility, as identified through geoogical and geophysical work.

2. The pumping tests only provide permeability values for the high permeability zone; these range from 20-60 m/d. From the tests we have no

TEST SITE BPT

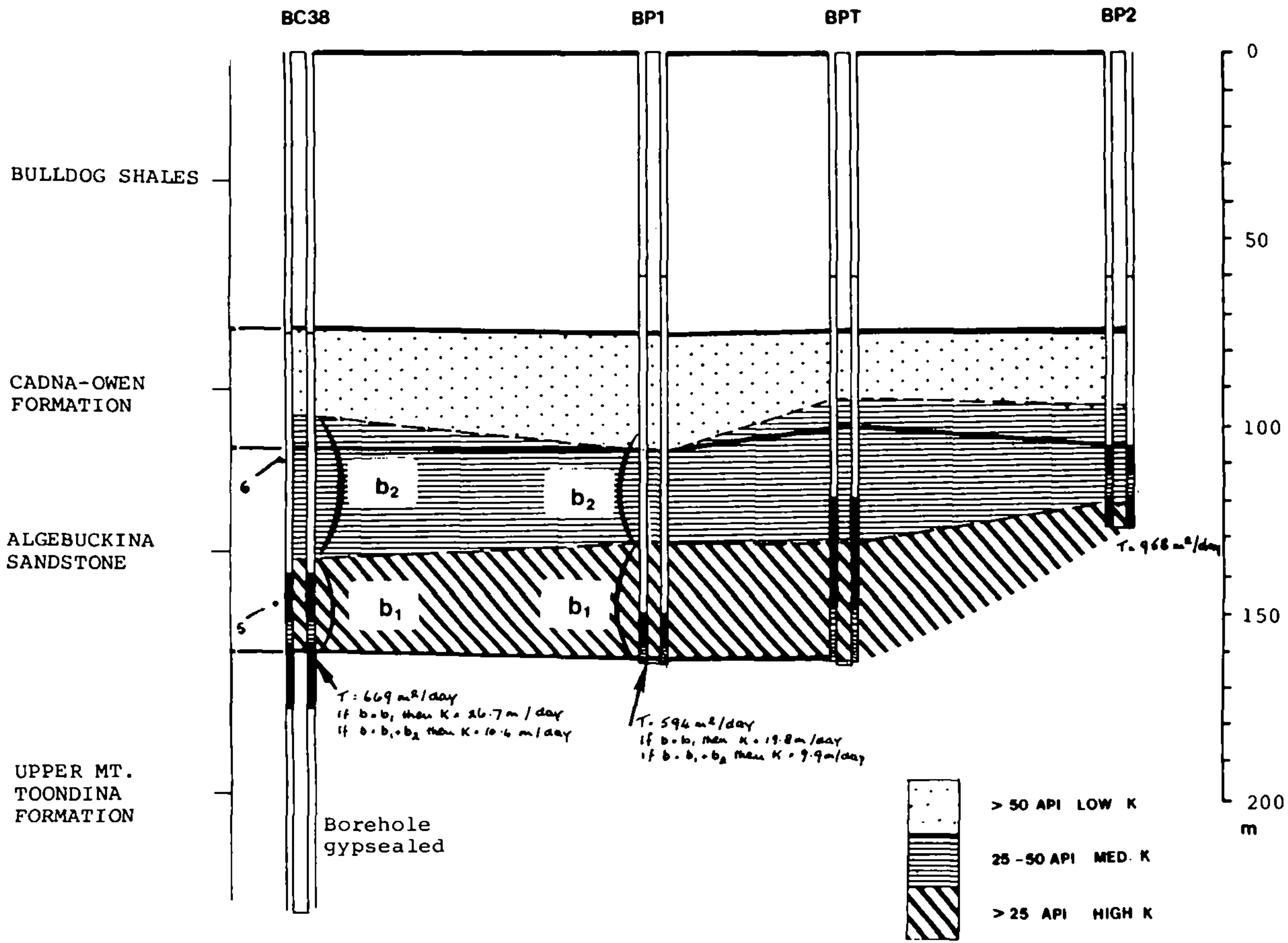


Figure 2

direct indication of the permeability of the overlying medum and low permeability zones.

3. To attempt to place values on these higher layers we suggest that use might be made of the grain size analyses given in the December 1983 report, Figure 7. Using grain size analyses Hazen[1] developed a widely used technique which employs the relationship

$$K = 864 (d_{10})^2$$

where K is in m/d (permeability

d_{10} is the ten percentile grain size passing (MM)

By reference to the grain size analyses given in Figure 7 of the December 1983 report and using this relationship it is possible to obtain an approximate permeability value for each analysis.

Grain size analyses number 3, 6 and 5 fall within the zones designated low, medium and high permeability (Figs 1 and 2). Using the above relationship gives values of $<$ .01, 12 and 31 m/d respectively for the low medium and high permeability zones.

The value of 30 m/d for the high permeability zone falls comfortably within the range 20-60 m/d indicated by the pumping tests.

4. The absolute values of permeability quoted above should not be taken to be particularly accurate since the method used to obtain them is obviously very crude. Nevertheless the exercise serves to demonstrate the relative importance of each layer. It shows for example that the upper part of the Cadne-Owen formation is of relatively little importance in comparison to the two lower zones. Figure 3 shows schematically the distribution of permeability at each of the two test sites.

5. The storage coefficients derived from the pumping tests range from 3.6 x 10^{-3} to 1.1 x 10^{-5}. Some errors will have been introduced by taking large aquifer thickness, however, given the very low values of confined storage generally, these errors are not significant.

[1]Williams D.B. Fundamental concepts of well design. Ground Work V.19 No.5 1981

6. Because water levels were not drawn down below the top of the aquifer unconfined storage (or specific yield) has not been obtained from the tests. Instead the report has adopted an overall figure of 20% based on published data and known specific yields of similar granular aquifers. We feel the estimate is entirely reasonable but would point out that although the mean specific yield of the entire aquifer may be 20% it will be distributed in much the same manner as permeability. In this way the high permeability layer will have a storage greater than 20% and the low layer much less than 20%.

Numerical Model

Time has not permitted detailed checking of the Numerical Model Output, as our comments on this aspect of the report will be brief and general.

The model has assumed an overal permeability of 7 m/d and a specific yield of 20% for the main aquifer with very low values assigned to the upper and lower aquicludes. Given an initial saturated aquifer thickness of 100 m the permeability translates to a transmissivity of 700 m^2/d.

Our own albeit crude estimates would suggest that an averaged permeability of 12 m/d and a transmissivity of 1200 m^2/day might be a better approximation. However the fact is that insufficient data exists to confirm whether 7 or 12 is the more accurate estimate, and we are prepared to accept that 7 m/d is a reasonable estimate at this early stage of investigation.

A point that should be emphasised is that the model assumes flow in 2 dimensions and does not recognize vertical changes in permeability and storage. An even distribution throughout is assumed. As we have seen however the aquifer is in reality highly stratified with respect to permeability and storage. This fact should not be overlooked when considering the problem of dewatering. We consider the problems posed in the following sections.

Dewatering Scheme

The dewatering requirements were estimated from a finite element numerical model using an idealised geological profile and the following parameters.

We are unable to provide an independent check on the model predictions without full details of the model. It represents an average condition based on what seems to be reasonable asumptions regarding interconnection and specific yield. The model results can only be refined by obtaining data on variations within the sequence and using a three-dimensional, multi-layered model. Figure 3 gives an indication of these variations. The hard sandstone bands within the top part of the Cadna-Owie Formation may cause perched aquifers to form after lowering of the main piezometric surface and could give rise to high level cascades into the open-cut mine.

The model should take into account the storage to be removed to dewater the open-cut and subsequently the amount of groundwater moving towards the mine as a result of the imposed change in head and any upward leakage from the UTM.

A line of production wells around the mine perimeter will be used to dewater the mine area. For the mine area alone some 80 million m^3 of water will have to be removed assuming a specific yield of 0.2 and a thickness of 100 m. As the aquifer will be dewatered, i.e. transmissivity will decrease with continued pumping, the Dupuit steady state equation for radial flow cannot be used to provide an independent estimate of annual flow towards the mine. However, flow through the aquifer can be estimated as 28 million m^3/year when the piezometric surface is lowered to the base of the Bulldog Shale.

The production well screen is capable of transmitting 40 m^3/h/m. It is proposed to lower water levels to about 10 = 15 , above the base of the Mesozoic sandstones. A 10 m screen length remaining will allow a pumping rate of 10 l/s, about twice that predicted as the long term abstraction rate. However, other hydraulic criteria need to be examined, such as approach velocities or Reynolds Number. The basis of the slot size selection is not given but based on the samples from BC 38 given in Figure 7 a slot size of 1 mm might be more appropriate than the 2 mm suggested.

The zone of highest permeability and specific yield at the base of the Algebuckina Formation cannot be dewatered by the limitations imposed by using production wells for dewatering. Over a 15 m thickness this represents 12 million m^3 within the mine area which will have to be removed by other methods. Our estimates of the permeability of this basal zone indicates a

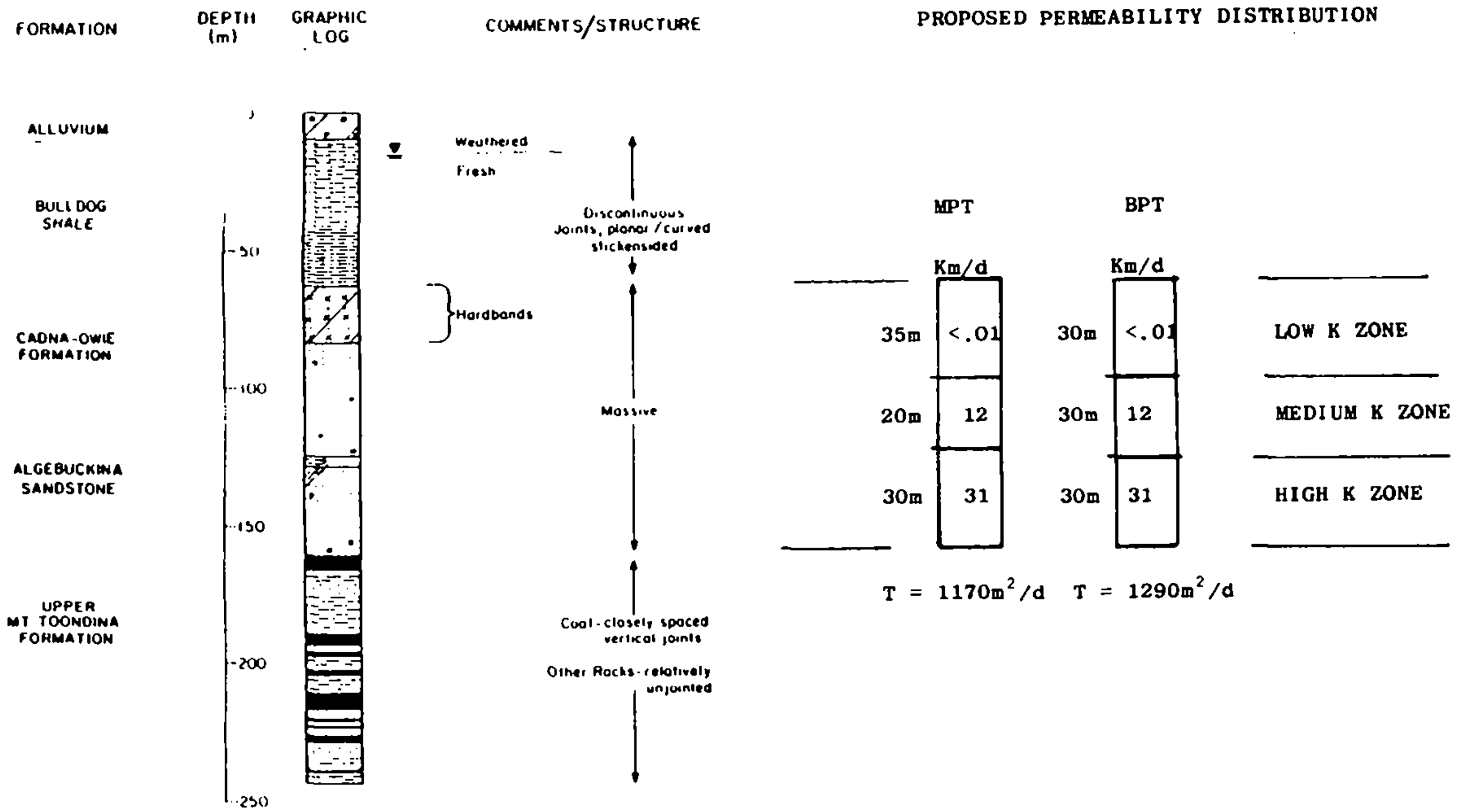

FORMATION
DEPTH (m)
GRAPHIC LOG
COMMENTS/STRUCTURE
PROPOSED PERMEABILITY DISTRIBUTION
ALLUVIUM
BULLDOG SHALE
CADNA-OWIE FORMATION
ALGEBUCKINA SANDSTONE
UPPER MT TOONDINA FORMATION
50
100
150
200
250
Weathered
Fresh
Hardbands
Discontinuous Joints, planar / curved slickensided
Massive
Coal - closely spaced vertical joints
Other Rocks - relatively unjointed
MPT
BPT
Km/d
35m
<.01
20m
12
30m
31
30m
<.01
30m
12
30m
31
LOW K ZONE
MEDIUM K ZONE
HIGH K ZONE
T = 1170m²/d
T = 1290m²/d

Figure 3

transmissivity of about 300 ≃ 450 m^2d when levels are lowered to with 10 ≃ 15 m of the base. It will be necessary to check the effect of decreasing transmissivity and head losses.

There general comments suggest that a phased dewatering scheme may be necessary to take account of feasible vertical variations in aquifer properties.

SUMMARY AND CONCLUDING REMARKS

The hydrogeological study has been carried out at a feasibility level. At this stage the broad features of the groundwater system have been identified together with the volumes of water to be removed and appropriate methods to abstract these volumes.

1. It is clear that exceedingly large volumes of water under a considerable head will have to be removed, due to the presence of a thick and very permeable Mesozoic Sandstone aquifer overlying the coal measures. There is no reference to any schemes operating under similar conditions.

2. Local variations within the groundwater system will be of major importance in the design and cost of the dewatering scheme. The tests undertaken, whilst detailed in some respects, may not be wholly representative of these variations since they were carried out at only one location within the mine area. There is evidence to suggest that local variations occur.

Such variations may not radically alter the broad conclusions of the feasibility study. However, there are wide differences in permeability and storativity with depth in particular. Of some importance in this respect are, for example, the permeability of the lower part of the Mesozoic Sandstones or the influence of hard sandstone bands in the Cadna-Owie Formation and clay bands within the Algebuckina Sandstone on vertical leakage and interconnection.

3. A large-scale pumping test and detailed digital modelling (presumably as a three-dimensional, layered model) were recommended to examine the volumes involved in dewatering in greater detail. In view of the high yields, a large scale test may not provide specific yield values and no recommendations are given as to the investigations necessary to provide the right sort of information for more detailed modelling. For example, the test results from the MPT site could be extended at relatively low cost by using laboratory methods to determine variations in permeability, porosity and specific yield using plugs taken from core samples, or estimates of permeability from further sieve analyses or from packer/conventional tests at depth intervals through the sequence to be dewatered.

4. Water level data were collected but the use made of the well inventory or existing well sites is rather limited. Levelling-in available sites would allow flow directions and gradients to be established to estimate natural flow through the aquifer as well as providing data for elevation of various inputs to the model.

5. Several assumptions are made regarding interconnection between parts of the sequence. Multiple piezometers with screens at different depths would have allowed this to be studied using the MPT test site. The method of drilling prevented identification of different piezometric surfaces which may be associated with different parts of the sequence. Hydraulic gradients could be reversed by dewatering.

6. The dewatering scheme will have to cope with throughflow, upward or downward leakage and remove water from storage. The disposal of this water is only examined very briefly and the additional cost of re-injection will be high. The water quality restricts the use of the water but some consideration could be given to the use for salt tolerant plants and stock water or disposal into the perched aquifers of the Bulldog Shale.

From our review, which largely excludes the model predictions of dewatering volumes, we conclude that the hydrogeological feasibility study presents an acceptable description of the geology and groundwater system.

However, aquifer parameters are based mainly on only one test site within the mine area. Detailed modelling and wellfield design will require further study of the variations with depth across the mine area.

Several questions are raised by our review:

* what further investigations are planned to assess and quantify variations in aquifer conditions across the mine area

* what sort of model is to be developed for more detailed assessment and will this be able to take into account layered variations within the sequence

* will a detailed hydraulic analysis of the proposed production well design be undertaken and has the inflow/storage of the basal part of the Mesozoic sandstones been fully taken into account in the dewatering scheme proposed.

* will further work be done to assess the feasibility of disposing of the large volumes of water generated by dewatering operations.