Applicability of the ‘Observational Method’ to Manage Slope
Depressurisation in a Large Open-Cut Mine, South East Prongs Pit, Tom
Price, Western Australia

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Abstract
Dewatering at the South East Prongs (SEP) pit has lowered in-pit water levels approximately 81 metres below
the pre-mining water table. As a result a steep hydraulic gradient has developed behind the pit slope as the more
permeable ore material has been dewatered and water levels (pore pressures) remain elevated in the less
permeable waste rock materials. The SEP geological setting is complex, with more than 7 tectonic structural
events identified. The main orebody is located within a large syncline, disrupted by numerous faults and dykes.
Consequently, the hydrogeological model is complex and compartmentalised.

Geotechnical design assessments have determined that without depressurisation the required Factor of Safety
(FoS) to satisfy design acceptance criteria cannot be achieved. Historically, generic depressurisation designs
have been utilised, and have been successful in achieving stable slope objectives. However, until recently
limited monitoring of pore pressures was undertaken to optimise these designs. To address this, a total of 82
horizontal depressurisation holes were completed from 2009 to 2010 and the resultant vibrating wire piezometer
(VWP) data analysed to characterise the mechanisms controlling slope depressurisation. Four distinct response
trends were identified. The Observational Method, as defined by Peck (1969) has been used to design and
optimise the depressurisation drilling programme for the final pit design, and to update the slope design
recommendations for the remaining life of mine. Practical application of the Observational Method (supported
by comprehensive instrumentation monitoring arrays) aims to save costs and time whilst maintaining an
acceptable FoS by optimising depressurisation drilling requirements.

1  Introduction
Mining of iron ore from Tom Price open pit operations (Fig. 1), located in the Hamersley Basin, by Rio Tinto
Iron Ore (RTIO) commenced in 1966; cumulative production to date (mid-2010) is estimated at over 800 Mt.
The South East Prongs (SEP) pit hosts one of the prime remaining sources of high grade low impurity Hematite
ore at Tom Price.

The SEP pit itself is structurally complex; the permeable orebody (mineralised Dales Gorge Member of the
Brockman Iron Formation) is hosted within a doubly-plunging syncline bounded by the low-permeability Mount
McRae Shale (Williams et al. 2007). Two north-west trending normal faults (the Southern Batter Fault to the
south and the SEP Fault to the north) act to confine the mineralisation (RTIO 2010a). Multiple deformation
events resulted in significant additional folding and faulting. As a consequence of this complexity, construction
of a structural geology model with any confidence has been difficult, which corresponds to problematic
groundwater model calibration. In a heterogeneous environment like the SEP pit this leads to modelling
predictions which can only be used with low confidence. In this situation an observational approach provides a
better option in order to validate and optimise the pit mining strategy during development.
Groundwater abstraction for dewatering purposes first commenced at SEP pit in 1994; the current pit floor (600 mRL) is approximately 74 m below the pre-mining water table (~674 mRL). As a result, a steep hydraulic gradient has developed behind the pit slope as the more permeable ore material has been dewatered and water levels remain elevated in the less permeable footwall material. Geotechnical design assessments have determined that without depressurisation the required Factor of Safety (FoS) to meet design cannot be met.

The requirement to complete horizontal depressurisation drilling programmes in order to achieve the appropriate slope FoS is costly, and will greatly impact upon the pit development schedule. The alternative is to design a flatter pit slope angle to account for saturated slopes, which then significantly increases the strip ratio and reduces the economics of the pit. In order to minimise this constraint, this study proposes to review the effectiveness of the current standardised approach to depressurisation drilling, and determine whether application of the Observational Method (Terzaghi & Peck 1948; Peck 1969) will enable the project scope to be optimised (number and/or depth of holes) during pit development based on an increased understanding of the hydrogeological response of the rock mass.

2 Physical setting

2.1 Geology

The SEP pit lies within the 80,000 km² Hamersley Province (Fig. 1), host to one of the largest resources of iron ore in the world (Bitencourt et al. 2005). The 2,500 m thick Late Archaean – Palaeoproterozoic Hamersley Group is host to the mineralised banded iron formations (BIF) targeted by mining at Tom Price. The Brockman Iron Formation of the Hamersley Group is host to iron-rich deposits mined at numerous Pilbara mine sites. It comprises mostly of BIF, with minor fine tuff, mudrock (shale), dolomite and chert. The 620 m thick sequence (where unmineralised) is divided into four members: the lowermost Dales Gorge Member, the Whaleback Shale Member, Joffre Member and the Yandicoogina Shale Member. The SEP pit targets the hematite-rich orebody within the Dales Gorge Member and upper mineralised “skin” of the footwall zone (FWZ) within the Mount McRae Shale. The Dales Gorge Member (DG) is a ~150 m thick alternating sequence of BIF and shale...
macrobands (10 cm to several metres), whilst the Mount McRae Shale (MCS) is a 50 to 60 m thick carbonaceous shale unit with interbedded chert and minor BIF (Trendall & Blockley 1968, 1970; Harmsworth et al. 1990; Blake & Barley 1992).

The Tom Price deposit, approximately 7.5 km long and 1 km wide, is located on the southern limb of the Turner Syncline. Several pits extend along the length of the deposit, with additional Brockman Iron and Marra Mamba deposits mined to the south of the primary mineralised zone. The SEP pit marks the eastern end of the main deposit, where mineralisation of the Dales Gorge Member extends to 250 m depth below natural surface.

Extensive, predominantly east-west trending faulting at the SEP orebody play a major role in hydrogeological and geotechnical considerations for pit development. Overall, the SEP faulting configuration mimics a horst and graben structure proposed by Dalstra (2006) for the Paraburdoo Ranges. The north wall of the SEP pit hosts south-dipping normal faults of the SEP Fault Zone whilst a north-dipping normal fault in the south wall of SEP forms the southern fault of the graben (Croft 2008). The SEP Fault Zone comprises vertical to south-dipping normal faults extending east-west along the length of the pit; vertical displacement is up to 140 m in the northeast corner of the pit as the fault zone narrows. Due to the complex structural setting, limited marker bands present and poor drilling resolution, mapping of faults in the western half of the pit is challenging. This factor is noted as a limiting factor in the hydrogeological conceptualisation of the SEP pit, and the potential factors which may control groundwater flow.

2.2 Hydrogeology

2.2.1 Setting

The primary aquifer within the SEP pit comprises the mineralised sequences of the Dales Gorge Member and footwall zone (FWZ) within the Mount McRae Shale. The “orebody aquifer” is bounded by two aquitards: the Whaleback Shale Member above and the Mount McRae Shale below, both of which have hydraulic conductivities two orders of magnitude lower than the orebody aquifer (Table 1). The Whaleback Shale Member does not play a significant role in the conceptual hydrogeological understanding of the pit in that it has been largely mined out in order to gain access to the mineralised orebody.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Hydraulic Conductivity (m/d)</th>
<th>Specific Yield</th>
</tr>
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<tbody>
<tr>
<td>Dales Gorge (mineralised)</td>
<td>1 - 5</td>
<td>0.04 – 0.06</td>
</tr>
<tr>
<td>Mount McRae Shale</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Bruno’s Band</td>
<td>5 - 17</td>
<td>0.01</td>
</tr>
<tr>
<td>Mount Sylvia Formation</td>
<td>0.001 - 0.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Bee Gorge Member</td>
<td>0.01 - 0.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Fault zones</td>
<td>0.5 - 10</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The doubly-plunging synclinal structure at SEP the walls of the pit are largely within the Mount McRae Shale, restricting groundwater flow to the open pit. A prominent chert band (Bruno’s Band) marking the contact between the Mount McRae Shale and Mount Sylvia Formation, is a high conductivity unit which acts as an aquifer and preferential flow path for water behind the pit wall. The Wittenoom Formation, which is the major regional aquifer, is present approximately 100 m behind the pit walls and is considered the primary recharge source to the orebody aquifer.

Faulting and folding are also considered to lead to localised compartmentalisation of groundwater behind the pit walls, potentially resulting in zones of elevated pore water pressure where the effectiveness of depressurisation is
spatially limited. In developing our conceptual understanding of the local hydrogeology of SEP the influence of structural controls such as faulting require rigorous consideration. Understanding and attempting to replicate the conceptual hydrogeology of the pit using groundwater and geotechnical models is problematic given the difficulties in structural mapping of the SEP pit outlined above. Application of the Observational Method to depressurisation is an attempt to overcome these difficulties. Figure 2 (from Lim 2010) shows the current conceptual hydrogeological model for SEP.

Figure 2. Conceptual hydrogeological model of SEP Pit, along E-W and N-S section views (adapted from Lim 2010).

### 2.2.2 Dewatering and depressurisation history

Groundwater abstraction for dewatering purposes first commenced at SEP pit during 1994; dewatering in the pit has been continuous from that time. The pre-dewatering groundwater level at SEP was approximately 674 mRL; no hydraulic gradient existed across the Mount McRae Shale and Dales Gorge Member (Coffey and Partners 1991). The current groundwater level is approximately 593 mRL, 7 metres below the pit floor (600 mRL). Water levels behind the pit wall however have remained elevated as the more permeable orebody aquifer has been dewatered; a steep gradient has developed between the pit walls (Mount McRae Shale) and orebody (Dales Gorge Member).

A developing hydraulic gradient across the pit wall in the SEP pit, first noted in the early 2000’s following the development of seepage faces, highlighted that elevated pore pressure behind the pit slope may be a determining
factor in maintaining slope stability. At the time the SEP geotechnical design reviews assumed an unsaturated rock mass, or fully drained groundwater conditions behind the pit slope. As a result, a depressurisation drilling strategy was adopted for the SEP pit.

Between 2004 and 2008 approximately 130 horizontal depressurisation holes (>21,000 m) were completed, generally drilled at 25 m horizontal spacing, to variable depths of between 50 and 255 m (New 2010). There was no formalised approach to drill-hole design based on stratigraphy, structural features or geotechnical risk (i.e. More holes in areas of the pit wall with a lower FoS), nor a clear metric or target for depressurisation based on the geotechnical design. Depressurisation results were determined by a series of open standpipe piezometers outside the pit, which measured the overall phreatic response to drilling but not the piezometric response in discrete stratigraphic units. Historically, generic depressurisation designs have been successful in achieving stable slope objectives.

Simple two dimensional (2D) numerical groundwater modelling was completed using SEEP/W in 2007 to assist with designing a depressurisation programme (Williams et al. 2007). The aim of the modelling was to predict indicative depressurisation results based on varying depressurisation drilling designs (namely depth of hole) and to define the ideal drain hole spacing. The modelling results suggested a horizontal hole spacing of 25 m and hole depths of 50 to 100 m were suitable to deliver adequate depressurisation.

3 The ‘Observational Method’

The Observational Method is a technique commonly applied in civil engineering projects to address the inherent uncertainty in our understanding of soil/rock mechanics, by adopting a progressive modification approach to the engineering design on the basis of information (monitoring, observations) collected during construction. Peck (1969) outlined a formal framework for application of the Observational Method, consisting of eight rules:

1. Exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail.
2. Assessment of the most probable conditions and the most unfavourable conceivable deviations from these conditions. In this assessment geology often plays a major role.
3. Establishment of the design based on a working hypothesis of behaviour anticipated under the most probable conditions.
4. Selection of quantities to be observed as construction proceeds and calculation of their anticipated values on the basis of the working hypothesis.
5. Calculation of values of the same quantities under the most unfavourable conditions compatible with the available data concerning the subsurface conditions.
6. Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.
7. Measurement of quantities to be observed and evaluation of actual conditions.
8. Modification of design to suit actual conditions.

Application of the Observational Method, as defined by Peck (1969) and later modified by Powderham (1994), has been widespread across the world since the 1970’s. Applications include piling, cut and cover tunnelling, tunnelling, open excavation (road cutting), road and railway design, and construction dewatering (Peck 1969, 2001; Powderham 1994; Roberts & Preene 1994; Kovari & Lunardi 2000; Baynes et al. 2005). No published examples could be found of the formal application of the Observational Method to slope depressurisation.
4 Results

4.1 Geotechnical design

The interim SEP Laydown pit design was approved in March 2009 and mining commenced in April 2009. The geotechnical design review (Mining One 2009) which supported the approval of the interim pit design highlighted elevated pore pressure to be one of the key controls impacting upon slope stability. The geotechnical review outlined the depressurisation profile required to meet slope stability as well as the recommended horizontal drilling design to achieve the required target. A drilling programme was scoped and executed to establish a vibrating wire piezometer (VWP) monitoring network to track depressurisation performance (RTIO 2009a, 2009b) and a horizontal depressurisation drilling programme initiated in mid-2009.

At the time, a comprehensive study of the mechanisms controlling groundwater movement behind the pit slope had not been completed and no depressurisation strategy had been developed for the SEP pit. This is largely the result of previous depressurisation drilling results being poorly documented and the limited, low-resolution monitoring data collected. The Mining One (2009) geotechnical design review did however specify the depressurisation profile required for long-term stability (Table 2, Fig. 3) that resulted in an adequate FoS being met for the proposed pit slope design.

Table 2. Phreatic profile required for long-term stability.

<table>
<thead>
<tr>
<th>Height above floor (m)</th>
<th>Horizontal distance to water table (m)</th>
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<tr>
<td>5 m</td>
<td>15 m</td>
</tr>
<tr>
<td>15 m</td>
<td>30 m</td>
</tr>
<tr>
<td>30 m and above</td>
<td>35 m or greater</td>
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Figure 3. Conceptual phreatic profile required (in red) for long-term stability, North wall of SEP looking East.
Horizontal depressurisation drilling targets were scoped with the following constraints:

- Holes to be completed on each 10 m bench from the 660 mRl and below on the north wall and west wall north of 10,490 mN.
- Holes to be evenly distributed at 25 m horizontal spacing, based on previous experience and modelling (Williams et al. 2007). Where holes are not drilled perpendicular to the wall 25 m horizontal spacing was to be measured at the tail of the hole.
- Holes to be drilled through trim shots.
- The hole depth should ensure they intersect the key stratigraphic units (Mount McRae Shale, Mount Sylvia Formation and Wittenoom Formation) and faults which may compartmentalise groundwater flow.

4.2 Depressurisation drilling results

A total of 82 horizontal depressurisation drill holes were completed to support the development of the SEP Laydown Pit design; 23, 29 and 30 holes respectively on the 660 mRl to 640 mRl benches. Holes were drilled at 150 mm diameter using air-hammer methods to full depth (up to 210 m) at an inclination of +5º, which would allow the hole to free drain. Sample cuttings were taken during drilling of each hole and geologically logged, and an estimate of water yield was recorded on completion.

Monitoring data from the 28 VWPs located behind the wall were collected at three-hourly intervals from the time of construction. Water level hydrographs were plotted to monitor the rock mass response to depressurisation drilling and other events such as blasting over time. A diary of events was kept in order to document the time each horizontal depressurisation drill hole was completed or a blast in the SEP pit occurred. In most cases VWP monitoring showed an instantaneous response to depressurisation drilling or blasting. As a result each VWP pore pressure response could be attributed to a particular event.

VWP monitoring data was collected and analysed to determine the effectiveness of 82 horizontal depressurisation holes completed on the 660 to 640 mRl benches in meeting the required depressurisation profile to ensure slope stability for the interim SEP Laydown pit design. Four distinct response trends were identified (Fig. 4), as per the approach for classification completed by Schlumberger Water Services (2010), from the 28 VWPs assessed: Class A (steep fall), Class B (moderate fall), Class C (steady, no response) and Class D (rising). For each class, a review of the geology, hydrogeology, structural constraints, spatial location and initial water level conditions were completed to develop an understanding for the controlling factors affecting the rock mass and hydrogeological response to depressurisation drilling.

5 ‘Observational Method’ application to depressurisation

Peck’s observational method framework was applied to develop a depressurisation strategy for the SEP final pit design: Conceptual Depressurisation Regime (Rules ‘1’ and ‘2’), Proposed Drilling Design (Rule ‘3’), Anticipated Behaviour (Rules ‘4’ and ‘5’) and Contingency Plans (Rule ‘6’). Peck’s Rules ‘7’ and ‘8’ are related to the execution phase of the Observational Method and are not outlined here. This study incorporated horizontal drilling to meet the required depressurisation profile for slope stability only and did not include the modification of the final pit design based on information of a slope stability nature collected during pit development.

Utilisation of the Observational Method in the development of a depressurisation strategy for the final pit design was based on the results gathered from the 660 to 640 mRl drilling outlined above.
Figure 4. Water level hydrograph of Class A to D vibrating wire piezometer (VWP) responses (New 2010).

5.1 Conceptual depressurisation regime

Given the complex structural nature of the site, there is a degree of uncertainty inherent in the geological (block and structural) models and geotechnical design. The most unfavourable conditions for slope depressurisation would be where unforeseen, more adversely located and oriented faults and/or folds inhibit the spatial effectiveness of horizontal drilling by compartmentalising the rock mass. In this situation, additional horizontal holes would be required where zones of elevated water pressure persist after completing the planned drill targets. This uncertainty must be addressed by ensuring sufficient monitoring (VWP) coverage is in place across stratigraphy and known major structural features.

The results of the study completed for the SEP pit Laydown design can be applied to outline the most probable conditions and/or rock mass response to horizontal depressurisation drilling on the North and West walls. If the depressurisation profile required for long-term slope stability is applied to the conceptual final pit design, the Mount McRae Shale and Mount Sylvia Formation units on the North and West walls, plus the Dales Gorge Member and Footwall Zone on the south wall require depressurisation. The Bee Gorge Member, as the primary regional recharge source to these units, must also be targeted to lower the far-field water level gradient behind the pit slope.

Rates of depressurisation have been determined from the 660 to 640 mRL horizontal drilling for the Bee Gorge Member and Mount Sylvia Formation. Given the theoretical hydraulic conductivity for the Mount McRae Shale
and Mount Sylvia Formation are the same (~0.01 m/d) it is assumed that the rate of depressurisation will be similar for both units. If this is not the case (Mount McRae Shale demonstrates a lower rate of depressurisation), then additional in-fill depressurisation holes may be required.

5.2 Proposed drilling design

Given the required depressurisation profile prescribed in the geotechnical design, the following general design guidelines apply to all horizontal depressurisation drilling completed in the SEP pit:

1. Horizontal hole design to be completed as per existing design. That is,
   a. 200 mm collar diameter to a depth of 3 to 6 m to allow a 150 mm ABS collar to be fitted, held in place using AB foam. A collar allows holes to be reticulated should the yield require additional control.
   b. 125 to 150 mm diameter hole using air-hammer methods to full depth, at an inclination of +5°.
   c. Holes to be cased with 50 mm diameter Class 12 slotted uPVC, installed by hand to the maximum possible depth.

2. Where safety allows, all horizontal holes to be drilled on the final pit wall and not through trims. This ensures all holes remain operable for the life of the pit and allows for regular measurements of yield to be completed.

3. Horizontal drilling to commence where water levels in the Mount Sylvia Formation or Mount McRae Shale are above the bench level in that section of the wall (i.e. North, West or South wall), regardless of whether the required profile is already met. This to ensure the rate of depressurisation achieved in the low conductivity units above is in advance of the vertical pit progression rate.

There is insufficient data to challenge the current horizontal hole spacing of 25 m, prescribed by high-level 2D depressurisation modelling in Williams et al. (2007). The drill hole design must also consider whether the rate of depressurisation achieved is sufficient to meet the pit development plan, as the required depressurisation profile could be met with fewer holes but cause a greater time delay to achieve that result. To this end, the following horizontal drill hole depth and spacing is prescribed for the North and West walls (no horizontal drilling required on South wall):

- Holes to be evenly spaced 25 m apart at the tail of the hole.
- Each hole to be drilled to intersect the Mount McRae Shale and/or Mount Sylvia Formation, ensuring each tail is behind FSEP Fault on the North wall and F12 Fault on the West wall. Based on the current structural model, holes will generally be 80 to 120 m deep.
- Every fourth hole (100 m horizontal spacing) on the North wall and Northwest corner of SEP to be extended to intersect the Bee Gorge Member, and F17 Fault (East of 15,550 mE) or Boxcut Fault (West of 15,550 mE). Holes may be up to 300 m deep. Consideration may be given for packers to be employed to prevent near-face recharge from far-field water.
- Hole coverage to extend to 15,850 mE, to ensure depressurisation behind the Northern Bullnose area.

5.3 Anticipated behaviour

5.3.1 Predicted results

The most probable response of each stratigraphic unit to horizontal depressurisation drilling as measured by the VWP network is:
- Mount McRae Shale: fall of ~0.5 m/month; instantaneous (<1 week) fall of up to 3 m (as assumed from Mount Sylvia Formation).
- Mount Sylvia Formation: fall of ~0.5 m/month; instantaneous (<1 week) fall of up to 3 m.
- Bee Gorge Member: fall of ~1.2 m/month; instantaneous (<1 week) fall of up to 8 m.
- Dales Gorge Member/Footwall Zone: slope depressurised due to in-pit dewatering, no horizontal holes required.

The least favourable response of each stratigraphic unit to horizontal depressurisation drilling as measured by the VWP network is:

- Mount McRae Shale: fall of <0.5 m/month; instantaneous (<1 week) fall less than 1 m (as assumed from Mount Sylvia Formation).
- Mount Sylvia Formation: fall of <0.5 m/month; instantaneous (<1 week) fall less than 1 m.
- Bee Gorge Member: fall of 0.4 m/month or less; instantaneous (<1 week) fall of up to 2 m.
- Dales Gorge Member/Footwall Zone: in-pit dewatering spatially ineffective due to poor bore utilisation, seepage faces develop at toe of pit slope.

5.3.2 Monitoring plan

Contingency plans must be developed for all plausible outcomes, therefore it is imperative that the correct observations are collected and measured. This includes ensuring adequate spatial coverage where structural controls may influence the rock mass response to depressurisation drilling and correctly analysing the data to separate depressurisation induced events from background “noise”. If an onerous monitoring regime is required to apply the Observational Method the cost involved may outweigh the benefits. Vibrating Wire Piezometers (VWP) will be utilised as the primary monitoring tool to measure depressurisation performance behind the pit slope.

For this study the rate at which depressurisation occurs is a critical factor in executing a depressurisation strategy to minimise delays to pit development. As the completion of horizontal depressurisation drilling is on the critical path (the next task can not commence until drilling has been completed) any unforeseen delays to complete monitoring data analysis, communicate the results and possibly trigger contingency plans can have a significant impact on the mine schedule. Radio telemetry to transfer VWP data will allow access to near real-time data on a consistent basis. This will permit progressive modifications to be made to the drilling plan on a hole-by-hole basis if desired, plus initiate contingency plans in an efficient manner to minimise additional delays to mining. Monitoring data will be plotted as hydrographs and combined to map the water level surface so that performance against the required depressurisation profile can be readily reviewed. In addition, regular monitoring of the flow rate from each completed horizontal hole should be performed.

5.4 Contingency plans

Where the results of monitoring indicate the required depressurisation profile has not been met after completion of the horizontal drilling programme to scope, contingency plans are required. Four contingency plans are outlined: advanced depressurisation, short-term mining delay, in-fill horizontal drilling and south wall depressurisation drilling. Plans are covered in more detail in New (2010).

6 Integration into final design

Geological structural control is the primary limiting slope stability factor, driven by adversely oriented weak shale beds interbedded with dense BIF units interacting with fault release planes. Due to the late stage mining in
SEP, limited slope geometrical changes are available, and consequently dissipation of high pore pressures on sliding planes is required to achieve the design acceptance criteria and maximise ore recovery.

The predicted phreatic surfaces derived from observations collected to date have been used as the base case for stability modelling purposes, and have provided confirmation of the critical importance of management of pore pressures in achieving stable slopes in the north and western slope sectors. Hydrogeologic and structural conditions are appreciably more favourable in the south wall. Sensitivity assessments were undertaken by adopting the ‘anticipated’ condition as well as ‘worst case’ conditions. The chosen phreatic surface selected for design purposes typically coincided with the expected condition, however localised changes were adopted in some slope sectors in accordance with hydrogeological and geotechnical model confidence.

Sensitivity assessments allowed geotechnical risk areas to be identified, and for the mining sequence to be optimised to maximise ore recovery with minimal risk. ‘Worst case’ phreatic surfaces were used to indicate which areas were most sensitive to rates of drawdown. Such areas may be constrained in their vertical mining rates by lags in depressurisation, which was taken into account in the mine planning process.

7 Conclusions

The Observational Method, described in the framework given by Peck (1969), has been applied to optimise the horizontal depressurisation drilling strategy for the SEP pit. The conceptual depressurisation regime is defined and rates of depressurisation (predicted results) for each stratigraphic unit assumed after a review of results of the horizontal drilling completed on the 660 to 640 mRL benches. The proposed drilling design is based on the most probable conditions for the SEP pit; where the required depressurisation profile is not met contingency plans are in place to mitigate the potential risk of slope failure due to elevated pore water pressure. A monitoring plan has been specified to ensure the correct observations are collected and measured during completion of drilling. It should be noted that a review of the VWP monitoring resolution should be undertaken to determine whether additional spatial data may assist in further optimising the horizontal drilling design.

Recommendations for future work include:

- Implementation of radio telemetry to access to near- or real-time data, to allow the practical application of the Observational Method.
- Optimisation of the required depressurisation profile, by means of sensitivity analyses for each discrete pit domain.
- Development of Risk Management Tools, in order to clearly define responsibilities, including continuous monitoring and reviewing processes and interaction protocols between involved parties.
- A review of VWP spacing (currently 60 m horizontally) should be completed to assess whether additional monitoring points will allow the current horizontal hole spacing (25 m) to be challenged.

8 Acknowledgements

The authors would like to acknowledge the efforts of the Tom Price Hydrogeology team in the collection and processing of much of the drilling and monitoring results, particularly Alessandro Greggio, David Sepe, Graham Lavery and Eddie Newell. Rio Tinto is also thanked for sponsoring the initial project as part of postgraduate studies by the principal author.
9 References


