Yallourn Open Cut Mine East Field Overburden Dewatering and Southern Dump Stability Analysis

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Summary A new area of mine development has been planned for the Yallourn Open Cut Mine's East Field region. The overburden material removed from this area is to be placed in the Southern Overburden Dump. This paper discusses the geology and hydrogeology of the area concerned, different methods of dewatering the East Field overburden that have been considered, and the final conclusions that were made. Results indicate that coal hydrofracturing and pump-bores are the most effective and economical method of dewatering the East Field. Overburden materials removed from the East Field are being placed in the Southern Overburden Dump area. The slope stability analysis of the dump has also been studied, and the impact of the different materials on stability is discussed.

1. INTRODUCTION

The Yallourn Open Cut Mine, which supplies brown coal for power generation, is situated in the Latrobe Valley, Victoria, Australia (Figure 1). It produces approximately 17 Mt of brown coal and 5 M m^3 of overburden per annum. Coal in the East Field is on average 20 m below the surface of interbedded clays, sands, silts, minor volcanics, and overburden aquifers. The coal and overburden material is removed via large bucket wheel excavators. The geology of the area is very complex, and associated geotechnical factors critically affect the mining operation. Extensive geotechnical investigations have been carried out in this area. It is expected that as the overburden removal proceeds, the ground condition will continue to deteriorate.

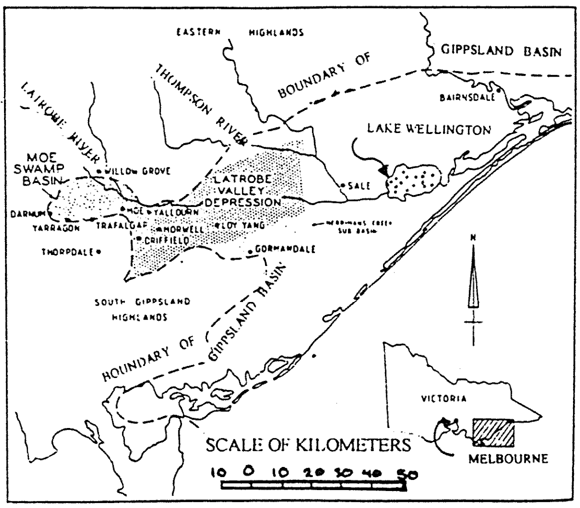

Figure 1. Mine location.

Groundwater withdrawal from the aquifer associated with tertiary sediments in the area is essential to allow coal mining to proceed to depth.

The Southern Overburden Dump requires good material for capping. With the current situation, there will be inadequate good material unless the quality of the weaker material is improved. The only way to do this is by dewatering the East Field overburden. If this is not done, the bearing capacity and slope stability of the Southern Overburden Dump will be affected.

2. BACKGROUND

The aquifer and groundwater systems in the Latrobe Valley are very complex and interrelated, with some aquifers extending over large areas and partly extending through complex structures into the offshore part of the Gippsland Basin, whilst others are only of local extent (Reid & Brumley, 1982).

Withdrawal of groundwater from the aquifers associated with the Tertiary sediments in the Latrobe Valley is essential to allow coal mining to proceed to depth. Water within the overburden layers, coal seams and interseams must be drained to avoid flooding during the mining process.

Around 60% of total overburden thickness consists of saturated sands. The sand in the western part of Yallourn's East Field is relatively thin, except along the northern batter where it averages around 6 m. East of the Old Morwell River channel the sand is more extensive and increases in thickness to well over 15 m. In all parts of the East Field the water table is close to the ground surface. To ensure batter stability in the mine face and on the Southern Overburden Dump, and also to minimise digging and handling problems, the overburden aquifer must be dewatered.

3. REGIONAL AND LOCAL GEOLOGY

3.1 Regional Geology

The Latrobe Valley Depression (Figure 2) is an east–west trending basin, with an internal structure described as an "elongated east plunging, asymmetrical syncline" (Brumley & Holdgate, 1983). The Latrobe Valley Depression is bounded to the south by the Budgeree Fault and Carrajung Monocline, to the east by the Lake Wellington Depression, and it has the Yallourn Monocline Fault forming its northern and western boundaries (Douglas & Ferguson, 1988).

The Latrobe Valley Group, which is made up of the Yallourn, Morwell and Traralgon Formations, overlies the Paleozoic and Mesozoic basement rocks. The deepest and most extensive formation, the Traralgon, occurs over the entire Latrobe Valley Depression and merges in the west with the Thorpdale Volcanics and the Childers Formation. The Traralgon Formation is typically several hundred metres thick and contains major coal and clay seams interbedded with sands and gravels. The Morwell Formation contains several extensive coal seams interbedded with clay and a limited amount of sand. This sequence extends from the Haunted Hills in the west to the Balook Formation at the edge of the Latrobe Valley Depression.

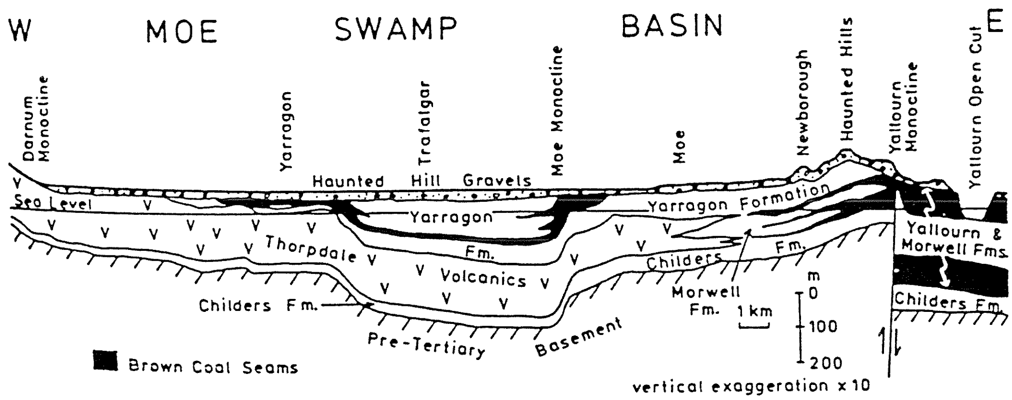

Figure 2. East–west regional geological section.

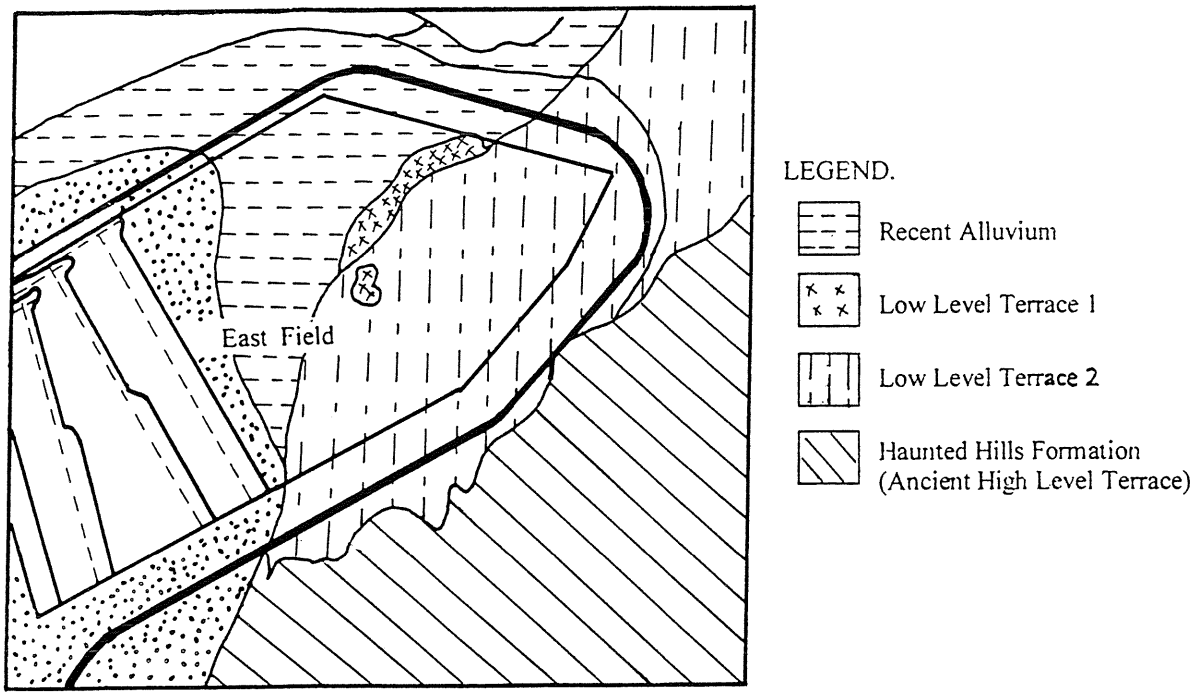

Figure 3. Site geological plan of the East Field region.

3.2 Site Geology

Overlying the Morwell Formation is the clay- and coal-rich Yallourn Formation. The Yallourn Coal seam is usually around 55 m thick, increasing to 75–80 m thick to the east of the Yallourn Syncline.

The Yallourn Formation is, in turn, overlain by the Pliocene-aged Haunted Hills Formation (Figure 3). The Haunted Hills Formation is up to 100 m thick and covers most of the Latrobe Valley Depression. These sediments extend to a maximum thickness of 75 m where they form the ancient high-level river terrace deposits. They are made predominantly of silty and sandy clays (SM, SC), with some layers of clayey sand (CL, CM) and a basal layer of clean sands and gravels. North of the Morwell River Diversion Channel, the Haunted Hills Formation sediments are almost completely eroded, except where the Yallourn and Latrobe Syncline meet to form a depression in the top of the Yallourn seam. Material in this depression is made up of poorly graded clean coarse quartz sands (Jennings & McKinley, 1992). The maximum thickness of Haunted Hills Formation sediment deposited in the Latrobe Valley Depression is approximately 16 m.

Quaternary-aged Alluvium exists over the Morwell and Latrobe River flood plains and the lower-level terraces. Phases of deposition and erosion have resulted in the development of two distinct low-level alluvial terraces and the present flood plain. Low-level terrace 1 is generally 2 m above the flood plain, whilst terrace 2 is about 4 m above the flood plain (Jennings & McKinley, 1992). The sediments commonly comprise 3–8 m of silty and sandy clays (CL, CH) overlying up to 8 m of basal sands and gravels (SM, SC, SW, GP). The basal sands and gravels become increasingly coarse with depth, with a coarse gravel containing quartz pebbles up to 50 mm in diameter occurring directly above the Yallourn coal seam. Along the course of the old Morwell River the strata consist entirely of clays and sandy clays.

The external overburden dump was formed during the 1920s and 1930s by sluice dumping and boom stacker. The dump materials are normally consolidated ligneous and non-ligneous clays, silts and sands, with some coal.

4. EAST FIELD HYDROGEOLOGY

The East Field area comprises three basic hydrogeologic units, which correspond to the major geological units identified at the site. These are:

- *The Alluvium Aquifers, Low-lying areas*: a confined and semi-confined aquifer system comprising the Quaternary Alluvial basal sands and gravel and Haunted Hills Formation sands and gravel;
- *Haunted Hills Formation Aquifer, High-level Terrace*: an unconfined aquifer system consisting of Haunted Hills Formation silty and clayey sands, and sands and gravels forming the hills of the high-level river terrace;
- *Yallourn Coal Seam*: this has lower permeabilities due to open joints, particularly in the upper sections of the seam.

5. GROUNDWATER RECHARGE

The overburden sequence in the East Field contains an elongated body of saturated coarse sand and gravel up to 16.4 m thick, which trends in a north–northwesterly direction towards the Latrobe River. These coarse sand and gravel beds are covered with a 6.5 m thick impermeable clay layer (Figure 4). The East Field overburden material properties, and the sand and gravel layers, are similar to, but significantly thicker than, what has been previously encountered in the Township Field.

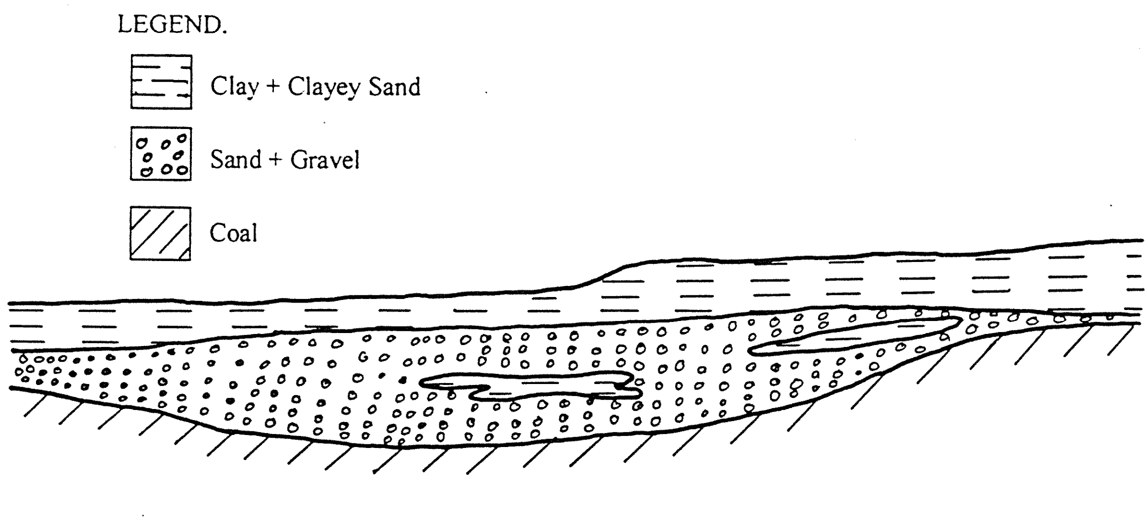

Figure 4. East Field mine face material types and aquifer discharge points.

The principal source of groundwater recharge for the sands and gravel beneath the low-lying areas appears to be via the aquifer sands and gravels from the high-level terrace. Additional sources include seepage from the "Blue Lagoon" lakes through the saturated soils of the external overburden dump, and diffuse infiltration from surface water across the low-lying areas.

Effluent groundwater is principally by seepage into the Latrobe and Morwell Rivers, either directly or indirectly as surface water from small creeks and springs. During periods of flooding, these normally effluent groundwater boundaries may become short-term influent groundwater boundaries (Crouch & Esposito, 1982). The Township Field adjacent to the East Field is another effluent boundary for groundwater within the Yallourn coal seam. In the vicinity of the Township Field, groundwater extends across the top of the coal as a perched groundwater table (Crouch & Esposito, 1982).

6. DEWATERING STRATEGIES

In the assessment of dewatering strategies it is understood that the various costs involved for the rectification of problems with the East Field aquifer system need be small when compared to the operational penalties that can occur. A number of traditional and modern dewatering options were considered. These include trenches, pump-bores, well points, sump pits, subsurface drains, do nothing, and alternatives to dewatering such as the use of mobile plant or revised digging plans.

6.1 Discussion of Dewatering Options

The finalised dewatering strategy could include only one of the above dewatering options or a combination of two or more. All options vary greatly in effectiveness but most are potentially feasible. The choice therefore comes down to a question of cost and the availability of funds. In all circumstances there are initial installation costs, and for most, ongoing operational and maintenance costs.

Below are points which outline various costs and other considerations involved when narrowing down the suitable method or methods of dewatering. They include pump-bores, well points, pits and subsurface drains in coal. These can be costed on a unit basis ($x/bore). Trenches and laser-guided horizontal drilling through the aquifer material can be costed on a metreage basis ($y/metre of trench). Any form of pumping requires power and a collection/discharge system. These factors will both add substantially to final and ongoing costs. Gravity drainage (without pumping) is potentially feasible for trenches and subsurface drains.

Trenches and hydrofractured bores within the aquifer offer the greatest exposed area of aquifer with a lower head. Dewatering by these methods would undoubtedly be the most effective. Any pumps, casing, pipes, etc. installed for drainage purposes would probably have to be removed prior to excavation. Nevertheless, some plastic or fibre-glass pipe might be able to remain.

Calculations of mine face stability (Jennings & McKinley, 1992) show that drawdowns to within 0.5 m of the top of coal are desired to prevent piping and slumping of the operating face. Currently the water level at the face is well above this required height, and consequently instabilities may occur. For this reason the "do nothing" option was considered not to be viable.

7. GROUNDWATER MODELLING

Three different dewatering methods – hydro-fractured bores, pump-bores, and sump pits – were modelled to determine the relative effectiveness of each. For the purpose of comparison, the pit and bores located in the deepest section of the aquifer were compared. This comparison was made for 6-, 12- and 24-month timeframes.

The groundwater modelling system developed by the US Department of Defence and the program ModFLOW were used to model the expected drawdowns for all models generated. ModFLOW is a simulation package used for modelling the groundwater flow within a three-dimensional finite difference groundwater flow model.

7.1 Modelling Methods

The East Field model was setup on a 50 x 50 m grid. In order to model the different dewatering strategies, the original grid was modified. Consequently the model results will simulate real conditions, and the results will be more accurate. The extent of groundwater recharge was not taken into account, since these rates are not accurately known at the present time. This will cause the resultant drawdowns to be greater than what would actually be observed in the field.

The three methods of dewatering were modelled in different ways:

- *Alternative 1, Hydrofractured Bore.* For this model to run successfully, the positioning of the bore was located on a 3 x 3 m influence area. The base of the bore was positioned 0.5 m above the top of coal level. The model was run using a static fixed head, where the starting level of the cell is fixed to an elevation above the top of coal.
- *Alternative 2, Pump-bore.* This model was run using the well package which simulates how a

pump-bore would operate, i.e. how much groundwater the pump can extract each day. A specified flow rate of 3.5 l/sec (300 m^3/day) was considered realistically achievable. The bottom of the bore was positioned approximately 3 m above the top of coal level, and was located on a 1 x 1 m influence area.

- *Alternative 3, Sump Pit.* The drain package was used to run this model because of its ability to simulate the real characteristics typical for drawdowns associated with sump pits. The base of the sump pit was positioned 8 m below the ground surface level. This height was decided upon after a recent trial sump pit had been located in similar ground conditions to the model. The dimensions for the modelled pit were possibly a conservative 6 x 10 m.

The location of the dewatering activity was focused in the area where the overburden was found to be the thickest. Therefore during the course of modelling, the dewatering activities were located approximately 900 m from the East Field operating mine face, in approximately 24 m of overburden.

7.2 Modelling Results

The outcomes for each alternative conducted are summarised in Table 1. The 6-monthly drawdown levels are also shown in Figures 5–7.

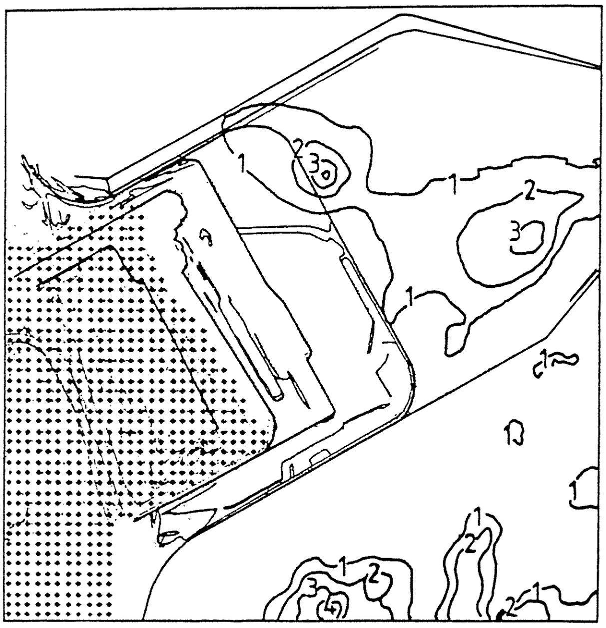

Figure 5. Model for a hydrofractured bore, 6-monthly drawdown.

Table 1. Dewatering modelling results.

	Maximum Drawdowns (m)		
	6 Months	12 Months	24 Months
Hydrofracturing	8.26	9.14	10.12
Pump Bore	9.94	10.57	11.31
Sump Pit	7.14	7.21	7.28

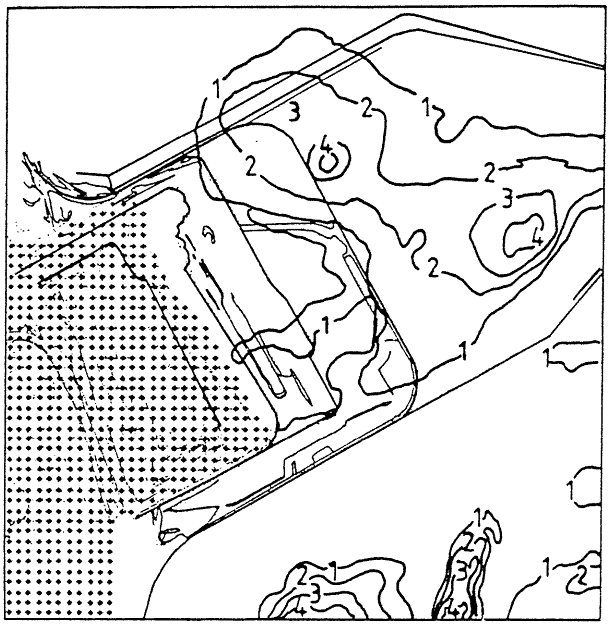

Figure 6. Model for a pump-bore, 6-monthly drawdown.

Figure 7. Model for a sump pit, 6-monthly drawdown.

7.3 Discussion of Results

Drawdown patterns and levels were found to be similar for both hydrofracturing and pump-bore methods. Pump-bores achieved a greater drawdown in the zone closer to the bore, while the hydrofractured bore gave a slightly larger drawdown in the area near the mine face. Both methods produced similar results east of the Old Morwell River. All methods gave high drawdowns in areas where the sands are thick, even though the deepest sands were found over 1 km away from the bore and sump pit modelling location.

Drawdown limitations existed with the sump pit method. Even though this method exposed a much greater area of exposed aquifer, the maximum amount of drawdown was restricted by the depth that the pit could be excavated to. Reservations also exist about the stability of the East Field overburden material when excavating pits to greater depths. Slumping of the edges due to poor material was a frequent occurrence in the trial sump pit excavated in February 1997. This poses safety concerns during the excavations of these types of pit to larger depths. Whilst sump pits achieve a rapid maximum drawdown initially, they are unable to continue this level of drawdown as pumping continues, when compared to a hydrofractured or pump-bore method.

8. SOUTHERN OVERBURDEN DUMP STABILITY

Investigations were carried out in relation to the slope stability of the Southern Overburden Dump. The geology and ground conditions in the area suggest that a circular type of dump failure is most likely. Spencer's and Bishop's methods of slices are used in this analysis, with Galena software (developed by BHP Engineering). The Southern Overburden Dump was successfully modelled using this package under a variety of different dump designs.

9. MATERIAL PROPERTIES

Extensive laboratory tests have been conducted to determine the different material properties of the East Field material (shown in Table 2). In general there are these types of material present in the East Field. The material properties were kept constant for all models analysed.

Table 2. Material properties.

Material	Cohesion, (kPa)	Angle of Shearing Resistance (°)	Unit Weight (kN/m^3)
Type 1	50	25	19.5
Type 2 & 3	0	33	18

Even though the material properties are listed as being the same for both type 2 and 3 materials, type 3 material was modelled as being in a fully saturated condition. This is because type 3 material tends to soften and/or liquify during transportation to the Southern Overburden Dump, whereas type 2 material has similar handling characteristics to type 1 material, depending on its proximity to the water table in the overburden face.

10. SOUTHERN DUMP MODELLING

A variety of realistic and hypothetical scenarios of possible dump constructions were developed. A number of models were considered to determine the various factors of safety for three main dump constructions. The different dump designs are shown in Table 3, and a typical dump model layout is shown in Figure 8.

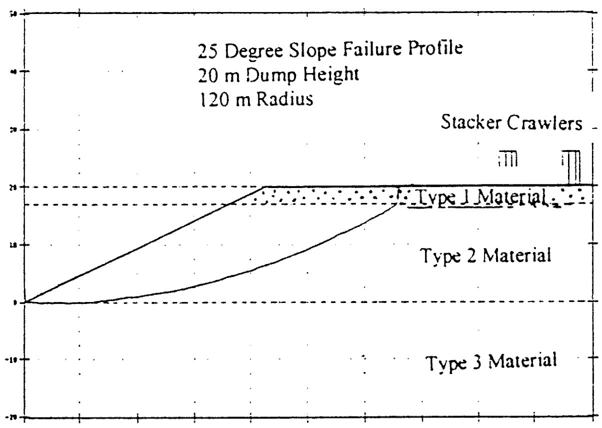

Figure 8. Model of ideal dump conditions (Model 1).

Table 3. Design of dumping conditions.

	20 Metre Dump			15 Metre Dump	
	Ideal, (m)	Okay, (m)	Worst, (m)	Okay, (m)	Worst, (m)
Type 1	Top 3	Top 3	Top 3	Top 3	Top 3
Type 2	Middle 8.5	Middle 3	-	Middle 3	-
Type 3	Lower 8.5	Lower 14	Lower 17	Lower 9	Lower 12

Table 4. Modelling results.

	Dump Conditions	Maximum Slope Angle, (°)	Radius, (m)	Distance From Tension Crack To Crawlers, (m)
Model 1	Ideal, 20 m	31	100	-
Model 2	Okay, 20 m	20	100	-
Model 3	Worst, 20 m	17	150	-
Model 4	Ideal with stacker, 20 m	31	100	15.5
Model 5	Okay with stacker, 20 m	20	100	16.5
Model 6	Worst with stacker, 20 m	17	150	18.5
Model 7	Okay with stacker, 15 m	29	120	18.5
Model 8	Worst with stacker, 15 m	20	110	19.5

10.1 Selection of Analysis Method

Both Bishop's and Spencer's methods were available when analysing the Southern Overburden Dump slope stability. These methods were chosen as they are capable of modelling circular failure surfaces. The results of the sensitivity analysis that was conducted revealed that Spencer's multiple circle analysis should be used.

11. MODELLING RESULTS

In a mining environment, a factor of safety of 1.2 is considered to be efficient. Therefore all slope batter angles listed are at the optimum angle equal to a factor of safety of 1.2. Results are summarised in Table 4.

12. DISCUSSION OF RESULTS

A number of general conclusions can be made from the results produced from the various models. These include results for ideal, okay and worst possible dump conditions which resulted in the same factor of safety when the model was run with and without the stacker crawlers. This occurred because the stacker crawlers were positioned outside the computer-generated failure circle, and played no part in the actual slope failure. The distance between the stacker crawlers and the modelled tension crack increased as the slope angle increased, since the minimum distance between the stacker and the nearest crack must be 20 m. However, most models recorded a distance less than 20 m between the stacker and the model-generated tension crack. Increases in the radius of the failure circle lead to increases in the factor of safety for each modelled slope angle. The slope profile of the dump can increase as the amount of type 2 material (moist sand, coal, clayey sand and sandy clays) increases. However, this increase in the amount of type 2 material will only be possible by the implementation of a successful aquifer de-watering system.

13. OVERALL CONCLUSION

The result of the dewatering modelling indicated that a field of pump and hydrofractured bores should be strategically positioned in critical areas in the East Field overburden region. These areas include the regions of thick sands and the depression in the top of coal surface.

It is clear from the modelling that significant drawdowns can be achieved with time. However, it should be understood that the model must portray the real conditions. As previously stated, factors such as aquifer recharge were excluded from all models, when in fact there is likely to be recharge from the Latrobe and Morwell Rivers, the external Overburden Dump, and underlying coal. Actual field conditions indicate the true duration needed for adequate dewatering. This period of dewatering would ultimately be determined by the availability of resources and capital, the amount of time for which the pump could be established, and the availability of sufficient time to assess and respond to any problems in a particular location before mining reaches that point.

Initially, dewatering operations are being concentrated in the area west of the Old Morwell River, and they proceed to the east as the mining face advances. Previous modelling results (Pilkington, 1986) indicate that three years is an appropriate dewatering period. Even though a two-year pumping period would delay expenditure, it would also limit the response and recovery time if a major problem occurred.

It is obvious for the need to fully understand the implications that different dewatering strategies could have in the delicate East Field environment. A greater understanding of these factors would drastically improve the accuracy, economy and safety of any future dewatering modelling results.

Realistically it would be almost impossible to achieve a dump that could be constructed under ideal conditions at the present time, due to the large amount of type 3 material currently in the operating face. Nevertheless, a dump operating under or close to the design for okay conditions could be achieved with the successful dewatering of the East Field. The Southern Overburden Dump should operate under the present conditions unless there are threats of slope instabilities due to the large amounts of type 3 material being dumped, or unless the dump formation becomes excessively weakened from the effects of the material below it.

14. ACKNOWLEDGMENTS

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