Development and Implementation of Thickened Tailings Discharge at Osborne Mine, Queensland, Australia.

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Abstract: Osborne Mine is an underground copper-gold operation in Northern Queensland that mines an ironstone deposit which hosts magnetite and silica with chalcopyrite, pyrite, and pyrrhotite. The mine setting is arid with the majority of make-up water being supplied from boreholes located on the edge of the Great Artesian Basin, some 28 km away. The development and implementation of thickened discharge for tailings management was initially motivated on the basis of potential water savings as well as the potential to reduce wall raising costs on the tailings dam. As trials progressed however, it became apparent that thickened discharge would not only achieve these but also would enable reductions in operating costs, improved rehabilitation potential, and more efficient use of available storage capacity.

This paper describes the development and implementation of thickened discharge at Osborne. The operating strategy and the operating cost savings that have been realised are discussed, as is the design philosophy for a new tailings storage facility to accommodate the new method of deposition. The economic, geotechnical and rehabilitation assessments necessary to obtain regulatory approvals and to proceed with this method of deposition on a long term basis are also detailed.

1.1 INTRODUCTION

Osborne Mine in Northern Queensland, Australia is located in outback Australia approximately 1,000 km inland from the eastern coast as indicated in Figure 1.1-1. It is an underground copper-gold operation that mines an ironstone deposit which hosts magnetite and silica with chalcopyrite, pyrite, and pyrrhotite. The mine setting is arid with an average annual rainfall of 335 mm. Rainfall generally occurs between October and March and is dependent on cyclone activity over the north of the Australian continent. The majority of make-up water for the mine is supplied from boreholes located on the edge of the Great Artesian Basin, some 28 km away. While there are vast quantities of water stored in the basin, regulators are conscientious in encouraging users to maximise water use efficiency. In addition, Osborne's sustainability commitments serve as major drivers in the development of strategies to reduce water use from the Great Artesian Basin.

1. Metago Environmental Engineers (Australia) Pty Ltd
2. Osborne Mines Pty Ltd
3. Metago Environmental Engineers (Pty) Ltd

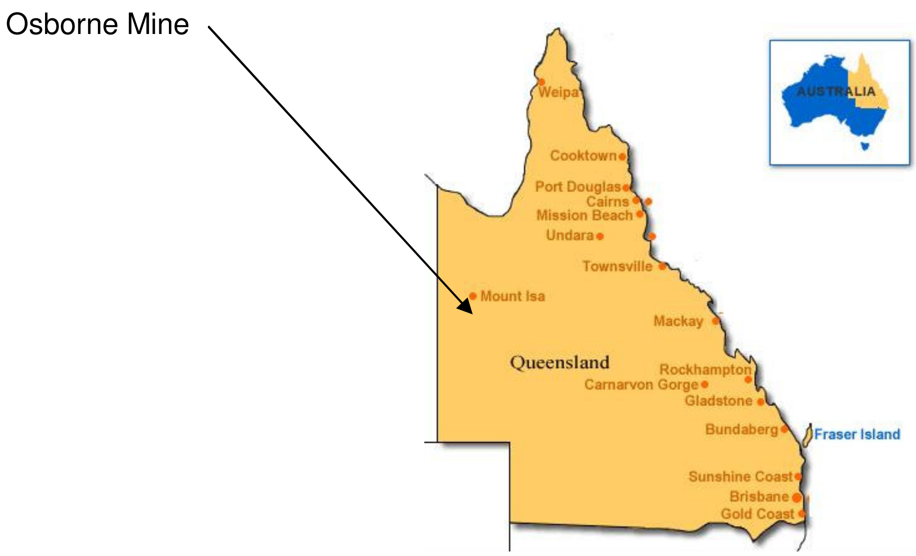

Figure 1.1-1 : Locality map

Osborne has been operating since 1996 and generates approximately 112,000 tonnes of tailings per month. The majority of water loss in the process water circuit occurs in the tailings system as a result of evaporation. Thickened discharge provides a means for significantly reducing water losses since, by putting less water on to the tailings facility, there is less opportunity for evaporation.

It is the norm in Australia to construct tailings facilities in a series of controlled lifts. The confining embankment around the perimeter of each lift comprises compacted material made up mostly of clay. Construction of a lift is a significant cost in tailings operations and for a medium sized facility can cost between \$1 m and \$2 m. Since the lifts are usually less than 3 m in height and rates of rise usually 3 m per year it is common for a lift to be constructed annually or at least every two years. Lift costs are therefore very significant over the life of the tailings dam. Thickened discharge provides a means for reducing lift costs since it enables the “stacking” of tailings.

Against the background of the above potential benefits Osborne elected to carry out trials to assess the efficacy of the implementation of thickened discharge. Specifically the following issues required detailed evaluation:

- The method of generating thickened tails and the reliability of this method
- Pumping implications
- The beaching profile of the thickened tails, specifically whether it would stack at a steep enough angle to enable a reduction in lift requirements.

- Operational issues relating to the management of discharge points specifically accessibility.
- The practicality of management options for dealing with periods when the process plant is unable to generate thickened tailings
- Realisable water savings
- Geotechnical stability
- Erosional stability
- Decommissioning and closure implications

To assess the above issues a staged programme of evaluation was implemented over a period of two years. During the first year modifications were made to the process plant, specifically the hydrocyclones that separate coarse fraction from fine fraction immediately ahead of the thickener (prior to re-combining with the thickened fines after the thickener), and flocculation procedures to generate a thicker tailings slurry. The tailings were pumped onto existing facilities such that cones were formed in the corners of the facilities. During the second year, after commissioning of a new tailings facility and implementing further improvements to the hydrocyclone and thickener installations in the process plant, a further trial was conducted within the new facility to form an advancing cone. Before, during and after the above trials hydrotransport, beaching, geotechnical, erosion and decommissioning assessments were carried out.

This paper describes the trials and assessments and summarises the key results.

1.2 OSBORNE TAILINGS MATERIALS

1.2.1 Mineralogy

The tailings comprises mostly magnetite but contains a number of sulphide minerals notably pyrite with traces of chalcopyrite together with gypsum. Sulfides make up 3 to 4% of mass of the tailings. The sulfides are moderately reactive and to counter their acid generating capacity lime is added in the course of mineral processing. The gypsum is a result of the neutralisation reactions.

Over the long term the tailings has significant potential to generate acid although measurements to date both in the lab as well as in the field indicate that the reaction rates are slow.

As a result of the high iron content of the tailings the particle specific gravity is 3.4 to 3.6.

1.2.2 Particle size distribution

Figure 1.2-1 shows typical particle size distributions for the tailings.

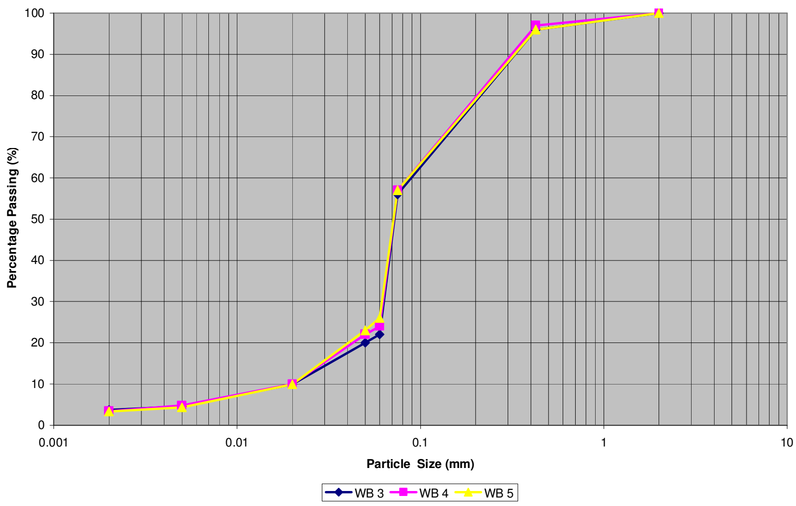

Figure 1.2-1: Typical particle size distributions of the tailings

From Figure 1.2-1 it is evident that:

- 60% of the tailings is finer than 75 microns
- The maximum particle size is 2mm
- Approximately 25% of the tailings have a particle size in a narrow range from 0.6 mm to 0.8 mm.

1.2.3 Slurry characteristics

Slurry testing was conducted by Patterson and Cooke Consulting Engineers in the pipe loop located at Alrode in Johannesburg. Tests were conducted a range of water contents from 50% solids to 74% solids (slurry relative densities of 1.56 to 2.12 respectively) to determine settling rates, friction characteristics and pump de-rating factors. Figure 1.2-2 shows some of the results of the testing.

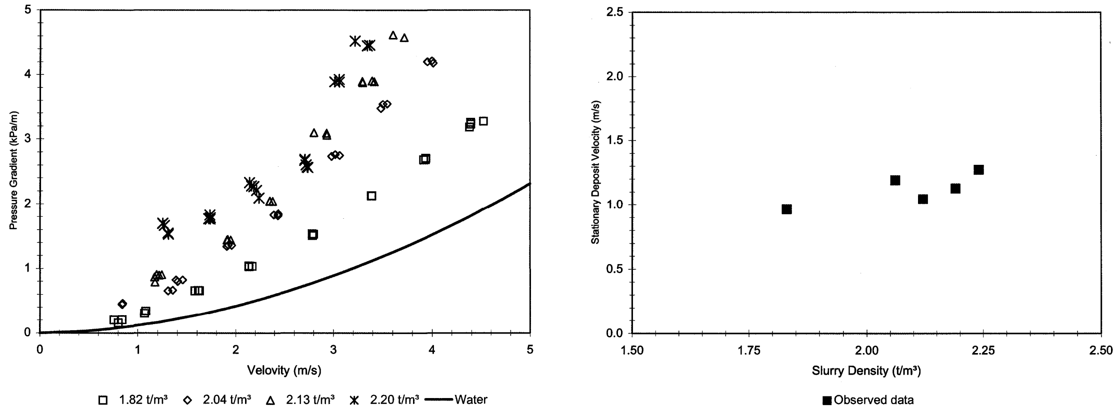

Figure 1.2-2: Pressure loss and settling velocities

1.3 HISTORICAL DEVELOPMENT OF THICKENED DISCHARGE AT OSBORNE

A detailed chronology of the assessment of thickened tailings through a number of deposition trials is provided below:

Pre June 2000 Tailings was pumped to old tailings storage facility in purely conventional manner. Tailings deposited at a density of approximately 55%. Flotation density was around 50% hence tailings dewatering circuit was not being utilized well.

June 2000 The concept of high density tailings was first discussed and a program decided upon to investigate its potential.

July 2000 Control loops were tuned through entire circuit from grinding, through flotation to tailings to allow more stable operation and allow targeting of higher density.

Sept 2000 JKSimmet models were developed for tailings cyclones and smaller rubber spigots trialled to increase cyclone underflow density and increase the amount of solids feeding the thickener. Rubber spigots of first 57mm then 51mm trialled. Cyclone underflow densities with the various spigots were as follows:

70mm spigots -	57% solids
57mm spigots -	64% solids
51mm spigots -	74% solids

Oct 2000 Feedwell deflector cone mounts were modified to allow for a larger spacing. The attaching rods were extended allowing a gap of 280mm compared to 140mm. This allowed more material to be fed to the thickener by preventing the feedwell from boiling over.

Nov 2000 Steadier operation of the thickener and operating with higher flocculant dosage and a higher bed level enabled the thickener underflow density to be increased from around 55% solids to around 67% solids.

Dec 2000 A Bredel pump was installed in the thickener underflow line to prevent blocking of the U/F line and allow operation with higher density underflow stream.

Jan 2001 Pipe loop test work was conducted in Johannesburg with Patterson and Cooke to determine characteristics of pumping Osborne tailings. Specifically to quantify the pressure drop per unit metre at a variety of densities, to measure the settling and deposition velocities and to measure the beach angle formed by deposition at various densities and the segregation of solids during deposition. Pipe loop tests were conducted at slurry densities of 62%, 69%, 73%, 74% and 76% solids. Deposition velocities were determined to be in the range of 1.5-2.0m/s. Deposition tests were conducted at densities of 68%, 72% and 75%. The test work indicated that a target density to achieve successful high density tailings pumping and deposition was in the order of 74-76% solids. Above 76% solids the pressure increased rapidly and the deposition velocity also increased.

Feb 2001 Modifications were made to the thickener underflow cone to remove obstructions and smooth the flow allow the Bredel pump to be removed and allowed a return to gravity flow of the thickener underflow material.

Feb 2001 Tailings was being pumped at a density of around 68% solids which allowed pumping to the far corner of the old tailings storage facility after the last wall lift, something that had been difficult to achieve previously. Surveys of the slope deposited at 68% solids showed that the beach angle was approximately 1 in 40, compared to slopes of around 1 in 90 with 55% solids deposition.

Apr 2001 Installed higher ranging bed mass gauge in thickener to allow more stable and reliable operation at higher bed masses. Installation of density gauges in thickener underflow line and in tailings pipeline to allow better monitoring of operation.

July 2001 Based on experiences to date and expectations of future improvements, the pumping and piping duties for the new tailings dam were specified and the design of the new system commenced. The design of a new dam to incorporate high density deposition commenced.

Sep 2001 Design criteria for pumping and piping system were finalized with pipe diameter selected to suit high density deposition. Valving, flushing systems and instrumentation were installed to suit high density pumping.

Oct 2001 A change of flocculant supplier and type to better suit duty allowed significant increase in thickener underflow density.

Dec 2001 Installed a second flocculant sparger in thickener feedwell to allow better dispersion and mixing of flocculant. Meanwhile deposition on the old dam to form mounds at the corners continued. Figure 1.3-1 shows the old tailings dam at Osborne. The two larger cells were used for thickened tailings trials with deposition in the corners to form mounds.

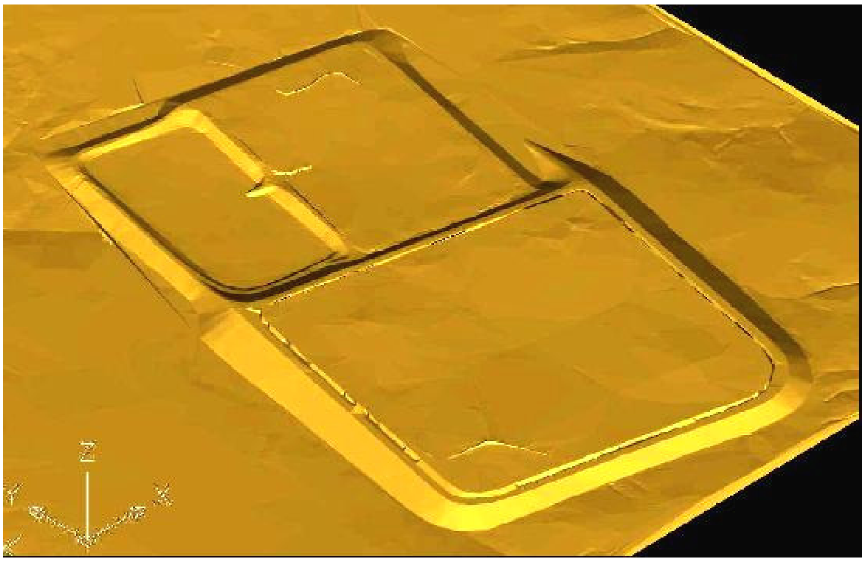

Figure 1.3-1: Isometric view of the old tailings facility showing the thickened mounds in the corners.

June 2002	The new tailings dam was commissioned, initially pumping to conventional spigots at around 68% solids. The reduced elevation of the dam, the reduced pumping distance, the higher density and more appropriately sized pipeline all lead to a reduction in pumping duty from in excess of 1800kPa with three pumps in series to one pump only with pressures of around 400kPa.
Aug 2002	Rubber cyclone spigots of first 47 then 41mm were trialled to further increase cyclone underflow density and overall tailings density. Following trials a mix of 41mm and 45mm ceramic spigots has been installed to allow operational changes to suit changing ore types.
Sep 2002	High density trial planned and location selected. Trial beach fitted with pipe work, monitoring instruments etc.
Oct 2003	High density deposition trial commences at spigot “SD1”. Densities of around 74-76% solids targeted.
Jan 2003	Instrumentation installation on trial beach completed.
Apr 2003	Installation of a number of standpipes to allow more accurate determination of water level within tailings beach at a variety of locations across and down the slope.
Oct 2003	Initial trial phase concluded with measurement of rainfall erosion potential, liquefaction potential and final slope.
Post Oct 2003	High density continues at SD1 and the new high density spigot ND2 to maximize tonnage of tailings placed at high density while analysis of trial continues and submission to the regulators is drawn up for approval of high density tailings as a long term strategy.
Feb 2004	Plan to install a flow meter in thickener underflow pipe, as almost invariably any problems with tails line beginning to block and causing problems originate from a loss of flow from the thickener underflow.

Details of the thickened trial on the new dam are described below.

1.4 THICKENED TAILINGS DEPOSITION TRIAL

1.4.1 Set up of the trial

Figure 1.4-1 below show a series of isometric views of the thickened trial on the new tailings facility. The isometrics are produced from detailed topo surveys.

Use was made of a natural ridge within the new tailings facility to form a launch point from which to advance a single discharge pipe. As tailings beached and filled to the pipe end additional lengths of pipe were added and this discharge point advanced forwards. In this way an advancing cone was formed. In addition, with each advance, the pipe discharge elevation was raised so that as the cone advanced the advancing face was at a rising elevation. This, together with the natural fall in the topography enabled the formation of a cone face of approximately 10 m in vertical height from the end of the beached tailings to the discharge head. To control the deposition direction a 60 degree “Y” section was introduced in one pipe length before the discharge point and discharge alternated between the two branches.

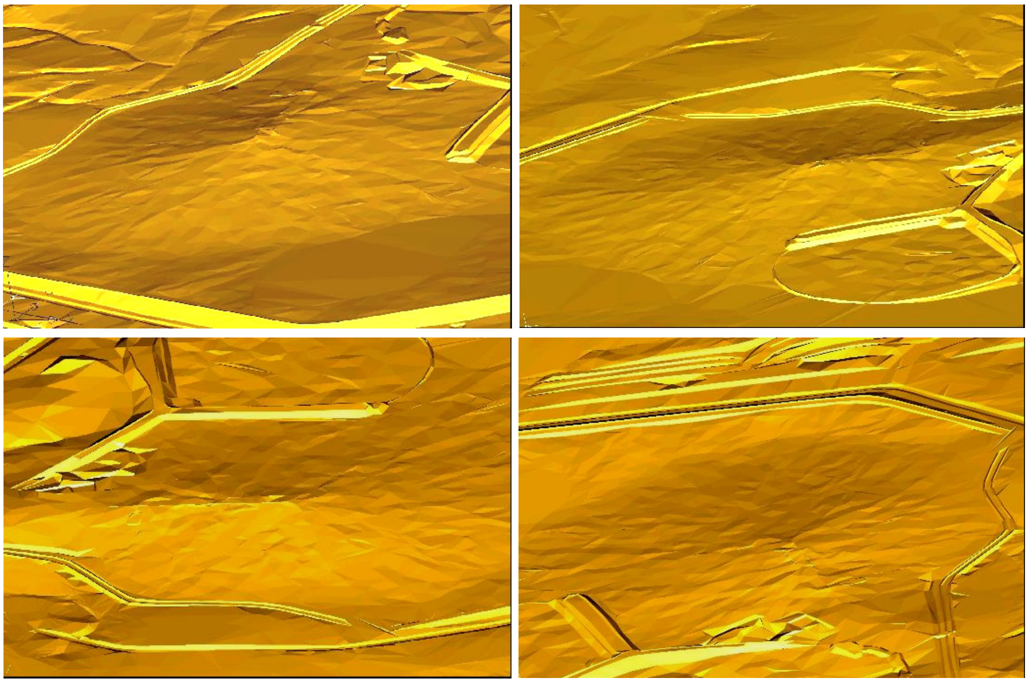

Figure 1.4-1 : Isometric views of the thickened trial on the new tailings facility

Figure 1.4-2 below shows a cross section through the mound drawn at natural scale. The slopes of the mound are 1 in 20 for the upper half of the beach length and 1 in 30 for the lower half giving an average beach slope of 1 in 25.

1.4.2 Topographical form of the thickened tailings mound

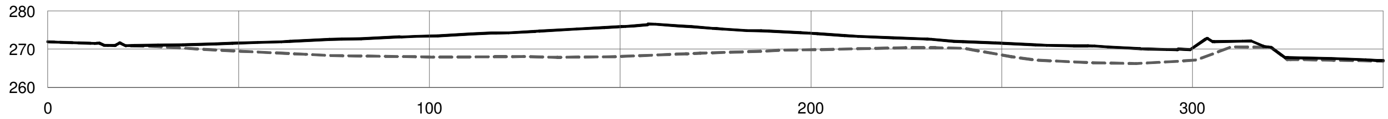

Figure 1.4-2: Cross section at natural scale through the thickened trial mound

Figure 1.4-3 below shows the measured beach profile calibrated against the beaching prediction methodology by McPhail [1] and Figure 1.4-4 shows the predicted particle size distributions down the beach. Comparison of the predicted particle size distributions with measured distributions indicates that there is less segregation than predicted.

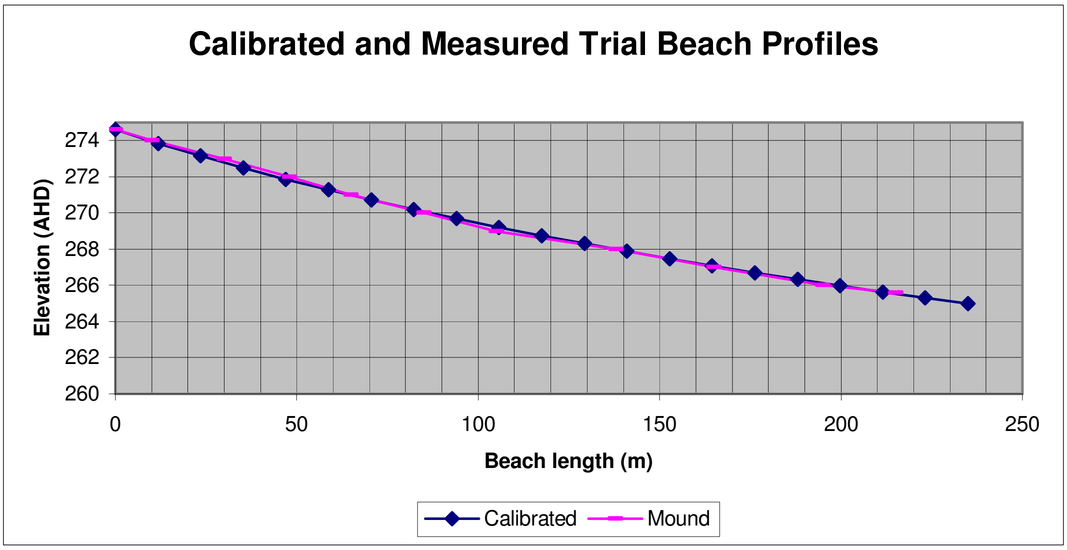

Figure 1.4-3: Calibrated and measured beach profiles

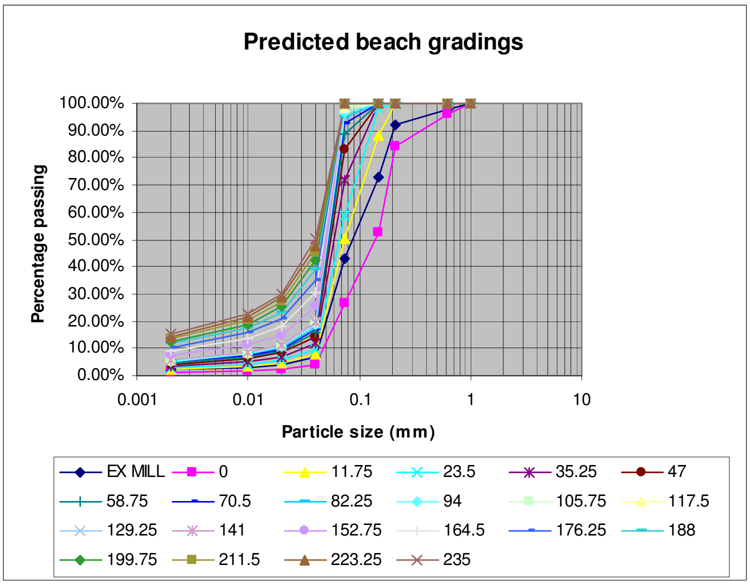

Figure 1.4-4 : Predicted particle size distributions down the beach

Figure 1.4-5 and Figure 1.4-5 below show two cross sections through the thickened mound. The locations of piezocone soundings are also indicated on the sections.

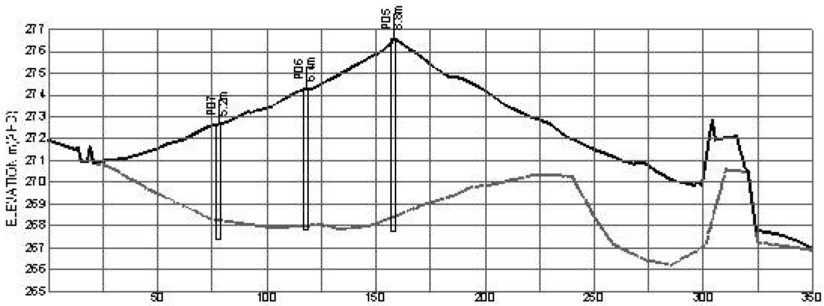

Figure 1.4-5: Section through the thickened mound from the outer confining embankment on the left to the pool wall on the right (Vertical scale exaggerated)

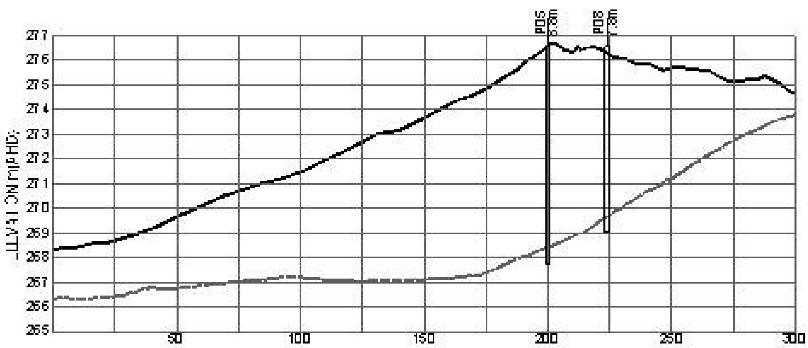

Figure 1.4-6: Section through the thickened mound along the delivery line route (Vertical scale exaggerated)

Approximately 270,000 tonnes of tailings had been placed in the mound at the time of the survey. At an average measured in situ density of 2.2 t/m^3 this represents approximately 127,000 m^3 of tailings fill.

1.4.3 Stage Capacity

Figure 1.4-5 below shows the stage-capacity curve for the thickened tailings mound based on actual deposition tonnage records. The stage-capacity curve is developed for an advancing cone arrangement and focuses on advance length to calculate slope length, marginal rate of vertical rise and total height.

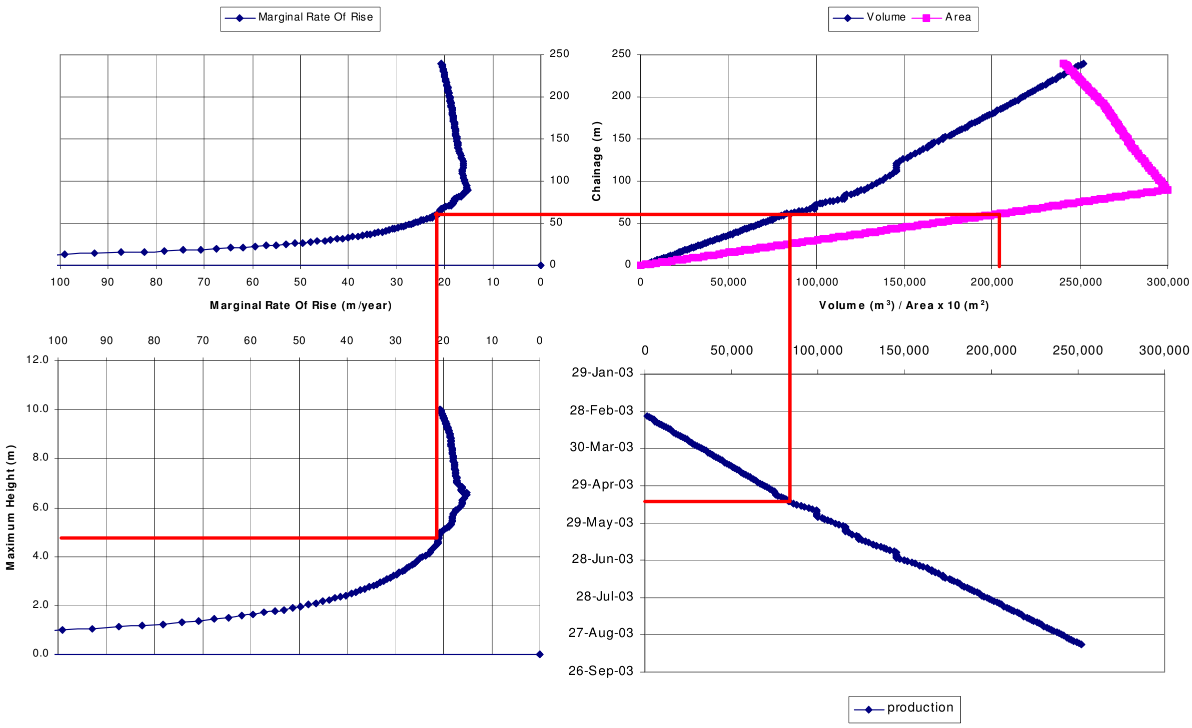

Figure 1.4-7: Stage-capacity curve for the thickened mound

It is particularly noteworthy that the vertical marginal rate of rise is generally of the order of 20 m per year. This has been achieved with no evidence of slumping, cracking or excessive seepage at the advancing toe.

1.4.4 Density control

To achieve the above special care was taken to ensure that only thickened tailings was discharged on the trial mound. A by-pass arrangement that was triggered as soon as the density dropped below a slurry relative density of 2 (70% solids) was incorporated into the flow control system. Flushing was kept to the minimum required to ensure that the delivery line would be clear enough to erode free on re-direction of the slurry to the trial area.

On average, over the duration of the trial, the slurry density has been maintained at an average of 2.06 (72% solids) with regular excursions to 76% solids.

1.4.5 Piezometric measurements

The mound has been instrumented using both standpipe piezometers as well as pore pressure transducers. The latter have experienced zero drift or failed scoring yet another victory for simplicity. The piezometers comprise PVC pipe slotted over the bottom 1m and covered with a geofabric sock. Figure 1.4-8 shows the locations of the piezometers and Figure 1.4-9 shows typical standpipe piezometer readings.

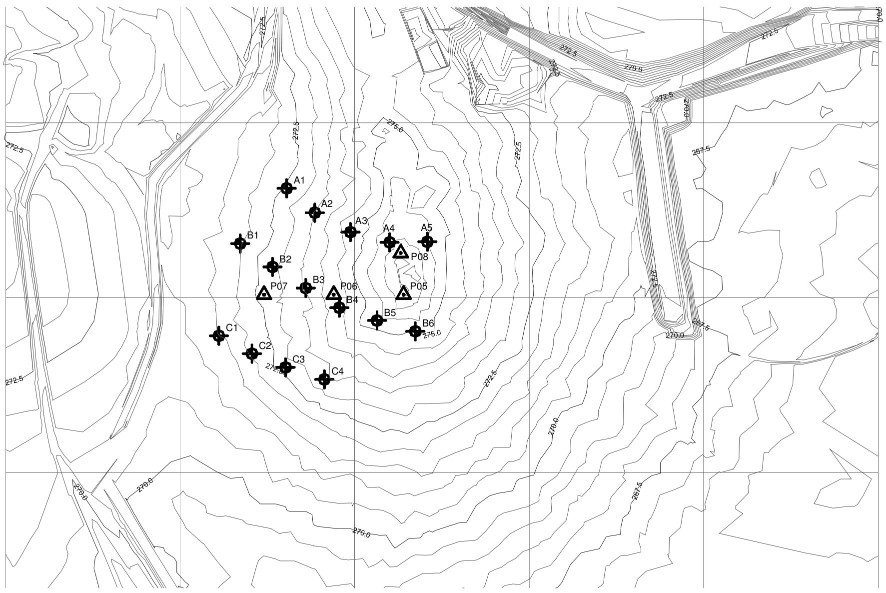

Figure 1.4-8: plan of thickened mound showing locations of piezometers (crosses) and piezometer cone soundings (triangles)

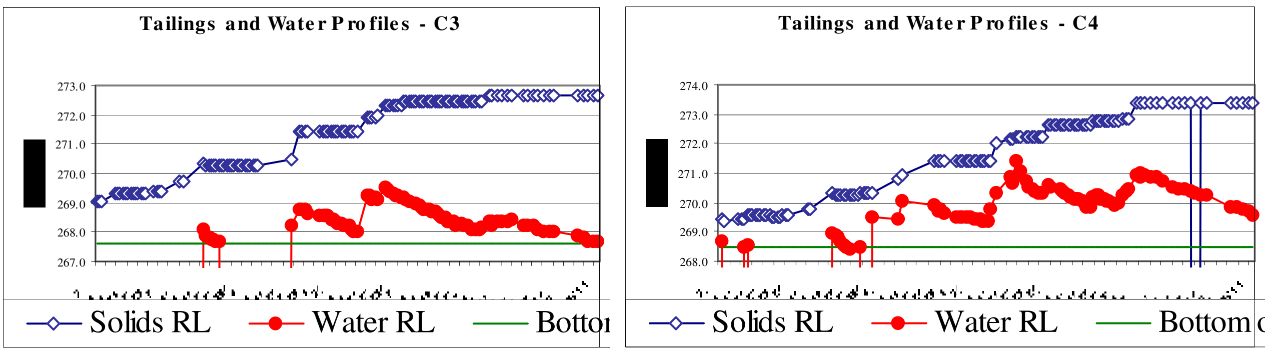

Figure 1.4-9: Typical standpipe piezometer measurements tracked against changes in tailings elevation at the standpipe

The rise and dissipation of the water levels is clearly evident from the piezometers; during deposition particular attention was paid to the extent to which piezometer levels recovered between deposition episodes as well as to the rising trend in the dissipated water level. It is also evident that the tailings coped well with the rates of rise in excess of 20 m per year.

1.5 TAILINGS GEOTECHNICAL ASSESSMENTS

In the course of the trial samples were collected from the tailings beach and submitted for geotechnical testing to Pretoria University where particle size distributions were determined stress path testing and consolidation testing was carried out. In addition field density tests were conducted by local laboratory personnel. The sections below summarise pertinent results.

1.5.1 Critical state testing

A vital issue in respect of the method of placement of the thickened tailings is that of liquefaction induced by slope failure. It is common to assess liquefaction potential by determining whether the material is contractive. Stress path testing in the method described by Papageorgiou [2] was conducted.

The stress path testing confirmed that the tailings could be contractive if at sufficiently high void ratio. The tests were conducted on loose hand-tamped samples, saturated, consolidated and then tested undrained with pore pressure measurements. Figure 1.5-1 shows the stress paths for tests at a range of initial densities and Figure 1.5-2 shows the initial and final void ratios as well as the derived critical state line.

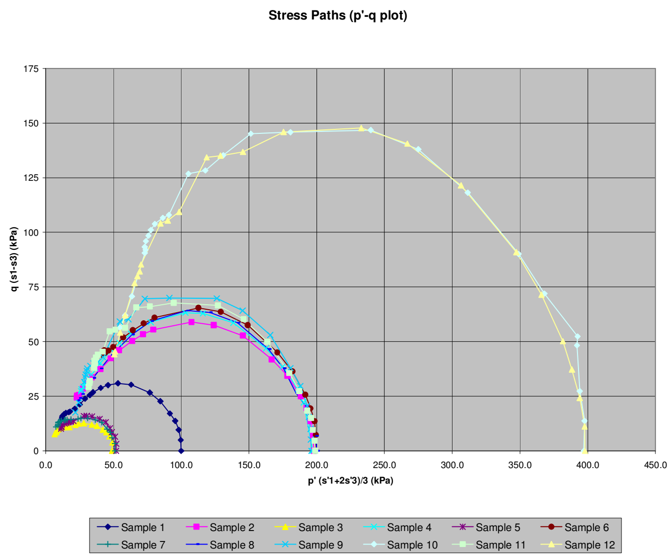

Figure 1.5-1: Stress path testing at a range of initial densities

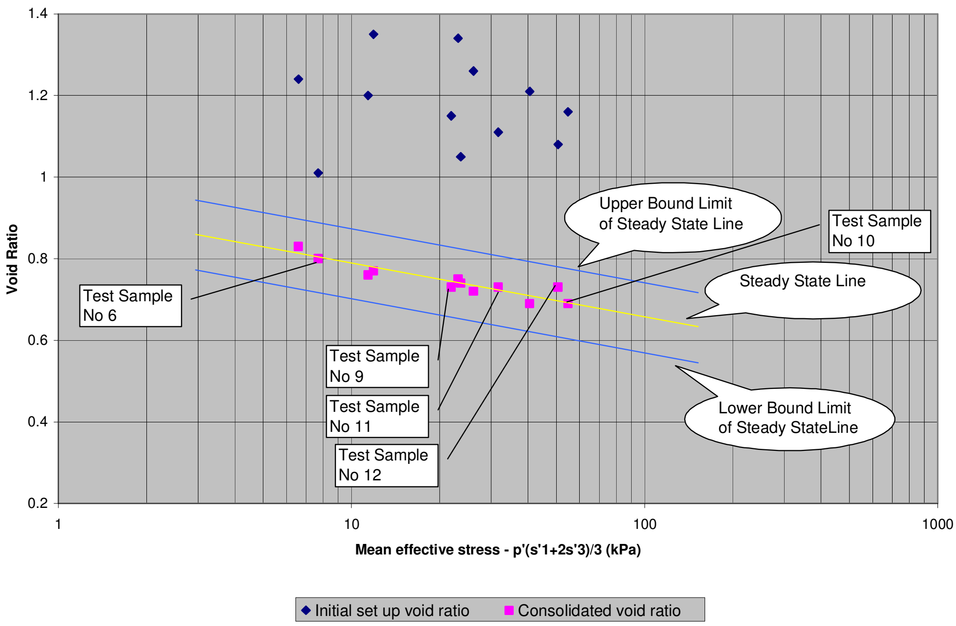

Figure 1.5-2: Critical state line

Tailings at stress and void ratio states that plot below the envelope indicated in Figure 1.5-2 are considered dilatant while those that plot above the envelope are considered contractive. Tailings that plot within the envelope are considered semi-contractive.

1.5.2 Rowe cell testing

To assess the likely stress state of an initially slurried sample of tailings undergoing drained consolidation testing was conducted in a Rowe Cell. This approach allows the determination of consolidation coefficients and permeabilities at a range of stress states and also allows the determination of the consolidated void ratio at each stress.

Figure 1.5-3 shows void ratio vs square root of time plots for an initially slurried sample of tailings from which the coefficient of consolidation and the permeability at each stress state were determined as indicated in Table 1.5-1

Figure 1.5-4 below shows the consolidation curve for the initially slurried sample.

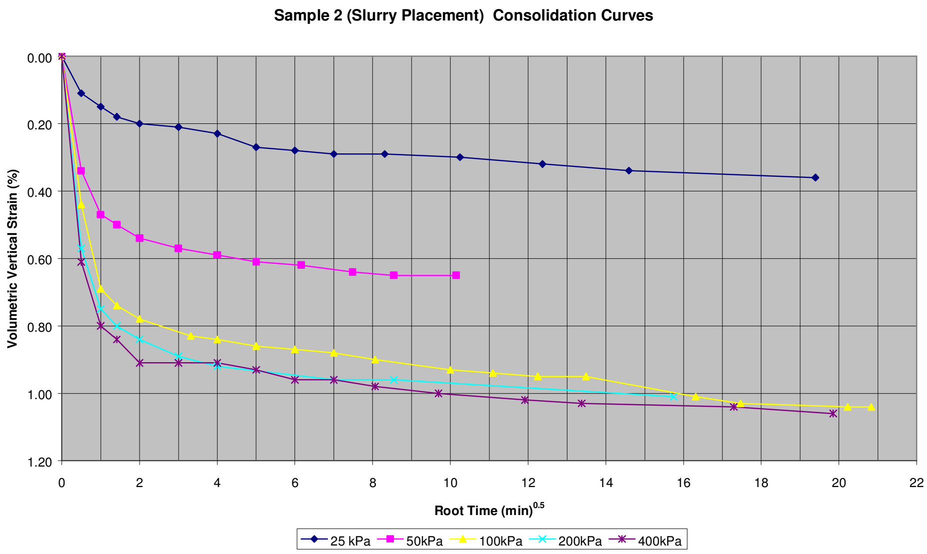

Figure 1.5-3: Void ratio vs Root time curves from the Rowe Cell

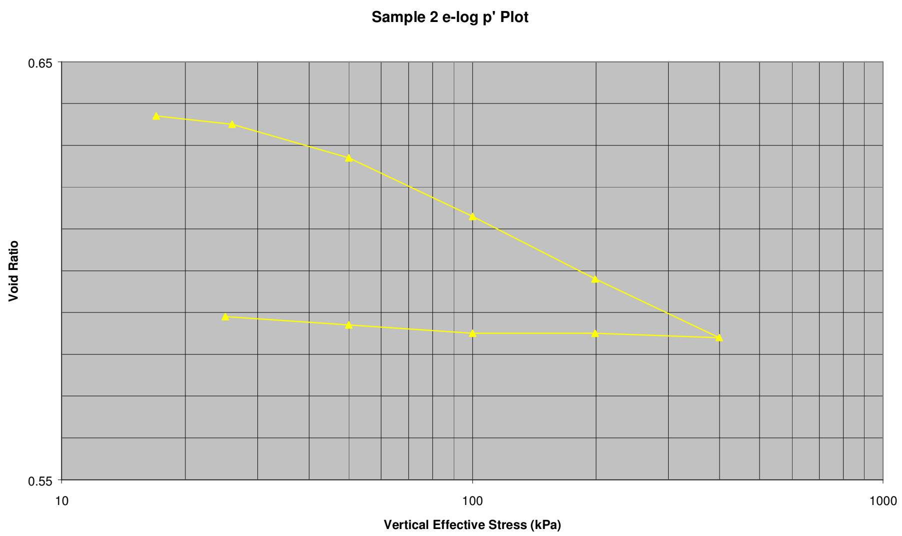

Figure 1.5-4: Consolidation curve from the Rowe Cell

Table 1.5-1: Coefficients of consolidation and permeabilities from the Rowe Cell tests

Vertical effective stress (kPa)	t_{90} (min)	C_v (m^2/yr)	k (m/s)
25	0.77	13362	8.5 x10^{-7}
50	1.32	7736	4.9 x10^{-7}
100	1.42	7224	3.9 x10^{-7}
200	1.27	8083	2.4 x10^{-7}
400	1.39	7347	1.0 x10^{-7}

The following points are noteworthy given the fine-grained nature of the tailings:

- The coefficients of consolidation are high, indicating that the tailings drain well. This is in line with insitu observations.
- The permeabilities are relatively high – approaching that for a fine grained sand at low stress levels.

1.5.3 Assessment of liquefaction potential

To assess the liquefaction potential of the tailings the consolidation test results were plotted together with the critical state points. The vertical stress in the consolidation test was used to determine the parameter p' using the equation:

$$p' = [\sigma_v' * (1+2K_0)]/3$$

where σ_v' is the vertical effective stress in the odometer and K_0 the coefficient of earth pressure at rest which is equal to 0.425 for an effective angle of friction of 32 degrees, a value representative of the tailings based on past testing..

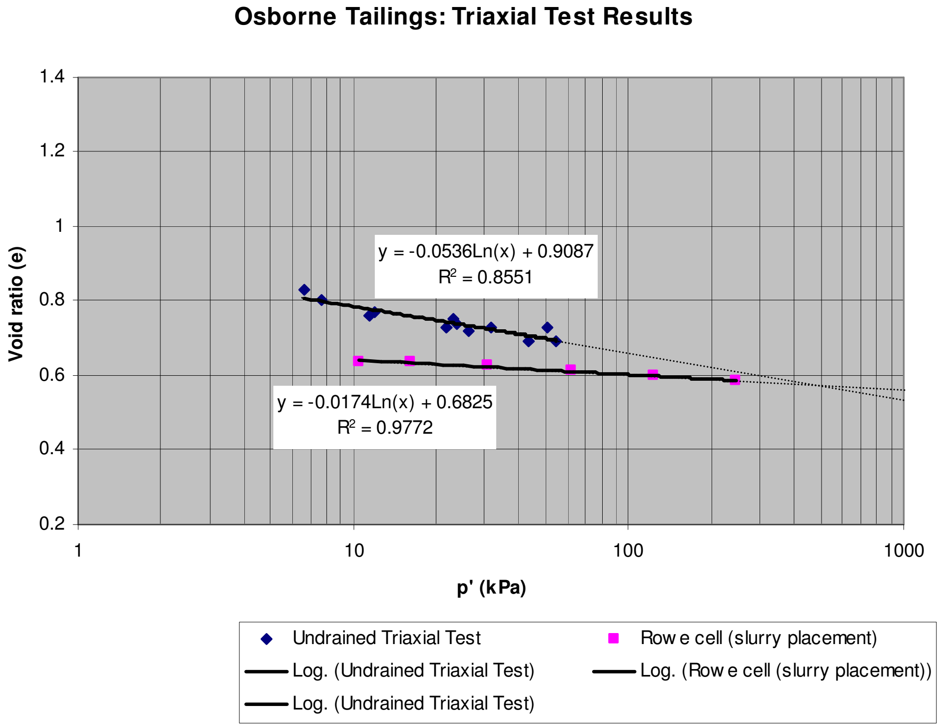

Figure 1.5-5: Plots of the critical state and the 1-D consolidation data

The following conclusions are drawn from an assessment of the results:

- The slurried sample is in the dilatant range stress state from the outset of the consolidation test.
- The slurried sample enters the semi-contractive range at a p' of 80 kPa (σ_v' = 130 kPa which at a density of 2.2 t/m^3 is approximately 6m of tailings)
- An extrapolated consolidation line meets an extrapolation of the critical state line at p' = 500 kPa (σ_v' = 810 kPa which at a density of 2.2 t/m^3 is approximately 37.5 m in height.)
- Since the maximum tailings slope height will be less than 37.5m the tailings is unlikely to cross the extrapolated intersection point and will therefore, at worst, exist in a semi-contractive (but nonetheless dilatant) state.

There is scope for considerable discussion in regard to the above since it is arguable whether simple extrapolation of the consolidation and critical state lines is valid. Unfortunately it is not possible to extend the stress path testing to beyond the stress levels indicated due to equipment limitations. These limitations are common to almost all commercial and university labs and relate to the maximum pressure in the triaxial cell apparatus.

The authors consider it inconceivable that a dilatant granular milled hard-rock material would become contractive at high stress unless the stress is high enough to cause the particles to crush. In the case of Osborne tailings this is likely to be at stresses in excess of 1 MPa.

Based on the above it is deduced that the tailings is unlikely to liquefy.

1.6 PIEZOCONE MEASUREMENTS

To verify the consolidation parameters measured in the lab as well as provide a check on the piezometer measurements four piezometer cone soundings were carried out in the tailings at the locations indicated in Figure 1.4-8. The results for the soundings at the deepest tailings locations are indicated in Figure 1.6-1 and Figure 1.6-2.

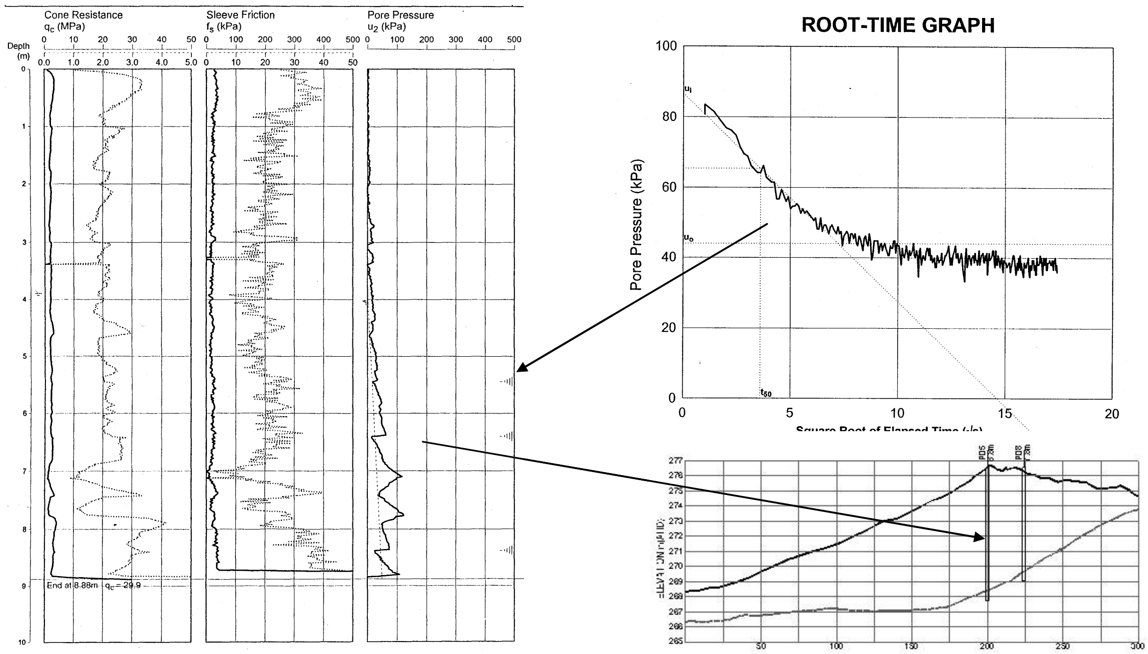

Figure 1.6-1: Piezometer cone sounding results at a location 40m behind the crest point

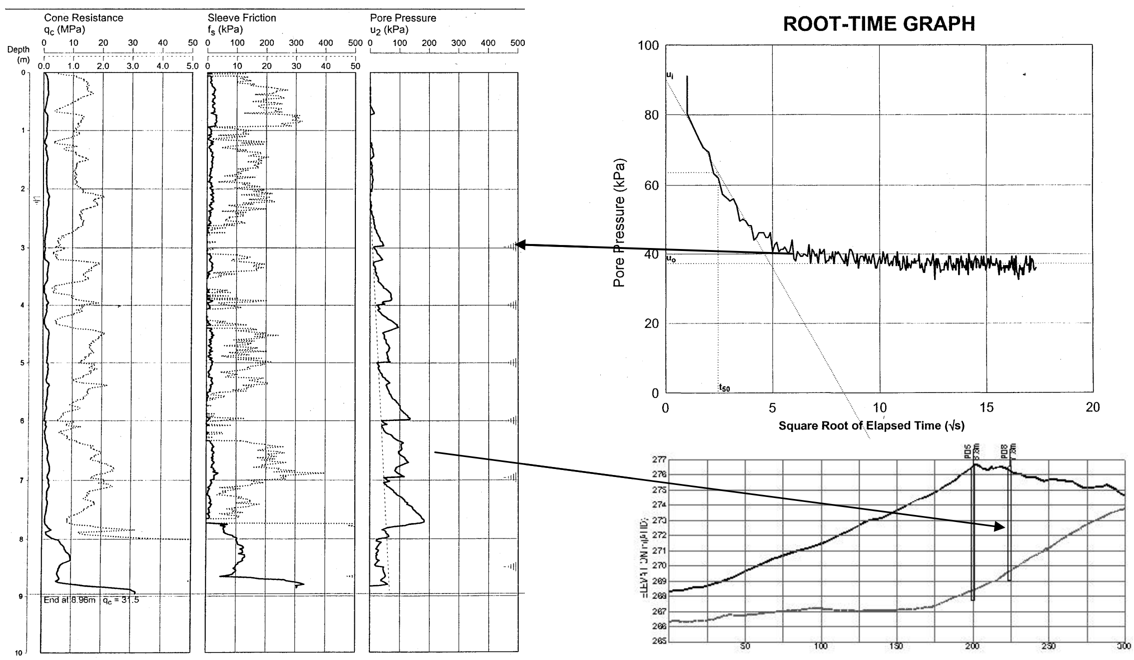

Figure 1.6-2: Piezometer cone sounding results for a test at the crest point

The following points are noteworthy from an assessment of the piezometer cone results:

- There is no sign of excess pore pressure
- Dissipation rates are similar to those measured in the Rowe Cell which indicates that the lab test is reasonably representative of the field situation
- Water pressures in the slope are in reasonable agreement with the standpipe piezometers.
- The cone resistance is greater than 0.5 MPa and, in the case of the sounding at the crest point, is generally 2 MPa. It is interesting to note the soft zones in the sounding back from the crest. This is attributed to variations in the slurry in the course of the trial.

1.7 SEEPAGE ASSESSMENTS

The average placed tailings relative density has been 2.06 (72% solids). This implies a water content of the tailings immediately after deposition of a maximum of 28%. There is some run off/bleeding but the majority of the water is initially locked up as interstitial water. The key question is how much of this water seeps down to the phreatic surface and how much is drawn back out of the mass through evaporation. To obtain a macro estimate of the recharge rate to the phreatic surface a seepage model of the mound was generated. The program SEEP/W was used with axi-symmetric settings. Figure 1.7-1 shows the calibrated section.

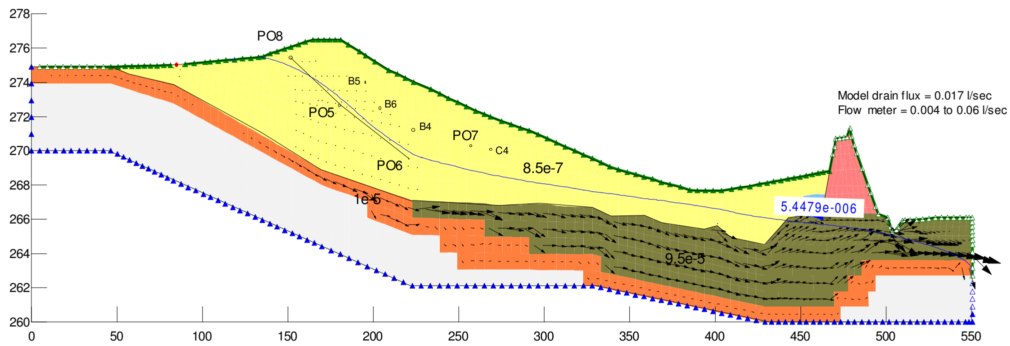

Figure 1.7-1: Calibrated seepage model (vertical scale exaggerated)

To achieve calibration influx rates from the beach face were varied and seepage pressures compared with the piezometer and piezocone measurements. It was found that while foundation conditions were central to the predicted profile of the phreatic surface it was the infiltration rate that determined its location.

The following points emerged from the seepage modelling:

- A reasonable calibration could be achieved with both piezometers as well as piezocone measurements.
- The infiltration rate is less than 1% which indicates that most of the water movement that takes place is through evaporation from the deposited mass.

The seepage modelling provides confirmation that with thickened discharge rates the seepage is reduced by between a half and one order of magnitude.

1.8 SLOPE STABILITY ASSESSMENTS

Application of the consolidation and seepage data to slope stability analyses has shown that factors of safety are above 2 and probabilities of failure below 1 in 10,000 even for very conservative assumptions on pore pressures, drainage conditions and shear strength. This is in keeping with the flat slope angles that are generated by the thickened tailings mound.

1.9 EROSION ASSESSMENTS

Erosion of the beaches of tailings placed at 50% solids is known to be very low. The thickened mound, on the other hand, is considerably steeper and the question of erosion of these slopes both during operation as well as after decommissioning needs to be assessed. To this end erosion testing and modelling has been carried out. The erosion testing has been carried out by Landloch Pty Ltd and Australian consultancy specialising in field measurements of erosion rates. Field measurements are carried out using a rainfall simulator which has been designed to ensure that the kinetic energy transmitted by the simulated rainfall is similar to natural rainfall. Gulleying is assessed by over-land flow tests. Figure 1.9-1 below shows the testing on both tailings as well as material that would be sued as topsoil or "growth medium". In both test types sedimentation samples are collected at short time intervals and flow rates accurately measured.

Figure 1.9-1: Rainfall and gulley erosion simulations (top is tailings and bottom is growth medium)

The results of the field measurements are used to derive erosion parameters that have been applied in the dynamic erosion modelling program SIBERIA. SIBERIA models long term landform evolution and works with a digital terrain model (DTM) of the surface. The DTM is adjusted with each iteration in the simulation which means that the model is able to simulate gulley formation.

Figure 1.9-2shows an isometric view from the DTM of the potential thickened tailings facility before erosion simulation. Figure 1.9-3 shows an isometric view of the DTM after 500 years of erosion on the bare tailings surface. It is evident from the isometric that there has been erosion of the confining embankment and spillage of eroded tails over the crest of the eroded confining embankment. The pool wall has also been swamped. Not withstanding these observations the cross-section in Figure 1.9-4 shows that erosion depths on the tailings surface are less than 500 mm over a 1,000 year simulation. This low erosion is attributed to the fact that the thickened tailings mound largely mirrors the slopes found in the surrounding country.

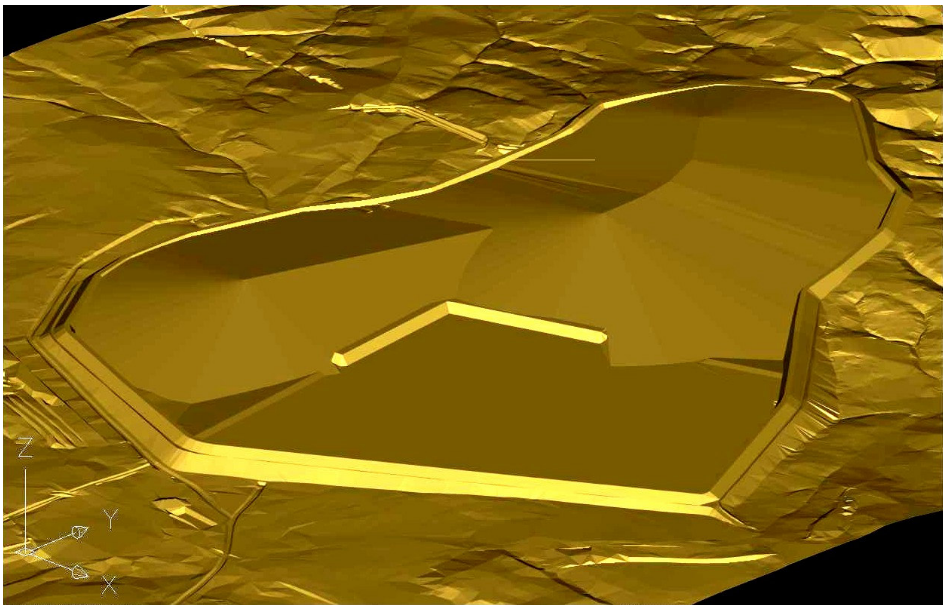

Figure 1.9-2: Isometric of thickened tails facility prior to erosion simulation

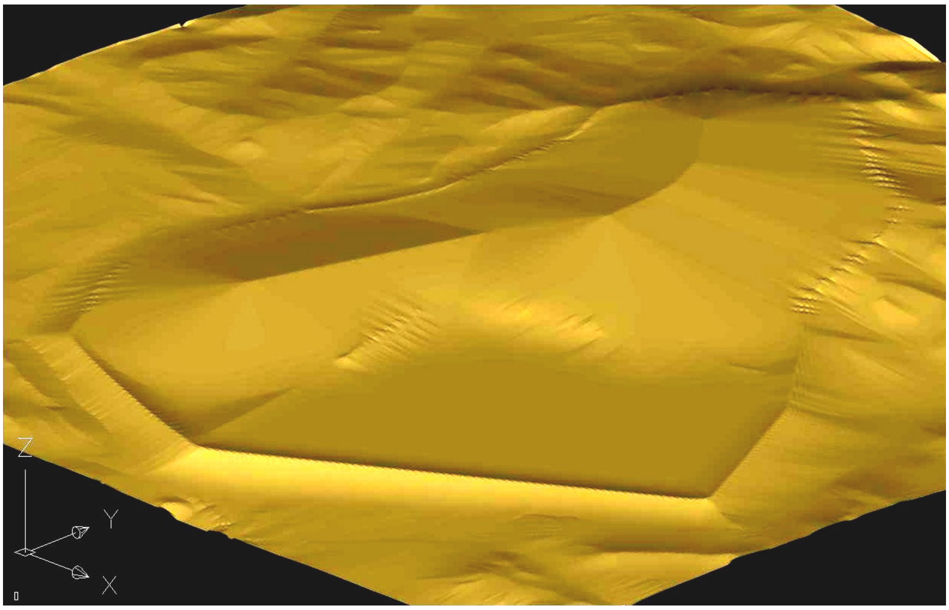

Figure 1.9-3: Isometric showing erosion of the tailings after 500 years of simulation

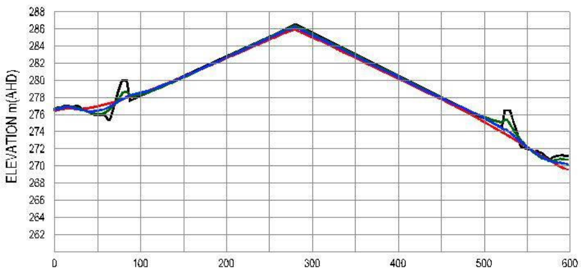

Figure 1.9-4: Section through tailings mound after erosion simulation

(green=200 years, blue=500 years, red=1,000 years)

Figure 1.9-5 shows an isometric of the DTM after 500 years of simulation for a situation where the tailings mound is covered with growth medium. It is evident from the isometric as well as the section shown in Figure 1.9-6 that erosion depths are considerably reduced. The growth medium is representative of the cover materials in the surrounding country. It is only the embankment slopes that show excessive erosion. The high erosion above the pool wall is induced by erosion of the pool wall itself.

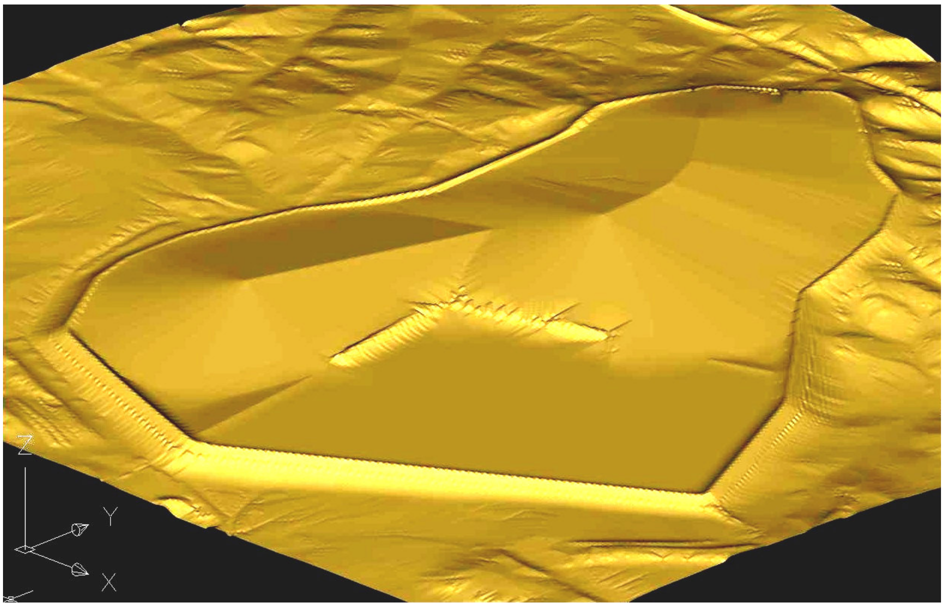

Figure 1.9-5: Isometric showing eroded mound with a cover of growth medium

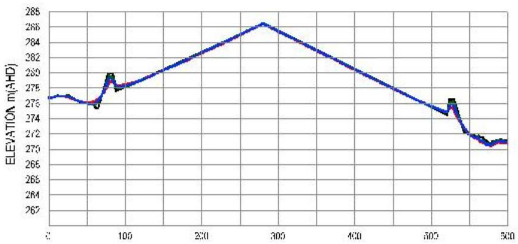

Figure 1.9-6: Section through tailings mound with growth medium cover after erosion simulation

(green=200 years, blue=500 years, red=1,000 years)

To place the Erosional performance in context Figure 1.9-7 shows an isometric of the old tailings dam after 500 years of erosion simulation based on the same parameters as used for the thickened tailings mound with growth medium cover. The influence of the steepness of the slopes of the confining embankments is clearly evident.

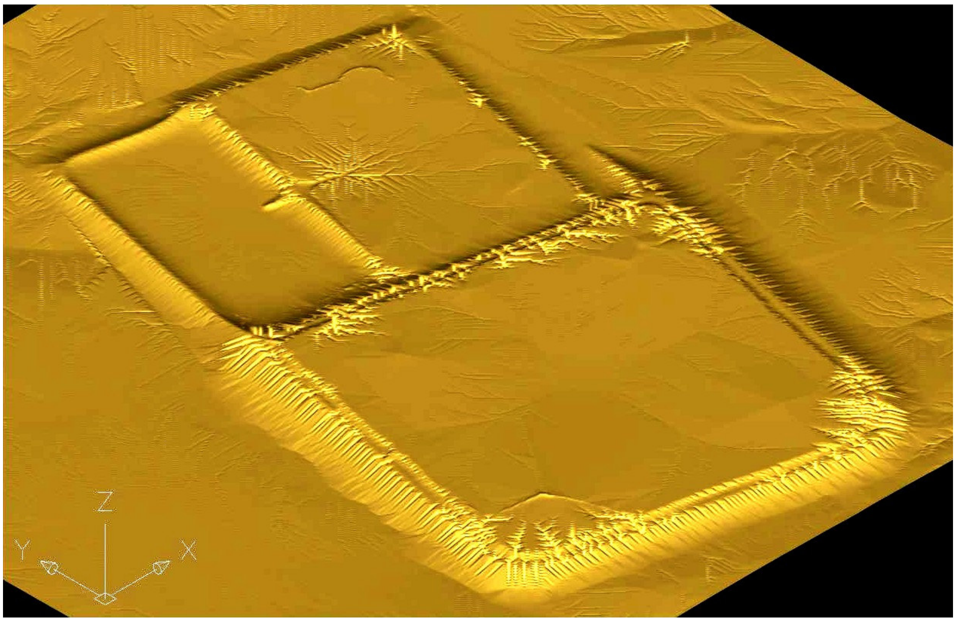

Figure 1.9-7: Isometric showing erosion after 500 years simulation on old tailings dam

It is concluded from the above that the thickened tailings mound is likely to perform considerably better than a conventional tailings dam with 1 in 3 outer slopes of similar height.

1.10 TAILINGS OPERATION EXPERIENCES

1.10.1 Plant and Equipment Changes

A summary of the modifications to the plant which were made to allow production of high density tailings were as follows:

- Tuning of all control loops from grinding through floatation and tailings to allow stable operation at desired density.
- Reduction in tailings cyclone spigot sizes from 70mm to 57, 51, 47, 45 and 41mm to increase underflow density and send more solids to the thickener.
- Tailings thickener feedwell deflector cone gap increased from 140mm to 280mm to handle increased flow to thickener.
- Modifications to the thickener underflow cone and piping to remove obstructions and allow freer gravity flow of underflow stream.
- Installation of higher ranging bed mass gauge in thickener.

- Installation of density gauges in thickener underflow line and tailings pipeline to allow closer monitoring of operation and targeting of specific densities.
- Change of type of flocculant to better suit duty and allow higher density underflow.
- Installation of second flocculant sparger in thickener feedwell.
- (Planned) Installation of flow meter in thickener underflow line.

Total cost of plant changes approximately $16 000. Instrumentation accounts for approximately $13 000 of this. This cost is for equipment only and doesn't include temporary trials.

1.10.2 New Dam Pumping and Piping System

Several aspects of the new dam pumping and piping system were designed specifically to suit the pumping and deposition of high density tailings. These included:

- Pipeline diameter and pressure rating designed specifically to suit both high density tailings and "normal" density.
- Installation of flow meters at plant and at valving station on dam wall to give indication of line blockages and ruptures.
- Installation of pressure gauge at valving station.
- Increased capacity of flushing system to allow lines to be cleared.
- Installation of a camera to monitor flow from spigots.
- Installation of emergency tailings pipeline to minimize impact of potential line blockages.

1.10.3 Operational Changes

The production and deposition of high density tailings have required a number of operation changes and strategies to be developed to minimize potential for line blockages and to allow for most efficient deposition. Some of these strategies and changes are as follows:

- Operating thickener with higher bed mass and flocculant dosage.

- Operating tailings hoppers at low levels to prevent build up and subsequent slumping of solids in the hoppers.
- Increased monitoring of operation with respect to densities, flows and pressures.
- On high density spigots a y-piece needs to be installed as close as practical to the deposition point to allow flushing of the line without excessive scouring of the high density beach. The entire line can then be flushed to this point, after which only a brief flush of the spigot is required.
- Strategies are in place for stopping deposition at a high density spigot should the density fall. This occurs immediately if the plant is shut down unexpectedly or if some major change occurs and also happens if the density drifts low for around half an hour and efforts to increase the density are unsuccessful.
- More regular monitoring and replacement of tailings cyclone spigots to ensure optimum density is maintained.
- Operational strategies to increase the tailings density if it drops are primarily related to the cyclones. A cyclone is turned off if possible, or if not possible then a combination of cyclones with smaller spigot diameters is put on line. The bed mass in the thickener can also be raised and the flocculant dosage increased.

1.10.4 Performance

The performance of the plant is reasonably steady with densities of between 72% and 76% solids able to be obtained for the majority of the time. Occasionally there is a difficulty in maintaining density which is attributed to a different SG or ore due to ore type changes. While the density drops, the performance at the dam may not necessarily be impaired. Test work is continuing to assess how the density impacts the deposition behaviour with different ore types.

The pipe loop test work allowed the pumping pressures required to be predicted. When this exercise was conducted the pressures calculated were obviously too high based on operational data from pumping to the old dam. A number of iterations of calculations were conducted after which a scale up factor from the pipe loop test work was arrived at. Use of this scale up factor effectively calibrated the theoretical numbers based on operational history to calculate a number which matched experience. While pumping to the old dam this was able to be checked by changing to more distant spigots and measuring the pressure change experienced by increasing the pumping distance. If the numbers from the pipe loop test work had been used to size equipment for a greenfields operation, then the predicted pressures would have been much too high. The scaling factor used from the test work was 0.38. The predicted pressures using this scaling factor matched very closely with those obtained after commencing pumping to the dam.

The predicted pressure drops after applying the scaling factor were in the range of 0.28 – 0.46 kPa/m in the density range of 68% to 75% solids. These correspond to pressures of around 400-680kPa at the furthest spigot, which are right in the range of the operating data. The test work indicated that at densities exceeding 76% solids the pumping performance would drop markedly with pressure drop per metre increasing rapidly. This is validated by operational experience. If the density increases above around 76%-78% solids for any length of time then the flow begins to drop in the pipeline and the pipe starts to sand up. If this is not noticed and remedied quickly the flow drops completely and the emergency line must be switched to while the duty line is flushed. To date this has occurred several times, so far the line has always been able to be cleared by flushing water and the line has not had to be split along the length to allow clearing.

1.10.5 Water savings

Implementation of thickened discharge over the trial period has shown that significant reductions in water lass are achievable. The simplified water balances shown in Figure 1.10-1 and Figure 1.10-2, which are prior to and after implementation of the thickened trial respectively, indicates a reduction in borefield abstraction from 81 m^3/hr to 51 m^3/hr, a reduction of 37% based on an achieved average percent solids in February 2004 of 75%. This reduction is will increase further in the event of a decision to proceed with thickened discharge beyond the trial since it will be possible to direct a proportion of the process water underground to drive hydraulic equipment and, in so doing, displace borefield water.

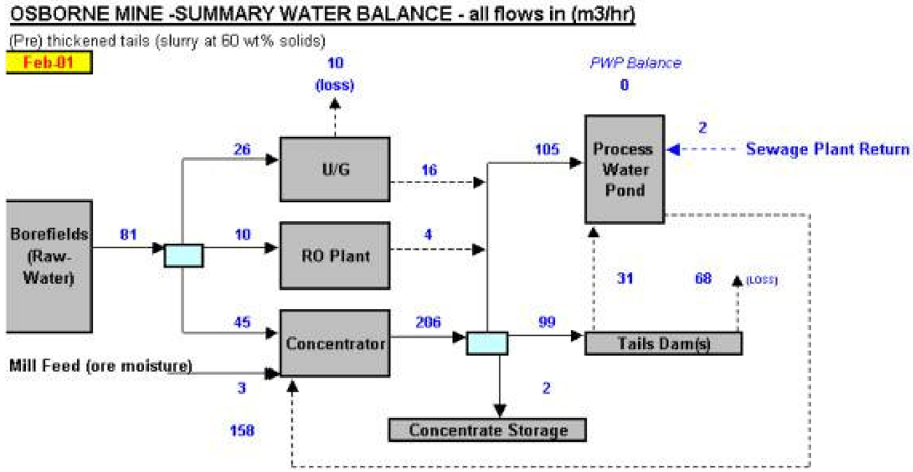

Figure 1.10-1: Simplified water balance prior to the thickened trial

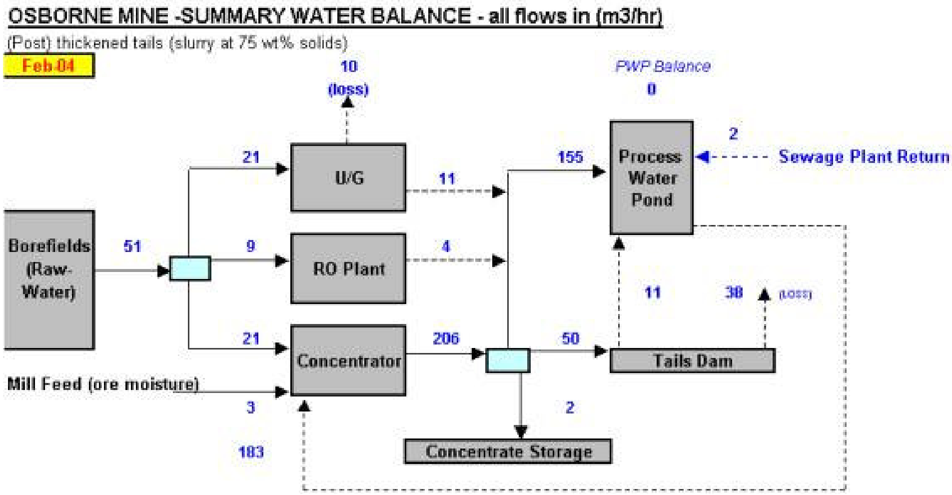

Figure 1.10-2: Simplified water balance during the thickened trial (which is on-going)

1.10.6 Operating and cost benefits

The benefits of high density tailings deposition include:

- Storage of tailings in elevated beaches above the height of the dam wall means that the wall needs fewer lifts to store the same volume of solids, leading to considerable savings in wall construction costs. It is estimated that these savings may be in the order of $2.5 million over the 6 year life of the dam.

- High density tailings deposition leads to an increase in the in-situ density of the tailings which allows a greater mass of tailings to be stored in the same volume, which also contributes to a saving in wall construction costs.
- Reduction in pumping power. Most of the reduction in power in pumping to the new dam is related to the closer distance and lower elevation, but the reduction in flow to the dam will translate to a saving in power. It is estimated that this is equivalent to around a 30kW saving, which at a power cost of $0.13 / kWhr translates to a saving of around $30,000 per year.
- Reduction in water losses. The quantity of water deposited in the dam at 75% solids is around 500,000 cubic metres per year, compared to around 1,200,000 cubic metres at 55% solids. The reduced quantity of water sent to the dam has to result in a reduction of losses through entrainment in the dam and evaporation. It is difficult to quantify this gain but based on flows from the borefields it is likely that the reduction in losses is around 30,000 cubic metres per year. Each cubic metre of water from the borefield costs around $0.36 to pump to site so this translates to a saving of some $11,000 per annum.
- The reduction in water losses has a direct cost saving, but the reduction in water drawn from the borefields also has significant benefit in terms of responsible environmental behaviour and a reduction in post closure costs until the level in the artesian aquifer is restored.
- Reduction in return water pumping. With the reduced quantity of water deposited ion the dam, the pumping requirement to return this water to the process water pond is reduced. It is estimated that this saving is in the order of $10,000 per year.
- Reduction in pump maintenance. Again most of this is related to the changed duty, but the reduced flow at higher densities means slower pump speeds which will have some saving. It is estimated that the total pump maintenance savings are around $45,000 per year of which perhaps $5,000 is attributed to the higher density.

The sum of the smaller benefits is around $56,000 per year, but clearly the main benefit is the potential to save $2.5 million in wall raise costs.

1.11 LONG TERM PLANNING

The trial results have prompted Osborne to commission long term planning on the basis of thickened discharge so as to evaluate more fully the benefits and implications. This, together with detailed reports on the geotechnical, water management and erosion aspects will form the basis for approaching the regulators for necessary approvals. As with all mining operations a range of life of mine tonnage scenarios exist as exploration is on-going. Figure 1.1-1 below shows the potential geometry and the broad deposition sequence for one of these scenarios. As there are intermittent backfill operations underground during which unthickened backfill plant overflow needs to be deposited in the conventional tailings deposition area this has been retained at a scale to allow flexibility. This is the clear area indicated in each picture in Figure 1.1-1. The conventional area also accommodates tailings deposition during periods when thickened tailings production is disrupted.

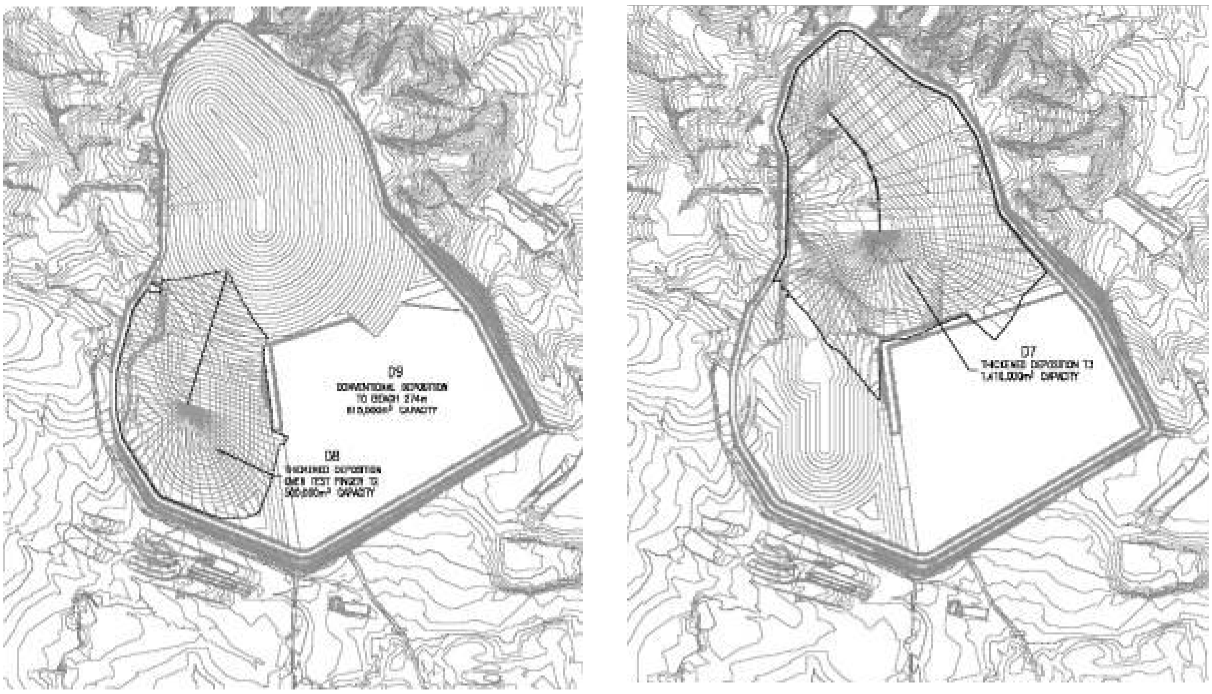

Figure 1.11-1: Potential long term thickened tailings deposition geometry at Osborne

The scenario above formed the base DTM for the erosion assessments described previously.

1.12 CONCLUSIONS

From the thickened discharge trial and assessments summarised in this paper it is evident that there are considerable merits in implementing thickened discharge. Not only are there significant reductions in capital expenditure and water use but there are improved operating conditions. The tailings mound presents less of an issue with regard to erosion management both during operation as well as after closure. It has been shown by the geotechnical assessments that there will be less potential for seepage into the foundation materials and geotechnical risks will be manageable.

Thickened discharge has shown potential to bring about the above benefits since technology began to make it possible to thicken to appropriate densities reliably as well as to pump the thickened slurry. The assessments documented in this paper provide tangible evidence that this potential is realisable.

1.13 ACKNOWLEDGEMENTS

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