Mining Warden
Yallourn Mine Batter Failure Inquiry

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EXECUTIVE SUMMARY

I was appointed a Mining Warden in the State of Victoria and requested to undertake an Inquiry into the Yallourn Mine Batter Failure. The Terms of Reference for the inquiry were to:

a) Establish the facts, circumstances and causes surrounding the collapse,

b) Examine any mine safety issues and

c) Make high level recommendations to prevent or minimise the risk of similar future events.

This executive summary is presented as a brief summary of the findings of the Inquiry. The main body of the report includes detailed discussion on all elements. The executive summary should not be taken out of context or read in isolation from the main report.

The failure occurred between 1:30am and 2:10am on 14th November 2007. The failure is located on the northeast batter (NE Batter) of the Yallourn East Field Mine (YEF). The NE Batter was in the process of final completion when the failure occurred. The failure was very large, it encompassed about six million cubic metres of material, was 500m long and occurred on a slope that was approximately 80m high.

The failure occurred by a mechanism called block sliding, where a large block of coal slid horizontally across the mine floor. The failure extended as far back as the Latrobe River, which was completely diverted into the mine by the failure.

There were two main causes for the failure. The principal cause was water pressure in a joint along the rear of the failure. The joint, which is a naturally occurring crack in the coal, connected with the Latrobe River. The water in the joint exerted a horizontal pressure on the coal block. The other main cause of the failure was water pressures in the interseam clays underlying the block of coal. These water pressures caused a buoyancy effect on the block of coal reducing the resistance to sliding along its base.

This failure was not new or unusual and is the principal mechanism of batter failure in the Latrobe Valley Mines.

There is a long history of open cut mining in the Latrobe Valley. That history has led to a very good understanding of ground movements around the mines and that understanding was developed well before the start of the YEF in 1997. In summary the historic understanding of geotechnical knowledge relevant to the failure was:

1. Because of the character of the coal and other materials, large movements of the sides of the mine occur and these movements can lead to cracking.
2. The cracks usually developed preferentially along the pre-existing joints in the coal.
3. Water pressures can develop in these joints due to the existing groundwater and or rainfall runoff.
4. Control of water pressures in these joints is critical for batter stability.
5. The principal batter failure mechanism is block sliding of the coal along the underlying interseam clays.
6. Sudden and unpredictable movements or failure can occur due to the block sliding.
7. Horizontal bores are essential to control water pressures in the coal.
8. Deep aquifer depressurisation below the coal seam floor is required for stability of the mine floor and this also assists to reduce pore pressures in the interseam clays.
9. There was potential for the large movements associated with mining to lead to opening of joints and block sliding, thus forming a direct hydraulic connection between the Latrobe River and the mine. In simple terms this is what actually occurred in the lead up to the failure and an accurate scenario for this was postulated as part of design studies in 1997.
10. Monitoring and ongoing review of stability is part of the normal mine management required to maintain stability.

This is a fairly clear and simple geotechnical model for mine slope design. However over time as the YEF developed this model became less clear and some of the key components required to maintain stability were no longer applied.

The YEF Mining Licence was granted in 1996. In 2002 there was a significant change to the Mining Licence including a new mine layout and implementation of new mining methods. The design of the NE Batter and the determination of the 150m stand off distance from the Latrobe River was carried out in 2001.

The change to the mine layout in 2002 had significance for the failure because this layout imposed potential limitations and technical challenges in two important areas for batter stability; namely monitoring of the slope and groundwater drainage. Although these limitations were recognised in part at the time, it is not clear how these initial limitations and challenges were dealt with over time. In any event, leading up to the collapse, the significance of the monitoring data was not appreciated and adequate control of groundwater pressures in the NE Batter was not achieved.

The monitoring data shows the whole NE Batter was subject to large scale deep seated movements for a number of years prior to the collapse. The area of movement was of the order of four times or more larger than the eventual failure. The movements followed a long-term accelerating pattern and extensive experience shows that unless these movements ceased or were stabilised, failure was always likely to occur. There was also upward creep of the mine floor.

These movements, in about the last year and a half prior to the failure, caused disturbances to the existing groundwater regime around the NE Batter. These disturbances occurred within the batter itself in the coal and also extended to considerable depth below the coal in the interseam clays. These movements and disturbances were occurring well before the coal mining reached the final NE Batter.

In simple terms the historical experience in the Latrobe Valley coal mines had shown the critical technical components for mine batter stability were:

1. Maintaining a low groundwater level in the coal seams, using horizontal bores.
2. Ensuring low groundwater pressures in the aquifers and interseam clays below the mine floor and the batters. Traditionally this was carried out by deep aquifer dewatering.

Commencing around 2002, the documents indicate there was an effort to try and improve the overall efficiency of the mine, with questions raised over the need for routine horizontal bores, the requirement for continued deep aquifer dewatering and whether the monitoring and external engineering support could be reduced. Over time, studies and engineering modelling were carried out and some trials undertaken to assess some of these questions.

In about 2002 or 2003 following external evaluation and advice a decision was taken to stop routine drilling of horizontal bores. Although this evaluation was for the older part of the YEF, with different geotechnical conditions, somehow this decision also became applied to the NE Batter. Given the geotechnical conditions in the NE Batter, horizontal bores were always required and were critical for stability. The absence of horizontal bores was a major factor in the failure.

In 2004 following external assessment and advice from a number of different consultants, the deep aquifer dewatering bores in the mine floor were switched off and the bores were allowed to free flow under artesian conditions. The decision was also influenced by changes in the hydrogeological model in this part of the Yallourn Mine. The implications of these changes were not fully appreciated. The models used for assessing the impacts of cessation of deep aquifer dewatering were a simple weight balance model. The analyses centred around this model were focussed on rises in interseam pore pressures associated with rises in aquifer groundwater pressures. When significant rises did not occur the conclusion was drawn that there is no problem. However the impact of high, relative to the mine floor, and unchanging interseam pore pressures does not appear to have been appreciated.

The critical flaw in the thinking was a belief that problems with pressure below the mine floor would always manifest themselves by visible signs of floor heave. However unless there is significant deformation you can't "see" pressure. Hence high pore water pressures can remain in the interseam clays, but not manifest themselves as visible signs of deformation in the mine floor.

The impact of high groundwater and interseam pore pressures causing large scale deep seated movement of the whole NE Batter for a number of years leading up to the collapse were important factors in the failure.

TRUenergy operated a comprehensive geotechnical management system including; mine site ownership and control; a series of rigorous inspection and monitoring schedules; written work plans, monthly reporting, external specialist consulting advice and annual third party reviews. This system had all the requisite components to ensure success.

Annual geotechnical reviews were included as a condition in the 2002 Mining License to ensure the geotechnical risks with stability were adequately covered. The reviews gave qualified support for shutting off the deep aquifer dewatering and approval to stop routine drilling of horizontal bores, albeit in a different part of the YEF to the NE Batter. The reviews also indicated the NE Batter design had a high factor of safety and was stable. I understand on reading these reviews how mine management would take comfort that the geotechnical issues were being properly addressed and there were no major technical issues.

From 2001 to 2006 there were a number of general and specific studies of the northern and NE Batters by external consultants. Over time an incorrect design failure model became accepted and this model showed the NE Batter had a high factor of safety and was stable. This was also supported by the annual geotechnical review.

Hence from this point forward all the subsequent events that happened on and around the NE Batter were interpreted within the paradigms that:

1. Large movements of the mine batters are expected.
2. Despite the movements the batter is stable.
3. Any problems with high groundwater pressures below the mine floor and batters will manifest themselves as visible heave of the mine floor.

From early in 2007 cracks were observed in and around the NE Batter. The first major cracks were observed in July 2007 on the Latrobe River Levee. Thereafter the cracks continued to multiply, extend and become worse, leading up to the failure. Significant rises in groundwater levels in two bores were also observed in September and November.

There was an unexceptional rainfall event on 4th November (57mm). Following this rainfall very large water flows, 200 to 300 litres per second, were observed on the NE Batter. Some days later, review of the monitoring indicated this rainfall event had caused a global movement of the NE Batter by up to 0.2m. Over time the flows abated to around 80 to 100 litres per second.

External consulting advice on the cracks was sought in October and a comprehensive external review of the cracks and the stability of the NE Batter was carried out on 7th and 8th November by a different consultant. This was the final overall review prior to the collapse. In summary the review concluded the NE Batter had a high factor of safety (and hence it was stable), that it was safe to continue mining coal at the toe of the NE Batter, that the cracks were related to normal stress relief movements, not incipient failure of the slope, and the source of the water on the slope was not the Latrobe River. The failure mechanism was also not correctly identified. Overall the review gave a positive interpretation of the stability of the NE Batter and was interpreted as such by TRUenergy.

On the day prior to the collapse, 13th November, two geotechnical consultants were called to the site one of whom had undertaken the review on the 7th and 8th November. This action was taken because the conditions had worsened noticeably and the water flows had increased to around 500 litres per second. The advice from at least one consultant was that although there was a major stability risk, catastrophic failure was unlikely and there was no immediate safety hazard.

The monitoring data and the many important signs evident prior to the collapse all showed that failure was imminent. However these signs were not interpreted correctly and on the day prior to the collapse advice was given that catastrophic failure was unlikely. The NE Batter failed suddenly and the failed mass travelled a large distance (250m) across the mine floor.

The geotechnical management system at Yallourn was comprehensive and on the face of it should have been sufficient to prevent the collapse. However there was a failure of the geotechnical management system at all levels and the future significance of many important signs was not recognised either internally or externally by some of TRUenergy's technical advisers and reviewers. These signs manifested themselves to various extents in the years, months, weeks and days prior to the collapse.

The failure had a very long gestation period and commenced with the new mining method and mine layout for the YEF, approved in 2002. This change had important ramifications in two key areas; monitoring and groundwater control. The new technical challenges appeared to be recognised, in part at the time, however any concerns appeared to have been superseded over time by other technical matters or issues.

Overall I consider the safety aspects around the NE Batter were well managed. However in the final days prior to the collapse there were two significant errors of judgement that had potential safety implications:

1. The review on the 7th and 8th November and subsequent documentation which advised the NE Batter had a high Factor of Safety, hence it was stable, and it was safe to continue mining coal.
2. The advice on the 13th November that:

   "it is unlikely that a catastrophic failure will occur, resulting in an immediate safety hazard".

Although there is conflicting advice over whether this latter recommendation was withdrawn later on the 13th November. In any event action was taken to place a horizontal drain hole drilling rig on the NE Batter, and this action would probably not have been taken if it was considered that a catastrophic failure could occur.

In order to understand the implications of the Yallourn Mine Batter Failure for the future it is firstly necessary to understand those aspects peculiar to the Latrobe Valley in regards to:

1. Security of Coal Supply and Power Generation.
2. The coal mining and coal delivery systems.
3. The engineering character of the materials in the Latrobe Valley coal mines.
4. The regional setting.

The character of the Latrobe Valley coal is such that it is difficult to stockpile and store coal. Coal is delivered to coal bunkers at the power station. The mine operates on a "just in time" coal supply basis. The Yallourn mining systems are comparatively inflexible. The coal delivery systems themselves are also located on the final batters. In normal engineering practice this situation should demand a high reliability in the engineering models and high design factors of safety.

The open cut mines in the Latrobe Valley are very large excavations. The mines are not rigid structures, they are highly deformable and the deformations spread a long way outside the mine perimeters. The coal mines are developed in a semi-rural to semi-urban environment. They are in part surrounded by natural and man-made infrastructure. This infrastructure is often quite rigid or inflexible. In an engineering sense deformable structures next to inflexible infrastructure can result in some incompatibility, which in a wider context means risk.

In addition because of the engineering characteristics, the scale of the mines and the scale of the dewatering required for stability, subsidence and ground movements are occurring over very large areas. The mines are interacting with each other and their environment over a large area.

In the course of the Inquiry I have also become aware of other technical issues that have occurred and these are of a nature that I am satisfied that the NE Batter failure is a manifestation, in part, of the need for a more global assessment of all aspects relative to the open cut mining in the Latrobe Valley.

Because of the factors described above, the Latrobe Valley is unlike any other major mining region in Australia, it is unique and requires a holistic approach to planning, and not just the mining approvals.

The overall recommendations are:

1. **Ground and Surface Water**

   Groundwater control is essential for all the coal mines. However this also has large scale widespread ramifications. There is a need for a more all encompassing approach to all aspects of ground and surface water in the Latrobe Valley.

2. **Planning**

   There also needs to be a more all encompassing approach to planning for all future developments in the Latrobe Valley that recognises the somewhat competing demands of all the various elements.

3. **Management and Control of Mining Risk**

   Given the complexity and scale of the technical issues, effective regulation of the current and future mining is difficult. It is recommended that the Government instigates the establishment of a technical review board that undertakes annual or bi-annual reviews of all the mining operations and their potential impacts.

   It is further recommended that DPI review the Mining Licence notification conditions.

4. **Technical**

   The issues exposed by the NE Batter failure highlight the need for the mine and their advisers to:

   (a) Continue to develop their hydrogeological models,

   (b) Continue to develop their geotechnical models,

   (c) Ensure the disciplines of geology, hydrogeology and soil mechanics are fully integrated into a comprehensive geotechnical models of stability,

   (d) Ensure that any new or significant changes to mine plans, mine layouts or mining systems are thoroughly evaluated from a geotechnical and hydrogeological perspective before they are adopted and

   (e) The last recommendation is perhaps more nebulous but is probably the most important. It is critical for maintenance of future stability in mining that the historic experience and understanding is not lost but effectively captured in the new and evolving models of understanding.

CONTENTS

1. INTRODUCTION

On 30 January 2008 I was appointed a Mining Warden by the Governor in Council of the State of Victoria. I was requested by the Minister for Energy and Resources to undertake an Inquiry under Section 98 of the Mineral Resources (Sustainable Development) Act 1990 to investigate, report and make recommendations regarding the Yallourn Mine Batter Failure in accordance with the Terms of Reference (TOR) as set out in Section 3.0 of my report.

2. BACKGROUND

2.1. Setting

In the early hours of Wednesday 14 November 2007, TRUenergy's Yallourn Coal Mine experienced a major collapse on the northern batter of the East Field pit. I understand this resulted in damage to mine infrastructure, halting of coal production from East Field and inflow of the entire flow of the Latrobe River into the open pit mine. The Latrobe River, which is outside the mine boundary, flows along the northern border of the power station and the mine.

I also understand the mine provides coal to the Yallourn power station located in the Latrobe Valley, providing up to 20 per cent of the electricity supply capacity available to Victoria.

The batter failed by large scale block sliding of the Yallourn Coal Seam. The sliding took place along the underlying interseam clays and was driven by water pressures. A detailed description of the failure is included in Section 9.0 of my report.

2.2. Terminology

In open cut mining, issues to do with mine batter design and stability fall within the ambit of geotechnical engineering. In this context geotechnical engineering includes geology, groundwater (hydrogeology), surface water hydrology and geotechnical engineering itself, where all these disciplines are inter-related. Because this is a technical enquiry, there will be of necessity recourse to the use of some technical jargon. In order to assist the reader I have included a glossary at the end of the report, where the main terms are explained.

In this report I refer to the mine wall where the failure occurred as the NE Batter, in order to distinguish it from the older northern batter that was mined up to about 2002. The NE Batter is located along the extreme northern limit of the Yallourn East Field pit (YEF) and lies adjacent to the Latrobe River.

2.3. Yallourn Mine

The Yallourn Mine is owned by TRUenergy but the mine is operated by the Yallourn Mine Alliance (YMA), a partnership between TRUenergy and the Roche / Thiess / Linfox (RTL) Joint Venture.

Matters to do with Geology, Groundwater and Geotechnical Engineering and stability in the Yallourn Mine were the responsibility of the Mine Geologist. The Mine Geologist reported to the Mine Planning Manager. The Mine Planning Manager reported to the YMA Mine Manager, who reports to the YMA Board. The TRUenergy Manager Mining is a member of the YMA Board.

Where relevant advice or guidance was provided by external parties, these have been referred to as appropriate.

2.4. Discussion of Timeframes for Investigation

The failure of the NE Batter at Yallourn mine occurred during the early hours of 14 November 2007.

When a major mine failure occurs, experience shows it has often come about, at least in part, from issues and circumstances spanning some years. These issues or circumstances often include elements such as the mine plan and the batter design studies.

Long experience has also shown that in nearly every circumstance, major mine failures give warning of the impending collapse. Hence it is also necessary to look closely at what occurred in the days, weeks and months preceding the failure in order to understand the issues and circumstances that may have contributed to the final collapse.

When dealing with potential safety related issues the timeframe is normally shorter again and depending on the individual mine circumstances, this is often focussed on the days or possibly weeks prior to the failure. This assumes that appropriate systems to manage the operations and safety in the mine have been developed and have been used.

Consequently, in summary the general focus and investigation timeframes for this Inquiry are:

1. Planning and design issues – months to years.
2. Understanding of the emerging problem and implementation of preventative measures – weeks to months.
3. Safety – days to weeks.

3. TERMS OF REFERENCE

This Inquiry into the Yallourn mine batter failure has been conducted under the Mineral Resources (*Sustainable Development) Act 1990* (MRSDA). The objectives of the Inquiry are to:

(a) Establish the facts, circumstances and causes surrounding the collapse of the Yallourn mine wall in the early hours of Wednesday 14 November 2007,

(b) Examine any mine safety issues and

(c) Make high level recommendations on actions to prevent or minimise the risks of a similar event occurring in the future.

In the TOR I have been directed that the Inquiry should be confined to the facts, circumstances and causes of the incident. In addition to the three Inquiry objectives set out above, I have also been requested to give consideration to the suitability of the mine design, mining concept and operations.

4. ACCESS TO INFORMATION AND LIMITATIONS

As discussed above the Yallourn mine batter failure was impacted by events extending back over many years. During that time studies were undertaken by a number of companies. Many of the individuals who undertook work on behalf of these companies no longer work for them and their whereabouts are unknown. In addition some of the companies which undertook work at the mine are no longer in existence.

The Mine Geologist became ill on the day of the failure, remained sick for the majority of the Inquiry, was unavailable for interview on medical advice and then took extended leave. The extended leave was planned well before the failure. It was not possible to interview the Mine Geologist.

An opportunity was extended to Snowden to assist the Inquiry but no written documentation was provided. However I was able to obtain various documents from TRUenergy. A written response to the draft report was received from the legal representatives of Snowden that included a number of assertions. In the preparation of my report I have had regard to all the information and given it appropriate consideration.

This set of circumstances may be construed as possibly placing limitations on the Inquiry. However while this potential is acknowledged, the technical issues are considered fairly straightforward and there is sufficient documentation available to be able to follow the evolution of the thinking and decision-making in regard to these technical issues.

On balance, while these limitations have impacted on the process and the time taken to complete the Inquiry, I consider these limitations have not materially affected the findings of the Inquiry formulated in response to the TOR.

5. CHRONOLOGY

5.1. Introduction

In this section of my report I briefly set out the chronology of the main events prior to the failure. The chronology is divided into the three general timeframes as described in Section 2.4.

It was necessary to provide this chronology because of the very long history leading up to the failure. This section of my report is of necessity a summary. I have included selected quotations from important documents as appropriate in order to provide a framework of understanding for the findings and conclusions within the main body of the report. The subject matter relevant to the quotations is addressed more fully, where appropriate, within the body of the report. Where appropriate and to assist the reader I have also added notes to the chronology.

5.2. Chronology of Main Events

The chronology of the main events relevant to the YEF and the Inquiry includes:

- 1996 (19 March) – Mining Licence 5003 granted for YEF.
- 2001 (1 March) – Preliminary Design Study approves 150m separation between NE Batter and Latrobe River.
- 2001 (October) – Morwell River Diversion (MRD) commenced. This is the second diversion of the Morwell River. The first diversion was carried out by the SECV in the early 1980's.
- 2002 (24 January) – Changes to Mine Plan and MRD approved.
  - – This includes changes to mining systems, from dredgers (bucketwheel excavators) to bulldozers and inpit Feeder-Breakers (FB1 to FB4), termed slope mining.
  - – Changes to the active mining face layout.
- 2002 (December) – Annual geotechnical reviews commenced.
- 2002-2003 – Decision taken not to drill horizontal bores in NE Batter.
- 2004 (1 September) – Bores used for deep aquifer dewatering in YEF were switched off.
- 2005 (31 May) – MRD completed and Morwell River diverted.

5.3. Events Leading up to the Failure

The chronology of significant events and observations leading up to the failure comprises:

- July 2005 – Sign of "stress relief" identified in mine floor (Reference 75 July 2005).
- February 2007 – TRUenergy monthly reports, note cracks observed.
- March 2007 – Water seepage in the bottom of seam at RL-48 noted as a problem (Reference 75 March 2007).
- 5 March 2007 – Cracks observed on NE Batter and assumed by Mine Geologist to be typical of those experienced generally around the mine.
- 30 May 2007 – Significant cracking observed and additional monitoring installed.
- 5 July 2007 – Cracking observed on Latrobe River Levee and considered by the Mine Geologist to be part of the natural response of the mine slopes.
- 11 July 2007 – Cracks inspected in field by the Geotechnical Engineer and a consultant and monitoring data provided by email for assessment by the consultant.
- 19 July 2007 – Letter provided commenting on the cracks that were inspected in field (Reference 33):

  > *"TRUenergy has also asked Golder Associates to provide comment on cracks that were observed in the Latrobe River levee bank. Cracks were observed in two locations along the levee bank, with both being approximately parallel to the open pit face. These cracks extended diagonally across the width of the levee bank at the locations observed.*
  >
  > *We understand that further survey monitoring of the cracks is proposed and we will provide comment on the cracks following our review of the data."*

  – I could find no record of further assessment of this issue.
- August 2007 – Cracking on Latrobe River Levee extends, and considered by the Mine Geologist to be

part of the natural response of the mine slopes and not related to slope failure.

- 20 September 2007 – Mine Geologist reviews monitoring for NE Batter.
  – Monitoring data sent to consultant for review.
  – Elevated water level noted in one bore on the northern batter (Bore No. 25985), Figure 19.
- 1 October 2007 – Annual Geotechnical Review postponed from 1 November 2007 till early in 2008.
- 12 October 2007 – Further cracking observed and concern raised by Mine Geologist over the form of the cracks. Cracks inspected by consultant and reference to a "mini-graben type" feature and the pin data (presumably referring to the monitoring pins).
  – Request by email from TRUenergy to consultant for explanation of cracks and graben.
- 17 October 2007 – Consultant advises TRUenergy they would like to look at the batter slope in some detail in order to answer the questions raised.
- 18 October 2007 – Request from TRUenergy to another consultant (second consultant) to visit site for a second opinion on cracking.
- 19 October 2007 – Letter from first consultant giving formal advice following notification of 17 October (Reference 35):

  "TRUenergy has also asked Golder Associates to provide comment on cracks that were observed behind the northern pit wall. Based on preliminary information provided by TRUenergy, the northern pit wall is approximately 90m in height and survey monitoring data indicates that it has moved by up to 2m laterally towards the open pit. This has been attributed to stress relief by TRUenergy, and you advise the movements are generally consistent with those observed on the other pit walls. During the site visit, a number of cracks were observed behind the northern coal batter face and Latrobe River levee bank. All of these cracks were approximately parallel to the open pit face.

Notwithstanding the history of large lateral movements, attributed to stress relief, given the proximity to the Latrobe river it is considered that possible global stability issues associated with the cracking and the northern pit wall movements should be further investigated. We suggest it is important to try to better understand the nature of the movements, the significance of the cracking and the stability / risk to the northern pit wall. We would be pleased to assist in such studies if required "

- 20 October 2007 – Note to file by the Mine Geologist setting out the history and background to cracking and stability in YEF.

5.4. Events Immediately Prior to Failure

The chronology of events, observations and advice immediately prior to the failure comprises:

- 4 November – 57mm Rainfall event; note this date was recorded as 2nd to 3rd November in Reference 79.

  – Monitoring pins show 200mm movement as a result of rainfall (however this movement was not noted till 11 November).
- 4 November – 600m long crack observed on Southern Batter near FB1.
- 5 November – "Heavy water flow" recorded from NE Batter FB3 slope; 200 to 300 litres per second.
- 6 November – Internal email from the Mine Geologist.

  "Over the last few days an enormous amount of water has been pouring into cracks in the drains on the frontside of E108.

  That water is now finding its way out of the bedding planes, joints and cracks in the coal above FB3.

  Over the next few days we need to keep a very close watch on any water or cracks appearing in the northern batters.

  It took a few days for the water to get in and it will take a few days for the water to come out.

As a priority we need to seal up the cracks where they cross the drains on the frontside and backside of E108.

After sealing we need to be vigilant about monitoring the drains to ensure that the seals are effective."

- 7-8 November – Second consultant visits site to give second opinion on NE Batter stability.
- 9 November – Second consultant's draft report addresses the following issues and includes the following answers to specific questions present for the review by TRUenergy (Reference 45):

  "This report provides the Snowden's assessment of geotechnical conditions in this area and of the management of geotechnically related risks to the mine."

  "The results suggest the current slope design has a high factor of safety for all normal conditions."

  "Snowden believes that mining of the lower batter can continue safely."

  "Snowden has concluded that the water flows occurring on the mid seam bench are caused by surface run-off water draining into tension cracks on the bench above ... rather than any connection to river-water ..."
- 10 November – Water in Bore 25846, which is located where the failure occurred, rises by 15m, Figure 13. I note this is a substantial rise.
- 11 November – Internal note to file by Mine Geologist "Water Inflow Latrobe River batters November 2007."
- 11 November – Water flow from NE Batter recorded as reduced to 80 to 100 litres per second.
- 11 November – Internal email by Mine Geologist requesting meeting to discuss "few concerns" with NE Batter.
- 12 November – Email from second consultant advises (Reference 82): *"lowest FoS for entire slope is 1.36"*. I note that a Factor of Safety (FoS) greater than 1.3 would in normal engineering practice be taken to mean the slope is stable.

- 12 November – Approval to drill horizontal bores in NE Batter.
- 12 November – Water samples taken to determine source of NE Batter water.
- 13 November – Coal mining stops on NE Batter (near FB3) due to increased water flows overnight.
- 13 November (late morning) – Third consultant onsite reviewing situation and issues.
- 13 November – Horizontal bore drilling rig installed on NE Batter.
- 13 November (4.30pm) – Third consultant returns to site and issues letter advising (Reference 58):

  > *"Given the available information and observations made today, GHD believe that this is a major stability risk but that it is unlikely that a catastrophic failure will occur, resulting in an immediate safety hazard, provided remediation is undertaken. Access is therefore considered permissible along the levee bank, overburden and L308 levels."*

- 13 November (6pm) – Second consultant returns to site to review situation.
- 13 November – No activities apart from checking allowed in this area of the mine.
- 13 November – Manager Mining sends internal email to senior management of TRUenergy advising (Reference 83):

  > *"In speaking to consultants the probability of the river moving into mine is considered low."*
  >
  > *"We have meetings with DPI tomorrow morning and we have GHD and Snowden working together and they will reinforce the requirement to redirect river."*

- 14 November (1.30am) – Manager Mining receives phone call from operations at the mine advising of distress to conveyors on NE Batter.
- 14 November (2.10am) – Mine Manager and Manager Mining on site and NE Batter fails.

6. MINE DEVELOPMENT IMPLICATIONS

The Yallourn East Field Mine (YEF) was approved in 1996 and commenced mining in the southwest advancing towards the northeast. Final batters were formed progressively on the north western and south eastern sides as the mine advanced. The active mining faces which were formed by "dredgers" (bucketwheel excavators) were located on the north eastern side of the mine and were much flatter than the final batters to allow for the mining to take place, Figure 1.

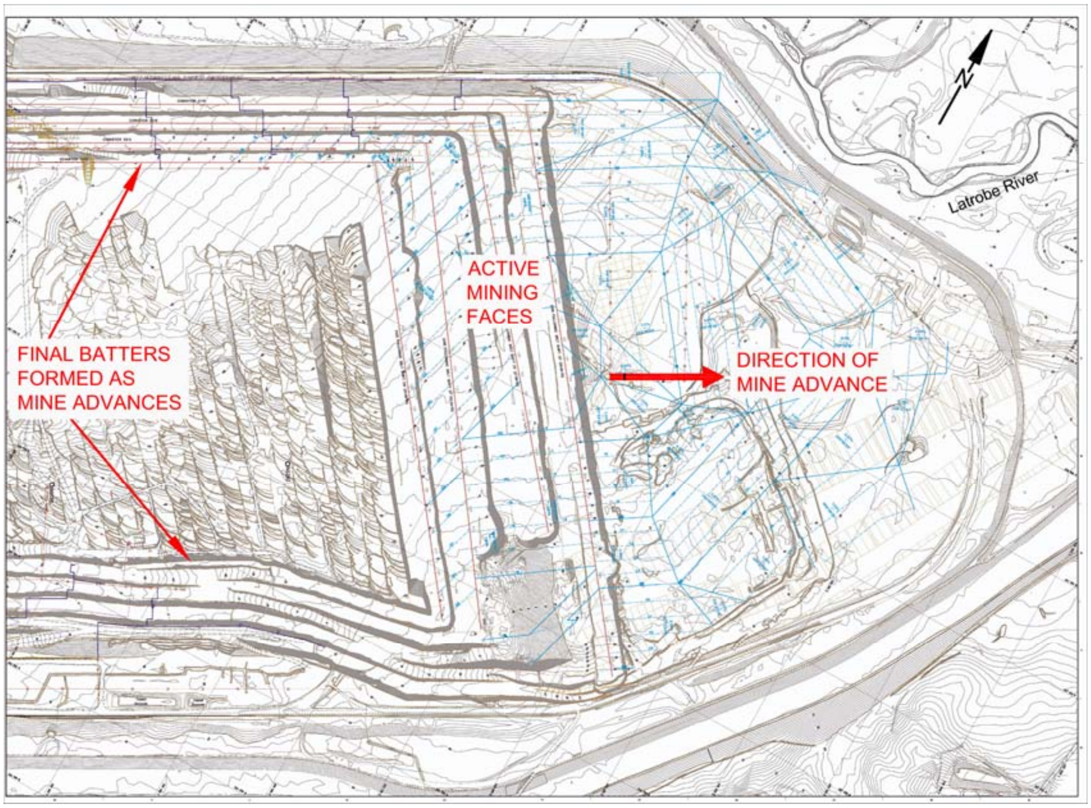


Figure 1: Yallourn East Field – 2002

The geotechnical advantages of this layout include:

1. The final batters were completed progressively and thus the stability performance may be monitored and compared to predictions.
2. Horizontal bores were installed progressively on each bench as the mine progressed.
3. These horizontal bores played an essential role in controlling groundwater pressures behind the mine wall by providing and allowing drainage.
4. Because the final batters were completed, there was no ongoing disturbance due to mining, and the movement monitoring network would

show the situation after mining was completed. This means conclusions about batter stability were more straightforward.

In 2002 a change to the mining layout and system was approved by DPI. The dredgers were progressively replaced by bulldozers and feeder breakers (FB1 to FB4). There was also a change in the orientation of the northern batter, from the northeast-southwest alignment to east-west, Figure 2. This east-west alignment is the final NE Batter which includes where the failure occurred. The active mining benches were then pivoted about their north western contact point with the northern batter and swivelled towards the north. These active mining faces then advanced towards the final NE Batter. The final NE Batter comprised three benches and the approximate time period over which each was completed comprises:

1. Upper overburden and coal batter – September 2005 to June 2006.
2. Middle bench – December 2005 to June 2007, Figure 3.
3. Lower bench – June 2007 onwards, with a small wedge of coal remaining at the eastern end of the NE Batter at the time of the failure, Figure 4.

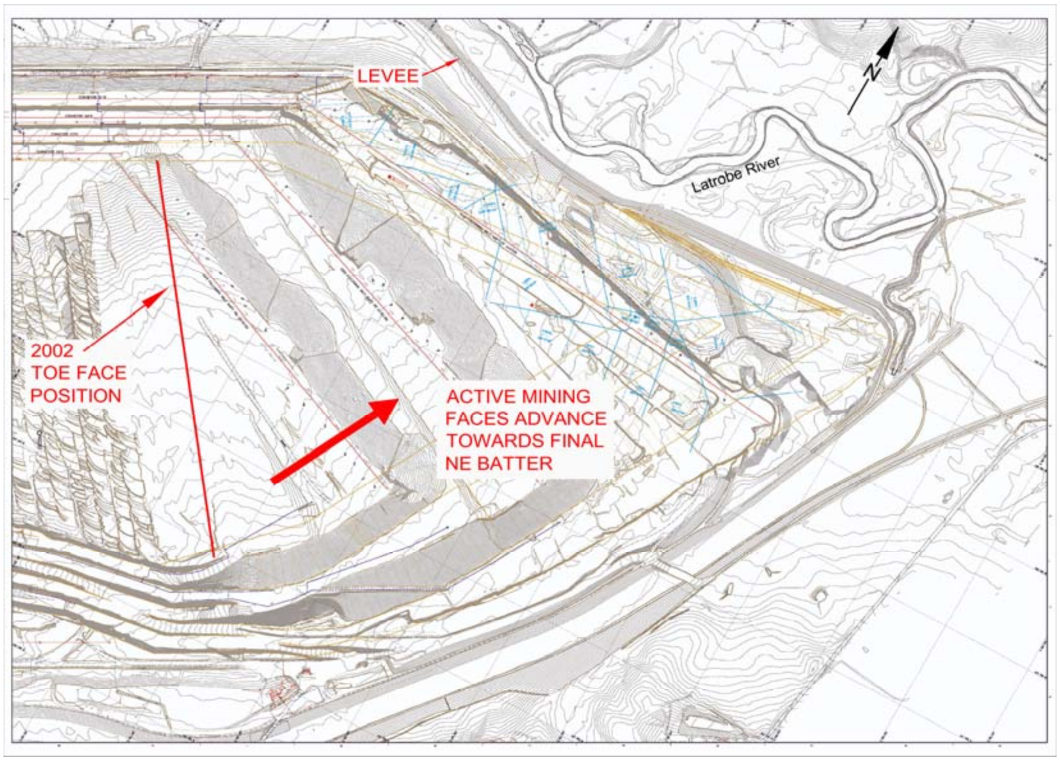


Figure 2: Yallourn East Field March 2005

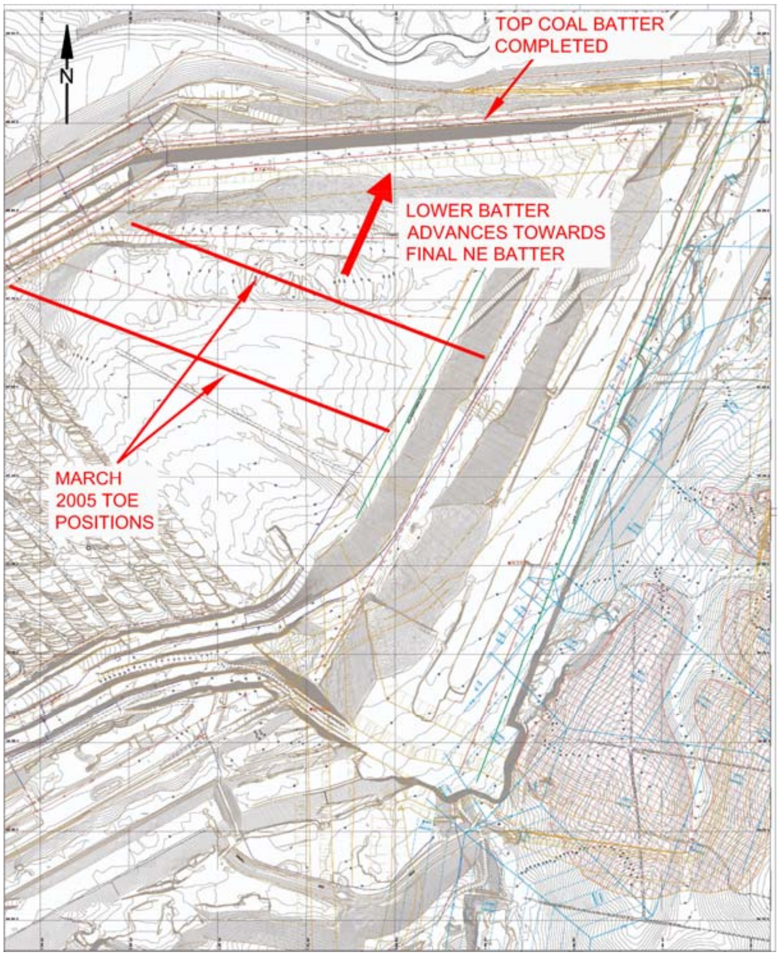


Figure 3: Yallourn East Field - June 2007

The final slice of coal remaining along each bench was excavated by advancing from west to east along the NE Batter, Figure 4.

This new mine development had significant geotechnical implications in a number of key areas:

1. Because the final NE Batter was continually being excavated, from September 2005 till the failure, there was no effective time when excavation was completed from a mining viewpoint. Hence the final batter was not formed until almost the end of mining. I consider this could make it more difficult to evaluate the slope movement monitoring data.
2. The dominant joint sets in the coal in the YEF are aligned west northwest to east southeast and form an acute angle with the NE Batter, refer to Section 8.4. Because each bench of the final batter was formed by excavating from west to east, Figure 4, these joints did not "daylight" in the final batter (that is form an intersection with the final batter) until the excavation had advanced towards the eastern end of the NE Batter. Hence

there was limited opportunity for natural drainage of water pressures out of the joints to occur.

3. The combination of the increased individual bench heights and the direction of advance of the mining faces meant it was more difficult, compared to the pre-2002 mining system and layout, to install an effective horizontal bore system.
4. Implementation of a groundwater system for control of groundwater levels in and below the NE Batter would have been more difficult.

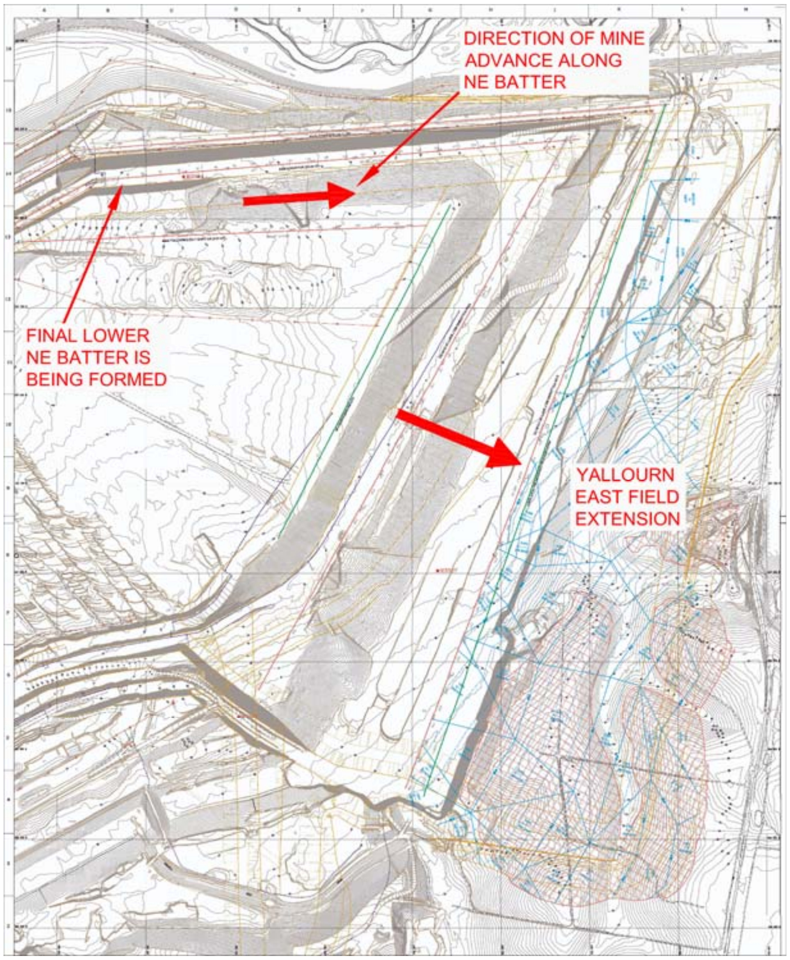


Figure 4: Yallourn East Field – September 2007

Hence in two of the important geotechnical areas, namely monitoring and groundwater drainage, the new mining system and layout imposed some significant limitations. These limitations needed to be recognised at an early stage and an effective strategic plan developed.

These potential issues were broadly recognised, at least in part, by the Mine Geologist in 2001 (References 46 and 47) and discussed with and recognised by a consulting group (Reference 57):

> *“Change in Mining Method*
>
> *BW informed Geo-Eng that YEF will be developed by slope mining methods and that this change in mining method will affect future works in Hydrogeology and Slope Stability. Hydrogeology and Slope Stability will be effected in the following ways.*
>
> > *Field Operations*
> > *Ian Kennedy’s monitoring,*
> > *Rehabilitation*
> > *Location of future bores*
> >
> > *Planning*
> > *How many pump, pilot and obs bores,*
> > *When drilled*
> > *Pump bores and drawdown to fit in with slope mine schedules*
>
> *No action necessary yet, BW used the meeting as a way of formally notifying Geo-Eng of the change in mining method.”*

It is not clear from the documents what happened over time in regard to these initial concerns. However, I assume TRUenergy and their advisers became comfortable that the technical challenges could be effectively managed.

7. GEOTECHNICAL MANAGEMENT SYSTEM AT YALLOURN MINE

7.1. Roles and Responsibilities YMA

The Mine Geologist was responsible for the day-to-day operation of the Ground Management Plan which included; monitoring (both water and movement), inspection, evaluation of remediation measures as required and monthly reporting. The Mine Geologist was also responsible for organising assistance from external consultants as and when deemed necessary (References 36, 37 and 38).

The Mine Geologist also set the Brief, in consultation with TRUenergy senior management, for the Annual Geotechnical Reviews. The reviews were organised by the Mine Geologist.

7.2. Geotechnical Management System

The geotechnical management system as set up for the Yallourn Mine over the period from about 2001 to the time of the failure appears on face value to have been comprehensive. In summary, the system entailed:

1. Mine site “ownership” and control of geotechnical issues.
2. External specialist consulting advice in key technical areas.
3. Sometimes advice on the same important technical issue was sought from a number of different consulting groups.
4. A series of inspection and monitoring schedules covering; drainage, mine inspections, aquifer and stability monitoring reviews; and pin monitoring on a one to 12 monthly schedule.
5. Monthly reporting during 2002 to 2007 by the Mine Geologist.
6. Annual independent third party reviews, from 2002 till 2007.
7. An extensive system of written Work Plans (References 48 to 53).

Overall I consider such a system should have had the requisite components to ensure success.

7.3. External Consulting Support for Mine Geologist

Technical support for the Mine Geologist in the areas of groundwater and geotechnical engineering was provided by a large number of different organisations including: Geo-Eng Pty Ltd, BFP Consultants Pty Ltd, URS, Golder Associates Pty Ltd, M.A. Coulthard and Associates, RMIT, Monash University, GHD, Curtin University of Technology and Snowden.

Of these organisations Geo-Eng and BFP Consultants Pty Ltd are no longer in existence.

Commencing from about early 2001 and extending up to about the time just prior to the failure the Mine Geologist was responsible for all technical interaction and liaison with the consultants and reviewers.

The history of involvement for the consulting groups and the general technical areas in which they were involved comprised:

1.	1996 to August 2001	**Geo-Eng Pty Ltd** Monthly review reports and overall six monthly reviews; plus individual design tasks such as the 150m setback for the NE Batters.
2.	2001 to 2003	**BFP Consultants Pty Ltd** A three year contract providing the majority of the geotechnical consulting work for Yallourn Mine over that period.
3.	2001 to 2003	**URS** Worked initially in partnership with BFP on studies, then provided specific separate advice on groundwater matters.

4.	2001 to 2005	**M.A. Coulthard and Associates** Worked as a specialist sub-consultant to BFP on computer based geotechnical modelling.
5.	2001 to 2005	**RMIT** Four undergraduate projects on stability in Yallourn Mine; 2001, 2003, 2004 and 2005. Two of these studies, namely 2003 and 2004, were carried out under the supervision of BFP.
6.	2003 to 2006	**GHD** A number of narrowly focussed studies including documents on a horizontal bore strategy, review of deep aquifer dewatering and review of the stability of the northern and NE Batters.
7.	2001 to 2002	**Golder Associates Pty Ltd** Mainly working on the MRD, including deep aquifer dewatering and its impact on MRD stability.
8.	2006 to 2007	**Golder Associates Pty Ltd** General technical assistance; and advice on and review of cracking and monitoring data for NE Batter.
9.	2007	**Snowden** Geotechnical advice in period from 7 to 13 November immediately prior to the failure.
10.	2007	**GHD** Geotechnical advice on 13 November immediately prior to the failure.

From about 2004/2005 it appears there was less input from external consultants and the Mine Geologist undertook an increasingly independent role with geotechnical matters at the mine.

7.4. Annual Geotechnical Review

Annual geotechnical reviews formed part of the 2002 Mining Licence Conditions. These reviews commenced in 2002 and the last review was in January 2007 (References 40 to 44). The late 2007 review scheduled for 1 November, was postponed till early 2008 by TRUenergy on 1 October 2007. I have been advised by TRUenergy the review was postponed because of illness in the family of the Mine Geologist. It is unfortunate this review was postponed, particularly given the cracking and the heightened concern about the NE Batter stability at that time.

Although not part of the formal annual review process, a separate review of the NE Batter was undertaken on 7 and 8 November 2007 (Reference 45).

The reviewers reported to the Mine Geologist and the reviews were of short duration and appeared to be somewhat limited in scope, as the brief from the Mine Geologist followed a Question and Answer format. I note from internal TRUenergy documents the Mine Geologist considered the "intent" of the Question and Answer format was to "focus the review on particular areas". However, in many cases the final question(s) posed by the Mine Geologist was an over-arching request to identify any other issues of concern.

The annual geotechnical reviews were undertaken by:

- Snowden (Dr P. Lilly) – 2002, 2003 and 2004,
- Curtin University of Technology (Professor P. Lilly) – 2005 and
- Dr J. Read – 2007.

The last annual review, January 2007, entailed only one and a half days duration on site. The review was also undertaken by someone new to the mine. The questions posed by the Mine Geologist were focussed principally on dumps and stability analysis techniques/software for the dumps. Given the scale of the mine, the nature of the technical issues associated with each mine batter face, the focus on dump issues, the limitation set on the available time onsite and the fact the reviewer was new to the site, it is considered unreasonable to have expected the stability of the NE Batter to be addressed in detail, other than if there were obvious aspects evident during the mine inspection.

The four earlier annual reviews, 2002 to 2005, were undertaken by the same person and covered a wide range of technical issues at Yallourn Mine, including the NE Batter. It is noted that these reviews were also of limited duration on site, one to two days each, and were also in the Question and Answer format. However I would have expected in these circumstances that over the period of the reviews and given the range of technical issues posed by the Mine Geologist, that there would be in total sufficient time and exposure, to be able to identify the important technical issues and any significant gaps or uncertainties.

7.5. Work Plans

TRUenergy maintains a comprehensive system of project procedures covering the mine. The principal procedures, plans and work instructions of relevance to the Inquiry are:

1. Occupational Health and Safety Plan (Reference 54).
2. Design Management Plan: Mine Planning Slope Stability and Groundwater (Reference 50).
3. Operational Slope Stability (Reference 51).
4. Maintenance of Yallourn Mine Drainage System (Reference 49).
5. Environmental Management Plan – Attachment 4.02 – Groundwater Extraction (Reference 52).

6. Drainage and Slope Stability Note (Reference 53).
7. Mining Hazard Register.
8. Operational Risk Register.

I note that accompanying these plans there are also comprehensive monitoring and inspection timetables that appear to have been planned, at least in 2007, on an annual basis.

Any significant geotechnical issues identified by the Mine Geologist are included in the monthly reports to the YMA Board.

7.6. Key Reference Documents on Slope Stability in Yallourn Mine

The Work Instruction – Operational Slope Stability (Reference 51) lists the key technical reports, which the Mine Geologist relied on:

> *"Key Consultants Reports Relevant to Slope Stability*
>
> *These consultants' reports contain detailed stability assessments and plans showing the locations of the various bores and instruments referred to in this procedure.*
>
> *The Yallourn Mine Alliance Geologist holds the reports.*
>
> 1. *Mine Inspections Field Sheets Folder – contains data and pro formas filled out during field inspections*
> 2. *Yallourn Coal Mine, Township Field, Western Batters Updated Stability Analysis Results – BFP Consultants September 2002*
> 3. *Yallourn Coal Mine Eastfield Analyses and Reviews of Slope Stability Models 2002 BFP Consultants December 2002*
> 4. *Stability of Coal Dyke Option 9 Alignment Yallourn Victoria – Golders Associates August 2001 – current models relevant to stability of River Diversion and Coal Dyke*
> 5. *Annual stability reviews reports by Geo-Eng for both Yallourn East Field and Western Batters from 1993 to 2001*
> 6. *Geotechnical Stability Analysis and Factor of Safety Summary – BFP Consultants 11 September 2003*
> 7. *Western Batters Sensitivity Analysis – Letter form BFP Consultants 19 February 2003*
> 8. *Yallourn Phreatic Surface Sensitivity Analysis North South UDEC Model – BFP Consultants February 2003*
> 9. *Pump Operations Deep Aquifer Modelling – Letter GHD Pty Ltd 10 June 2004 ref 31/14784/7697*

> 10. *Yallourn Energy A review of Geotechnical Issues – Snowden Mining Industry Consultants February 2004 and December 2004."*

Of these documents those of relevance to NE Batter are Items 3, 5, 6, 8, 9 and 10.

8. HISTORY OF GEOTECHNICAL KNOWLEDGE AND UNDERSTANDING

8.1. Introduction

There is a very long history of open cut mining in the Latrobe Valley that stretches back for many decades. In order to answer the TOR it was necessary for the Inquiry to establish the historic understanding and knowledge that underpinned mine design, mine development and stability in the Latrobe Valley. The aims of this historic review are to provide answers to the following general questions:

1. What were the general types of batter failures that had been experienced in the past?
2. What were the historic geotechnical and groundwater factors that controlled stability?
3. How well were these factors understood?
4. Was the Yallourn mine batter failure an unknown, unusual or new type of collapse?

In the following sections I have summarised the key aspects from the documentation made available as part of this Inquiry.

8.2. Deformations Associated with Open Pit Mining

8.2.1. Discussion

The natural materials surrounding the YEF are subject to many different stresses and resultant movements, including:

1. Stress relief due to excavation of the coal and overburden.
2. Elastic compression of the confined aquifers underlying the mine floor due to dewatering.
3. Consolidation (subsidence) of the materials due to lowering of groundwater pressures.
4. Creep movements of the open pit walls.
5. Periodic recharge of the groundwater system due to rainfall and possibly from other sources of surface water.
6. Upward heave or movement of the mine floor due to excess groundwater pressures below the floor.

These stresses can result in a sometimes complex pattern of movements, particularly where there are variable timeframes involved and when both the mine excavation and dewatering are continuing over time.

8.2.2. General Movements

There is a very long history of monitoring and understanding of ground movements around the Latrobe Valley Mines. That understanding was developed well before the start of mining in the YEF and for the YEF itself, extends back to at least 1997, (Reference 1):

> *"Stress relief movements related to mine excavation are a normal consequence of mining, particularly so in the Latrobe valley, where high in-situ stress and low deformation modulus coal combine to produce relatively large movements. A rough 'rule of thumb' for estimating the magnitude of ground movement, based on experience in the Latrobe valley open cuts, predicts a maximum horizontal ground movement of 300mm for this depth of excavation. The only means of controlling stress relief movements is by lowering the batter slope angle, and is not warranted in most cases. The implications of stress relief type movements on mining risk are an increase in ground strain on the batters and batter crests, however this seldom results in cracking of any significant magnitude. Sensitive structures such as the Morwell River Diversion channel may experience problems due to deformation and cracking of the clay lining, which could lead to leakage into the mine."*

And Reference 2:

> *"The major component of the ground movement measured on the southern and northern batters is due to stress relief associate with excavation of the open cut. Stress relief movements related to mine excavation are a normal consequence of mining, particularly so in the Latrobe Valley, here high in-situ stress and low coal deformation modulus result in relatively large ground movements (up to 1.5m). The implications of stress relief movements are an increase in ground strain on the batters and batter crests, which may result in localised cracking of the coal. Surface water entering these cracks may then result in block instabilities, placing the safety of equipment and personnel at risk."*

In simple terms it is clear that large movements of the sides of the mine are expected. These movements can lead to cracking of the mine batters and can also lead to instability due to rainfall runoff entering those cracks.

In the YEF, monitoring data (References 2 and 5) showed the following general scales of stress relief movements:

- Order of horizontal movement of mine batters - approximately 0.3 to 0.5m and

- Order of vertical movements - approximately 0.2 to 0.5m.

Much larger movements were apparently associated with the western batters. However those assessments appeared to be more related to marginal stability, not stress relief movements.

8.2.3. Cracking

Because of the geotechnical character of the materials and the many different stresses these materials are subject to, cracking is common (Reference 5). Numerous examples of significant cracks are described in the various reports, both internal and external, prepared over the last 10 to 11 years.

8.3. Role of Structure, Groundwater and Stability

The effect of these deformations (large movements) around the mines and the inter-relationship with pre-existing geological structures, mainly joints, was also very well understood (Reference 2):

> *"Incidents of cracking have occurred on the southern end of the coal dyke, adjacent to the pipe factory, over the last year (refer Geo-Eng report No. 5000/5). Cracks formed subparallel to the dominant joint set direction in the area (approximately 315° relative to grid north), and varied in width from 20 to 120mm. The cracking was found to be associated with high water levels in this part of the dyke (see Figure 4), due to the recirculation of water through the cut-off drain on the crest of the dyke. The high water levels resulted in high pore pressures on the interseam clays, and a high horizontal force component acting on the coal joints, which resulted in block sliding."*

The hydrogeological implications of these deformations and the cracking were also understood, together with the potential for a hydromechanical coupling with existing surface water bodies (Reference 2):

> *"Inspection of the cut-off drain after the recirculation of water from level 2 ceased revealed a large (≈300mm) crack at the base of the drain which would have acted as a conduit to feed water back into the coal dyke and out of the horizontal drains on level 2."*

In summary, the large movements of the sides of the mine tend to preferentially open pre-existing geological cracks (joints) in the coal. Any water entering these open joints can lead to block sliding of the batters due to groundwater pressures.

8.4. Geological Structure Data

In 1997 a geological survey of the YEF was carried out and the survey identified the joint sets in Table 8.1 and as shown in Figure 5 (Reference 3). It is noted that the two joint sets that are sub-parallel to the NE Batter, J1 and J2, are noted as:

> *"Dominant, … occurring throughout East Field."*

TABLE 8.1
CHARACTERISTICS OF JOINTS IN YEF 1997
(After Reference 3)

JOINT SET	DIP (deg)		DIP DIRECTION (deg)		COMMENTS
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	
J1	86	8	209	29	Dominant, sub-vertical set occurring throughout East Field
J2	88	9	243	10	Dominant, sub-vertical set occurring throughout East Field
J3	83	7	338	7	Uncommon sub-vertical set
J4	48	11	239	17	Critically dipping joint set
J5	12	4	240	99	Bedding parallel joints

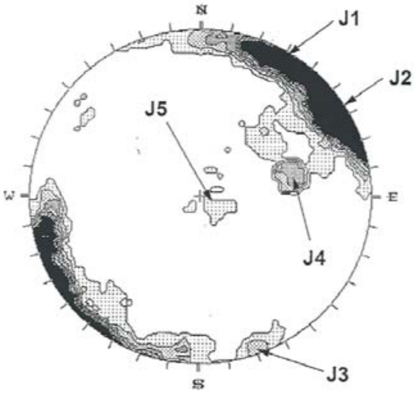
A further geological joint survey was carried out in April 1999 (Reference 11). The results of that survey are included in Table 8.2 and shown in Figure 5:

In regard to the joints Reference 11 notes:

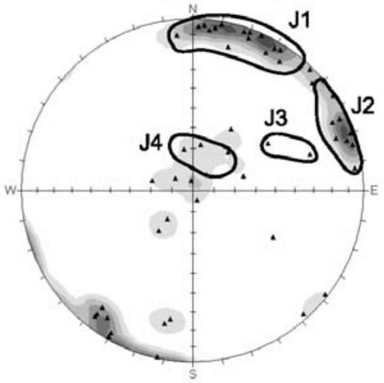
> *"Of the four joint sets defined, sets J1 and J2 are statistically the most significant."*
>
> *"These joint sets are sub-vertical; i.e. they have a dip in excess of approximately 80° and strike roughly east-west."*

And:

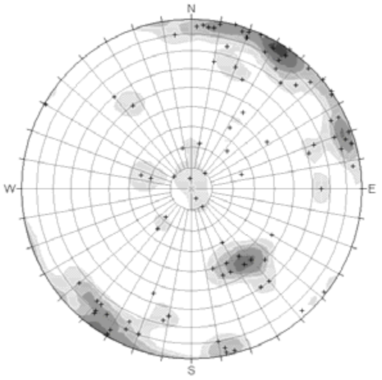
> *"Joints sets J1 and J2 are very continuous and appear to penetrate the entire coal seam in which they are located. These joints are planar with smooth and clean surfaces."*



Contoured Stereographic Plot of Joint Data 1997
(Reference 3)



1999 (Reference 11)



2003 (Includes 1999 data)
(Reference 55)

Figure 5: Contoured Stereographic Plots of Joint Data 1997, 1999 and 2003 (References 3, 11 and 55). Note the patterns are consistent for the three sets of data.

TABLE 8.2
CHARACTERISTICS OF JOINTS IN YEF 1999
(After Reference 11)

JOINT SET	DIP (DEG)		DIP DIRECTION (DEG)		COMMENTS
	Mean	Standard Deviation	Mean	Standard Deviation	
J1	85	3	180	9	Dominant, sub-vertical set
J2	85	3	225	5	Dominant, sub-vertical set
J3	47	2	299	8	Critically dipping joint set
J4	28	12	211	9	Uncommon joint

Further mapping was undertaken in 2003 as part of a thesis at RMIT under the supervision of BFP (Reference 55), Figure 5.

These three sets of data appear to comprise all the structure mapping in the YEF. In summary there is very good agreement between the three data sets. In relation to the final NE Batter, which has an east west alignment (090° to 270°), this data shows:

1. There are two sets of continuous joints, sets J1 and J2, that are aligned (strike) either at an acute angle or sub-parallel to the NE Batter.
2. These two sets are dominant, include joints that are very continuous, penetrate the whole of the Yallourn coal seam and are subvertical.

8.5. Key Parameters for Stability

The geotechnical model of understanding of factors or parameters for batter stability at the start of the YEF comprised (Reference 2):

> *"Monitoring of the unconfined water table in the coal batters, and pore pressure in the interseam clay ..."*
>
> *"The water level data is compared to target water levels required to maintain stability against batter sliding on the interseam clay. These target water levels are derived by means of block sliding analysis using the locally developed program BSLIDE."*

And (Reference 5):

> *"The critical parameters affecting the stability of the batters are the unconfined water level, the pore pressure in the interseam clay and the strength of the interseam clay."*

In 2000 the measures required to control block sliding of batters were set out (Reference 13):

> *"Recommendations on methods to reduce the probability of block sliding have been made in general reports. Detailed below are the measures which may be taken to reduce the risk of potential events occurring:*
>
> 1. *Ensure adequate coal batter drainage by means of sufficient horizontal drains;*
> 2. *Prevent surface water ingress by clay capping all exposed coal on the batters, and clay lining all toe drains;*
> 3. *Inspect batters routinely for signs of block movement;*
> 4. *Monitor ground movements of the batters as well as the river diversion;*
> 5. *Monitor water levels in the batters and overburden;*
> 6. *Install sufficient monitoring bores and survey pins, especially at the Southern Batters to monitor the batter performance;*
> 7. *Regular visual inspections of the River Diversion channel for cracks;*
> 8. *Continuous monitoring of groundwater and ground movement;*
> 9. *Drainage of the overburden aquifer;*
> 10. *Regular joint mapping to assess the likelihood of unfavourable joint orientations;*
> 11. *Placing a toe surcharge at the base of the batter, if required; and*
> 12. *Leaving a coal buffer at the toe of the batters, if required."*

This Reference which was an early geotechnical evaluation document covering the YEF, sets out the various methods required to control batter stability in the YEF, including a number of preventative measures (horizontal bores, prevention of water ingress and drainage of the overburden aquifer), monitoring (inspection, monitoring bores and survey pins), management (joint mapping) and remedial measures to control adverse movements (a toe surcharge or coal buffer).

It is evident from the above quotations and the preceding sections of this report, that the following parameters are critical for batter stability:

1. The water level in coal seams ("unconfined water level").

2. The water pressures in the clay beneath the coal seams ("pore pressure in the interseam clays").
3. The strength of the interseam clay.
4. The fourth factor, as identified in Section 8.3 is the role of water pressure in joints in the coal.

If effective control of water is not maintained, or incorrect parameters are used, then blocksliding can occur.

8.6. Ground and Surface Water Control Measures

8.6.1. Role of Horizontal Bores

Horizontal bores have had a very long term and essential role in maintaining stability of the mine batters in the Latrobe Valley (Reference 2):

> *"Horizontal drainage bores are drilled into the permanent batters to reduce the unconfined water (coal water) to an acceptable level to ensure long term stability. Drainage is facilitated by the intersection of water bearing coal joints by the horizontal bores. The optimum spacing of these horizontal bores has been found to be in the order of 30m, to ensure interaction between bores. Horizontal bores have been found to be the most cost effective means of lowering the unconfined water table, and thereby improving stability."*

And (Reference 5):

> *"The optimum spacing of these horizontal bores can only be determined by practical experience, but to ensure intersection of all possible vertical joints, 200m bores should be spaced a maximum of 60m apart on the northern and southern batters, and installed obliquely to the batters, at an orientation determined by the local dominant joint orientation."*

In the YEF the bore spacing was subsequently increased to 100m, based on monitored performance (Reference 10):

> *"However to ensure intersection of all possible vertical joints, 200m deep bores should be spaced a maximum of 100m apart on the Northern and Southern Batters, and installed obliquely to the batters, at an orientation determined by the local dominant joint orientation. This is an increase in the spacing of the horizontal bore (previously 60m) and will result in saving to Yallourn Energy."*

Horizontal bores are also essential to cope with increased groundwater pressures derived from rainfall events (Reference 7):

> *"However, the continued installation of horizontal drainage bores to cope with excessive rainfall periods, as well as to rapidly drain any vertical cracks which may form due to batter movement, is recommended."*

This means that horizontal bores are required to be drilled into the mine batters to drain the groundwater level in the coal seams by intersecting the joints and cracks in the coal. The horizontal bores are also required to allow drainage of rainfall runoff that has entered the joints in the coal. This water needs to be drained to stop the build-up of adverse water pressures, which could lead to block sliding of the batters.

8.6.2. Deep Aquifer Dewatering

The Latrobe Valley is underlain by very thick sequences of interbedded coal seams, interseam clays and sand aquifers. The sand aquifers are extensive and underlie the floors of all the Latrobe Valley Mines to varying extents. From early in the development of the coal mines it became clear that groundwater pressures in those aquifers deep below the floor of the coal mine had to be controlled to stop upward heave of the coal mine floor. Currently deep aquifer dewatering is undertaken at Hazelwood and Loy Yang Mines and the effects of this have spread to Yallourn. Dewatering of these aquifers also resulted in some lowering of the groundwater pore pressures in the interseam clays.

Up to about 2004, two to three deep aquifer bores were pumped at Yallourn Mine to control deep groundwater.

Three main aquifers were identified as potentially significant for mine stability (Reference 10):

1. Yallourn Aquifer
   Not well developed across the YEF.
   In 1998/1999 no groundwater was extracted from this aquifer and it appeared to be controlled by induced drainage to the underlying MIA aquifer (Reference 10).
2. Upper MIA Aquifer
   Developed across the East Field.
3. Middle MIA Aquifer
   This aquifer is located 50m below the MIA coal seam.

In 1998 the subfloor aquifer depressurisation comprised (Reference 9):

- N4934 - Pump bore,
- N5056 - Pump bore and
- N5055 - Free flowing bore.

These were installed in the period from June to December 1998 to control aquifer pressures in the MIA Aquifer. The last deep aquifer pump well in YEF was installed in April 2000, Number N5280. In addition, in the period up to February 2001, four observation bores in YEF were allowed to free flow under artesian conditions. The recommendations in February 2001 (Reference 14) were:

> *"As the mine develops to the east, consistent pumping from bores N4934, N5056 and N5280 will be required to manage aquifer pressures and maintain safe weight balance conditions for the Upper M1A Aquifer. In addition, a fourth pump bore will be required in early 2001 to reduce Upper M1A Aquifer pressures to the east of the current bore field's influence."*

And:

> *"As the mine develops to the east, consistent pumping from bores N4934, N5056 and N5280 will be required to manage aquifer pressures and maintain safe weight balance conditions for the Middle M1A Aquifer."*

The June 2001 report recommended the development of a risk based approach to deep aquifer dewatering. This risk based approach was to be designed to fit with the TRUenergy company "business risk profile" (Reference 14).

Hence deep aquifer dewatering was required to control groundwater pressures in aquifers below the pit floor and thus to control floor heave. However this dewatering also acted to reduce interseam pore pressure in the clays below the coal seams.

8.6.3. Overburden Dewatering

The Yallourn Coal seam is overlain by sandy clays, sand and gravel formed in a meandering fluvial depositional environment (Reference 6). These materials are present in the final northern batters and extend under the Latrobe River. These sands and gravels have the potential to continuously recharge the groundwater in the coal, inhibiting natural drainage.

Control of the shallow overburden aquifers is also required for stability in some instances. This would particularly be the case if these aquifers had the potential to feed water into the joints in the coal seams.

8.7. Mining Risks

8.7.1. Implications of Marginal Stability and Slope Performance

Where adequate stability cannot be maintained, the following risks to the mining operations were identified in 1997 (Reference 2):

> *"A factor of safety of less than 1.0 implies that … the likelihood of overall batter failure due to sliding on the interseam clay is high. In practice this means that large horizontal movements of the batters may be expected, with the following risks to mining operations:*
>
> - *Extensive cracking on upper levels, posing a safety risk to mining personnel where cracks (potentially 500mm wide or more) traverse roads;*

- *Sudden, unpredictable movement of the batters or the mine floor, placing the dredger at risk if in the immediate area;*
- *Misalignment of conveyor system, placing coal supply at risk;*
- *Deformation, leading to cracking, of fire service pipelines. Excess water will further charge any cracks in the batters, thereby increasing the potential horizontal movement; and*
- *Deformation and cracking of the Morwell River Diversion clay liner, resulting in leakage from the river into the mine, and potential flooding."*

Hence the body of knowledge prior to development of the YEF entailed:

1. If the stability of the batters is marginal then large horizontal movements may be expected.
2. This could lead to development of extensive cracking.
3. Excess water in these cracks could increase the horizontal movements.
4. Failure or large movement of the batters could be sudden and unpredictable.

8.7.2. Hazard Due to Mining Near Latrobe River

8.7.2.1 Risks

The potential risks of mining adjacent to the Latrobe River was also well understood and was a major concern when the planning and design studies for the NE Batter were first undertaken (Reference 6):

> *"The most significant geotechnical hazard identified was the breaching of the Latrobe River Channel due to block movement of the batters, and subsequent flooding of East Field due to uncontrolled leakage."*

And (Reference 6):

> *"HAZARD IDENTIFICATION*
> *Some of the geotechnical hazards associated with permanent mine batters in the Latrobe Valley Brown Coal Mines are listed as follows:*

HAZARD	*POTENTIAL CONSEQUENCES*
1. Block sliding of batters during excavation	- *Injury to dredger crew.* - *Damage to dredger.*
2. Block sliding of batters after excavation	- *Injury / damage to vehicular traffic due to cracking of roads.* - *Damage to fire service main.* - *Misalignment / damage to conveyor system, possibly affecting coal supply if movement occurs on all batters.*
3. Block sliding of batters back to Latrobe River	- *Creation of conduit from Latrobe River into East Field, and mine flooding.*

> *For the purposes of this assessment, the risk associated with hazards 1 and 2 above were not evaluated, as these risks are considered to be independent of the width of buffer between the batters and the river.*
>
> *The risk associated with block sliding back to the Latrobe River is considered to be highly dependent on the width of buffer between the Latrobe River and the permanent batters. Furthermore, the consequences of batter sliding resulting in leakage from the Latrobe River into the mine could result in temporary shut-down of the mine and power station, costly remedial works, and severe environmental repercussions. For these reasons, the probability of such an event occurring has been identified as the overriding geotechnical consideration when evaluating the feasibility of mining fringe coal in this area. This event is referred to as 'total failure' in this assessment."*

8.7.2.2 Latrobe River Standoff Distance

The setback distance between the Latrobe River and the mine has been subject to a number of studies. In 1997 it was found that (Reference 6):

> *"The analysis of block sliding indicated that there is a high probability of block sliding of the batters irrespective of the final batter position. The most likely limit of the sliding in all cases however is the crest of the overall batter, and hence the further the batter crest is located from the river, the less likely the river channel will be affected by the movement."*

And:

> *"… it may be possible to extend the batters to somewhere between 230m and 110m from the Latrobe River Levee toe."*

8.7.2.3 150m Latrobe River Buffer Design for NE Batter

A preliminary assessment of the stability of the NE Batter was undertaken in February 2001 (Reference 57). This appears to be the first design assessment for the 150m buffer distance. A range of groundwater conditions were modelled and the overall conclusions were:

> *"The above table indicates that stability of the NE Batters is highly dependent on ground water level variation. Coal block sliding would likely to occur, if the coal water level has not reduced."*
>
> And:
>
> *"Based on the scenarios adopted in the analyses, it is believed that installation of sufficient horizontal drains in all levels will be critical to maintain stability of the NE batters."*
>
> And:
>
> *"It appears that the proposed excavation method may result in increased risk of block sliding compared to the normal mine development."*
>
> And:
>
> *"The coal water phreatic surface used in the calculations was maintained at the highest practical level in order to model the effect of not being able to install horizontal drains in the NE batter. The coal water phreatic surface was also maintained at a low level to model the effect of the horizontal drains."*

It is believed the limitations referred to above relate to being able to install horizontal bores in the new higher coal batters, Figures 2 and 3.

It is clear from these quotations that the groundwater significance and some of the limitations of the new YEF mine development plan (post 2002) were evident.

Because of this, the following recommendations for further assessment were made:

> *"The impact of ground water seepage from the river-overburden on recharge of the coal joints requires a further assessment. Further review of the risks and potential management methods is considered appropriate."*
>
> *"Based on coal water levels and interseam pore pressures adopted in the analyses, it is believed that installation of sufficient horizontal drains in all levels should be carried out to lower the coal water level, and hence maintain the stability of the NE batters."*

> *"Further review of the risks and potential management methods is considered appropriate."*

> *"It is considered that mine designers, operators and geotechnical advisers should discuss this issue to ensure appropriate practical operational practices are instigated to manage slope stability."*

Notwithstanding the recommendations for further assessment, in the summary to the letter, the 150m setback was approved, at least in principal:

> *"Based on the stability analyses and the ground movements modelling, the NE batters can be aligned at a 150m buffer from the Latrobe River."*

Although in the body of the report the approval was more equivocal and subject to a large number of qualifications:

> *"Based on the current analyses of the coal block sliding, the 150m buffer width may be feasible subject to the following:*
>
> - *Sufficient drilling in the NE area is undertaken to adequately define the stratigraphy in this area,*
> - *Re-assess stability and groundwater conditions as additional data becomes available,*
> - *Overburden strength parameters should be measured to confirm or to revise the current overburden face stability analysis,*
> - *3:1 permanent overburden face should be maintained,*
> - *The overburden face should be flattened, if substantial water seepage is observed which may destabilise the face,*
> - *Drainage of the overburden aquifer,*
> - *Erosion protection should be properly designed and be maintained at all time.*
> - *Regular monitoring of the face for signs of instability should be undertaken, particularly during wet seasons,*
> - *Installation of a sufficient horizontal drains in the NE batters, as each cut is completed in order to reduce the potential of failure of the batters,*
> - *Further assess the likelihood and risk of high coal water level,*
> - *Develop appropriate management plans, alternative dewatering methods and place emergency pumping equipment on alert should water levels and/or ground movements show adverse conditions and*
> - *Regular inspection of the buffer zone for any sign of cracks."*

And:

> *"Regardless of the outcome of the decision to reduce the buffer width to 150m, the following risk management measures are recommended.*
>
> - *Installation of horizontal drains,*
> - *Adequate drainage and clay capping on all levels to prevent surface water ingress,*
> - *Ground movement and ground water levels to be monitored at the levee of the Latrobe River and at the crest of the NE batters,*
> - *Regular batter inspections to provide early indications of batter stability problems,*
> - *Placing a surcharged dump, if the inspection indicates an adverse situation,*
> - *Regular joint assessments to augment the existing database and detect any variations from existing distributions. Carrying out stability analysis of coal wedges which may dislodge from the batters, in particular the NE batters and*
> - *Re-assessment of the shear strength parameters used in the stability analysis of the NE batters, should be carried out upon extra strength data from the NE batters becomes available."*

I note the report was termed "Preliminary" and there were a large number of recommendations and qualifications. However, I consider that the recommendation for the 150m buffer design was probably not proven to a "feasible" level because of the following factors:

1. The stability analysis results showed the slope was unstable for a reasonable range of groundwater levels.
2. The difficulties identified with installing drainage due to the new mining system were recognised.
3. The importance of this batter in regard to the Latrobe River was well known.
4. The general risks and the location of essential coal supply infrastructure on this batter were well known.

8.7.2.4 Hydromechanical Coupling with Latrobe River

The potential for hydromechanical coupling with the Latrobe River was recognised early and the sequence of probable events clearly established (Reference 6):

> *"A sequence of events that could most likely result in a flooding event is proposed as follows:*

> 1. *Horizontal stress-relief movement of the batters, resulting in relaxation and opening of coal joints.*
> 2. *Block sliding of permanent batters, due to high and maintained coal water levels and interseam pore pressure.*
> 3. *Block sliding of permanent batters back to position of Latrobe River.*
> 4. *Formation of open cracks in the Latrobe River Channel.*
> 5. *Hydraulic connection between cracks in Latrobe River Channel and the North Eastern Batters.*
> 6. *Permeability of crack system high enough to permit large volume of water to enter the mine."*

8.7.2.5 Summary

Based on this assessment the hazards and risks of mining near the Latrobe River were well understood. The measures required to ensure stability of this batter were also well understood. Furthermore I consider the proposed sequence of events leading to a direct hydraulic connection between the Latrobe River and the mine is a good approximation of the actual events that occurred in 2007, leading up to and including the failure.

8.8. <u>Role of Monitoring</u>

8.8.1. Planning

A comprehensive monitoring network comprising surface movement, monitoring pins, overburden and coal groundwater monitoring bores; stability monitoring bores and subsurface movement monitoring bores was planned prior to the YEF development in 1996. This network covered the whole of the YEF (Reference 1).

8.8.2. Monitoring and Preventative Measures for Water Control

The critical importance of ongoing inspection, monitoring and remediation to maintain stability is clearly set out in (Reference 10):

> *"The calculated probability of sliding, for Southern Batters, Northern Batters and the Coal Dyke is considered to be acceptable. Despite the improvement of the stability condition, lowering of the unconfined ground water table in the coal is still required and that additional horizontal drains should be installed to assist achieve this.*
>
> *With the size of the No.4 Cut excavation now being significant, the potential for major batter movement due to poor drainage on the southern batters is expected to increase. Therefore, it is necessary to maintain good surface drainage, prevent ponding of water, clay cover benches and clay seal any open coal joints. The ongoing installation of horizontal drains will assist in lowering ground water levels. It is critical that ongoing monitoring of ground movement and ground water level is undertaken to manage the risk of potential batter instability."*

8.8.3. Subsurface Extensometers to Monitor Movement Below Coal

Wire extensometers installed in bores have traditionally been used as part of the monitoring network (Reference 10):

> *"These extensometers are installed to define the plane of movement in the interseam clays, and to provide an estimate of the magnitude of horizontal movement due to sliding. This information will be used to refine the stability analyses, thereby reducing the level of inherent uncertainty and risk."*

And:

> *"Figure 31, Northern Batter, illustrates that extensometer N5042 was experiencing slight movement. This movement occurred on a surface located approximately between RL -15 and RL -20. Readings of extensometer N5052 is currently showing steady conditions at the bottom of the mine. The extensometers indicate some 400mm of differential movement has occurred since mid 1997, towards the mine, between the base of coal and the underlying interseam."*

I note that no extensometers have been installed in YEF in recent years.

8.9. Summary from Historic Knowledge and Understanding

Based on the historic information collated and summarised above, the geotechnical knowledge and understanding for the YEF prior to the new mine development in 2002 comprised:

1. Large movements of the sides of the mine are expected.
2. These movements can lead to cracking.
3. Where cracking occurs it is usually developed preferentially along the pre-existing joints in the coal.
4. Water pressures can develop in these cracks (joints) due to existing groundwater and or rainfall runoff.
5. Control of water pressures in these cracks (joints) is critical for batter stability.
6. The principal batter failure mechanism is block sliding of the coal along the underlying interseam clays.
7. Sudden and unpredictable movements or failure can occur due to the block sliding.
8. The three key parameters for maintaining the stability of final batters are:
   - Water level in coal,
   - Water pressures in the interseam clays beneath the coal and

- Strength of the interseam clays.

9. Horizontal bores are essential in most cases to control water pressures in the coal.
10. Deep aquifer depressurisation below the coal seam floor is required for stability of the mine floor and this assists to reduce pore pressures in the interseam clays.
11. There are two sets of well developed, continuous joints that are aligned subparallel to and or at an acute angle to the NE Batter.
12. There is potential for the large movements associated with mining to lead to opening of joints and block sliding, thus forming a direct hydraulic connection between the Latrobe River and the mine.
13. An approximate scenario for the actual events that occurred in 2007 and including the failure was postulated in 1997 as part of engineering studies.
14. Monitoring and ongoing review of stability is part of the normal mine management required to maintain stability.

9. TECHNICAL ISSUES SURROUNDING THE FAILURE

9.1. Introduction

In this section of the report I provide an assessment of the following technical issues relevant to the failure:

1. Description of the failure and the role of geological structure.
2. A view of the conditions on the day preceding the failure.
3. Movement monitoring prior to the failure.
4. Groundwater monitoring prior to the failure.
5. Shear strength of interseam clays.
6. Horizontal bores.
7. Deep aquifer dewatering and interseam pore pressures.
8. Reviews of stability of the northern and NE Batters.
9. Role of Geotechnical Review.
10. Advice on cracking and movement.

These issues are addressed in the following sections.

9.2. Description of Failure

9.2.1. General Description

The NE Batter failure occurred by block sliding of the coal seam along the interseam clays underlying the coal seam. The basal failure plane was along or close to the coal interseam clay boundary. The total failure is almost square in plan view and the release plane along the northern side of the failure is linear in plan view and is formed along a substantial joint or set of joints in the coal.

This joint or set of joints intersected a bend in the Latrobe River and daylighted or approximately daylighted in the eastern end of the NE Batter near where FB3 was excavating coal to form the final lower bench immediately prior to the failure. The failure pivoted about the point where the joint intersected the Latrobe River and rotated in a clockwise direction. The failure travelled for up to 250m across the mine floor.

The failure is very large, about 500m long, as measured along the NE Batter, up to 150m deep, as measured in a north-south direction, and entailed approximately six million cubic metres of material.

Figures 6 and 7 show the location and date that cracks were located prior to and after the failure. Cracks were mapped for distance of up to 300 to 400m to the north of the NE Batter crest and were still being located up to one and a half months after the failure. The areal extent of the cracks together with the monitoring shows that the whole NE Batter was moving and could potentially have been included in a collapse. The groundwater monitoring data also shows that the mass involved in this movement was also deep seated and located in the interseam clays well below the coal. The actual NE Batter failure was only a small portion of the mass that was moving.

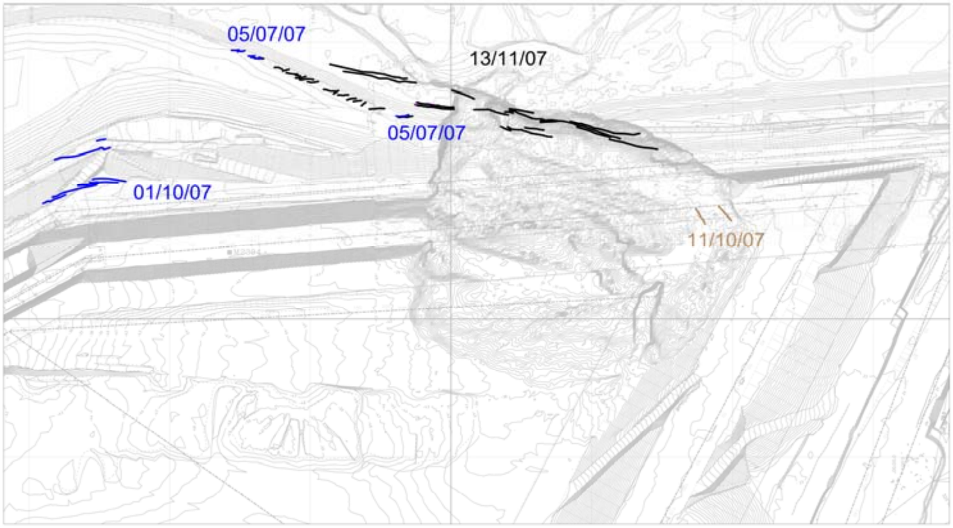


Figure 6: Cracks mapped prior to failure; colour coded with dates shown

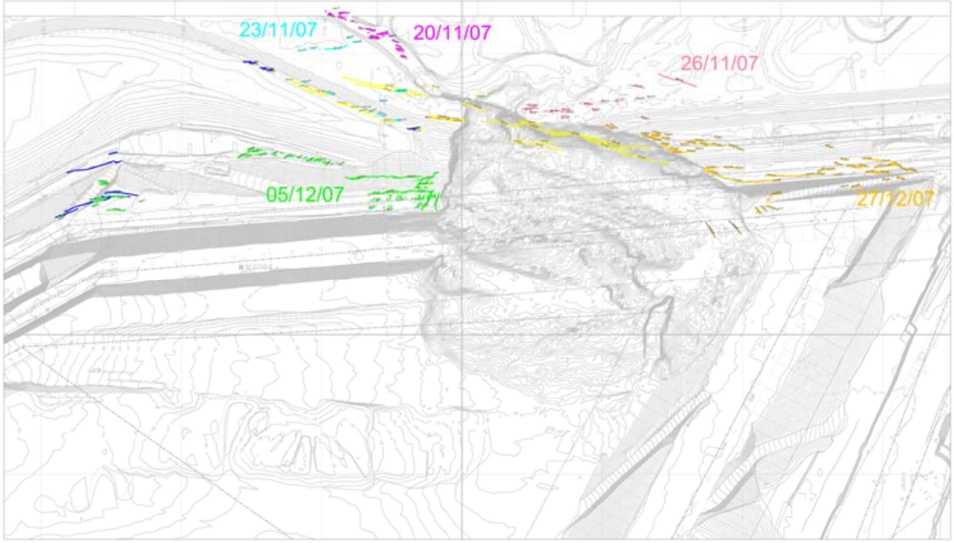


Figure 7: Cracks mapped after the failure; colour coded with dates shown

Figure 8 is a comparison of the 1997 joint data with the cracks mapped before the failure. This shows the cracks were formed parallel to the main joint sets.

Based on this description I conclude the failure is generally in accordance with the historic experience with batter failures in the Latrobe Valley.

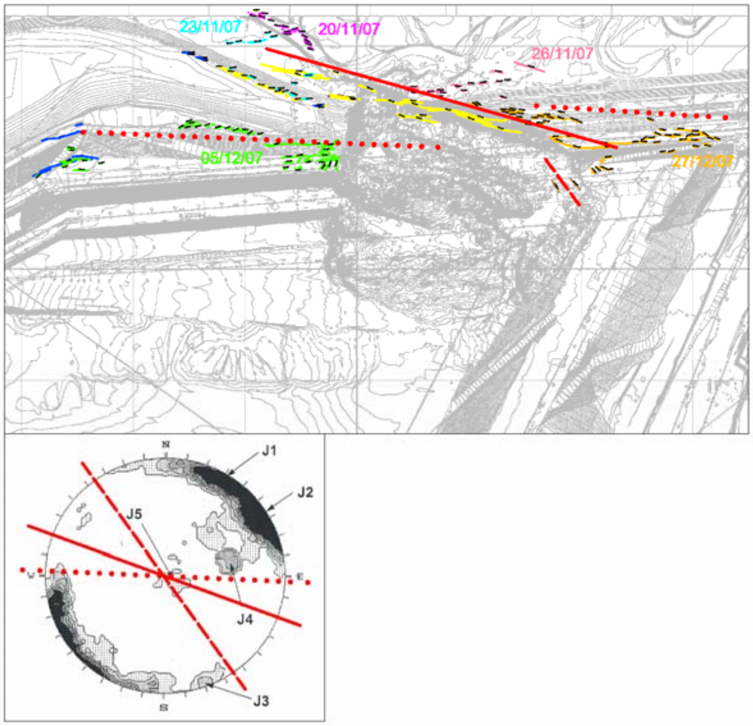


Figure 8: Comparison between cracks and joint data (1997)

9.2.2. View of NE Batter Immediately Prior to Failure

Figures 9 to 12 are photographs provided to the Mining Manager on 13th November 2007. These photographs provide a general tour of the main features evident around the NE Batter on the day immediately prior to the failure.

I consider the features evident in the photographs in general speak for themselves about the conditions and stability:

- Figure 9 – View along the NE Batter towards the east. Note the very pronounced bends in the pipeline and the line of power poles. Also note the very large volume of water on the mid height bench in coal. The batter stability design assumption was no water at this elevation.
- Figure 10 – These photographs show some of the cracks and subsidence across the road on top of the Latrobe River Levee.
- Figure 11 – These photographs shows the volume of water, estimated at 500 litres per second, flowing from the middle bench of the NE Batter later on 13th November.
- Figure 12 – These photographs show the wide open crack in the Latrobe River Floodplain that connected directly with the Latrobe River as shown in the second photograph. This is part of the cracks mapped on 13th November and shown in Figures 6 and 7.

Given these set of photographs and the monitoring data, I consider the logical conclusions are:

1. The Latrobe River is the predominant source of the water flows.
2. The slope is only marginally stable and failure is likely.
3. This failure could occur at any time.

Figure 9: General view along, NE Batter, note the bends in the pipeline and the line of power poles

Figure 10: Cracks and subsidence across the Latrobe River Levee

Figure 11: Water flow from mid coal bench

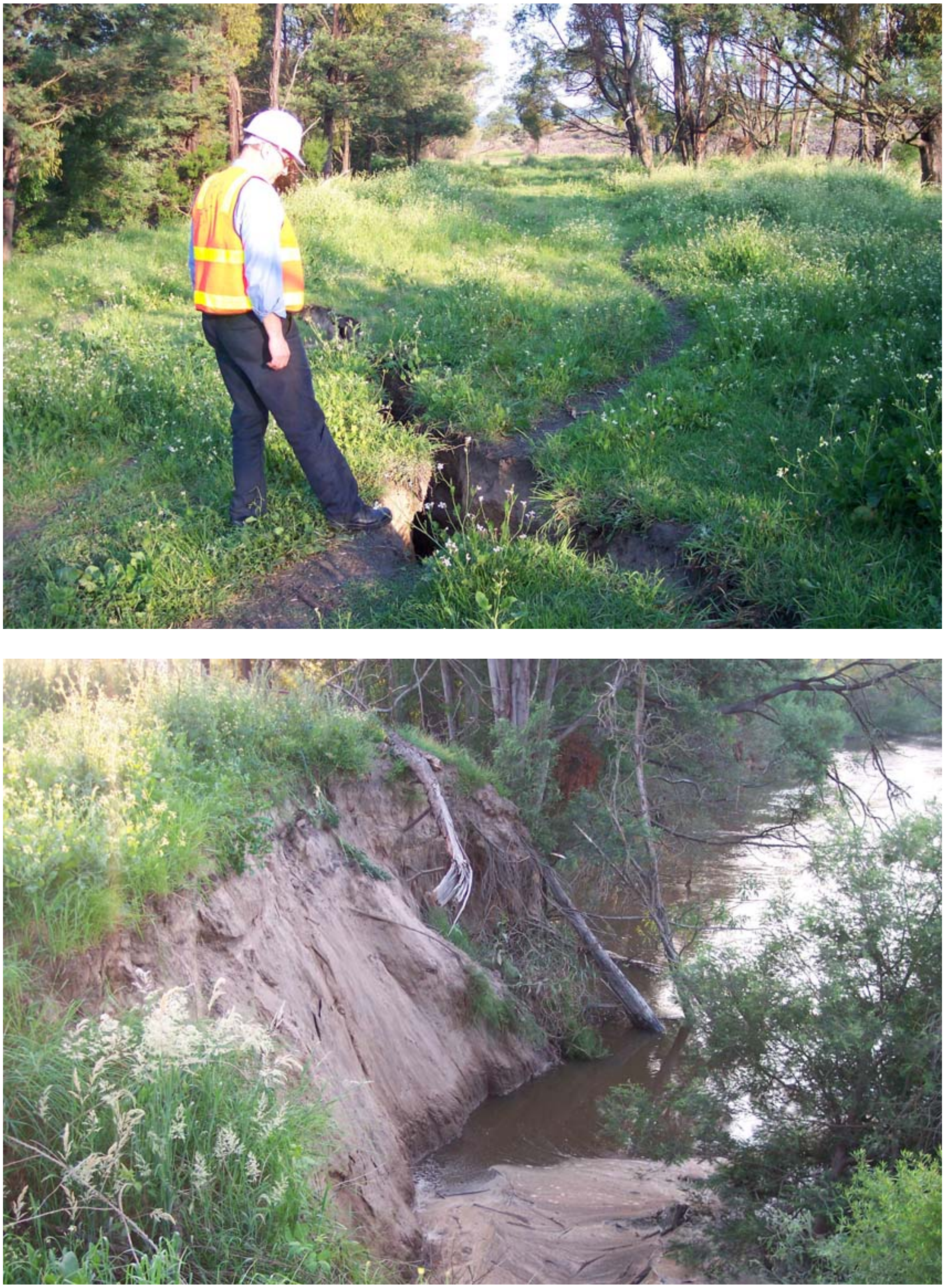


Figure 12: Crack in Latrobe River Floodplain and Latrobe River

9.3. Movement Monitoring

9.3.1. Mine Floor

There was an extensive network of pins monitoring the mine floor in the area mined up to about 2002, Figure 13. However at the time of the failure only three floor pins, YE4_29 to YE4_31, were being monitored in the eastern part of YEF.

In the north eastern half of the YEF, east of about 399000mE, the floor pins show continued upward movement over time. West of this approximate boundary the scale of movement is much less, there is no uniform upward trend of movement and the movement pattern is erratic.

Monitoring data for these two areas is illustrated in Figure 14 for:

- East of 399000mE – YE4_30 and YE4_31
- West of 399000mE – YE4_5 and YE4_6.

This shows the eastern end of the YEF has been subject to long term upward creep of the floor probably due to groundwater pressures.

Figure 13: Movement pins YEF

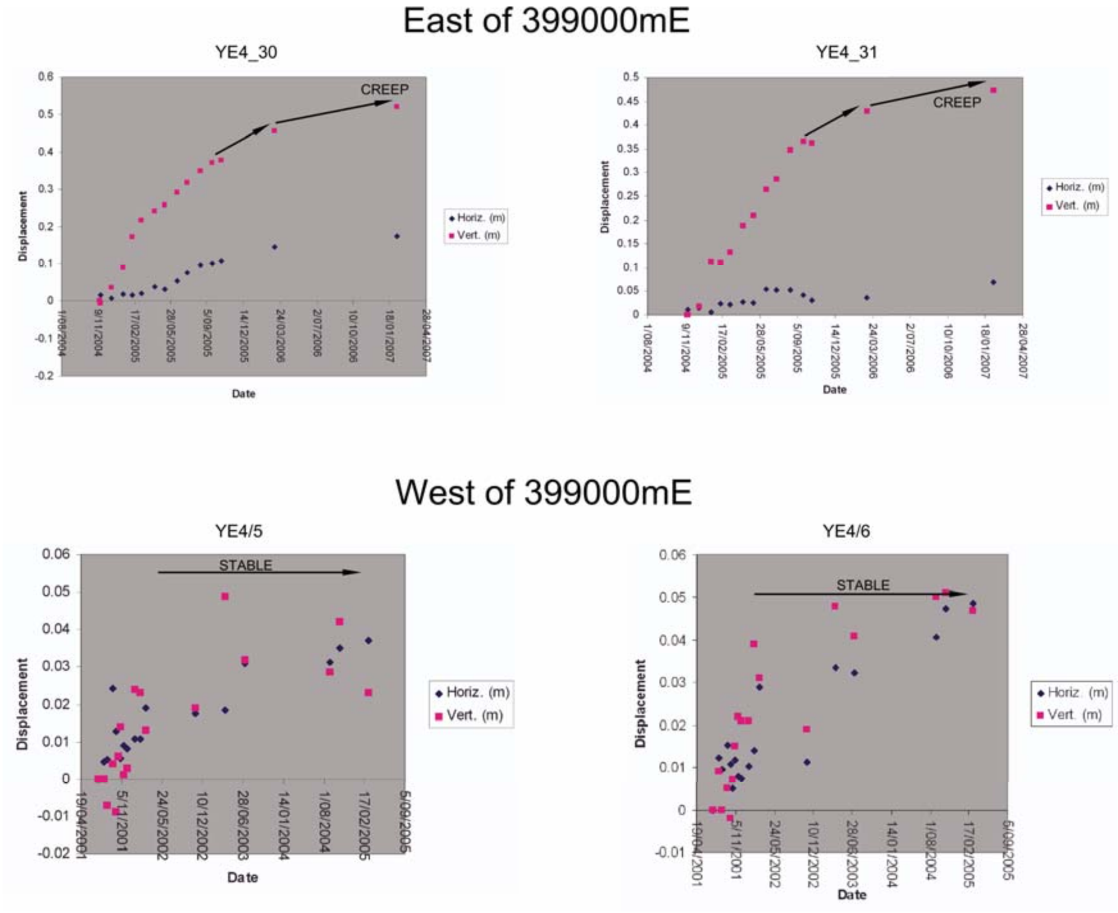


Figure 14: Mine floor movement pins

9.3.2. Batters

The batters and areas behind the final NE Batter were also monitored with pins, Figure 13. There are a number of long term pins that illustrate the movement of the batter over time, including YE2_55, YE2_56 and E110_slab. Figure 15 shows the movement trend for YE2_56. This pin shows long term accelerating movement with a pronounced acceleration starting in early 2005. The acceleration and movement had been occurring over many years prior to the failure. The total magnitude of movement is also relevant and is approaching 2m.

Figure 16 compares the movement pattern for a pin located immediately in the failure, YE2_60, and a pin located west of the failure, YE2_69. These pins show the same long term accelerating cycle of movements but for a shorter period, late 2005 till the failure. The magnitude of movement is around 1.0 to 1.3m over this period. There is a 0.2m "jump" in movement in early November and this is interpreted as the effect of the rainfall event on 4 November 2007.

Figure 16 also shows the movement pattern for two pins, YE2_16 and YE2_17, located in the old northern batter (west of the NE Batter), which was excavated prior to 2002. These pins show a completely different pattern with an initial stress relief movement that stabilises over time. The total movement is also relevant and is approximately 0.6m over eight years.

9.3.3. Summary

In summary this data confirms that the whole of the NE Batter was subject to long term accelerating movements extending for a period of many years. Unless this acceleration slowed or stabilised, refer to pins YE2_16 and YE2_17, there was a high likelihood of failure occurring at sometime.

The accelerating movements also began years before the final NE Batter was being formed and at a time when the active mining faces, Figures 2 and 3, were a long way from the Latrobe River. In the normal course of events it would be expected that with the active mining faces situated at such a large distance from the Latrobe River, that this would provide a stabilising buttress to inhibit movement. The fact that substantial movements were still occurring, even with these "stabilising buttresses" in place, means that water pressure both in the coal and more probably in the interseam clays under the coal, were playing a role in the movements. The movement of the floor pins confirms this latter effect. It is noted the numerical modelling predicted similar large scale deep seated movements (References 63 to 72).

If there were questions or uncertainties about these movements at the time, the usual procedure would be to compare the movement patterns for the NE Batter with other similar areas. The best comparison would be with the old northern batter where cracking had not occurred. This would have shown:

1. Substantially less total movement; about 0.6m compared with up to 1.5 to 2.0m in the NE Batter.

2. Movement rates for the NE Batter of over 1.0mm per day compared to close to zero in the old northern batter.
3. In the stable area, the old northern batter, the movements had stabilised over time and there was no long term acceleration.

The next step would be a comparison between the design assumptions for the NE Batter, mainly in regard to the groundwater conditions, and the actual water levels operating at that time.

Extensive experience has shown that long term accelerating movement patterns like that for the NE Batter, Figures 15 and 16, means that failure was always likely to occur, unless the movements could be stabilised by remedial measures.

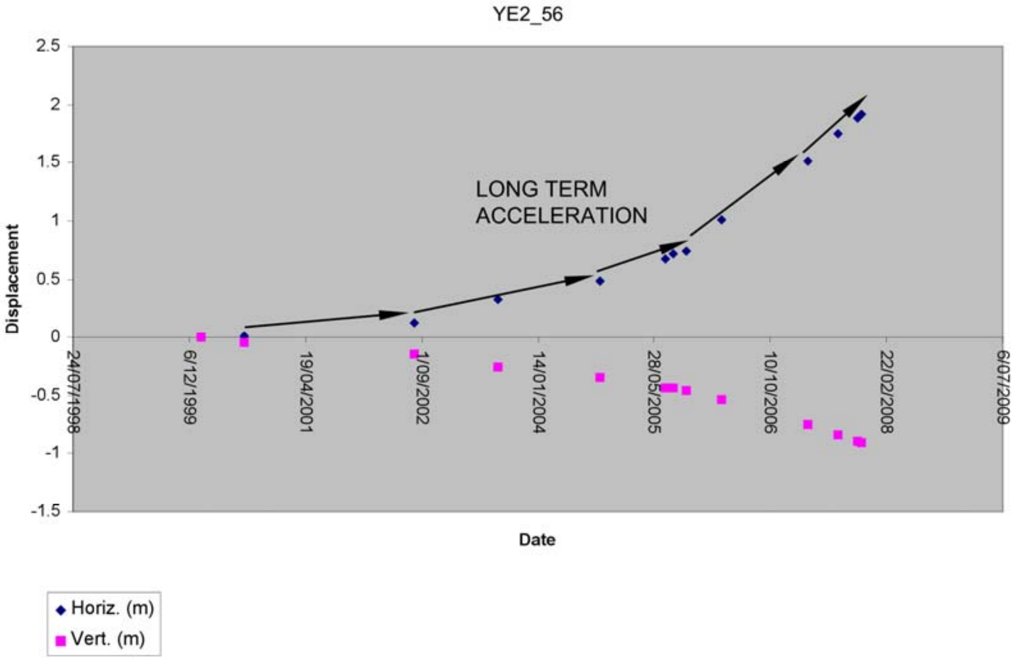


Figure 15: Long term movement for Batter pin YE2_56

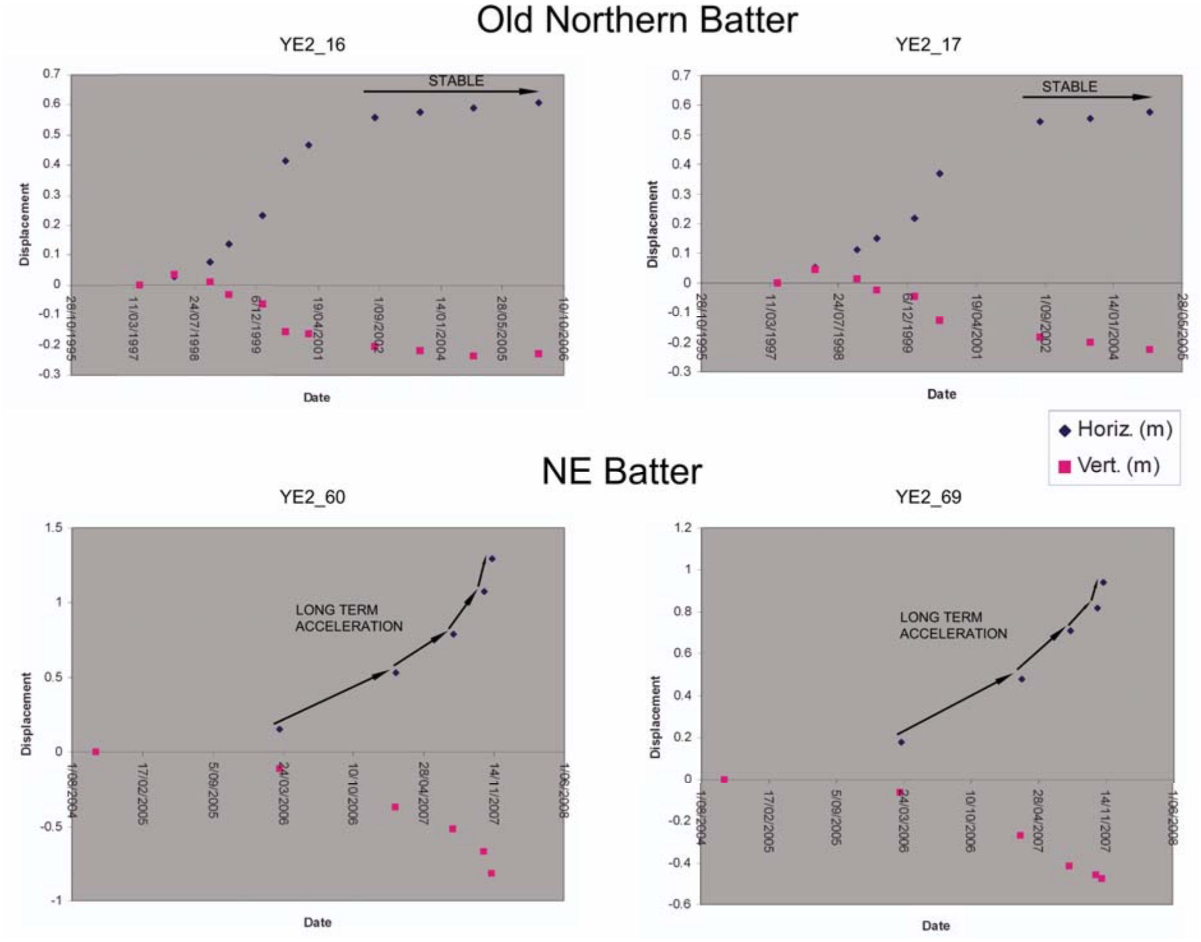


Figure 16: Comparison of Batter movements old Northern Batter and NE Batter

9.4. Groundwater Monitoring

9.4.1. Piezometric Levels

The piezometer locations are shown in Figure 17. The groundwater level (piezometric) data for the NE Batter area is shown in Figure 18. The data extends from about mid 1998 till the time of the failure. These piezometers are also included in Figure 19 for the period from 2004 till immediately after the failure.

Figure 17: Piezometer locations around the NE Batter

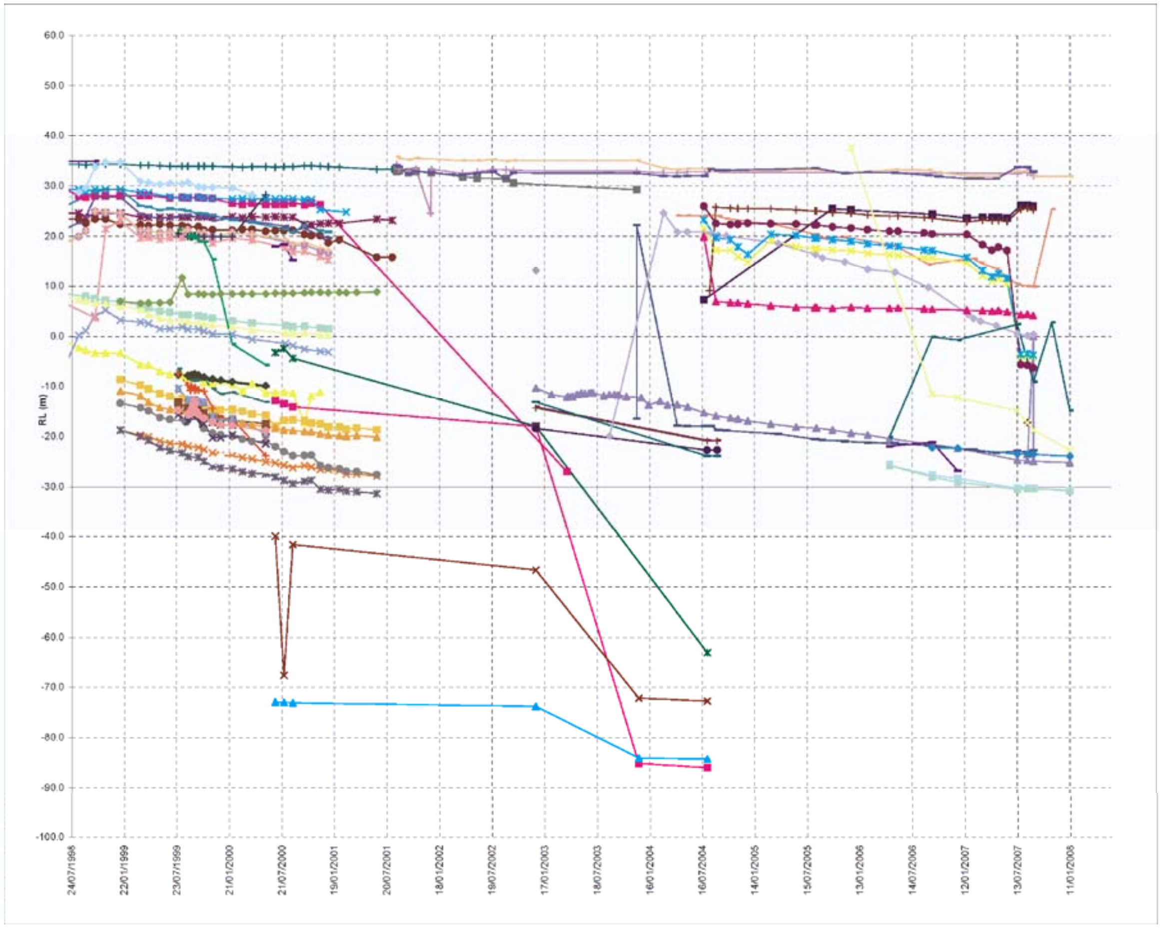


Figure 18: Hydrograph for NE Batter area piezometers

Ignoring what appear to be errors, this data shows:

1. A long term decreasing trend for most piezometers, 1998 till 2008.
2. A relatively steady pattern up till about early to mid 2006.
3. Disruptions to this steady pattern at the following approximate times:
    (a) Mid 2006,
    (b) January 2007,
    (c) June 2007 and
    (d) September 2007.
4. The disruptions include both rises and falls in levels or pressures.
5. These rises and falls are occurring through the profile and extend at depth into the interseam clays 10’s of metres below the base of the coal seam.
6. A 15m rise in piezometer 25846 S01 between 7th September and 10th November 2007. This piezometer is located near the northern part of the failure.

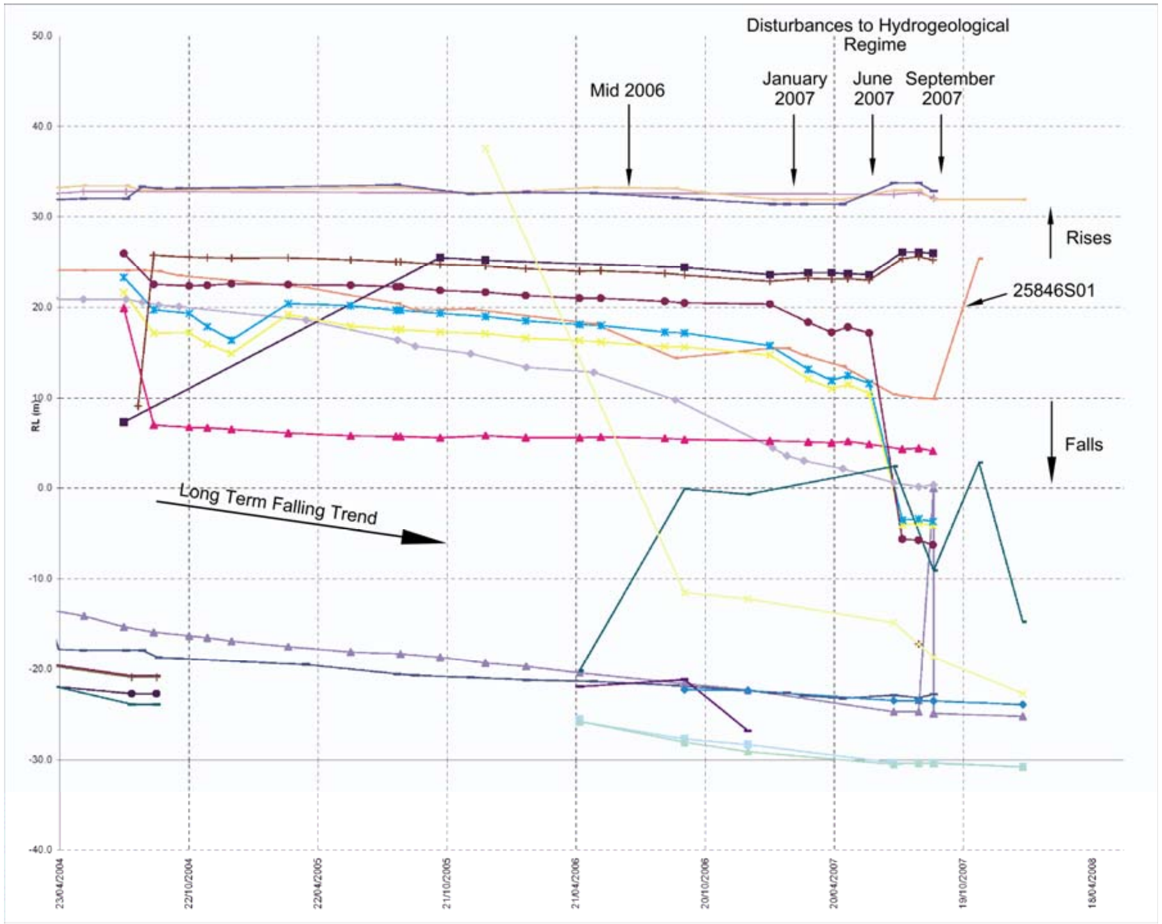


Figure 19: NE Batter piezometers 2004 to 2008

These changes in patterns are interpreted to be the result of disturbances to the existing hydrogeological regime due to the large scale and deep seated ongoing movement of the NE Batter. This eventually led to hydraulic connection between the Latrobe River and the joints in the coal. The rise in 25846 S01 which is located at the rear of the failure was 15 to 16m. This rise is clearly a result of almost direct hydraulic connection between the Latrobe River and the joints/cracks that eventually formed the rear release plane of the failure.

As movements continued, the majority of the piezometers in coal and below it along the northern and NE Batters showed significant changes in level in the period from mid 2006 to November 2007.

Figure 20 shows the piezometer pressures with depth over time compared with a notional hydrostatic pressure line, which assumes a groundwater level at the collar of the piezometer and this pressure line increases at 10 kilopascals for every metre in depth. Where the piezometer level is above this line, it indicates artesian conditions and hence an upwards groundwater gradient.

9.4.2. Piezometric Level Below the Mine Floor

The mine floor in the YEF near the NE Batter is at about -40 to -50m RL. Piezometers installed in the interseam clay below the floor, for example 25326, show piezometric pressures at some depth below the mine floor, in excess of 10 to 15m above the mine floor level, Figure 20. Similarly monitoring bores below the mine floor elsewhere in the YEF also shows pressure levels significantly above the mine floor.

The three deep aquifer dewatering bores are located in the south west of the YEF. After the pumps were switched off in 2004 these were allowed to free flow under artesian conditions. The piezometric data for the piezometers below the base of the Yallourn seam, equivalent to the floor of the mine, all indicate the pressure is highest in the northeast at the eastern end of the NE Batter and falls towards the southwest in the direction of the artesian bores.

I consider that high pore pressures in the interseam clays below the mine floor and the NE Batter have contributed to large scale and deep seated long term movement of the NE Batter.

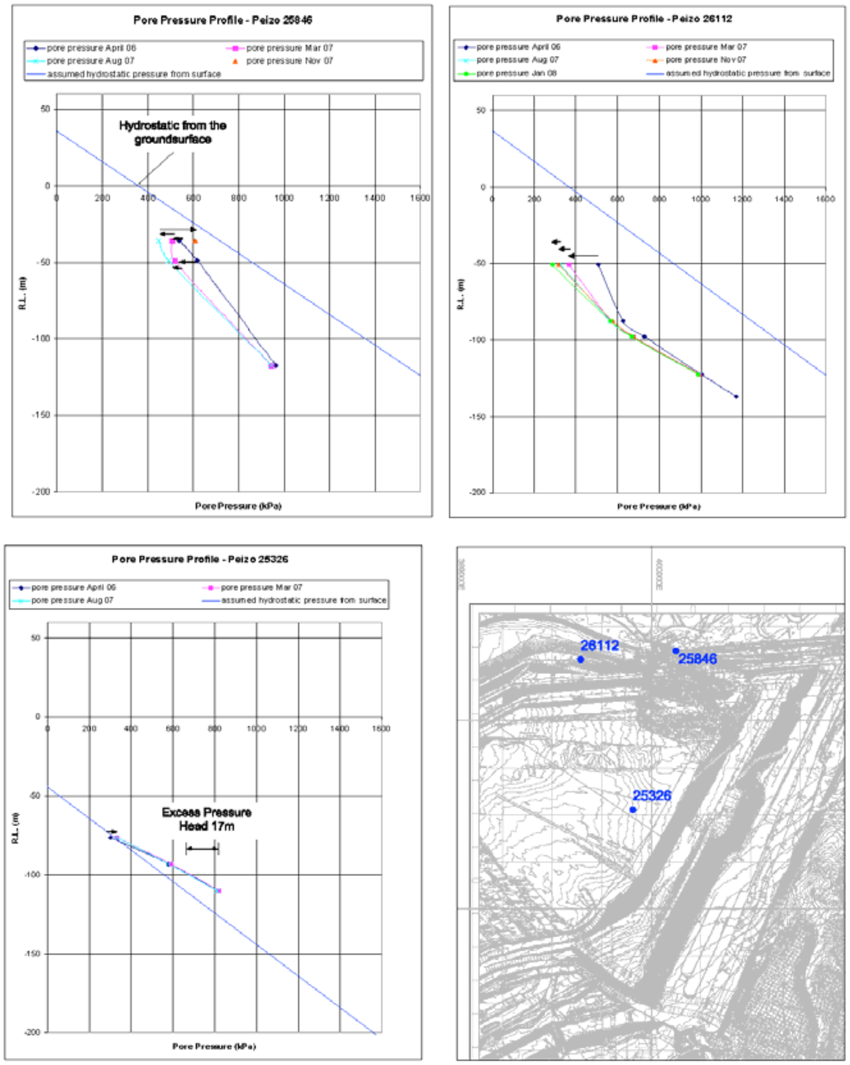


Figure 20: Piezometric pressures with depth showing changes over time

9.5. Shear Strength of the Interseam Clays

The material strengths used in analyses have evolved over time, in general decreasing as the geotechnical model has also evolved. This was in part a result of the large "unexpected movements" of the MRD. In about 2003 during construction of the MRD a very large and unexpected movement of the MRD was identified by survey monitoring (Reference 59). The movement occurred in a clay layer that was 10m below the coal. The clay layer contained horizontal planes that had a shear strength of 16°, which was substantially lower than the design strengths used to that date in YEF.

The material strengths were reviewed in 2004 (Reference 15), and the main conclusion of relevance of the NE batter stability is:

> *"Based on calibration against horizontal movements observed in coal batters due to the Eastfield mining, it was suggested by Golder (2004) that the predicted movements were in reasonable agreement by using low strength values (ie residual strength)."*

The peak angle of friction used for design of the coal interseam clay interface is around 22° and 23°, compared to a residual strength of 16°.

It is noted the NE Batter showed long term accelerating movements despite the fact the piezometric levels were decreasing, Figure 18. This means the movements were increasing at the same time as the destabilising pressures were decreasing. Although it is also recognised that the ongoing coal mining was also reducing the resistance to movement.

However given the scale of movement that had occurred, the strength on the plane below the coal would be reducing from a peak towards a lower residual strength over time.

In this instance good engineering practice would dictate that residual strength parameters would be used to check the NE Batter stability, as noted in Reference 15 above.

I have carried out check analyses of stability of the NE Batter using these peak and residual strengths. The analyses show that for the residual strength the Factor of Safety approaches and falls below 1.0 depending on the groundwater pressures input into the analyses. Hence if large movements occur and the strength approaches residual the NE Batter will become unstable unless the coal seam water levels and interseam clay pore pressures can be lowered.

9.6. <u>Horizontal Bores</u>

9.6.1. 2002 Review

The response of the groundwater level in the coal to mining and horizontal bores was reviewed in 2002 (Reference 39). The objective of the review was:

> *"The objective of this evaluation was to ascertain whether the horizontal bores effectively reduced water levels in the permanent coal batters in the YEF pit."*

Although the review only looked at data for the southern batter the conclusions were assigned to the YEF in general and comprised:

> *"Evaluation of hydrographs ... suggests that the main factor resulting in lowering of the coal water table is deepening of the pit. Excavation of the YEF fourth cut resulted in the most rapid drawdown of the coal water table. Installation of the YEF horizontal bore drains did not lower the coal water table further."*

And:

> *"The analysis of selected YEF bore hydrographs indicates that the YEF batters are draining adequately under the influence of free flow into the YEF pit."*

And:

> *"This indicates that the YEF horizontal bores are not necessary to significantly reduce pore pressures within the coal behind the pit batters."*

The final recommendation was:

> *"Therefore, it is recommended that a sensitivity analysis with regards to coal water levels be conducted using the previously constructed north-south UDEC model. If the results of the modelling indicate that the batters would be stable with coal water levels shown schematically in Figure 11, then additional horizontal bores would probably not be necessary to promote drainage."*

I note Figure 11 in this Reference showed a water table in the coal rising from zero at the toe of the batter at a slope of about 9.5° from the horizontal. I also note the assessment and the recommendation applied to the pre 2002 YEF mine batters.

9.6.2. 2003 Advice

Further advice was given in 2003 (Reference 67):

> *"In 2002, a series of horizontal de-watering bores were drilled into the Southern Batters of Eastfield on a pre-determined pattern, based on the advice of Yallourn Energy's previous technical consultant. Hydrogeology work completed by BFP-URS Joint Venture in late 2002 concluded that there was no technical merit in drilling de-watering bores in Eastfield. It was concluded that the advancing pit void had more effect on the phreatic surface than the horizontal bores."*

I note this recommendation is unqualified and applies to the whole of the YEF.

9.6.3. 2003 Review

A further re-assessment of the horizontal bore strategy for Yallourn Mine was undertaken in 2003 (Reference 18). Based on observations in the mine and discussions with TRUenergy, the following general argument was put forward in regard to the horizontal bore strategy:

> *"The combination of mining (promoting drainage through the vertical lowering and additional coal exposures) and joints favourably aligned to the batters in many instances (providing preferential flow paths for drainage into the mine) has achieved adequate reductions in the unconfined water table levels within the coal batters as expected. If the drainholes have not provided additional benefits in either lowering groundwater levels in general, or aiding rapid drainage needs*

> *associated with the effect of extreme rainfall events on open cracks or structures within the batters, then the value of these in some areas and overall strategy should be reviewed."*

The review focuses mainly on the southern batters and the observations made at that time were:

> *"Based on the available information there appears to be a definite opportunity to modify the program and potentially phase out the drainhole strategy by progressively reducing the amount of drains and completely avoiding them in some areas."*
>
> *"The ability to firstly reduce, and then possibly completely avoid drainholes, particularly for the southern batters …"*

Although this latter recommendation was made in relation to the southern batters, there were also very qualified recommendations in regard to the northern batter:

> *"The northern batters were not inspected in any detail, however a similar rationale could possibly apply to this area as well depending on the circumstances. Given the increased exposure with these batters in terms of conveyor infrastructure and the associated consequences in the event of batter stability issues, a risk based approach may prove beneficial in determining the need for drainholes."*

And:

> *"In addition to this though, the future NE batter adjacent to the Latrobe River is likely to possess significantly different groundwater conditions to those along the current southern and northern batters and will need to be addressed accordingly."*

The decision to stop routine drilling of horizontal bores appears to have been driven at least in part, by a desire to reduce costs and optimise the mining:

> *"There are likely to be cost saving opportunities in modifying the program and becoming selective to the point of avoiding drainholes completely in some areas."*

And:

> *"There is certainly an opportunity to rationalise your drainhole program as outlined and avoid such installations in some areas based on the information provided and conditions observed, and subject to a few additional checks in line with the recommendations provided."*

A six step assessment and study program was recommended in order to provide engineering support to phase out horizontal bores in the southern area. I can find no evidence this program was carried out.

9.6.4. Horizontal Bore Effectiveness and Structure

I have reviewed the base data used for the 2002 review and evaluated the responses in relation to the orientation of the mine batter relative to the structural data on joints. I conclude that in relation to the data and the southern batter at that time:

1. The horizontal bores are showing a response in some areas of the southern batter.
2. The excavation of the mine batter is showing a greater response in some areas.
3. The response due to excavation of the mine face is entirely expected because the joints in the coal are trending west northwest to south southeast (approximately 300° to 120°). The southern batter is trending west southwest to east northeast (240° to 060°). Hence the joints will intersect the batter face (“daylight”) as excavation proceeds.

However I consider this same logic and methodology does not apply to the eastern part of the YEF and the NE Batter in particular because:

1. For the NE Batter the joints form an acute angle with the Batter and do not “daylight” till final excavation of the batter is largely completed, Figure 8.
2. A secondary role the horizontal bores fulfil is allowing the rapid drainage of rainfall runoff. The essential need for this is demonstrated by the cracking on the southern batter and the 200mm jump in movement of the NE Batter, following the rainfall event of 4th November 2007.

9.6.5. Summary

Overall it is difficult to reconcile some of the recommendations above with the previous experience, regarding the essential role that horizontal bores have played in batter stability over many decades.

No horizontal bores were drilled in the NE Batter until after the failure. From the available information it appears routine drilling of horizontal bores was stopped sometime around 2002. Although a small number of short bores were drilled in the upper northern batter in 2005.

I note that approval was given in the 2002 annual geotechnical review to stop drilling horizontal bores (Reference 40). However this was for the southern batters. I can find no other documentation regarding the NE Batter.

I consider a major factor in the failure was the absence of horizontal drains or an alternate groundwater drainage control system in the NE Batter.

9.7. Deep Aquifer Dewatering

9.7.1. Stability Model for Floor Heave

The stability model traditionally used in the Latrobe Valley for assessment of floor heave is a simple "Weight Balance" model; where the weight of the overlying material counteracts the upward groundwater pressure in the aquifers well below the mine floor. This weight balance model is used to determine the maximum allowable groundwater pressure in the aquifers below the mine floor.

9.7.2. Summary of TRUenergy Thinking on Deep Aquifer Dewatering and Stability

In about mid 2001 the Mine Geologist produced a discussion paper on the impact of aquifer pressures in the YEF (Reference 19) and circulated it to three consulting groups for discussion. The discussion paper was apparently prepared because of concern that the "current practices are conservative". In summary TRUenergy planned to:

> *"Following recent analysis, consideration of the various models, and observation of the current conditions in the mine, Yallourn Energy proposed to switch off pump bore N5056 and to measure the precise effects of allowing high aquifer pressure to build up underneath Yallourn East Field.*
>
> *The hypothesis is put forward that high aquifer pressures could cause floor heave and water ingress into the floor of East Field and that if this were allowed to occur it could be manageable. It is further hypothesised that high aquifer pressures, floor heave and water ingress would not cause instability of the permanent batters.*
>
> *If the above hypothesis proves to be correct, changes could be made in the way aquifer pressures are managed in Yallourn East Field and Maryvale, these changes would result in savings to Yallourn Energy resulting from decreased aquifer pumping and less drilling."*

An internal note by the Mine Geologist in April 2002 summarised the thinking on deep aquifer dewatering and stability (Reference 26):

> *"For various reasons it had become apparent that it was appropriate to challenge assumptions and methodologies inherent in the current slope stability and aquifer dewatering strategies."*

And:

> *"The Yallourn geologist wanted to get ideas from various companies across the industry rather than rely on any single company approach to the problem. Consequently a paper containing 3 key questions and a summary of current*

> *understandings and practices and was given to Geo-Eng, Golders and BFP Consultants."*

This situation appears to have arisen, at least in part, from changes in the hydrogeological model in YEF. Rather than thick continuous aquifers below the mine floor, drilling indicated "the aquifer sands are discontinuous". In addition observations in the YEF showed existing aquifer pressures were 10m above the "weight tolerance" that is for the weight balance floor heave stability model and no floor heave was apparently observed (Reference 19).

In the traditional Latrobe Valley stability model it was well recognised that high aquifer pressures may adversely affect the stability of permanent batters. However based on the issues above, TRUenergy questioned the applicability of the traditional stability model (Reference 22):

> *"I believe that the thinking and modelling used in the management of aquifer pressures in the Latrobe Valley to date has proved to be relevant to Loy Yang and Hazelwood but may be less relevant at Yallourn."*

In May 2002 TRUenergy were even more definite in their thinking (Reference 27):

> *"Yallourn's interest in the aquifer pressures is summarised in the following four paragraphs:*
>
> *The recent shutdown test on N5056 and the relatively short shutdown of N4934 shows that the threat to mining operations, floor stability and batter stability from deep aquifer pressures is far less significant than was previously thought. Considerable savings in future drilling costs and pumping costs can be made if we continue with the shutdown test to better assess what levels the aquifers will recover to.*
>
> *The previous drilling and pumping methodologies could impact significantly upon the operation of the proposed new mining method. We are on the verge of proving that there is far less need for pump bores and observation bores. This means that all activities associated with these bores can have far less impact upon the slope mine operation.*
>
> *Modelling done prior to the shutdown, and the results of the shutdown, indicate that interseam pressures will recover relatively slowly and that the recovery can easily be measured. Monitoring programs can easily identify whether or not the interseam pressures are rising significantly and whether or not there is sufficient rise to be a threat to the stability of the permanent batters or the MRD embankment."*

The three questions posed to each consulting group were (Reference 19).

> *"The questions for the reviewer to answer are:*

1. *Given the description of the stratigraphy and aquifer pressures in this paper, are the aquifer pressures a threat to the stability of the permanent batters. If the aquifer pressures are a threat, how are they a threat – what is the mechanism of failure that would operate in order for the aquifer pressures to threaten mine operations or the stability of the permanent batters?*
2. *Assuming aquifer pressures are not a threat to the stability of the permanent batters, then what is threatened? What would be the first sign that aquifer pressures are about to impact upon the safety operation of the mine?*
3. *What is the worst thing that can happen in Yallourn East Field if Yallourn Energy were to switch off pump bore N5056 and allow aquifer pressures to increase?"*

9.7.3. Answers to Questions

9.7.3.1 First Consultant

In reply to the questions posed by Yallourn Energy Pty Ltd the responses from the first consultant were (Reference 23):

> Answer 1:
> *"Yes, we expect a rise in aquifer pressures would affect the groundwater pressure above and below the Yallourn Interseam layer and thereby increase the risk of failure of the southern batter by block sliding. Similar concern would apply to the western batter."*
>
> Answer 2:
> *"Ignoring the threat to permanent batter stability, a significant rise in aquifer pressures could affect stability of the excavation floor. Expected effects, most likely in the deepest part of the pit, would be some uplift, cracking, seepage and softening of clayey materials."*
>
> Answer 3:
> *"Failure of the southern permanent batter could lead to a breach of the current Morwell River Diversion. The western batter and the future River Diversion might also be affected but it is further from N5056."*

The report also noted:

> *"The factor of safety against block sliding is significantly affected by an increase of 20 m in the groundwater head at the Interseam."*

And:

> *"… water pressures behind the batter and above and below the Interseam can be strongly influenced by aquifer pressures."*

And:

> *"Our conclusion from this work is that it may be possible with careful monitoring to justify reducing pumping rates at the existing bores or for future dewatering to introduce pressure relief bores rather than pumping bores but it is not likely that dewatering of the aquifers beneath the pit can be eliminated."*

Following receipt of that advice Yallourn Energy made the following request to the consultant (Reference 24):

> *"Restate the question*
> *Briefly answer the question in a very direct way.*
> *Discuss the issues"*

And:

> *"For example the answer to question 3 may look like this ……………..*
>
> *Original Question: What is the worst thing that can happen in Yallourn East Field if Yallourn Energy were to switch off pump bore N5056 and allow aquifer pressures to increase?*
>
> *Answer: The worst thing that could happen is failure of the permanent batters leading to a breach of the River Diversion on the Southern Batters.*
>
> *Discussion: Following our analysis we have deduced that the interseam pore pressure will rise as the aquifer pressures rise. This will cause massive block sliding which will threaten the stability of the river diversion. However floor heave will probably occur before batter failure and the following symptoms will be seen around the mine as the pore pressures increase ………………… etc"*

In response to a further series of questions from Yallourn Energy the following reply of note was made (Reference 28):

> *"Is it possible to agree to continue with the shutdown test and carefully monitor the interseam pressures and to switch the pumps on if the interseam pressures reach previously defined critical levels?*
>
> *It is possible. However, we recommend a discussion with all parties involved to resolve the issues and responsibilities and we expect the meeting scheduled on 28 May 2002 would take this further."*

Although this recommendation appears to relate mainly to the MRD.

Despite the earlier documents referring to the impacts of interseam pressures on batter stability, it appears that subsequently the issue of ceasing deep aquifer dewatering and the impacts on interseam pore pressures as they may affect batter stability, was considered with the reference to the MRD stability only.

However, a qualification was also provided with reference to applying this philosophy to areas other than the MRD (Reference 29):

> *"In assessing the observed responses, we consider that we do not have a good enough understanding of the detailed hydrogeology of the aquifers and vertical leakage paths to make general predictions about the magnitude and timing of the effects of pumping in one place on water pressures at another place. However, the observations from the shutdown tests show that for the interseam pressures in the western batter area:*
>
> - *Pumping at N4934 appears to be more important than N5056*
> - *The observed responses occurred within a few days rather than weeks of each shutdown"*
>
> *"We consider that we have to take an empirical approach; that is, observe the effects of shutdowns in the areas which are important to slope stability and be prepared to act if necessary."*

And:

> ***"Effectiveness of Pumps***
>
> *The water levels observed in the network of piezometers show that the pumps have lowered the water level in the deep aquifers within the East Field mining. Whether this depressurisation of deep aquifers is necessary for stability of the floor and the coal batters is the question.*
>
> *We understand Yallourn Energy has engaged three different consultants (including us) to address this question. The consultants, however, were asked to assess the stability of the southern and northern batters only, as those were the main batters of concern with regard to the operation of the mine. The response was that the stability of the floor and the batters could be controlled by relief wells in the floor and horizontal drains within the batters."*

I consider in general this reply was focussed on the MRD stability. However, the reply in total was also qualified and there were numerous references to the effects of interseam pore pressures and stability. There were also warnings about applying the concepts and understanding to other areas of YEF.

9.7.3.2 Second Consultant

The reply from the second consultant (Reference 60) was supportive of switching off the pumps:

> ***"Batter Stability***
> *One-dimensional numerical groundwater modelling and subsequent batter stability predictions were carried out for two locations at YEF (N4948 on the northern batters and N5173 on the southern batters) to simulate a shutdown of the deep aquifer pump bore network. The results of the groundwater modelling and stability analyses suggest that:*
>
> - *Yallourn Interseam pressures will increase by approximately 1.0m in the vicinity of bore N4948 (Stability Section N2) after 10 years. It is considered that a 1.0m rise in Yallourn Interseam pressures along Section N2 over 10 years will not have a significant impact on batter stability.*
> - *After year 5, groundwater modelling predicts a 4.5m increase in Yallourn Interseam pressure in the vicinity of bore N5173. Stability analyses indicate that for the modelled combination of residual shear strength, coal water level and interseam pore pressure, the factor of safety against block sliding at this time and location will be greater than the design value of 1.2.*
> - *After approximately 10 years, stability analyses for bore site N5173 suggest that for the modelled combination of residual shear strength, coal water level and interseam pore pressure, the factor of safety against block sliding will be less than the design value of 1.2.*
>
> *If the deep aquifer pumps are shut down, the following controls are recommended to minimise the risk of batter failure:*
>
> - *Increased monitoring of groundwater and movement during the shutdown,*
> - *If Yallourn Interseam pressures recover to levels approaching critical factor of safety values at any point in YEF, the pumps should be immediately restarted,*
> - *Survey pins should be installed at the base of the mine, toe of the batters and on the operating benches,*
> - *Horizontal bores should be drilled, especially close to the batter toes, in order to ensure coal water levels are maintained at an acceptable level,*
> - *Frequent batter inspections should be conducted to provide early indications of batter stability problems and*
> - *Adequate surface drainage and clay capping of exposed benches should be maintained to prevent surface water ingress."*

The modelling predictions showed only small rises (1.0m) in interseam pressures, which would have minimal impact on batter stability. However the recommendations were predicated on a groundwater model that had both coal seam and interseam pressures falling to zero at the toe of the batter, Figure 21. I note there are a number of recommendations and warnings including about interseam pressures and installing horizontal bores.

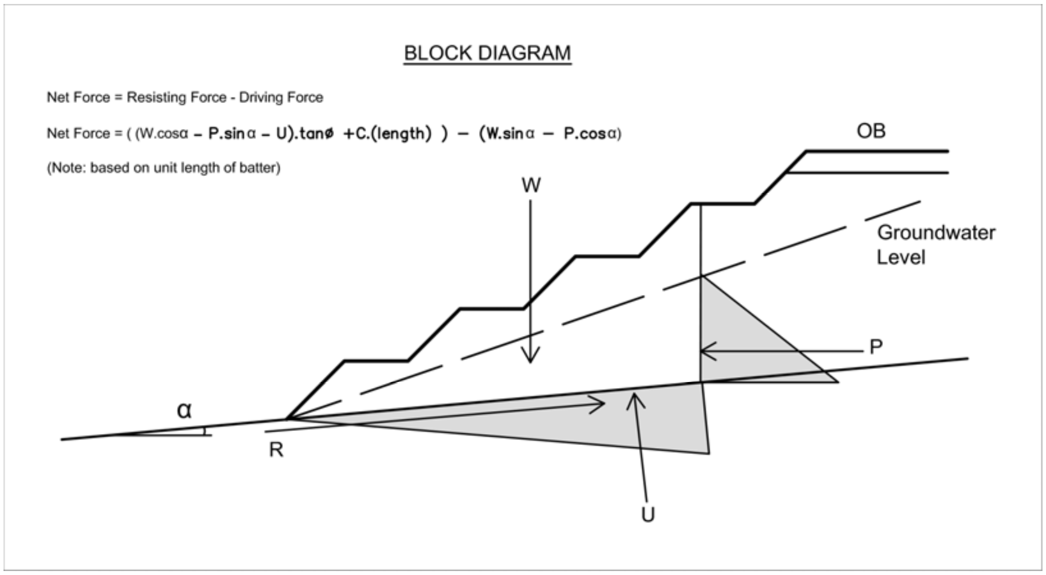


Figure 21: Groundwater model for block sliding Batter stability 2001 (Reference 60)

The deep aquifer shutdown tests were reviewed and modelled in 2004 (Reference 71). The results showed no significant rises in aquifer pore pressures. However there were recommendations for further work, including increased monitoring and:

> *"Further work is recommended using slope stability models to determine whether or not this expected increase in pore pressures threatens the stability of the permanent batters."*

9.7.3.3 Third Consultant

The summary reply to these questions by the third consultant was (Reference 64):

> *"This report answers three questions put to BFP by Yallourn Energy regarding aquifer pressures and slope stability. The questions and answers are in the body of the report.*
>
> *To date all Hydrogeology works and aquifer pressure management in Yallourn East Field has been based upon assumptions and deductions that seem to originate from problems with aquifer pressures encountered in Morwell Mine in the 1960s. A very simple "weight balance" concept has been the basis of these aquifer pressure management strategies. That is the weight of the materials above the aquifers offsets the upward pressure from the aquifers.*

> *Modelling of aquifer geology, groundwater pressures and stability of the Yallourn East Field south and north batters indicates that the situation at Yallourn East Field is different from Morwell Mine in the 1960. The modelling indicates that the current batters would be stable if the aquifer pressures in the vicinity of the pit floor were to be allowed to increase by up to 40m, from the current levels at RL -20m to RL +20m.*
>
> *These results indicate that it is possible to allow aquifer water pressures to increase from their current levels without threatening the stability of the batters.*
>
> *The first effect of high aquifer pressures upon the mine operation is expected to be seen in the base of the mine and is expected to be floor heave. Careful monitoring of floor and batter movements as aquifer pressures are allowed to increase will provide valuable data for future aquifer pressure and risk management strategies."*

I note this modelling showed that large scale deep seated movement could occur in some batters as the groundwater pressure is increased. This movement is akin to that which occurred on the whole NE Batter prior to the failure.

Although I note these analyses included the coal seam groundwater table as a triangular distribution rising from zero at the toe of the batter. In addition and importantly, there was no pressure in the interseam clay, but a positive aquifer pressure was applied at a depth of 25m below the mine floor. Hence above the aquifer and below the coal there was no pore pressure. I consider that if interseam pore pressures had been included, the modelling results would have been different.

9.7.4. Summary

The Mine Geologist summarised the responses as (Reference 26):

> *"All companies agreed that the worst thing that would happen would be catastrophic failure of the southern batters.*
>
> *However, it was clear from the reports that it would be possible to switch off pump bore N5056 and monitor various parameters around the mine and get sufficient warning of any batter or floor movements well before any significant movements threatened any infrastructure or personnel.*
>
> *All companies agree that after switching the pump off the aquifer pressures would rise and the first sign of instability would be seen as floor heave. It is a relatively simple matter to install survey pins to monitor floor heave and therefore have early warning that aquifer pressures are affecting the stability of the mine.*
>
> *Although all companies agreed on the above points there were significant differences in various other details of the responses. The three companies ran different types of models."*

Based on a review following a test shutdown of deep aquifer Bore N5056 the Mine Geologist concluded (Reference 25):

> *"Monitoring of a series of Pins located across the YEF pit floor and the north and south batters have indicated negligible movement."*

And:

> *"In conclusion, the monitoring of the piezometric levels in the "aquifer zone" and the interseams show varying recoveries to levels no greater than -10mRL, which is 30m below where modelling indicated the start of visible responses at the surface, ie heave."*

However as noted above, some of the modelling did not include interseam pore pressures and hence the critical groundwater pressure level would have been over-estimated.

In summary the main points arising from this are:

1. TRUenergy rightly questioned the traditional deep aquifer dewatering model on the basis of evidence that showed thick continuous aquifers were not present at shallow depths below the YEF floor.
2. Three different consulting groups were approached for their advice.
3. The models used by each group were different and focussed in part on a traditional weight balance model of floor heave.
4. All groups agreed about the general outcomes relative to this simple model.
5. One group ran models that were deficient because they did not include pore pressures in the interseam clay layer under the coal.
6. One group answered the questions mainly in the context of the MRD stability, which was their project at Yallourn, but also included a number of warnings regarding pore pressures in interseam clays and the problems with extrapolating their advice to elsewhere in YEF.
7. Some groups appeared to assume that horizontal bores would be installed.
8. TRUenergy appears to have combined the responses, interpreted the results in terms of the weight balance model alone, but failed to appreciate the current and future significance of the assumptions about horizontal bores installed together with the warnings about interseam pore pressures and batter stability.

The critical flaw in the TRUenergy thinking was a belief that problems with pressure below the mine floor would always manifest themselves by measurable signs of floor heave. However unless there is significant deformation you can't "see" pressure. Hence high pore water pressures can remain in the interseam clays, but not manifest themselves as visible signs in the mine floor.

The model used for assessing the impacts of cessation of deep aquifer dewatering was a simple weight balance model. The analyses centred around this model were focussed on rises in interseam pore pressures associated with rises in aquifer groundwater pressures. When significant rises did not occur the conclusion was there is no problem. However the impact of high, relative to the mine floor, and unchanging interseam pore pressures does not appear to have been appreciated.

The critical role of interseam clay pore pressures in batter stability was not fully appreciated. The impact of high interseam pore pressures on large scale and deep seated batter movements and stability were important factors in the movements and the failure.

9.8. Reviews of Stability Northern and NE Batters

9.8.1. Introduction

As noted above in Section 8.7.2.3 a preliminary design for the NE Batter was carried out in 2001. Over the period from 2001 to 2006 a number of other studies were undertaken assessing the stability of the northern and NE Batters. The main design reports appear to be:

2002	Analyses and Reviews of Slope Stability Models 2002 (Reference 66),
2003	Yallourn Phreatic Surface Feasibility Analysis North-South UDEC Model (Reference 67),
2003	Geotechnical Stability Analyses and Factor of Safety Summary (Reference 69),
2004	Design of the North Batters at Yallourn East Field (Reference 56),
2004	E110-E210 Stability (Reference 17),
2005	E110-E210 Stability Review – Sensitivity to Groundwater – Northern Batters (Reference 16) and
2006	Report for East Field Region Aquifer Pressure and Stability Review (Reference 62).

9.8.2. Study Results

In 2002 additional stability modelling for the northern and southern batters was carried out (Reference 66). This was a refinement of the model used to assess the impacts of switching off the deep aquifer pumps (Reference 63). This modelling showed the northern batter was stable but the southern batter showed:

> *"… strain softening of the interseam floor, heave and toe movement could occur when the aquifer pressures recover to RL -15."*

It is noted this modelling did not include any interseam pore pressures.

The sensitivity of the southern batters to different groundwater conditions was then examined (Reference 67).

Around this time a study on the NE Batter stability was undertaken by a student at RMIT (Reference 56). This study was supervised by BFP Consultant Pty Ltd. The study explored a new potential batter failure mechanism, not block sliding:

> *"The idea of a tension crack developing has been discussed with the supervisors of this project and it was revealed that there has never been any evidence of tension cracks leading to large-scale batter failure within Eastfield."*

And:

> *"For this reason a tension crack has not been included in the model for this design project."*

Although it is not clear why this conclusion could be drawn, because later in the thesis it is noted:

> *"Within coal in the Latrobe Valley jointing is well developed and consists of smooth, near vertical fractures, many of which can be traced through the entire seam."*

And:

> *"The February 2000 Report included a structural review of the five main geological structures within the coal and indicated that continuous sub-vertical structures play an important part in failure initiation."*

In stability modelling a tension crack would normally be introduced if the geotechnical model showed it was possible to have continuous sub-vertical joints in the coal seam. By not introducing a tension crack this analysis effectively precluded the dominant batter failure mechanism, block sliding, that had occurred for decades in the Latrobe Valley.

The analysis focussed on a different failure mechanism, Figure 22, compared to the traditional block sliding model in Figure 21. This mechanism is closer to a circular failure. The analyses also assumed the coal groundwater level and the interseam clay pore pressure distributions were zero at the toe of the batter.

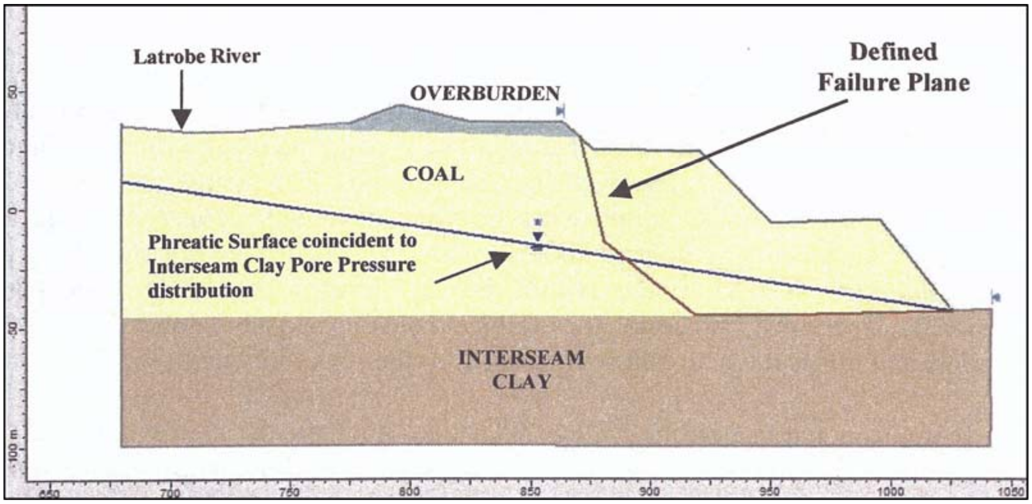


Figure 22: Failure mechanism for NE Batter
(After Reference 56)

The origins of this mechanism were:

> *"In this current study the failure mechanism used in the Slide model was determined by previous UDEC modelling."*

However this UDEC modelling did not include interseam pore pressures.

Overall the report concluded:

> *"The Slide analysis reveals that the proposed design for the North Batters has a satisfactory factor of safety."*

And:

> *"This design has a factor of safety in excess of 3.0, indicating a safe slope."*

The stability of the northern batter was reassessed in 2004, Reference 17:

> *"GHD conducted analysis for both block sliding and coal-mass failure mechanisms at several scales for one section through the northern batters."*
>
> *"Several scale failures were analysed including:*
>
> - *Overall failure – from behind crest to toe (both coal mass and block sliding),*
> - *Multi-batter – incorporating several batters (coal mass) and*
> - *Batter scale (coal mass).*

The section is located in the western half of the YEF, that is, it is not the NE Batter area.

Based on the modelling analysis results and ignoring historic experience in the Latrobe Valley, a different potential failure mechanism was identified:

> *"The results considered most appropriate however, include stability at a single to double bench scale for a coal-mass style of failure (pseudo-circular), taking into consideration the existing tension cracks and observed seepage from high in the batters. This results in a FoS of approximately 1.6 using historically adopted coal-mass strength parameters."*

The section was analysed again in 2005 (Reference 16). This analysis was requested by TRUenergy in order to assess the sensitivity of the Factor of Safety (FOS) to various groundwater conditions:

> *"However results indicated that for block sliding, with a phreatic surface gradient of 9° or greater the FoS falls below acceptable levels."*

And:

> *"… the sensitivity of the (FoS) to groundwater levels on this section. It was requested to analyse increasing phreatic surface level slope (or gradient) from the toe of the batter and graphically represent the results."*

The gradient of 9° applies to a water table rising up from the toe of the batter (Figure 21). It should be noted that the overall batter slopes are around 17° to 23° so a 9° groundwater table slope is very flat and indicates a low groundwater level.

The important conclusions from these analyses are that the stability "falls below acceptable levels" which means the FOS falls below 1.0, using residual strengths when the groundwater table gradient increases above about 10°. The stability is extremely sensitive to groundwater levels, with falls in FOS of about 0.125 for every 1° rise in groundwater levels above the 9° "design" line. The report concludes with:

> *"The importance of understanding groundwater regime is highlighted in the above analysis given the variation in FoS and demonstrated sensitivity."*

In 2006 TRUenergy sought further reassurance regarding aquifer pressures and stability (Reference 62):

> *"TRUenergy requested GHD to review the significance of aquifer pressures at Yallourn by considering the following two questions:*
>
> *1. Given the current data in the "Yallourn Hydrogeology Database" that defines the aquifer levels at Yallourn Mine, do you consider the aquifer levels to be a threat to the stability of the mine?"*

The summary response in answer was:

> *"1. It is considered unlikely that aquifer pressures will impact the stability of the current mine floor and batters. Consequently, aquifer depressurisation within the current Eastfield is not required."*

Although it is apparent this report was focussed on floor heave potential and the weight balance model, it is noted the report also deals with interseam clay pore pressures and makes observations and statements about general stability:

> *"3.1 General and Stability Performance*
>
> *The geotechnical issues under consideration principally include floor and batter stability in the context of an altered pumping strategy, combined with the various responses and trends detailed throughout Section 2 of this report. To our knowledge geotechnical performance with respect to floor and batter stability over the last five years has been acceptable, with no known or reported events of significance, and no ground movement concerns based on monitoring and inspection processes completed."*
>
> And:
>
> *"3.3 Batter Stability*
>
> *Detailed modelling of batter stability has not been undertaken as part of this exercise, as it is considered to be outside the scope of the brief. A variety of previous rigorous assessments have been undertaken previously, confirming the adequacy of the batter system. Gaps remain at this stage in constructing detailed models, and due to the fact that the current conditions (absolute aquifer pressures, groundwater conditions and the associated trends) to GHD's knowledge are not at odds with the fundamental conditions assumed/modelled for previous analyses, conducting such work is likely to yield little value if any at this stage.*
>
> *Unconfined water levels and the pore pressures in the interseam remain the critical parameters affecting the stability of the batters. In the overall scheme of the dataset reviewed, coal water levels and interseam pore pressures remain steady or continue to fall slightly. Therefore, the factor of safety against block sliding is similar and the probability of failure is therefore equivalent to or less than previously assessed."*

9.8.3. Summary

From the work undertaken in the period from 2001 till early 2004 it would appear that the following occurred:

1. Stability modelling using a new analytical tool (UDEC), but with a limited groundwater model, because no interseam pore pressures were included, provided the following:

    (a) Identification of a different failure mechanism to that historically experienced in the Latrobe Valley with more circular failure path, Figure 22 rather than block sliding, Figure 21.

    (b) Analyses for this new failure path showed the NE Batter was stable.

    (c) The modelling indicated the main stability issue was the southern batter not the northern.

    (d) The modelling predicted large scale deep seated movements could occur once groundwater pressures recovered to critical levels. Similar movements would also occur if high unrelieved pore pressures were maintained in the interseam clays.

2. This new failure mechanism, was supported by a subsequent study at RMIT that also focussed on a “circular” failure path model and showed high Factors of Safety for the NE Batter.
3. The stability models continued to use groundwater levels in the coal that fell to zero at the toe of the batter. This was despite the fact it was known that horizontal bores were not installed. It appears this assumption was carried forward from the review of horizontal bores, which concluded natural drainage was occurring due to mining.

From 2004 till 2006 some more limited studies of the northern batter were undertaken.

The excavation to form the complete final NE Batters in coal only commenced in early 2007. Hence installation of horizontal bores would have been difficult and not optimal, prior to that time.

There was not a clear geotechnical and stability model for the NE Batter. Hence it appears from the documentation that there were significant differences in interpretation between TRUenergy and some consultants. From the reading of the documents there also appears to be some fundamental gaps between TRUenergy and some consultants.

9.9. <u>Role of Geotechnical Review</u>

9.9.1. Introduction

The Annual Geotechnical Review formed part of the 2002 Work Plan. It is understood this requirement was included at that time in order for DPI to be comfortable that the geotechnical risks in the mine were properly addressed.

It was noted the reviews were somewhat limited in that time onsite was short, of the order of one to two days, and the reviews followed a question and answer format.

9.9.2. 2002 Review

In 2002, for the first annual review, TRUenergy posed the following question (Reference 40):

> *"3.0 YALLOURN EAST FIELD*
>
> *3.1 ISSUES TO BE ADDRESSED*
>
> *Is it safe to stop drilling horizontal bores in the southern batters?"*

And specifically in the Appendix to Reference 40:

> *"6. The URS letter regarding the drainage of the southern batters indicates that there seems to be no need to install horizontal bores in YEF southern batters.*
>
> *Bearing in mind the following:*
>
> - *YTF northern batters have never had any stability problems and have never had any horizontal bores installed.*
> - *YTF northern batters are almost parallel to YEF southern batters (see aerial photo).*
> - *It seems reasonable to believe that drains are not necessary for stability of the batters. As the dominant jointset is almost at 90 degrees to the southern batters it seems reasonable to assume that the batters could easily be self-draining.*
>
> *Are there any flaws in this logic? Is it safe to stop drilling horizontal bores in the southern batters? If I did cease the horizontal bores I would of course monitor the coal water levels very closely to check the hypothesis that the batters are self draining."*

The answer included some detail but in summary the response was unqualified and concluded:

> *"3.2 YEF Southern and Northern Batters"*
>
> *"Based on these observations and the work of URS noted above, the reviewer concurs with the view that, on a cost-benefit basis, horizontal bores are unlikely to significantly augment wall stability."*

This approval appears to refer to the situation with the mine in 2002 and to the old northern and southern batters at that time.

A question was also asked about deep aquifer dewatering:

> *"What sort of aquifer pressures should the pit floor able to withstand with a reasonable factor of safety?"*

The question and the answer were focussed only on the model of floor heave due to aquifer groundwater pressures and while the answer is detailed, it concludes with a strong recommendation for study:

> *"However, the reviewer suggests that a very detailed understanding of the nature of these aquifers is needed before this assumption is permitted to influence decision-making."*

9.9.3. 2003 Review

In the second review, 2003, TRUenergy posed the following question (Reference 41):

> *"Given the various BFP reports regarding the effect of the deep aquifer pressures upon mine stability, the results of the two shutdown tests, and on site discussions and data inspected regarding aquifer recoveries, is it likely that shutting off both pumps at the same time will cause any instability in the Mine?"*

The question could be read in two ways; either purely in terms of floor heave according to the weight balance model or as an all encompassing question about any affects on mine stability. However, given the reference to the BFP reports, which model both floor heave and batter stability, the question more probably refers to global stability. However it appears the answer refers more to the floor heave model:

> *"Consequently, provided aquifer pressures and excavation contours were appropriately monitored, the writer would not consider the simultaneous shutting down of both pumps to be a stability risk to the mine."*

Monitoring and rates of movement were addressed in a number of questions in relation to the western batters of Yallourn Township Field (YTF):

> Question:
> *"BFP Consultants have indicated that movements of up to 10mm per day could be tolerated in slopes like the western batters without undue concern. Given your own experience in slope stability and the stick slip model that we have discussed what "triggered levels" would you use as an acceptable/non acceptable threshold for daily movements?"*
>
> Answer:
> *"If movements in excess of 4mm per day were sustained for more than three or four months at a time this would suggest to the writer that progressive behavior may have started. That is, movement rates would have to increase by a factor of 10 before one would be concerned."*

> Question:
> *"Are there other indicators that we should be using that are better and more reliable than a daily movement rate?*
>
> Answer:
> *Monitoring the rate of change of displacement (velocity) is a valuable tool. If acceleration is sustained (that is, if velocity begins to increase over time) then this normally indicates that progressive behavior has commenced."*

Although these questions and answers are included under a YTF heading, the latter questions and answers could be read more generally. The significance of these questions and answers is that it appears these guidelines have been used generally by the Mine Geologist when assessing the monitoring data.

In general I consider these rates are too high. They may be appropriate in some instances, but not in the situation with the NE Batter and the Latrobe River.

9.9.4. 2004 Review

In the third review, 2004, TRUenergy became aware of the shortcomings in some of the previous stability modelling and approached the reviewer for a further opinion (Reference 42). The complete questions and answers are:

> Question:
> *"PORE PRESSURES IN UDEC MODELS*
> *BFP have provided a letter that states that the interseam pore pressures were not included in the UDEC models used to assess the FOS on the permanent batters. The letter is attached in zip file called UDEC models. My initial question was: "Which data from which bores was used to define the phreatic and piezometric surfaces in the UDEC models? I would like to compare current data with the data used in the models to see what has changed." BFP then gave me a simple conceptual model that represents in schematic form what data was input to the UDEC models. Following agreement upon the conceptual model that was used BFP then gave me the attached letter as an answer to the question above. I am concerned that the piezometric surface (from piezometers in the interseam) was never input to the models. These models have been used to give me current factors of safety for the permanent batters. BFP now state that they don't know what the effect of the interseam pressures would be upon the models. I have some concerns about this and would value your answer to the following questions. Given the BFP letter and conceptual model, is the omission of the piezometric surface (interseam pore pressures) from the UDEC models a serious issue? All slope stability modeling done at Yallourn in the past used the interseam pressures as input to the models."*
>
> Answer:
> *Elevated pore pressures within foundation materials have a significant effect on the shear strength of those materials and hence their ability to bear load. By not modeling these pressures, the modeler runs the risk of underestimating the stability of any engineering structures formed in or on such materials."*

> Question:
> *"Should the interseam pore pressures be included in slope stability models as a matter of routine?*
>
> Answer:
> *Yes. If pore pressure cannot be explicitly modeled in a software package then, at the very least, the effective stress conditions associated with the layer or block should be estimated and modeled."*
>
> Question:
> *"Could it be argued that having the phreatic surface acting upon the base of the coal and pushing upwards is the equivalent of the interseam pore pressures as the pore pressures are in equilibrium with the interseam pressures? Given that this is how the UDEC model is set up do we even need to include the interseam pressures?*
>
> Answer:
> *The phreatic surface would have the effect of creating an uplift pressure on the base of the coal where it meets the (relatively impermeable) clay zone, so this is perfectly valid. In fact, this is the classic rock mechanics approach. However, because the foundation material (the clay) is a soil (not a strong, impermeable rock) and because the pore pressures will have a significant effect on the strength of the clay, a different effect is created when the pore pressures in the foundation are included. It may, in fact, be easier for a (rotational) failure surface to form through the foundation when compared with the block translational sliding mechanism along the contact. If the pore pressures are not included, this other potential (and perhaps more likely) failure mechanism may end up being ignored."*
>
> Question:
> *"I have some concerns about the format of the answer, and the admission that BFP don't know what the effect of adding interseam pressures to the model would be. At the moment I cannot determine whether or not it is my own lack of understanding of the UDEC modeling system or other things that are frustrating me, my intuition is that there could be a problem here but I am not 100% sure. Peter, are you able to comment?*
>
> Answer:
> *As noted above, by adding the pore pressure into the calculations, a different failure mechanism from the one being modeled may result (both in theory and in practice). The writer's understanding is that UDEC (designed to model sliding or toppling blocks primarily in rock mechanics applications) does not consider pore pressures in the materials between the planar structures that form the block boundaries. However, it should be possible to input the effective shear strength parameters for these blocks during modelling, which has the same or similar effect."*

The stability of the NE Batter was also addressed in two questions:

> Question:
> *"PROXIMITY TO LATROBE RIVER*
> *An RMIT Engineering Geology student has done a final year design project on the permanent northern batters beside the Latrobe River. The report indicates that the final batters are stable with a FOS greater than 1.5 for worst possible scenario of highest water levels and lowest strengths. Do you agree with the conclusions of the assessment?"*
>
> Answer:
> "*The writer concurs with the conclusions of the report to the extent that the particular failure mechanism modelled (block sliding on the coal-clay contact) could occur."*
>
> Question:
> *"Have you any comments on the way the modeling was done?"*
>
> Answer:
> "*A check calculation for rotational failure (rather than block translation) using the same parameters used in the RMIT report yields a base case factor of safety of 2.1 (see Figure 1) that is significantly less than the value of 3.4 obtained in the RMIT study. The lower bound factor of safety for the mechanism shown in Figure 1 is likely to be no more than 1.2. On the face of it, therefore, the rotation failure mechanism is more likely than the block-sliding mechanism modeled in the RMIT report. However, the conclusions remain broadly the same."*

In regards to the trials of switching off the deep aquifer dewatering the question and answer were:

> Question:
> *"DEEP AQUIFERS*
>
> *Pump bore N4934 was switched off approximately 18 Months ago on 31 March 2003. Pump Bore N5056 was switched off approximately 6 weeks ago on 3 September 2004. To date we have seen no obvious effects or impacts upon the mine floor or permanent batters. Some of the piezometers have shown that the aquifer pressures have risen by up to 25 metres, other piezometers show little or no rise in aquifer pressures. The data gathered during the shutdowns will be presented and discussed during the site visit. Question 9.1. In your opinion when do we finally and definitively conclude that the aquifer pressures have no effect upon the mine?*
>
> Answer:
> *The writer noted in his 2003 visit report that "provided aquifer pressures and excavation contours were appropriately monitored, the writer would not consider the simultaneous shutting down of both pumps to be a stability risk to the mine." The writer still holds this opinion."*

9.9.5. 2005 Review

In 2005 the question on deep aquifer dewatering was once again posed (Reference 43). The question and reply was:

> Question:
> *"Question 3: Given that both of the deep aquifer pumps have been switched off or over 12 months now and that aquifer levels have stabilized do you consider the aquifer pressures to be a threat to the mine or the MRD?"*
>
> Answer:
> *"Figure 3 shows an example of how aquifer levels have changed with time. On two occasions between April 2001 and January 2004 the pumps were turned off. It can be seen from the RL profiles that, whilst aquifer pressures increase quite rapidly after each shutdown, they do not recover to the levels that existed before. The achieved levels tend to plateau well below their original positions. As noted in prior reports, the writer does not believe that aquifer pressures are a threat to either the mine or the MRD. However, on going monitoring would be prudent."*

There was also a further question concerning movement of the floor of the mine: The question and reply was:

> Question:
> *"Question 4: Some movement in the base of the mine has been interpreted by the mine geologist as stress relief rather than floor heave caused by aquifer pressures - what is your opinion? Are these movements anything to be concerned about?"*
>
> Answer:
> *"When coal is removed over a large area, the following phenomena are known to occur (Mr. Bill Wood, personal communication):*
>
> *The exposed floor rises 400 to 500mm.*
> *The pit walls in coal move inward by up to 1000mm.*
>
> *The former can be explained in terms of the underlying rock mass response to the removal of the vertical load and the latter in terms of a response to the removal of the lateral confinement.*
>
> *A combination of these two phenomena, coupled with creep behaviour along bedding in a down-dip direction, would give rise to buckling in surface laminations as seen in the pit floor. The orientation of the buckling-induced cracks (shown in yellow in Figure 4) can be explained in terms of the structure contours (shown in red in Figure 4). The contours suggest that a structural basin exists in the vicinity of the two blue markers in the figure. To the north-west of this basin, a synform plunges broadly (at up to 4°) to the south-east. To the south-east of this basin, the stratigraphy dips at an even flatter angle, broadly towards the west-north-west. Creep and/or other movement swill most likely take place broadly along maximum dip vectors, creating cracking in the orientations*

> *shown at inflection points. In the writer's opinion, these cracks have nothing to do with aquifer pressures."*

9.9.6. Summary

I can find no evidence that any of the technical issues or concerns raised in response to the questions set out above were resolved. There did not appear to be a procedure operating, whereby outstanding issues or concerns were checked or re-addressed in the following annual reviews, other than that the same or similar questions were sometimes asked.

The problems with the UDEC modelling not including pore pressures in the inter seam clays were identified and questions regarding the implications of this brought to the attention of the reviewer. However despite this, subsequent analysis of the NE Batter stability by RMIT, which was based on a different failure model and one that arose from the UDEC modelling, was supported. The stability of the NE Batter was also analysed and high Factors of Safety were obtained.

Overall the replies to some questions give the message that the NE Batter is stable and there are no potential problems with switching off the deep aquifer bores.

The support for shutting off the deep aquifer dewatering was highly qualified in the earlier reviews. Subsequent reviews were less qualified but did include recommendations for appropriate monitoring.

It appears that the potential problems with high unchanged pore pressures in the interseam clays were not recognised.

It is noted that the 2002, 2003 and 2004 annual reviews included an all encompassing concluding question to the reviewer enquiring as to whether there was any other aspect the Mine Geologist needed to be aware of. In all cases the reply was positive and no elements were raised. The 2002 and 2003 reviews also went further and commented about the highly professional approach that was being taken onsite.

I understand on reading these reviews how mine management would take comfort that the geotechnical issues were being properly addressed and there were no major technical issues.

9.10. Advice on Cracking and Movements of NE Batters

9.10.1. Initial Advice

From early 2006 it appears that TRUenergy were gaining some advice on the cracking and movements on the NE Batter (Reference 31):

> *"Recently we have excavated a lot of coal in a relatively short period of time from our northern batters – cracking has occurred on various levels of the mine – I would value your opinion as to the cause and significance of the cracking."*

I can find no evidence of any response to this issue.

Further advice was sought in July 2007 (Reference 32):

> *"Short note on letterhead giving your interpretation of the cracking we observed on the Latrobe River Levee embankment – the attached JPEG shows vectors of survey pin movements as the mine has advanced into this area. In the JPEG the cracks show up as purple spots on the levee crests."*

The reply to this was (Reference 33):

> ***"Latrobe River Levee Banks***
> *TRUenergy has also asked Golder Associates to provide comment on cracks that were observed in the Latrobe River levee bank. Cracks were observed in two locations along the levee bank, with both being approximately parallel to the open pit face. These cracks extended diagonally across the width of the levee bank at the locations observed.*
>
> *We understand that further survey monitoring of the cracks is proposed and we will provide comment on the cracks following our review of the data."*

On 12th October 2007 further advice was sought (Reference 34):

> *"3. Do you agree with my interpretation of the cracks in the levee crest – ie caused by differential movements induced by proximity to the mining void?"*
>
> *"4. The small graben at the base of the levee appears to be an extension of the easternmost levee cracks – I am concerned that I don't understand why the graben has formed in the in situ material. Have you any suggestions or thoughts on how this graben was formed? – Is it simply due to differential movement similar to the suggested model for the cracks in the levee?"*

On both occasions a relatively junior professional was visiting the mine for another matter and the advice sought was incidental to the main purpose of the visit. I consider this advice was sought from a person without the requisite background and experience to make the appropriate assessment of the impact of either the monitoring or the deformations observed on the NE Batter.

The formal response following the October inspection, dated 19th October, was (Reference 35):

> *"Latrobe River Levee Banks TRU Energy has also asked Golder Associates to provide comment on cracks by TRU Energy, the northern pit wall is approximately 90 m in height and survey monitoring data indicates that it has moved by up to 3m laterally towards the open pit. This has been attributed to stress relief by TRU Energy, and you advise the movements are generally*

> *consistent with those observed on the other pit walls. During the site visit, a number of cracks were observed behind the northern coal batter face and Latrobe River levee bank. All of these cracks were approximately parallel to the open pit face.*
>
> *Notwithstanding the history of large lateral movements, attributed to stress relief, given the proximity to the Latrobe river, it is considered that possible global stability issues associated with the cracking and the northern pit wall movements should be further investigated. We suggest it is important to try to better understand, the nature of the movements, the significance of the cracking and the stability / risk to the northern pit wall. We would be pleased to assist in such studies if required."*

9.10.2. Geotechnical Review on 7th and 8th November 2007

Following the letter recommending a detailed study of the NE Batter, TRUenergy decided not to undertake this work and commissioned a further review from the company that undertook the first three Annual Geotechnical Reviews. It appears the further review was commissioned sometime on or before the 18th October (References 59 and 73) but did not take place for three weeks, which is surprising given the potential seriousness of the issues.

The onsite review was carried out on 7th and 8th November and a draft report, dated 9th November, was provided on 12th November to TRUenergy (Reference 81). The accompanying email noted the draft report was for comment by TRUenergy and was also being peer-reviewed internally within the company's Perth office.

The Mine Geologist posed a series of questions to the reviewer. Some of the key questions together with answers, either in whole or in part, are set out below (Reference 45):

> Question:
> *"1. Stability of Overall Batters*
>
> *Given your perusal of the data, inspections of the batters, discussions with the mine geologist and modeling done on site what is your opinion of the overall stability of the Latrobe River Coal Batters?*
>
> Answer:
> *A detailed inspection of the pit wall adjacent to the Latrobe River was undertaken, including all berms and batter faces, the levee and the flood plain between the levee and the river. A number of tension cracks were observed adjacent to the pit crest, on the levee and in the river flood plain that appeared recent in origin, with clear evidence of recent, substantial water inflows. Most of these cracks are aligned parallel to the pit wall indicating movement normal to the pit wall, although some cracks in the north-east corner of the pit ahead of the active mining face are aligned obliquely on a NW-SE trend, indicating movement is also occurring towards the advancing mining front.*

> *Large movements of survey points located on pit wall crests and within the pits have been recorded through-out the Yallourn operations as mining has progressed. The magnitudes of these movements are in line with predictions from numerical modelling studies, and are considered unexceptional for the operation. Movements of the wall in the vicinity of the current mining operations have not exceeded typical maximum movements recorded for other, similar sections of the pit wall where mining has been completed. In these areas the rates of movement have reduced to very low levels once mining has been completed.*
>
> *Although tension cracks are occurring on the berms, close observations of the conditions of the batter have not provided any evidence of bulging of faces or heaving occurring at the slope toes, either of which would indicate a degree of distress in the slope, possibly incipient slope failure.*
>
> *The slope stability analyses undertaken to date have generally applied conservative strength parameters. The parameters have been developed from a number of standard test programmes undertaken over many years, and are in general agreement with parameters for other operations mining the Latrobe Valley brown coal deposits. The results suggest the current slope design has a high factor of safety for all normal conditions."*

The subsequent failure of the NE Batter itself establishes this assessment was incorrect. I consider the site exposures, monitoring data and analyses shows the stability of the NE Batter was marginal and it was on the brink of failure.

The second question and the answer was:

> *"2. Mining the lower slope*
>
> *Do you consider it safe to continue mining the lower slope?*
>
> *Snowden believes that mining of the lower batter can continue safety."*

At the time, the coal mining was occurring at the eastern end of the lowest bench of the NE Batter. Given the failure which eventually occurred, Section 9.2, this block of coal was acting in part like a key block helping to stabilise the eastern side of the eventual failure. Any mining in this location could only make the situation worse. l consider this recommendation to continue mining this slope to be a serious error of judgement.

The interpretation of the possible causes of the cracking is one key element and is fundamental to an understanding of the present and future stability of the NE Batter. The alternate interpretations are, firstly the cracks are the result of the normal ground strains that occur around the mine due to excavation, or secondly they are the result of the onset of slope failure.

In regard to the cracking in general on the NE Batter and on the mid seam coal bench, the questions were:

> Question:
> *"3. Cracks around levee*
>
> *The mine geologist has interpreted various cracks around the Latrobe River Levee as being due to "relaxation" of the ground around the pit void rather than signs of a massive slope failure.*
>
> *Can you comment upon this interpretation?"*
>
> Answer:
> *"The tension cracks are considered a normal response to high tensile strains generated by reduction in lateral stress resulting from the removal of the coal in the pit. The tensile strains are being developed at the surface of the coal seam due to its low-modulus, ductile nature. Similar cracks have occurred elsewhere in the mine without a major slope failure developing."*
>
> Question:
> *"4. Cracking in Mid Seam Bench*
>
> *The mine geologist has interpreted cracking on the mid seam bench as being due to relaxation of the coal bench into the pit void with the cracks occurring where the batters are constrained by the southern batters.*
>
> *Can you comment upon this interpretation?"*
>
> Answer:
> *"The tension cracks occurring on the mid-seam bench reflect the sense of ground strain towards the mined section of the pit. In the north-east corner of the pit this direction is oblique to the orientation of both the north and east pit walls."*

The answer to both questions was that the cracking was related to the usual ground strains due to mining and not the onset of slope failure. I consider this interpretation was incorrect.

In regards to the sources of water issuing from the face the Mine Geologist held the following view:

> *"5. Water in mid seam Bench*
>
> *The mine geologist has interpreted water flowing from cracks in the mid seam bench to be associated with water flowing into cracks in the drain in the bench above. The water is finding its way out through bedding planes and pre existing tension cracks discussed in 4 above.*

> *Can you comment upon this interpretation?*

The response agreed with the interpretation of the Mine Geologist, with a small addition:

> *"Snowden has concluded that the water flows occurring on the mid seam bench are caused by surface run-off water draining into tension cracks on the bench above, and percolating along higher permeability layers of coal or joints within the coal."*
>
> *"Information received subsequent to the mine visit regarding continuation of the out-flow suggests that water may be draining from the overburden materials into the cracks in the top of the coal, then percolating into the pit through higher permeability layers within the seam.*

I have viewed photographs of the water flows. Figure 11 shows the extent of the flows on the 13th November. I have also viewed other photographs of the flows from earlier in November. I consider these flows to be major by any measure. I find it difficult to see how the main source of the water could be attributed to any source other than the Latrobe River. The cracks observed on the 13th November together with the whirlpool in the Latrobe River confirms this.

I note the report in answer to a further question makes recommendations for some additional monitoring and remedial measures. I also note there is no urgency or timing attached to these recommendations, as would be the case if they were associated with an impending slope failure. Given the timeframe required to implement most of these measures, I have not considered them further.

In regards to the potential failure mechanism the question and answer were:

> Question:
> *"7. Failure Mechanisms*
>
> *Following the inspection of the excavated faces, perusal of various reports and data, and discussions with the mine geologist, what do you consider to be the most relevant failure mechanism for these batters?"*
>
> Answer:
> *"Snowden believes that the most likely failure mechanism is rotational shear along a compound, curved path through the coal and along the inter-seam clay."*

This response is in agreement with the RMIT thesis (Reference 56) and the 2004 annual geotechnical review, Section 9.9.4. However, this answer is at odds with decades of experience in the Latrobe Valley and is not correct. The failure itself confirmed this.

I consider this geotechnical review, which in regard to the stability of the NE Batter was positive and interpreted by the mine as such (Reference 80), gave a completely false impression of the real stability situation for the NE Batter.

9.10.3. Geotechnical Review on 13th November 2007

Two geotechnical consultants were called to the site on 13th November 2007 to reassess the situation. The first consultant arrived in the morning of 13th, then left site after a couple of hours and a summary letter was written in the afternoon setting out the recommendations (Reference 74). The letter includes a large list of recommendations and these are considered to be appropriate with two exceptions. The first exception is the assessment of likelihood of failure, risk and safety hazards:

> *"Given the available information and observations made today, GHD believe that this is a major stability risk but that it is unlikely that a catastrophic failure will occur, resulting in an immediate safety hazard, provided remediation is undertaken. Access is therefore considered permissible along the levee bank, overburden and L308 levels."*

Given that catastrophic failure did occur that night, it is considered this assessment was a misinterpretation of the stability situation at that time.

The second exception arises from the misinterpretation of the stability situation. This entailed a recommendation to place a horizontal drilling rig onto the NE Batter. Although drains were clearly required urgently this is also considered to be an error of judgement given the overall setting at that time.

The geotechnical consultant who undertook the review on the 7th and 8th November also returned to site on the afternoon of 13th. The first consultant also returned to site in the late afternoon with the letter (Reference 74). It is understood that a further site inspection and meeting took place between TRUenergy and the two consultants late on 13th November.

I have been advised that by this time one of the cracks which had shown a vertical displacement in the morning of about 0.15m was then showing about 0.5m of vertical displacement. The water flows had also increased to about 500 litres per second.

No minutes or written record of this meeting are available and I have been given conflicting advice about the exact final recommendations, which I am not able to resolve.

Given the increased movements, 0.35m in half a day, and the very large increase in water flow, I consider the appropriate advice at that time would be that failure was imminent and could occur at any time. I would also have expected this advice should have been accompanied by a recommendation that no one should enter the area overnight. The arrangement would then be to review the situation again at first light on 14th November 2007.

10. OPERATIONAL MANAGEMENT OF GEOTECHNICAL SYSTEM

There are a number of aspects of the operation of the geotechnical management system at Yallourn Mine, which need to be discussed including:

1. Role of the Mine Geologist.
2. The mode in which external geotechnical advisers were used.
3. The manner in which annual reviewers were managed.
4. Delays and apparent lack of urgency.
5. Experience and expertise of the Mine Geologist.

External geotechnical advice and guidance at Yallourn Mine was formalised prior to 2003 and operated under contract in the period from 2001 to 2003. Thereafter the Mine Geologist undertook an increasing role in the basic geotechnical work for the mine. In the period after 2003/2004, any particular geotechnical studies were undertaken as directed by the Mine Geologist with a number of different groups and different individuals within consulting groups apparently as he saw fit.

In addition in the period prior to 2003, advice in the form of the similar or identical questions on two key elements; deep aquifer dewatering and horizontal bores was sought from a number of different consulting groups. The issue with this approach is that while there was some commonality of opinion between many of the various elements of advice, for example approval to cease deep aquifer dewatering, there were important differences in the qualifiers and the recommendations for further assessment. The support for a particular course of action then appeared to be presented to senior management of TRUenergy as support for a positive course of action. However it does not appear from the available evidence that a similar approach was adopted for some important qualifiers and recommendations for further study. The implicit understanding in this approach is that by seeking a number of opinions the Mine Geologist and TRUenergy assumes responsibility for ensuring that any differences, discrepancies or recommendations are followed through.

However this situation becomes complicated by the annual geotechnical reviews which appeared to give or could be interpreted as giving approval to a number of the key issues. The geotechnical reviews were generally positive and the early reviews were very complimentary about the highly professional approach that was being taken to geotechnical issues. On reading the reviews, I understand that mine management would be comfortable that issues were being adequately addressed.

In the later years and closer to the failure itself there are also some instances where external advice was sought on important elements from individuals who probably did not have the expertise and experience to properly assess the situation (References 31 to 35). If there are uncertainties or even small concerns about stability issues, particularly given the location, with important natural and mine infrastructure nearby, then it would be expected that the most experienced advice available would normally be sought. Further, in October 2007 when it seemed that serious stability issues could be developing, TRUenergy did not undertake a recommendation to evaluate the NE Batter stability in more detail (Reference 35), instead TRUenergy opted to approach another consultant to undertake a review.

In regards to the annual geotechnical reviews the limitations to the available time on site and the question and answer format are probably issues. The decision on 1st October 2007 to delay the 2007 annual geotechnical review, although it is understood this decision was taken because of family illness, is also somewhat inexplicable given the issues that had occurred on the NE Batter up to that time.

A number of other significant delays occurred that in hindsight are difficult to understand including:

- The three week delay between commissioning the second opinion on 18th October and the site review on 7th and 8th November.
- The delay in organising the horizontal bore drilling rig before the failure.
- The fact the TRUenergy Mining Manager, although aware of the problem, did not appear to become deeply involved with this issue until almost the last minute, 13th November 2007.
- The failure to increase the type and frequency of monitoring; including visual inspections, inclinometers, pin data and groundwater, in the months, weeks and days preceding the failure. At the very least, following the events around the rainfall on the 4th November, the pin monitoring frequency should have been increased to daily.

Overall the documents indicate a general lack of urgency which can only have come about from a misinterpretation of the real situation (References 76 and 77) and the fact that advice had been given that the NE Batter had a high Factor of Safety and was stable.

This leads onto the experience and expertise of the Mine Geologist. In that regard it is considered surprising that the open cracks on the Latrobe River floodplain, intersecting with the Latrobe River itself, were only discovered by the Manager Mining himself on the 13th November 2007.

The Mine Geologist appears to have either misinterpreted or generally adopted a more positive interpretation for every sign or event leading up to the failure, as set out in the following points:

1. The floor pins were surveyed in 2004 after the pumps were switched off (Reference 75) October 2004. The conclusions drawn were:

   "The survey pins were picked up again recently. Some of the pins are showing a steady upward trend, which is probably due to relaxation and stress relief. None of the pins are showing signs of movement that can be correlated with the pumps being switched off.

Pin YE4/9 shows relatively large movements compared to the adjacent pins, which show approximately half of YE4/9 movements. This pin is thought to have been affected by the adjacent dam and new pins will be placed nearby to further check the accuracy of YE4/9."

And in December 2004:

"It can be seen from Figure 5 5 2 2 that the floor pins are not responding to the pump bores – there is no floor heave occurring as a result of the pumps being switched off."

Figure 23 shows the floor movement data and illustrates a number of pins, which are the pins located towards the northeast in the YEF, show a long term upward trend, creep. Although the explanation by the Mine Geologist could be correct it could also be the result of an alternative effect, that is excess pore pressures in the interseam clays.

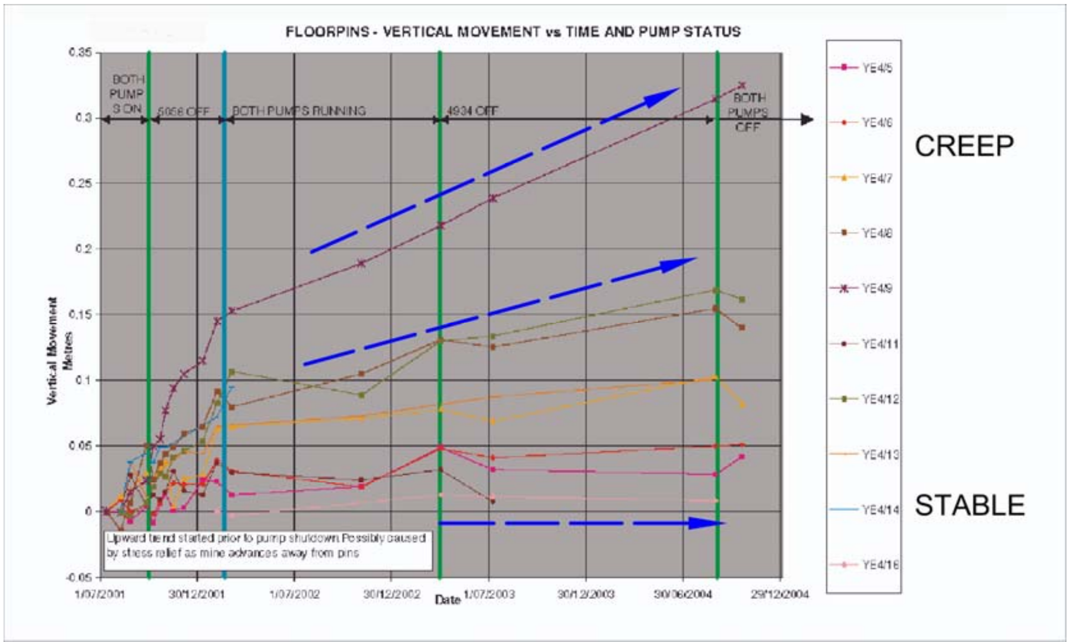


Figure 23: Floor pin movement data, October 2004
(Reference 75)

At the same time as this was taking place the Mine Geologist was receiving advice in regards to the MRD stability that concluded (Reference 75) January 2005:

> *"The critical pore pressures are these in the interseam layers."*

2. Throughout this period the mine floor was routinely inspected for signs of floor heave. However because (Reference 75 January 2004):

> *“Aquifer levels measured in observation bores are currently well below the critical levels identified by slope stability modelling.”*

There were no thoughts of other stability issues.

3. In January 2006 the routine monitoring showed (Reference 75):

“Batter above FB1, YEF north batters	*Cracking observed after coal toe removed from slope by dozer mining – natural relaxation of slope after removal of toe.*
Northern batters in general	*Minor cracking observed in perimeter road – probably due to water ingress into cracks in E110 toe drain and overall relaxation of slope due to removal of bottom coal by slope mining operations.”*

4. In July 2007 (Reference 75):

> *“Cracking has been observed in the Latrobe River Levee.*
>
> *This is a natural response due to the movement of the ground surrounding the mine void.*
>
> *The coal is under stress in the ground and has been squeezed and compressed both vertically and horizontally.*
>
> *As the mine excavation progresses, the ground beside the permanent batters decompresses and as it decompresses the surrounding ground moves into the pit void.”*

Figure 24 shows these cracks. In open pit mine batter stability, vertical displacement on a crack such as shown in Figure 24 is usually associated with early signs of an impending failure, not stress relief, which is usually manifested as a horizontal separation.

5. In September 2007 the NE Batter monitoring was reviewed (Reference 75 September 2007) and the conclusion was:

“YEF North Batters Pins	*Analysis of August pin data – Total movements of up to 1.8m associated with excavation of final northern batters – movements greater than expected. Future movements will be closely monitored.”*

Actual Ground Movements and Cracking Latrobe River Levee

See Fig. 7 below for cracking at base of levee

Figure 7 Cracking at base of levee Latrobe River Flood Plain

Mobile Phone & Pencil for Scale

Figure 24: Cracking and subsidence on NE Batter in July 2007

Figure 25 shows the movement data that was assessed at that time and this data shows:

1. The whole of the NE and part of the Northern Batter was moving.
2. In the six months of 2007 the movements were up to 0.7m. This is a movement rate of 3 to 4mm per day. This is a very high rate of movement and in my experience I would normally assume that this rate indicates a high likelihood of failure.
3. The pins immediately adjacent to the Latrobe River shows substantial movement, about 0.3 to 0.7m.
4. The conclusion is the whole slope is moving including the Latrobe River, the movements are very large and the movement rates are very high.

6. In regards to the very large volumes of water issuing from the slope after the rainfall event of 4th November the conclusion was (Reference 78):

> *"Over the last few days an enormous amount of water has been pouring into cracks in the drains on the frontside of E108.*
>
> *That water is not finding its way out of the bedding planes, joints and cracks in the coal above FB3.*
>
> *Over the next few days we need to keep a very close watch on any water or cracks appearing in the northern batters.*
>
> *It took a few days for the water to get in and it will take a few days for the water to come out.*
>
> *As a priority we need to seal up the cracks where they cross the drains on the frontside and backside of E108.*
>
> *After sealing we need to be vigilant about monitoring the drains to ensure that the seals are effective.*
>
> *I have a geotechnical engineer coming on Thursday who can give us some further advice on the cracking on E305 level."*

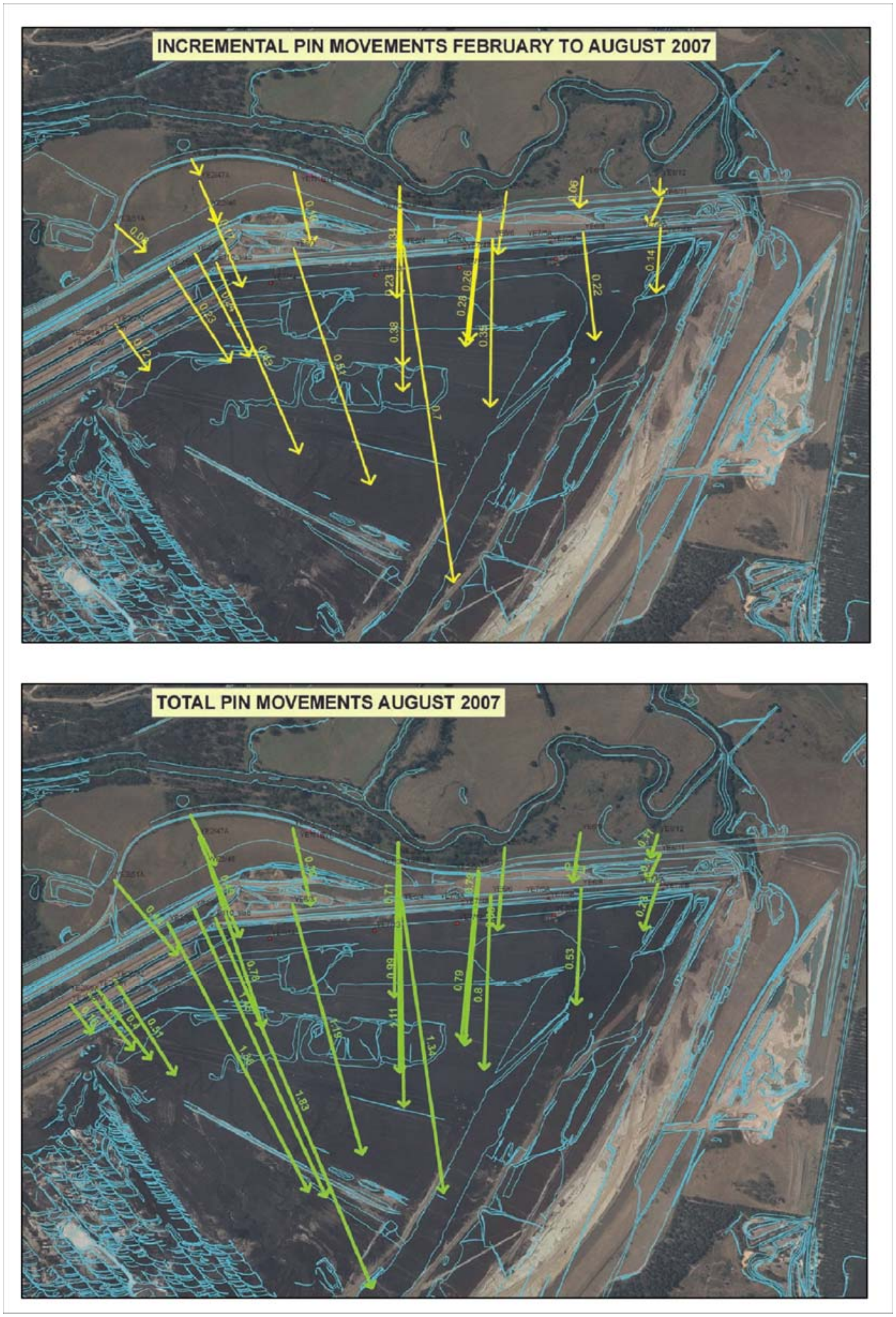


Figure 25: Vectors of movement for NE Batter in August 2007

7. Just prior to the 11th November 2007 a very large movement (0.2m) was noted in the pin data, which appeared to be caused by the rainfall event on 4th November. The interpretation was (Reference 79):

> *"On Tuesday 5 November, dayshift reported high water flows at feeder breaker 3.*
>
> *The mine geologist inspected the area and found water flowing up through cracks in the mid seam bench. The mine manager also inspected the area. The total flow from the bench and coal slope was estimated at 200-300 litre per second and has since reduced to approx 70 to 100 litres per second.*
>
> *Inspection of E108 bench proved that water had been flowing into cracks in the drains and that the high rainfall event had probably injected a large amount of water into the batter. It is not known how many other rainfall events may have poured into the cracks and how much water may be stored in the coal cracks under the drain.*
>
> *It is thought that the large inflow of water on Sunday 3 November caused the sharp movement seen in the survey pins.*
>
> *More frequent monitoring of the pins will be required over the next few weeks in order to determine whether or not there has been any significant changes to the trends in the ground movements."*

A sudden movement of this magnitude caused by what is a relatively small rainfall event means the whole NE Batter was just on the edge of stability. It is acknowledged that some water was probably entering cracks higher on the slope, but to get this volume of water appearing on a mine slope from any source other than the Latrobe River would be very unusual.

Overall in summary I consider the technical issues were not adequately assessed or managed in the years and months leading up to the failure and YMA contributed to this.

11. CONCLUSIONS

Collation of the historic understanding and geotechnical knowledge has demonstrated that at the start of the YEF, the key factors for control and maintenance of stable mine batters and a stable mine floor were very well understood and documented.

The failure on the 14th November was a typical Latrobe Valley batter failure, it occurred by a well known mechanism, block sliding along the base of the coal seam, and was caused by the two well known destabilising stresses; namely the groundwater in the coal and the pore pressure in the interseam clays under the coal. The rear scarp of the failure was formed along a joint or joint set, whose characteristics were mapped and documented a decade earlier. These joints opened sufficiently, as a result of long term creep of the whole NE slope, to allow a direct hydraulic connection between the Latrobe River and the mine. This potential mechanism was understood and documented a decade before the failure. A fundamental question for the Inquiry given this situation is:

> How then given this level of understanding could the failure have occurred?

Somehow the historic understanding and knowledge became lost or was no longer properly appreciated in the years prior to the failure.

The geotechnical management system at Yallourn was comprehensive and on the face of it should have been sufficient to prevent the collapse. However there was a failure of the geotechnical management system at all levels and the future significance of many important signs was not recognised either internally or externally by some of TRUenergy's technical advisers and reviewers. These signs manifested themselves to various extents in the years, months, weeks and days prior to the collapse.

The failure had a very long gestation period and commenced with the new mining method and mine layout for the YEF, approved in 2002. This change had important ramifications in two key areas; monitoring and groundwater control. The new technical challenges appeared to be recognised, in part at the time, however any concerns appeared to have been superseded over time by other technical matters or issues.

Commencing around 2002, the documents indicate there was an effort to try and improve the overall efficiency of the mine, with questions raised over:

1. The need for routine horizontal bores in the final batters to control groundwater pressures.
2. The requirement for continued deep aquifer dewatering below the floor of the mine.
3. Whether the monitoring equipment layout, equipment type, number and frequency of monitoring could be reduced.
4. Whether the previously high levels of external engineering support could be reduced.

Over time studies and modelling were carried out and some trials undertaken to assess these questions.

In about 2004 external approval was given, albeit to various extents by different parties, to switch off the deep aquifer dewatering. This decision was also reviewed externally.

In about 2002 or 2003 a decision, supported by external advice, was taken to stop routine drilling of horizontal bores. This decision was also reviewed externally. However while the approval was specifically for a different part of the mine, it somehow became applied to the NE Batter.

The decision to switch off the deep aquifer dewatering was based on a valid engineering model for one type of mine instability, mine floor heave. Investigation and study showed that Yallourn was different to other Latrobe Valley Mines and thick sand aquifers, at shallow depth below the mine floor, were not present. Without thick sand aquifers, mine floor heave would not occur. Hence the engineering studies showed that aquifer pressures below the mine floor could be allowed to either recover or to remain at significant levels well above the mine floor, without major deformation of the mine floor occurring. This engineering model governed the thinking leading up to the failure and all the mine inspections and interpretation of monitoring data were undertaken within this paradigm. However the interseam clays below the mine floor and below the NE Batter still had significant groundwater pressures. These pressures were sufficient to facilitate long term movement of the whole NE coal batter as it was excavated. These movements were not only widespread, but deep seated and extended 10's of metres below the base of the coal seam.

The new hydrogeological model for YEF had important geotechnical ramifications that were not fully appreciated and this was in part because these groundwater pressures were not included in some of the computer modelling undertaken to assess stability. This was a significant contributor to the failure.

The decision to not undertake routine drilling of horizontal bores may have had some validity for the mine slopes being excavated at the time, in 2002 and 2003. However there was no valid technical reason why horizontal bores were not essential for the NE Batter. This was a major contributor to the failure.

External advice and review was that the NE Batter had a high Factor of Safety and was stable. Hence many important signs were wrongly interpreted by TRUenergy within this context. Additional external advice, in the days immediately prior to the failure also concluded the NE Batter was stable.

The monitoring data and the many important signs evident prior to the collapse all showed that failure as imminent. However these signs were not interpreted correctly and on the day prior to the collapse external advice was given that catastrophic failure was unlikely.

The NE Batter failed suddenly and the failed mass travelled a large distance (250m) across the mine floor.

12. <u>SAFETY</u>

The Work Instruction – Operational Slope Stability (Reference 38) has the following scope and role in maintaining the safe stable conditions in the mine:

> *"This document outlines procedures that are to be followed to ensure that the permanent batters and operating faces of the mine are stable and do not present a threat to the personnel and plant working in the mine."*

This Work Plan also sets out background movement levels for monitoring:

> *"The following movements are known to occur in the mine and are well understood and are not considered to be a problem.*
>
> - *As the YEF pit void advances the Southern and Northern Batters move in toward the pit void a distance of approx 300mm in the first year.*
> - *Long term creep on the YTF Western Batters averages up to 0.5mm per day with brief episodes of accelerated movement of up to 1.5mm per day."*
>
> *"In the Western Batters movements of up to 4mm a day are acceptable without undue concern for slope failure."*

Based on field inspections a string of "Formal Inspections Trigger Events" are set out:

> *"There are two levels of trigger events:*
>
> - *Alert level – A significant change in a water level or ground movement has occurred and the cause needs to be identified and something is done to understand the reasons and reverse the change; and*
> - *Critical Level – A significant change in a water level or ground movement has occurred and there is an immediate threat to batter stability. People and plant could be at risk and access to the particular area should be limited immediately. After access has been controlled the cause needs to be identified and something is done to understand the reasons and reverse the change"*

And:

> *"Mine operations, excavations and slope design are managed in a way to ensure that all instruments should be below alert levels at all times."*

The Work Plan determines that:

> *"Significant increases in the groundwater levels, pore pressures or batter movements measured by the bores will also trigger formal inspections and investigations."*

The trigger alert levels are set out in Table 12.1:

TABLE 12.1
TRIGGER LEVELS
(From TRUenergy Reference 38 Appendix B)

PARAMETER	ALERT LEVEL	CRITICAL LEVEL	COMMENTS
Interseam pore pressure in permanent YEF Batters	12° or 5m rise between readings or constant steady increase in level	13.5°	
Coal water tables in permanent YEF Batters	12°	13.5°	From study of sensitivity to phreatic surface
YEF survey pins	4mm/day	10mm/day	Annual survey expect initial 300mm movement when mine advances past pin

Once a crack or hazard has been assessed the Work Plan identifies the following:

> *"Actions that may be implemented to minimise risk due to cracking are:*
>
> - *Seal the crack with clay to prevent water ingress*
> - *After an appropriate risk assessment deliberately excavate the cracked area by truck and shovel or bulldozer prior to a slope failure occurring*
> - *Install more horizontal bores in areas of known high water levels or areas of continual cracking*
> - *Move operations away form the cracked area to minimise exposure and leave the coal behind*
> - *Other actions may be deemed appropriate for a specific situation and would be implemented as necessary."*

If there is uncertainty the fallback position is:

> *"If the Mine Geologist or the General Superintendent or the Shift Manager or Supervisor deem that there is a risk that may affect the safety of personnel or plant then specialist geotechnical assistance is available immediately by contacting the Mine's Geotechnical Contractor who will then conduct a Geotechnical Inspection of the site in question and submit a formal report to the Mine Geologist."*

Based on the actions that occurred and the discussion around each event as set out in the monthly reports, I conclude that up to early November 2007 TRUenergy generally followed the Work Instruction on Operational Slope Stability.

One of the complicating factors is the alerts and triggers refer to what happens in final batters but it was not until after September 2007 that any substantive length of complete final batter was formed in the NE. By this time other events were occurring and external advice was being sought.

Overall I consider the safety aspects around the NE Batter were well managed.

However in the final days prior to the collapse there were two significant errors of judgement that had potential safety implications:

1. The review on the 7th and 8th November and subsequent documentation, which advised the NE Batter had a high Factor of Safety, hence it was stable, and that it was safe to continue mining coal on the NE Batter.

2. The advice on the 13th November that:

   > *"it is unlikely that a catastrophic failure will occur, resulting in an immediate safety hazard".*

   Although there is conflicting advice over whether this was withdrawn later on the 13th November. In any event a recommendation was made to place a horizontal drain hole drilling rig on the NE Batter, and this action would probably not have been taken if it was considered that a catastrophic failure could occur.

Both of these errors of judgement appear to have arisen from a misinterpretation of the geotechnical conditions and situation at the time.

13. RECOMMENDATIONS

13.1. Risk and Planning Issues

13.1.1. Setting

In order to understand the implications of the Yallourn Mine Batter Failure for the future it is firstly necessary to understand those aspects peculiar to the Latrobe Valley in regards to:

1. Security of Coal Supply and Power Generation,
2. The coal mining and coal delivery systems,
3. The engineering character of the materials in the Latrobe Valley coal mines and
4. The regional setting.

13.1.2. Coal Supply and Power Generation

The character of the Latrobe Valley coal is such that it is difficult to stockpile and store coal. Coal is delivered to coal bunkers at the power station and these bunkers themselves are limited in size because of the coal material handling characteristics. The bunker storage is only approximately one day's supply. Hence the mine operates on a "just in time" coal supply basis.

In order to manage the risks attached to such tight supply and scheduling constraints the upstream end of the coal supply chain becomes critical. In a normal mining operation this would entail trying to ensure flexibility in coal delivery system by either:

- Using multiple coal supply sources and/or
- Ensuring a high reliability in the mine design elements.

13.1.3. Coal Mining and Delivery Systems

The Yallourn mining systems are comparatively inflexible with dozers pushing to Feeder-Breakers at semi-fixed positions. The Feeder-Breakers deliver coal to the conveyors. This requires long term planning, for example the NE Batter failure occurred on a batter that was designed in 2001, for a mine plan formulated in 2002.

The coal delivery systems themselves are located on the final batters and hence these need to be stable and not subject to large scale ongoing movements.

The Yallourn Mine operates four Feeder Breakers in different locations which added some flexibility. However overall it is assessed that in comparison to most other open cut mines the Latrobe Valley Mines have a low flexibility. In normal engineering practice this situation should demand a high reliability in the engineering models and high design factors of safety.

13.1.4. Character of Latrobe Valley Mines

The open cut mines in the Latrobe Valley are very large excavations. The mines are not rigid structures, they are highly deformable and the deformations spread a long way outside the mine perimeters. This means opening of natural joints and formation of cracks is to be expected.

The coal seams are also very thick and of very low density. The low density means the stability of the final batters in coal are very susceptible to water pressures, either from groundwater or rainfall runoff. The thickness of the coal seams means the coal seams move as a unit, hence the deformations tend to spread through the seam and this increases the scale of any movement or instability.

These factors are important both during mining and also for the rehabilitation of slopes after mining is complete.

13.1.5. Regional Setting

The Latrobe Valley coal mines are developed in a semi-rural to semi-urban environment. They are in part surrounded by natural and man-made infrastructure. This infrastructure is often quite rigid or inflexible. In an engineering sense deformable structures next to inflexible infrastructure can result in some incompatibility, which in a wider context means risk.

In addition to this because of the engineering characteristics of the coal and overburden, which are close to soil in properties; the scale of the mines, the scale of the dewatering required for stability; subsidence and ground movements are occurring over very large areas. The mines are interacting with each other and their environment and this is also occurring over a very large area.

There are also other regional effects in the Latrobe such as the Sale groundwater supply and the offshore oil and gas development.

Hence is it considered that as well as local infrastructure issues around each mine there are also more widespread risk and infrastructure questions.

13.2. Other Technical Issues

It is relevant to the TOR for the Inquiry to ascertain whether this failure was an isolated issue or a manifestation of something wider. During the course of the Inquiry I became aware of three other issues and while these are not relevant themselves to the Yallourn Mine Batter Failure, I have included them briefly here because they are relevant to the TOR.

The Morwell River Diversion lies along the south-western side of the YEF. During construction in 2003 a very large movement of the MRD went unnoticed until the annual monitoring survey was carried out. The movement occurred along what appears to be a horizontal fault 10m below the base of the coal seam. This fault was located in a clay layer and had much lower strength than the surrounding materials. This unexpected movement resulted in a 2 million cubic metre buttress being added to the design for stability reasons.

The movement also highlighted other issues including:

1. The geotechnical model was incorrect as it did not include this fault.
2. It is unusual in construction of such an important piece of infrastructure to have such a large gap in monitoring.

I can also find no evidence that this new component of the geotechnical model, a horizontal fault of lower strength, in one part of the YEF lead to an investigation of the other areas of the YEF as a check on batter stability and design.

In 2004 cracks were observed in a TRUenergy dam. The dam is located above a state highway, which bisects the area between the mine and the dam, Figure 26. The dam was checked by consultants. However the Latrobe Valley mines are "deformable structures" and movements occur a long way outside the mine boundaries. It is somewhat incompatible to have fixed pieces of infrastructure such as dams and highways near other deformable structures (mines) and where movements could continue for a considerable time. The juxtaposition of these three structures also has potential safety implications. Appropriate engineering studies and evaluations of the dam may have been carried out. However the experience with the NE Batter highlights the need for careful consideration and overall planning of these issues.

The third example is the southern batter of the YEF. A 600m long crack developed along this batter after the rainfall event of 4th November. This indicates that at least for some period there was potential for failure of this batter as well. It is assumed that based on the information provided in discussion and contained in this report that TRUenergy and their advisers have now addressed this issue.

It is expected that issues that potentially extend beyond the strict limits of the mine and potentially affecting other infrastructure would be the subject of early notification to DPI.

Figure 26: Witts Gulley Dam

13.3. Licensing and Approval

The YEF was approved initially in 1996, Mining Licence 5003. The Licence conditions at that time were based on the traditional engineering understanding as developed by

State Electricity Commission of Victoria. Those conditions were appropriate for the mine.

There was a major variation to the Mining License in 2002. The new conditions included elements such as provision for an annual peer geotechnical review and this review was to report to the Environmental Review Committee (ERC). It is considered the ERC does not have the requisite expertise to either fully understand or question a peer geotechnical review report. Similarly any dewatering and groundwater monitoring were also to report to the ERC. It is noted that the ERC included representatives from Southern Rural Water. However given the discussions elsewhere in this report about the geotechnical and hydrogeological models and the implications for batter stability it is also questionable whether the ERC has the requisite expertise to effectively deal with the geotechnical and groundwater issues in regards to the Yallourn Mine stability.

The ERC performs a very necessary and valuable role at Yallourn. However this is not the forum to allow the DPI to effectively understand and or manage the risks in the geotechnical area and groundwater areas.

The scale and complexity of the Latrobe Valley Mines are changing. The DPI itself has also undergone significant changes over recent years. Community expectations are also changing in regards to aspects such as the environment and safety

It is questionable whether the DPI has the requisite skills or can acquire and maintain a high enough level of skill in this booming mining environment to adequately manage and review complex technical areas, given the failure of the system that has occurred in relation to the NE Batter.

The question then is how can the government effectively manage these issues?

13.4. Recommendations

Because of the factors described above, the Latrobe Valley is unlike any other major mining region in Australia, it is quite unique and requires a holistic approach to all planning and not just the mining approvals.

Based on the factors set out above there are a number of aspects of risk. The mines themselves carry a financial and a safety risk as illustrated by the Yallourn Failure. However there are also wider risk issues around elements of the mining, environment and society. Ultimately this risk lies further downstream probably at the government level.

The overall recommendations are:

1. **Ground and Surface Water**

   Groundwater control is essential for all the coal mines. However this also has large scale widespread ramifications. There is a need for a more all encompassing approach to all aspects of ground and surface water in the Latrobe Valley.

2. **Planning**

There also needs to be a more all encompassing approach to planning for all future developments in the Latrobe Valley that recognises the somewhat competing demands of all the various elements.

3. **Management and Control of Mining Risk**

Given the complexity and scale of the technical issues, effective regulation of the current and future mining is difficult. It is recommended that the Government instigates the establishment of a technical review board that undertakes annual or bi-annual reviews of all the mining operations and their potential impacts.

It is further recommended that DPI review the Mining Licence notification conditions.

4. **Technical**

The issues exposed by the NE Batter failure highlights the need for the mine and their advisers to:

(a) Continue to develop their hydrogeological models,

(b) Continue to develop their geotechnical models,

(c) Ensure the disciplines of geology, hydrogeology and soil mechanics are fully integrated into a comprehensive geotechnical models of stability,

(d) Ensure that any new or significant changes to mine plans, mine layouts or mining systems are thoroughly evaluated from a geotechnical and hydrogeological perspective before they are adopted and

(e) The last recommendation is perhaps more nebulous but is probably the most important. It is critical for maintenance of future stability in mining that the historic experience and understanding is not lost but effectively captured in the new and evolving models of understanding.

TIM SULLIVAN
MINING WARDEN

GLOSSARY

Acute angle	A sharp angle less than 90°.
Aquifer	A layer of relatively porous rock or soil that contains and transmits groundwater, usually the aquifers at Yallourn consist of sand beds.
Artesian aquifer	A confined aquifer containing groundwater that will flow upwards out of a well without the need for pumping.
Batter	General reference to the open cut mine wall, including individual benches.
Bench	One of the smaller steps in the overall batter face, inclined at a steeper angle than the overall batter and separated by berms.
Berm	The flat section of the open cut mine wall between benches.
Block sliding	The sliding of a mass of soil or rock by essentially horizontal translation along a weak zone or defect.
Coal mass failure	A failure wherein the failure surface breaks through intact coal material, rather than travels along a pre-existing joint or crack and is mainly in a circular form.
Crack	A separation in the coal caused by excavation, ground movement or water presence.
Crack Pins	A pair of pins located one either side of a crack. The distance between the pins is measured on a regular basis to determine the relative movement across the crack.
Creep movements	Ongoing time dependent movements of either the batter or the mine floor that occur as a result of excess stress and/or marginal stability.
Deformation Modulus	Also know as Youngs Modulus, it is the measure of the stiffness of the soil/rock.
Dewatering	Removal or drainage of water from behind the mine walls or floor, typically using horizontal bores or pumped wells. This term is also often used to refer to the depressurisation of aquifers.
Dip	The angle of an inclined bedding plane from the horizontal.
Dip Direction	The azimuth of the down dip direction.
Elastic compression of aquifer	The volumetric compression of an aquifer following reduction in pore pressure by dewatering.

Extensometer	An instrument in a borehole that can measure vertical or horizontal ground movements.
Factor of Safety	In slope design the factor of safety is the ratio of the magnitude of the resisting force and the magnitude of the disturbing force. A factor of safety of 1 means that the slope is only just stable (marginal) and could be very sensitive to any additional disturbing force. In the case of a slope failure the factor safety is the ratio of resisting forces to driving forces (slope is stable at FOS=1).
Feeder breaker	A semi mobile unit that breaks and feeds coal to the conveyor.
Geotechnical	The engineering behavior of rocks and soil.
Graben	A graben is the result of a block of land being downthrown between two faults, joints or cracks with a distinct scarp on each side.
Groundwater	Water occupying openings, cavities and spacings in soil or rock.
Groundwater table	The level at which the ground water pressure is equal to atmospheric pressure. It may be conveniently visualised as the 'surface' of the ground water in a given vicinity.
Hydrogeology	The study of the distribution and movement of groundwater in soil and rock.
Inclinometer	An instrument that is used to measure the horizontal change in the orientation of a vertical borehole over time and therefore gives a measure of ground movements over the entire length of the bore over that time.
Interseam	The layers of soil or rock between the coal seams.
Joint	A pre-existing discontinuity in the coal that has been caused by geological conditions before the mine was excavated. Often occurring as extensive fault subvertical planes in the coal seam.
Joint set	A group of joints that have similar alignments i.e. are generally parallel.
Levee	An embankment raised to prevent a river from overflowing.
Pascal	The SI derived unit for pressure, *see stress*.
Phreatic surface	*See groundwater table.*
Piezometer	An electronic instrument in a borehole that measures groundwater pressure at a point.

Pore Pressure	The pressure exerted by groundwater in soil or rock.
Overburden	Material that lies above the area of economic interest, i.e. the rock and soil that lies above the coal seam.
Shear strength	The ability of a material to withstand shear stress. Failure will occur when the shear stress exceeds the **peak** shear strength of a material. Once failure has occurred the shear strength of material typically reduces to a **residual** strength, which is usually significantly lower than the peak strength.
Standpipe	A hollow pipe inside a borehole that is dipped to measure water levels.
Stratified rocks	Layered earth materials, deposited as successive beds of sediment and solidified by compaction, cementation, or crystallisation.
Stratigraphy	The study of stratified rocks.
Stress	A measure of the amount of force exerted per unit area. In geology stress can comprise compression, tension or shearing. Usually measured in kilo-Pascals (kPa).
Stress relief movements	Referring to the movements of either the batter or the mine floor that occur as a result of excavation of the coal which reduces the load (stress) on the in-situ materials, allowing movement to occur. These are generally not time dependent in that they tend to stabilise with time.
Strike	The direction of the line formed by the intersection of a fault, bed, or other planar feature and a horizontal plane. Strike indicates the orientation of planar structural features such as joints.
Survey Pin	A mild steel bar 1 metre long and 1 centimetre diameter that is hammered into the ground to provide a permanent survey mark. Also known as a **Pin** or **Monitoring Pin**.

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