



Old Tailings Storage Facilities (South Shaft and Twin Shaft TSFs) Design Basis Report

South Deep Gold Mine

Gold Fields Limited

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Basis of Report

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Acronyms and Abbreviations

AE	Accountable Executive
AEP	Annual Exceedance Probability
ANCOLD	Australian National Committee on Large Dams
BAW	Beach Above Water
CDA	Canadian Dam Association
CPTu	Cone Penetration Test (with pore pressure measurement)
CRR	Cyclic Resistance Ratio
CSR	Cyclic Stress Ratios
DBR	Design Basis Report
DWS	Department of Water and Sanitation
EoR	Engineer of Record
FoS	Factor of Safety
GFL	Gold Fields Limited
GISTM	Global Industry Standards on Tailings Management
GSI	Geological Strength Index
ICMM	International Council on Mining and Metals
ICOLD	International Committee on Large Dams
LL	Liquid Limit
LoM	Life of Mine
LS	Linear Shrinkage
MCE	Maximum Credible Earthquake
MDE	Maximum Design Earthquake
OBE	Operating Basis Earthquake
OCR	Over Consolidation Ratio
PGA	Peak Ground Acceleration
PI	Plasticity Index
PMP	Probable Maximum Precipitation
RoR	Rate of Rise
RTFE	Responsible Tailings Facility Engineer
RWD	Return Water Dam
SANS	South African National Standard
SDGM	South Deep Gold Mine



SEE	Safety Evaluation Earthquake
SLR	SLR Consulting (South Africa) Pty Ltd
TMP	Tailings Management Plan
TSF	Tailings Storage Facility
UCS	Unconfined Compressive Strength
WGS 84	World Geodetic System 1984

Units

%	Percentage
c'	Effective/Drained Cohesion
C_u	Coefficient of Uniformity
C_v	Coefficient of consolidation
C_{max}	Maximum bed packing concentration
C_{free}	Freely settled bed packing concentration
hr	Hour
m	Metre(s)
m_i	Empirical Strength and Brittleness Parameter for Intact Rock
m/s	Metre(s) per Second
m/yr	Metre(s) per Year
m^3	Cubic Metre(s)
mm	Millimetre(s)
μm	Micrometer(s)
S_u	Undrained shear strength
S_u/σ_v'	Peak Undrained Shear Strength Ratio
S_r/σ_v'	Residual/Post-peak Undrained Shear Strength Ratio
t/m^3	Tonne(s) per Cubic Metre(s) (Density)
tpm	Tonne(s) per Month
ϕ'	Effective/Drained Friction Angle
ϕ'_{res}	Residual Effective Friction Angle
ϕ'_{CS}	Critical State Effective Friction Angle



1.0 Section 1: Purpose

The Global Industry Standard for Tailings Management (GISTM 2020) has introduced a formalised and thorough approach to the management of TSFs over their life cycle. Part of this entails the generation of specific documents, one of which is the requirement to produce a Design Basis Report (DBR). The DBR is a document that provides information on the baseline site conditions and characteristics, the design assumptions, design criteria, operational constraints, and performance criteria.

The Gold Fields Standard, "Group TSF Management Standard", dated January 2023, which aligns with the Global Industry Standards on Tailings Management (GISTM, 2020) calls for the Site Characterisation report and the DBR to form two separate reports. Therefore, only the design assumptions, design criteria and operational constraints are documented in the DBR. During the development of the DBR, the site characteristics report was still being prepared separately and will be referenced in the DBR update.

GISTM (2020) is a governance standard and not a technical design standard, so it does not provide guidance, stipulate, or prescribe:

- a) Technical design methods and approaches to follow.
- b) Acceptable output to be adopted from a design process, e.g. acceptable side slope factors of safety, acceptable seepage rates from a lining system, and deformation/settlement tolerances.
- c) Operating procedures.

Over and above defining good governance measures, the GISTM does, however, stipulate the loading criteria that should be adopted for storm and seismic events based on the TSFs Consequence Classification rating. Design methods and performance objectives are based on adopting international best practices, such as ICOLD design bulletins, Australian National Committee on Large Dams (ANCOLD) Guidelines (2019), SANS 10286, and Canadian Dam Association (CDA) design recommendations.

Conformance to GISTM (2020) or design standards like ANCOLD (2019) does not override local legislative requirements. Therefore, the design process must include checks to determine the most stringent guidelines, codes, or regulations. Generally, the final design must apply the most stringent requirements.

This DBR document has been structured into the following sections:

- Section 1: Purpose (this section).
- Section 2: Background Information.
- Section 3: Design Approach and Design Criteria.
- Section 4: Design Performance Requirements.
- Section 5: Operational Requirements.
- Section 6: Legal Conformance, Reference Standards and Guidelines.



2.0 Section 2: Background Information

South Deep Gold Mine (SDGM) is owned and operated by Gold Fields Ltd (GFL) and is located in Westonaria, South Africa (see Figure 2-1). There are five TSFs at SDGM, namely:

- TSF 1 and TSF 2 (South Shaft TSFs),
- TSF 3 and TSF 4 (Twin Shaft TSFs) and
- Doornpoort TSF.

The Old TSFs, i.e., South Shaft and Twin Shaft TSFs (see Figure 2-2), were commissioned in 1968 and 1982, respectively, and the Doornpoort TSF was commissioned in April 2011. TSF 1 and TSF 2 are currently undergoing hydraulic remining, TSF 3 and TSF 4 are under care and maintenance, and the Doornpoort TSF is the only operational TSF. TSFs 1 and 2 were originally designed by an unknown company, TSFs 3 and 4 were a “design and construct” project undertaken by Fraser Alexander, and the Doornpoort TSF was designed by WSP (previously Golder Associates) in a joint venture with SLR Consulting (South Africa) Pty Ltd (previously Metago Environmental Engineers (Pty) Ltd) in 2009.

The Old TSFs were initially formed by constructing what was thought to be nominal starter walls along the lower-lying areas. TSF development entailed the staged upstream raising of the tailings over the life of each facility utilising the traditional “day wall” paddock system. Doornpoort TSF was formed by constructing a starter wall along the lower-lying areas of the topography and has been raised above the starter wall in an upstream construction methodology using tailings. No design, operational or construction records are available for the Old TSFs.

This document is the SDGM Design Basis Report for the **Old TSFs** (only) as required by the Global Industry Standard on Tailings Management (GISTM) published in August 2020 (GISTM, 2020). Requirement 4.8 of the GISTM (2020) states the following:

"The EoR [Engineer of Record] shall prepare a Design Basis Report (DBR) that details the design assumptions and criteria, including operational constraints, and that provides the basis for the design of all phases of the tailings facility lifecycle. The DBR shall be reviewed by the ITRB or senior independent technical reviewer. The EOR shall update the DBR every time there is a material change in the design assumptions, design criteria, design or knowledge base and confirm internal consistency among those elements."

There is limited information/historical reports on the Old TSFs pre- and post-commissioning. Nonetheless, this DBR has been compiled using the best available information and discussions with individuals who have knowledge of the Old TSFs. The following details are presented:

- Design approach.
- Design criteria and assumptions.
- Design performance requirements.
- Operational requirements.
- Legal conformance, reference standards and guidelines.



This document must be updated every time there is a material change in the design assumptions, design criteria and design or knowledge base, as stated in GISTM (2020). This includes outcomes from ongoing field and laboratory investigation work, future design modifications, and when modern technologies are adopted in the operation of the facilities.

This DBR has been prepared based on the review of existing reports and input from SDGM. The basis of design serves as a record to document the SDGM Old TSFs design criteria, operational constraints, performance criteria and project decisions.



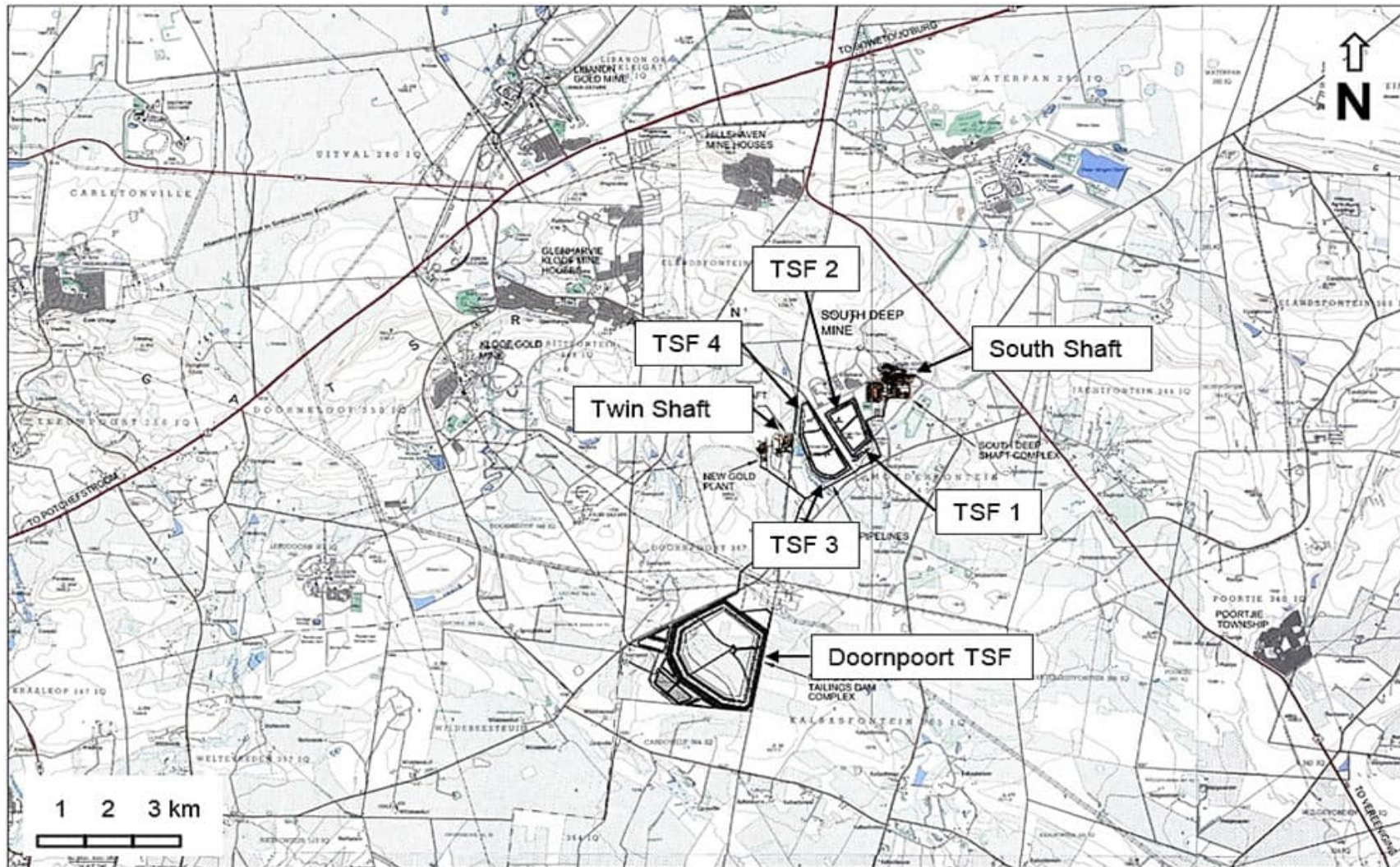


Figure 2-1: South Deep Gold Mine location in South Africa





Figure 2-2: South Deep Old TSFs (Google image dated 04 August 2023)



3.0 Section 3: Design Approach and Design Criteria

3.1 Design Approach

3.1.1 South Shaft TSFs (TSF 1 and TSF 2)

The south shaft TSFs are located southwest of the South Shaft Backfill Plant at 26°24'53.76"(S) and 27°40'35.96"(E). The TSFs were operational from 1968 using the traditional daywall - nightwall method of development that was used in the gold industry at that time. It was understood that around 1995, TSFs 1 and 2 had severe toe seepage problems along the toe of the side slopes and that a waste rock buttress was installed to improve stability. These TSFs were placed under care and maintenance in 2011, at the time when the Doornpoort TSF was commissioned. No tailings have been deposited on these facilities since being placed under care and maintenance. These TSFs are upstream raised day-night wall paddocked TSFs and the height of the TSF's highest point is 46 m (pre-reclamation).

Hydraulic reclamation commenced in September 2015, and the first 10 m of reclamation was completed in September 2018 (see Figure 3-1). After that, hydraulic reclamation of the top (first 10 m) of TSF 2 commenced in September 2018 and was completed in September 2020. The reclamation of the second drop in tailings (total of 20 m from the original top TSF surface for both TSF 1 and TSF 2) commenced in August 2020 after the construction of the second drop-down intake through the TSF wall and was completed in November 2023. The reclamation of the third drop in tailings (total of 30 m from the original top TSF surface for both TSF 1 and TSF 2) commenced in November 2023 after the construction of the third drop-down intake through the TSF wall and is currently still ongoing (refer to Figure 3-2).

The reclaimed slurry tailings are sent to the reclamation pump station on the west side of TSF 1 from where it is pumped to the process plant for gold extraction. Post-gold extraction of the milled underground ore and the reclaimed tailings (two separate metallurgical process circuits within the Processing Plant), the two streams are combined and sent to the backfill plant where either:

- The total tailings product is cycloned to extract a portion of the coarse material out of the total stream that is then sent underground for backfill purposes, while the remainder of the tailings stream is pumped from the backfill plant to the Doornpoort TSF, or
- No cycloning takes place, and the entire tailings stream is pumped from the Processing Plant to the Doornpoort TSF.

The south shaft TSFs (TSFs 1 and 2) have had three drop-down intakes which have all been located on TSF 1. The first and the second drop-down intakes have been decommissioned. The third drop-down intake (approximately 10 m lower in elevation than the first two drop-down intakes (i.e., 30 m below the original top surface of the TSFs) with an associated outlet pipe was constructed approximately in the same location as the first drop-down with the second drop-down being placed approximately 20 m to the south of the first drop-down intake on the southwestern flank of TSF 1. The first drop-down intake was decommissioned in August 2020. The second drop-down intake was decommissioned in November 2023. The third drop-down intake was installed within the basin of the TSF in November 2023.



The old existing elevated penstock on TSF 1 and TSF 2 has been reclaimed and is no longer operational.

A design and method statement for the second and third reclamation drop-down intakes were developed by the operators Stefanutti Stocks Inland (SSI) and reviewed by SLR in March 2020 and September 2023, respectively and have since been installed and constructed. The so-called “swimming pool” sump next to the new (third) drop-down outlet is being formed via the hydraulic reclamation process to its required size (in order to absorb large storm events for compliance with the ANCOLD freeboard requirements). Following the development of the “swimming pool”, the intention is to form a slurry launder from the sump/ swimming pool area to the north-eastern corner of TSF 2 and to reclaim the tailings material on either side of the launder (forming a herringbone shape) which will allow slurry to flow southwards to reach the drop-down inlet.



Figure 3-1: TSF 2 northern corner reclamation via high-pressure water jetting (26 March 2025)



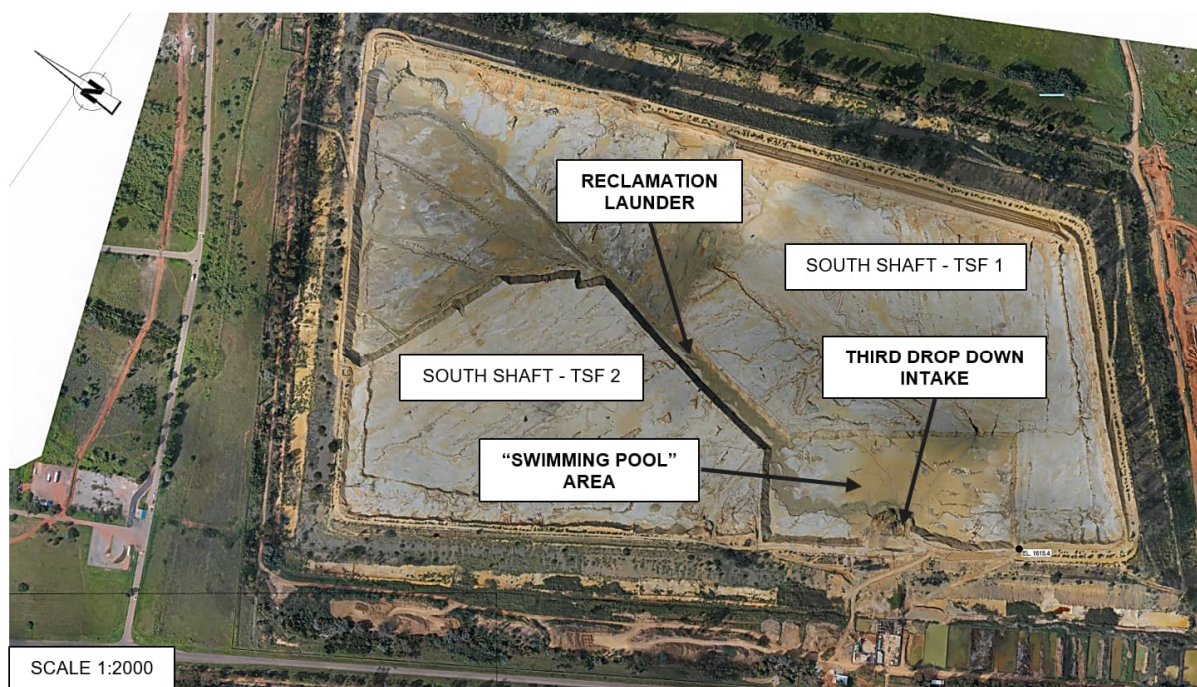


Figure 3-2: South Shaft TSFs (TSF 1 and TSF 2) reclaimed area (Drone image dated March 2025)

3.1.2 Twin Shaft TSFs (TSF 3 and TSF 4)

The twin shaft TSFs are located to the east of the Twin Shaft plant and the west of the south shaft TSFs at 26°25'3.99"(S) and 27°40'12.34"(E). The TSFs were commissioned in 1982 and similar to the South Shaft TSFs, were placed under care and maintenance in 2011, at the time when the Doornpoort TSF was commissioned. No tailings have been deposited on these facilities since being placed under care and maintenance. TSF 3 and TSF 4 are upstream raised "day-night wall" paddocked TSFs, and the height of TSF's highest point is 42 m. Hydraulic reclamation is planned to occur on these TSFs on completion of the reclamation of the entire South Shaft TSFs. The elevated penstocks on TSF 3 and TSF 4 are operational and able to decant water from the TSF surface towards the east (see Figure 3-3). The original decant pipes near ground level are understood to have been sealed at the intakes and the outlet ends are still visible at the toe of the TSFs. Although it has been sealed at the inlet, clear seepage discharges at the outlet end of the TSF penstock pipe into the solution trench.

The surface of TSFs 3 and 4 have been re-vegetated with grass and shrubs, and an irrigation system is in place. The underdrains within the TSFs are still operational and flowing, albeit marginally, and are monitored on a monthly basis.



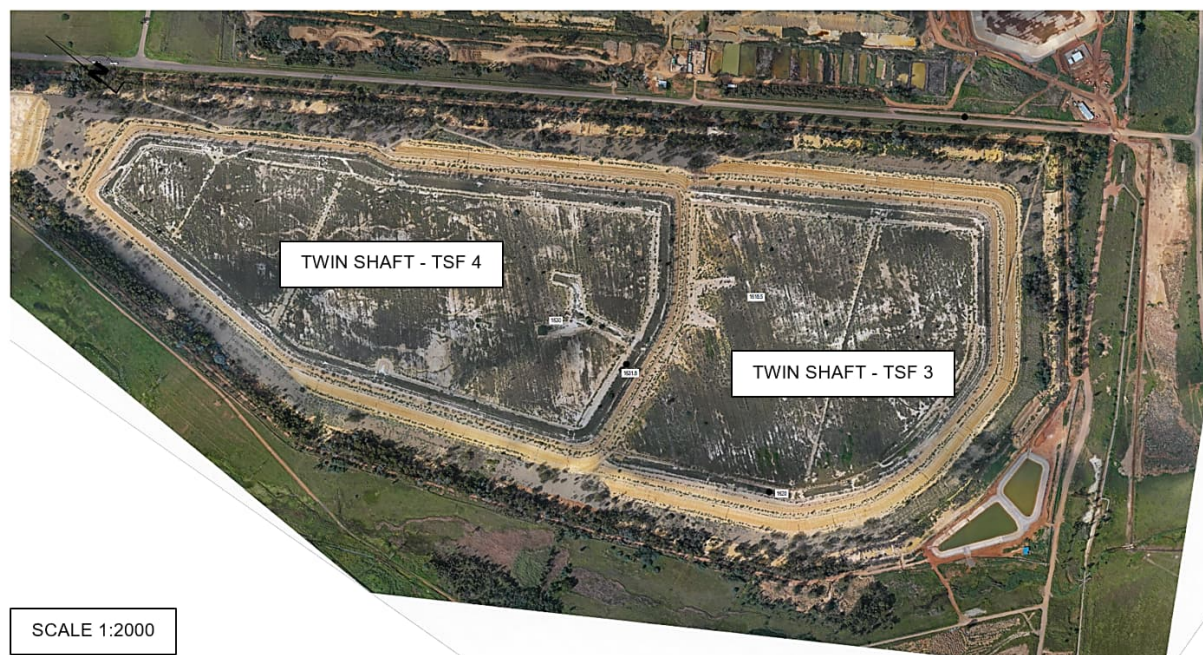


Figure 3-3: Twin Shaft TSFs (TSF 3 and TSF 4) under care and maintenance (Drone image March 2025)

3.2 Design Criteria for the Old TSFs

Table 3-1 presents the latest design criteria that have been adopted for the Old TSFs.



Table 3-1: Design criteria and assumptions

Item Description	TSF 1 and TSF 2	TSF 3 and TSF 4	Source
Technical Details			
Location	Latitude: 26°24'53.76"(S) Longitude: 27°40'35.96"(E)	Latitude: 26°25'3.99"(S) Longitude: 27°40'12.34"(E)	-
Tailings Type	Gold ore tailings	Gold ore tailings	SDGM
Survey Details	WSG 84	WSG 84	SDGM
TSF Development			
The previous delivery method to the site	Tailings slurry pumped to TSF via residue pipeline with during previous active phase with various tip points around the perimeter of the embankment. Hydraulically placed slurry into a day-wall, night-wall system.		Historical and most common method of development of gold tailings dams. Old day and night delivery pipes on the TSF indicate this was the method of development.
Development method	Upstream raised TSF with above-ground TSF deposition using the day-night wall method of deposition		
Deposition Methodology	Day-night wall method of deposition		
Footprint Area	63 Ha	96 Ha	Google Earth
Final elevation of TSF	TSF 1: 1 628 mamsl TSF 2: 1 633 mamsl	TSF 3: 1 620 mamsl TSF 4: 1 632 mamsl	SDGM, 2016 survey
Maximum Height of TSF	TSF 1: 45 m (pre-reclamation) TSF 2: 34 m (pre-reclamation)	TSF 3: 39 m TSF 4: 41 m	SDGM, 2016 survey
Maximum Height of TSF	TSF 1: 41 m (current height) TSF 2: 17.5 m (current height)	TSF 3: 39 m (current height) TSF 4: 41 m (current height)	SDGM, 2025 survey
Average Placed Dry Density during deposition	Unknown	Unknown	-
Rate of rise limit	Unknown	Unknown	-
Process Plant Production Criteria			
Overall Life of Mine (LoM)	1968-2011 (43 years)	1982-2011 (29 years)	SDGM
Total tonnes deposited	Unknown	Unknown	-
Total volume of TSF	Unknown	Unknown	-
Deposition rate	Unknown	Unknown	-
TSF Classification			
ANCOLD consequence classification	High B	High B	South Deep Old TSFs – Dam Break Assessment Update – Final, 4 November 2022, SLR
GISTM consequence classification	High	High	
Tailings Characteristics			
In situ placed dry density	1.92 t/m³		South Deep tailings Storage Facilitates 1 to 4 Geotechnical investigation and stability Report, July 2022, SLR
Saturated Density	2.07 t/m³		
Plasticity			
Fine Tailings	Low plasticity		
Intermediate Tailings	Non-plastic		
Coarse Tailings	Non-plastic		
Clay Content (%)			
Fine Tailings	<13%		
Intermediate Tailings	<8%		
Coarse Tailings	<5%		
Fines Content (%)			
Fine Tailings	75%		



Item Description	TSF 1 and TSF 2	TSF 3 and TSF 4	Source
Intermediate Tailings	55%		
Coarse Tailings	35%		
D50 (µm)			
Fine Tailings	50 µm		South Deep tailings Storage Facilitates 1 to 4 Geotechnical investigation and stability Report, July 2022, SLR
Intermediate Tailings	50 µm		
Coarse Tailings	60 µm		
Specific Gravity			
Fine Tailings	2.71		
Intermediate Tailings	2.74		
Coarse Tailings	2.71		
Uniformity Coefficient (C _u =D ₆₀ /D ₁₀)			
Fine Tailings	13 (C _u =D ₆₀ /D ₁₀)		
Intermediate Tailings	22 (C _u =D ₆₀ /D ₁₀)		
Coarse Tailings	20 (C _u =D ₆₀ /D ₁₀)		
Dry unit weight	18.8 kN/m³		
Saturated unit weight	20.3 kN/m³		
Shear Strength			
Peak friction angle	34.5°	33.5°	
Critical state friction angle	31°		
Apparent cohesion	3	3	
Peak Undrained Strength Ratio (Su/σ'v)	0.7		
Residual undrained strength ratio (Sr/ σ'v)	0.7		
FoS against cyclic loading (CRR/CSR)	1.3		
State Parameter (ψ)	-0.06 (Dilative)	-0.05	
Permeability			
Vertical and horizontal permeability	1E-08 m/s		
k _y /k _x	1		
Tailings Rheology			
Freely settled bed packing concentration (C _{free})			
Coarse Tailings	36.81%v	37.36%v	South Deep Old Tailings Storage Facilities - Dam Breach Assessment, 2021, SLR
Fine Tailings	37.07%v	37.05%v	
Maximum bed packing concentration (C _{max})			
Coarse Tailings	53.60%v	53.19%v	
Fine Tailings	53.46%v	55.21%v	
Foundation Soils Characteristics			
Plasticity			South Deep tailings Storage Facilitates 1 to 4 Geotechnical investigation and stability Report, July 2022, SLR
Residual Shale	Low to Intermediate plasticity		
Residual Diabase	Intermediate to High plasticity		
Liquid Limit			
Residual Shale	18 – 53 (average 34)		
Residual Diabase	54		



Item Description	TSF 1 and TSF 2	TSF 3 and TSF 4	Source
Clay Content (%)			South Deep tailings Storage Facilitates 1 to 4 Geotechnical investigation and stability Report, July 2022, SLR
Residual Shale	5 – 37 (average 18)		
Residual Diabase	19		
Fines Content (%)			
Residual Shale	32 – 84 (average 57)		
Residual Diabase	73		
D50 (µm)			
Residual Shale	0.015 - 0.25		
Residual Diabase	0.04		
Specific Gravity			
Residual Shale	2.56 - 2.76		
Residual Diabase	2.74		
State Parameter			
Residual Shale	-0.014		
Residual Diabase	-		
Uniformity Coefficient (C_u=D₆₀/D₁₀)			
Residual Shale	30 (C _u =D ₆₀ /D ₁₀)		
Residual Diabase	-		
Van der Merwe's Swelling Classification (Vander Merwe, 1964)			
Residual Shale	Low to Medium		
Residual Diabase	Medium		
Weston Swell Potential (Weston, 1980) at vertical pressure of 100kPa (%)			
Residual Shale	<0.1		
Residual Diabase	<0.2		
Average Shrinkage Limit (Hobbs et al., 2014) (%)			
Residual Shale	11 (Low to Medium)		
Residual Diabase	15 (Medium)		
Dry Unit Weight			
Residual Shale	15.0 kN/m³		
Residual Diabase			
Weakened Basal layer			
Saturated Unit Weight			
Residual Shale	19.5 kN/m³		
Residual Diabase			
Weakened Basal layer			
Unit Weight			
Parent Shale	23.0 kN/m³		
Parent Diabase	29.5 kN/m³		
Peak Effective Friction Angle			
Residual Shale	28.0°		
Residual Diabase	32.0°		



Item Description	TSF 1 and TSF 2	TSF 3 and TSF 4	Source
Weakened Basal layer	24.5°		South Deep tailings Storage Facilities 1 to 4 Geotechnical investigation and stability Report, July 2022, SLR
Brittleness Parameters			
a) Peak Undrained Strength Ratio (Su/σ'v)			
Residual Shale	0.4		
Residual Diabase	0.4		
Weakened Basal layer	-		
b) Post-Peak Strength			
Residual Shale (to be used instead of peak friction angle)	27.0°		
Residual Diabase (to be used instead of peak friction angle)	-		
c) Critical State Friction Angle			
Residual Shale	27.0°		
Residual Diabase	32.0°		
Weakened Basal layer	24.5°		
d) Apparent Cohesion			
Residual Shale	0 kPa		
Residual Diabase			
Weakened Basal layer			
e) Residual Undrained Strength Ratio (Sr/σ'v)			
Residual Shale	0.4		
Residual Diabase			
f) Progressive Failure (Weakened Basal Layer)			
Residual Shale	% Clay = 37; LL = 53%; ϕ' res = 22°; ϕ' CS = 27° Risk of progressive failure = Intermediate		
Residual Diabase	% Clay = 19; LL = 54% Risk of progressive failure = Low		
e) Cyclic Strength			
Tailings	CSR = 0.084 and CRR = 0.11 at 15 cycles, equivalent to an earthquake with a 7.5 magnitude		
Foundation Material	CSR = 0.082 and CRR = 0.14 at 15 cycles, equivalent to an earthquake with a 7.5 magnitude		
OCR of Tailings Beneath Footprint			
Residual Shale	1		
Residual Diabase	12		
OCR of Tailings Outside of Footprint			
Residual Shale	Between 3.9 and 9.7		
Residual Diabase	12		
Pre-Consolidation Pressures			
Residual Shale	Between 65 and 200 kPa (average of 135 kPa)		
Residual Diabase	270 kPa		
Uniaxial Compressive Strength (UCS)			
Parent Shale	Between 5 and 38 MPa (average of 18.2 MPa)		
Parent Diabase (given the same mass strength as the parent Shale)	Between 5 and 38 MPa (average of 18.2 MPa)		
Horizontal Permeability (k _h)			



Item Description	TSF 1 and TSF 2	TSF 3 and TSF 4	Source
Residual Shale	3E-08 m/s		
Residual Diabase	2E-06 m/s		
Parent Shale	3E-08 m/s		
Parent Diabase	2E-06 m/s		
ky/kx	1		
Hydrology Data			
Average annual precipitation	626 mm		South Deep Baseline Meteorology Report, Report 1AS017.087, July 2023, SRK
Average annual evaporation, S-Pan	1 544 mm		
Average annual air temperature and dew point temperature	16 C° and 7.1 C°		
Average relative humidity and wind speed	60.3% and 2.8 m/s		
Design Storm Events			
1:100-year, 24-hour storm depth	127 mm		South Deep Baseline Meteorology Report, Report 1AS017.087, July 2023, SRK
1:1 000-year, 24-hour storm depth	165 mm		
1:10 000-year, 24-hour storm depth	204 mm		
PMP, 24-hour storm depth	460 mm		
1:100-year, 72-hour storm depth	253.8 mm		Technical Memorandum, South Deep Rainfall Analysis-Draft for review, 8 November 2022, SLR
1:1 000-year, 72-hour storm depth	418.4 mm		
1:10 000-year, 72-hour storm depth	662.6 mm		
PMP, 72-hour storm depth	746.4 mm		
Design Earthquake Loadings (AEP)			
Operating Basis Earthquake (OBE)	1 in 475 AEP, PGA of about 0.15g 1 in 1000 AEP, PGA of 0.174g		Geotechnical Investigation and slope stability assessment, May 2019, SLR and ANCOLD, 2019a
Safety Evaluation Earthquake (SEE) (ANCOLD)	High A (LoM height) – 1:10 000 year, PGA = 0.25g High B (current height) – 1: 5 000 year, PGA = 0.23g		Technical Memorandum, South Deep Rainfall Analysis- Draft for review, 8 November 2022, SLR
Maximum Design Earthquake (MDE)	1 in 10 000-year AEP		ANCOLD, 2019
Post closure	Maximum Credible Earthquake		GISTM, 2020
Water Balance for Old TSFs			
Inflows			
Direct Rain pool	5 m³/d	6 m³/d	South Deep Gold Mine Water Balance Model 2024 Update, 41104818-REP-00001-DRAFT, January 2025, WSP
Rain Beach	791 m³/d	1 250 m³/d	
Irrigation	390 m³/d	0 m³/d	
Total Inflows	1 186 m³/d	1 256 m³/d	
Outflows			
Evaporation	981 m³/d	1 034 m³/d	South Deep Gold Mine Water Balance Model 2024 Update, 41104818-REP-00001-DRAFT, January 2025, WSP
Seepage and return to Pollution Control Dam (PCD)	178 m³/d	209 m³/d	
Seepage Environment	15 m³/d	15 m³/d	
Total Outflows	1 173 m³/d	1 260 m³/d	
Volume Variation in Storage	12 m³/d	-4 m³/d	



Item Description	TSF 1 and TSF 2	TSF 3 and TSF 4	Source
Balance Check	0%	0%	
Surface Water Management			
Surface Water Management Areas			
Tailings Area (Crest area)	36.8 Ha	55.46 Ha	Measured
Side Slopes	23.5 Ha	38.67 Ha	Measured
Catchment Paddocks	8.38 Ha	9.83 Ha	Measured
Stormwater Canal	Unknown	Unknown	-
Access Road	Unknown	Unknown	-
Berm and Pipeline Servitude	Unknown	Unknown	-
Tailings Area (Wet beach ratio)	N/a	N/a	-
Tailings Area (Dry beach ratio)	N/a	N/a	-
Seepage Volumes			
Seepage loss from tailings dam	Unknown	Unknown	-
Seepage collection by the toe drain	Unknown	Unknown	-
Seepage collection by the main drain	Unknown	Unknown	-
TSF / RWD stormwater storage capacity	Designed not to spill more than once every 50 years	Designed not to spill more than once every 50 years	In line with Regulation 704 of the National Water Act (no 36 of 1998), assumption
Maximum supernatant pond size	Unknown	Unknown	-
Design storm for permanent stormwater diversion trenches	Unknown	Unknown	-
Seepage Management			
TSF Liner type	None	None	Assumption. Pre-2013, South African legislation did not require TSF lining.
Toe drain underdrainage seepage collection system	100 mm clay outlet pipes (visible)	Unknown	-
	Inner pipe size	Unknown	-
Toe drain estimated seepage	Unknown	Unknown	-
Main drain underdrainage seepage collection system	Unknown	Unknown	-
Main drain estimated seepage	Unknown	Unknown	-
Decant System for TSF			
Permanent Penstock Intakes	TSF 1: Elevated penstock- unknown if still operational TSF 2: Reclaimed	TSF 3: Elevated penstock- still operational to decant storm water off the TSF TSF 4: Elevated penstock- still operational to decant storm water off the TSF	SDGM
Penstock Outfall pipe	TSF 1: Elevated penstock- unknown if still operational TSF 2: Reclaimed	TSF 3: Elevated penstock- still operational if required TSF 4: Elevated penstock- still operational if required	
Decant system abstraction rate specific to TSF	Unknown	Unknown	-
Closure			
Side slopes	Side slopes have been rock-cladded with the presence of vegetation	Side slopes have been rock-cladded with the presence of vegetation	Observation
Top surface	Under Reclamation	The top surface has been re-vegetated	Observation
Emergency Spillway Design Data			
Capacity	No emergency spillway		Observation



4.0 Section 4: Design Performance Requirements

The design performance requirements adopted for the detailed design of the Old TSFs are summarised in Table 4-1.



Table 4-1: Old TSFs design performance requirements

Item Description	Design Input TSF 1 and TSF 2	Design Input TSF 3 and TSF 4	Source
Acceptable Factors of Safety			
Slope Stability			
Long Term Drained	≥ 1.5		ANCOLD, 2019
Short-term undrained (potential loss of containment)	≥ 1.5		ANCOLD, 2019
Short-term undrained (no potential loss of containment)	≥ 1.3		ANCOLD, 2019
Residual Undrained (Post-liquified)	≥ 1.1		ANCOLD, 2019
Progressive Failure	≥ 1.1		LUL, 2019
Tolerable Displacements			
Maximum Movement - Trigger Level 0 (Green)	Small movements were noted during the annual survey, with no trends observed (i.e., random movements which could be errors) OR Movement less than 1 mm cumulative (above the noise of instrument) or shows no movement trend in instrument.		South Deep Trigger Action Response Plan, 2024, SLR
Maximum Movement - Trigger Level 1 (Yellow)	Movement rate of 0.5 mm/month or movement in layers where movement is not expected in an instrument (e.g. bedrock, Glacial Till) OR Movement greater than 1 mm cumulative movement.		
Maximum Movement - Trigger Level 2 (Orange)	Movements (>30mm) were noted during the annual survey, trending from one survey to the next. OR Movement rate of 0.5 mm/month or movement in layers where movement is not expected in multiple instruments. OR Movement greater than 1 mm cumulative movement on multiple layers within an instrument.		
Maximum Movement - Trigger Level 3 (Red)	Trigger Exceedance. ≥ 1 instrument in same unit on same transect exceeding modelled triggers + review. ≥ 2 instruments in same unit on same transect exceeding modelled triggers.		



	OR Movements (>40mm) were noted during the annual survey, trending from one survey to the next.	
Maximum Movement - Trigger Level 4 (Red)	Trigger Exceedance. ≥ 2 instruments in same unit on same transect in multiple units. ≥ 1 instrument at toe showing accelerated movement in each unit exceeding modelled triggers. OR Movements (>45mm) were noted during the annual survey, trending from one survey to the next.	
Maximum Movement - Trigger Level 5 (Red)	Trigger Exceedance. Accelerated movement observed in each unit on a toe inclinometer on exceeding modelled triggers + visual observations as defined in the visual inspection TARPs. OR Movements (>50mm) were noted during the annual survey, trending from one survey to the next.	
Freeboard		
Minimum surface water freeboard	Depth to contain Operational supernatant pond, plus Extreme storm event (1:100 AEP, 72hr flood), plus 1:100 notional AEP wet season runoff, plus 0.5 m storage capacity to minimum storage (wall/ spillway) level	ANCOLD, 2019b
Minimum surface water freeboard (GISTM, 2020)	Must contain the 24-hour PMP with no decanting	GISTM, 2020
Spillage to the Environment	The TSF/ RWD complex must not spill more than once in 50 years	Government Notice 704 of the National Water Act (no 36 of 1998)



5.0 Section 5: Operational Requirements

5.1 Tailings Management

For management of the SDGM Old TSFs, a Tailings Management Plan (TMP) is being developed, which will summarise the quantities of mine tailings that require management, the Capex and Opex cost estimates, and the identified risks of the facility. The operation of the TSF must adhere to the TMP.

5.2 Tailings Risk Management

A TSF Risk Management Plan (RMP) was issued on 13 August 2024 to centralise all tailings risk-related information associated with the SDGM TSFs. Should any material changes be made to the TSF, the RMP must be updated to consider the potential impact on the risk posed.

6.0 Section 6: Legal Compliance, Reference Standards and Guidelines

The following sections discuss the legislation, recommended technical standards, guidelines, and design criteria development procedures relevant to all future TSF designs at SDGM.

6.1 Legislation

Future designs, operations and developments should be carried out in accordance with the following South African acts and regulations:

- South African Legislative Documents:
 - o Republic of South Africa. 1996. Mine Health and Safety Act (No.) 29 of 1996.
 - o Republic of South Africa, 1996. The Constitution of South Africa Act (No.) 108 of 1996.
 - o Republic of South Africa, 1998. National Environmental Management Act (No.) 107 of 1998.
 - o Republic of South Africa, 1998. National Water Act (No.) 36 of 1998.
 - o Republic of South Africa 1999. Regulation on the use of water for mining and related activities aimed at the protection of water resources. Government Gazette 2019, 4 June (Published under Government Notice 704).
 - o Republic of South Africa, 2002. Mineral and Petroleum Resources Development Act (No.) 28 of 2002.
 - o Republic of South Africa, 2004. National Environmental Management; Air Quality Act (No.) 39 of 2004.
 - o Republic of South Africa, 2008. National Environmental Management Amendment Act No, 62 of 2008.



- o Republic of South Africa, 2008 National Environmental Management: Waste Act No, 59 of 2008.
- o Republic of South Africa, 2010. National Environmental Management Act, 1998 (Act No, 107 of 1998, as amended) publication of implementation guidelines for comment. Government Gazette (No.) 33333, 29 June (Published under Government Notice 654).
- o Republic of South Africa, 2010. National Environmental Management: Air Quality Act: List of activities which result in atmospheric emissions which have or may have a significant detrimental effect on the environment- commencement Government Gazette (No.) 33064, 31 March (Published under Government Notice R632).
- o Republic of South Africa, 2012. Regulations Regarding the Safety of Dams in terms of Section 123 (1) of the National Water Act, 1998. Government Gazette (No.) 35062, 24 February (Published under Government Notice R 139).
- o Republic of South Africa, 20013. National Norms and Standards for disposal of waste to landfill. Government Gazette (No.) 36784, 23 August (Published under Government Notice R636).
- o Republic of South Africa, 2013. National Norms and Standards for the assessment of waste for landfill disposal. Governmental Gazette (No.) 36784, 23 August (Published under Government Notice R635).
- o Republic of South Africa, 2013. Waste Classification and Management Regulations. Government Gazette (No.) 36784, 23 August (Published under Government Notice R 634).
- o Republic of South Africa, 2014. National Environmental Management Laws Amendment Act (No.) 25 of 2014.
- o Republic of South Africa, 2014. National Environmental Management Laws Amendment Act (No.) 25 of 2014.
- o Republic of South Africa, 2014. National Environmental Management: Biodiversity Act (No.) 10 of 2004.
- o Republic of South Africa, 2015. Regulations regarding the Planning and Management of Residue Stockpiles and Residue Deposits from a Prospecting, Mining, Exploration or Production Operation, Government Gazette (No.) 39020, 24 July (Published under Government Notice R632).
- o The Occupational Health and Safety Act, Act (No.) 85 of 1993.
- o The use of water for mining and related activities, GN704, 1999.
- o The Planning and Management of Residue Stockpiles and Residue Deposits, GN632, 2015.
- o Code of practice: mine residue – SABS 0286:1998.
- o National Water Act (36/1998): Regulation: Safety of dams, GN R.139.



- o The National Roads Act, Act (No.) 7 of 1998.
- o Minerals and Mining Act, Act 703 of 2006.
- o The Minerals Commission Act, Act 450 of 1993.
- o Environmental Protection Agency Act, Act 490 of 1994.

6.2 Technical Standards and Guidelines

Future TSF designs should be completed in accordance with the following industry standards and guidelines as they apply to tailings management:

- Industry Standards and Guidelines:
 - o ANCOLD Guidelines on Tailings Dams, Planning, Design, Construction, Operation and Closure, Revision 1, July 2019.
 - o ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquakes, 2019.
 - o Global Industry Standard on Tailings Management (GISTM), August 2020.
 - o Canadian Dam Association (CDA). Dam Safety Guidelines 2007 (Revised 2013).
 - o International Council on Mining and Metals (ICMM). Global Industry Standard on Tailings Management, August 2020.
 - o International Cyanide Management Code (ICMC), November 2002.
 - o South African National Standard for Mine Residue Deposits (SANS 10286), last revised in 1998.
- Client-Specific Standards and Guidelines:
 - o Gold Fields Limited Group TSF Management Standard, January 2023.

Geomembrane and geotextile lining standards to be adopted for design include, but are not limited to:

- GRI-GM13: Standard Specification for Test Methods, Test Properties and Testing Frequency for High-Density Polyethylene (HDPE) Smooth and Textured Geomembranes.
- GRI-GT12 (a): Test Methods and Properties of Nonwoven Geotextiles Used as Protection (or Cushioning) Materials (ASTM).
- GRI-GT13 (a): Test Methods and Properties for Geotextiles Used as Separation Between Subgrade Soil and Aggregates.

All concrete design work was based on the following South African standards:

- South African National Standards (SANS) 1200 G: Concrete (Structural).
- South African National Standards (SANS) 1200 GA: Concrete (Small Works).



7.0 Concluding Remarks

The information was extracted from existing SDGM design reports, various studies, and recent design work carried out for SDGM. Should new and or significant information pertaining to the design of the Old TSFs become available, this report must be updated to reflect these changes.

8.0 References

- ANCOLD Guidelines for Design of Dams and Appurtenant Structures for Earthquakes, 2019.
- ANCOLD, “Guidelines on Tailings Dams: Planning, Design, Construction, Operation and Closure”, Australian National Committee on Large Dams Incorporated, July 2019b.
- GISTM, “Global Industry Standard on Tailings Management”, Global Tailings Review.org, dated August 2020.
- Hobbs, P.R.N., Jones, L.D., Kirkham, M.P., Roberts, P., Haslam, E.P. & Gunn, D.A., “A new apparatus for determining the shrinkage limit of clay soils”, *Géotechnique* 64, No.3, 195-203, 2014.
- LUL, “Earth Structures-Guide for slope stability analyses”, document number: G0054B, Issue number A4, TfL Management System, Transport for London Underground, 2019.
- SLR geotechnical Investigation and slope stability assessment, May 2019/ ANCOLD, 2019a.
- SLR Report, “South Deep Tailings Storage Facilities 1 to 4 Geotechnical Investigation and Stability Report”, dated July 2022.
- SLR Technical memorandum, “South Deep Old TSFs – Dam Break Assessment Update (DRAFT)”, dated 4 November 2022.
- SLR Technical Memorandum, “South Deep Rainfall Analysis- Draft for review”, 8 November 2022.
- SRK Consulting, “South Deep Baseline Meteorology Report”, Report 1AS017.087, July 2023.
- Van der Merwe, D.H., “The prediction of Heave from the Plasticity Index and the Clay Fraction”, *Civil Engineering*, South Africa, vol. 6, no. 6, 1964.
- Weston, D.J., “Expansive roadbed treatment for Southern Africa. Proceedings, 3rd International Research and Engineering Conference on Expansive Clays”, Denver, CO, Vol. 1, 339–360, 1980.
- SLR Report, “South Deep Old Tailings Storage Facilities - Dam Breach Assessment”, 2021.



- WSP, “South Deep Gold Mine Water Balance Model 2024 Update”, 41104818-REP-00001-DRAFT, January 2025.



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Making Sustainability Happen

Metago

Environmental Engineers (Pty) Ltd



DESIGN REPORT: DETAILED DESIGN OF THE DOORNPOORT TAILINGS DAM COMPLEX AT SOUTH DEEP MINE

Prepared For

South Deep Gold Mine

PROJECT NUMBER G001-02

REPORT NO.01 Final

May 2009

**Design Report: Detailed Design of the
Doornpoort Tailings Dam Complex at South
Deep**

Prepared For

South Deep Gold Mine

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REPORT NO. 01 Final

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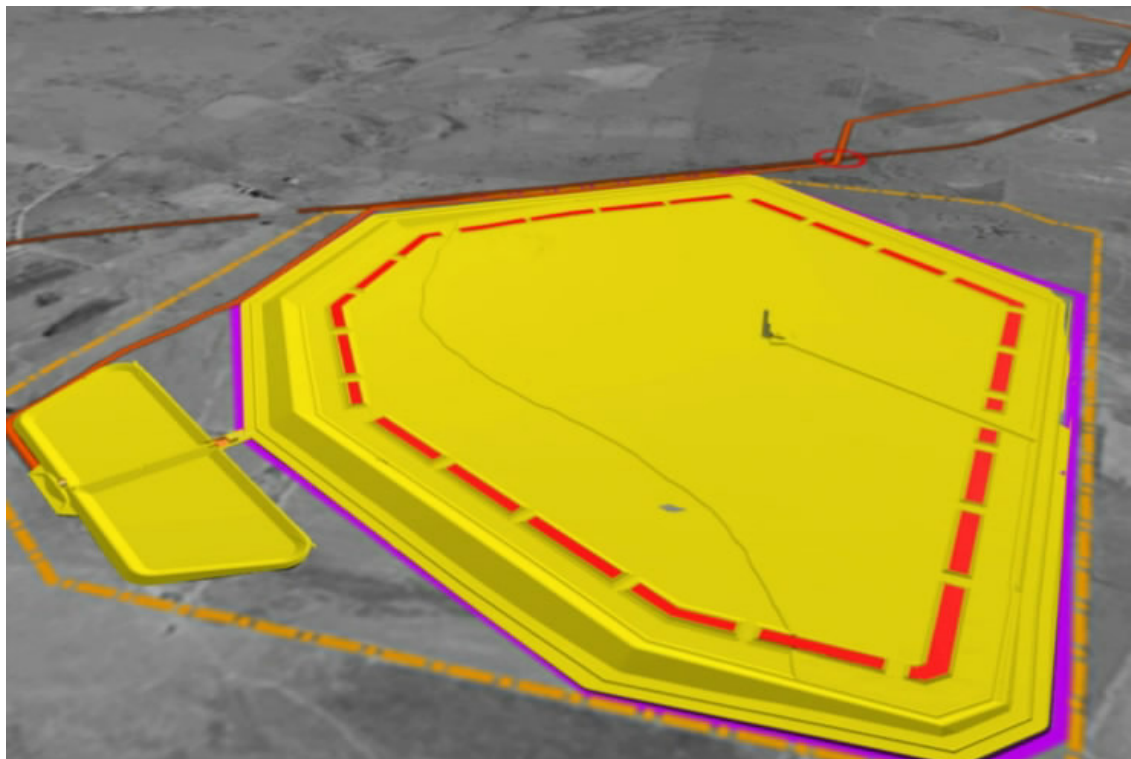
EXECUTIVE SUMMARY

Metago Environmental Engineers (Pty) Ltd (Metago) in a joint venture with Golder and Associates Africa (GAA) were appointed by South Deep Gold Mine to conduct the detailed design of a new tailings dam for the South Deep operation. In terms of the agreement between GAA and Metago, GAA were responsible for the design of the slurry delivery and return water system, neutralisation plant, thickeners and desilting pump system. Metago were responsible for the design of the tailings dam and its associated earthworks, decant system, silt trap, return water dam and surface water management facilities around the tailings dam. This report documents the design of the tailings dam as per Metago's scope of work.

South Deep Mine is located in South Western Gauteng, about 10km south of Westonaria, and currently has 2 tailings dams in operation, a set of cascade ponds and associated infrastructure.

South Deep Mine currently operates two slimes dams which are the Old Dam built in 1968 and the New Dam built in 1982. The dams are both approaching the end of their life both in terms of height and expected rate of rise based on the increase tonnage planned. The conceptual design for the new TSF was completed by Metago in 2005 as part of the South Deep Gold Mine Feasibility Study. The design for the dam was based on 330 000 tonnes per month (tpm) less backfill giving a figure of approximately 220 000 tpm to the slimes dam. The new dam (refer to Figure I) is planned to be commissioned in October 2010 with preparatory works (Phase 1) commencing June 2009.

FIGURE I: OBLIQUE VIEW OF THE PROPOSED DOORNPOORT TAILINGS DAM PRIOR TO DEPOSITION (UNPHASED CONSTRUCTION)



The initial design criterion was to design a tailings dam to accept 330 ktpm over 50 years. In December 2007 South Deep requested that we provide an alternative design for 220 ktpm. Considerable work had been completed on the 330 ktpm case and the design quantities have been scaled from the 330 ktpm case to the 220 ktpm case for the purpose of Board approval. Re-measurement of the Bill of Quantities (BOQ) was carried out prior to tender.

The final construction drawings which have been produced subsequent to December 2007 are for the 220 ktpm case.

Where there is a significant difference, the specialist investigation reports prepared prior to December 2007 refer to both the 330 ktpm and 220 ktpm cases. However, this design report describes only the 220 ktpm case, unless specifically stated otherwise.

The following conclusions arise from this study:

Site Selection

The Doornpoort Site (Site 5 in Figure 12-3) is the preferred site from the point of view of environmental impacts (see Environmental Impact Assessment Metago Report 168-006 No. 2). Although the capital cost of site 5 is relatively high compared to sites 3 and 4, the size of the site facilities a much longer life of dam and/ or higher production rates. The cost per tonne of tailings disposed is thus lower than for the other sites considered.

Stage Capacity

- The tailings dam has a volumetric capacity (up to 1624 mamsl) of approximately 152 000 000 m³ (205 000 000 tonnes) which is more than the 79 500 000 m³ (107 300 000 tonnes) required according to the mine planning schedule provided;
- Based on the production ramp up provided by the Mine, the required elevation of the starter wall is 1562.1 mamsl, which equates to a maximum starter wall height of 16.6 m*;
- The maximum elevation of the crest of the tailings dam corresponding to an airspace volume of 79 500 000 m³ is 1591.4 mamsl, which equates to a maximum height of 45.9 m*;
- The rate of rise at the final planned elevation of 1591.4 mamsl will be 0.2 m/yr;
- The construction of the TSF may be completed in two preparatory phases referred to as Phase 1, comprising the lower portion and Phase 2 comprising the upper portion of the tailings dam. Phase 2 must be completed within 12.5 years (149 months) from the date of first deposition;

* All heights are measured as the difference between the lowest point along the toe and the crest elevation.

- Coverage of the entire tailings dam footprint will be achieved at a crest elevation of 1584 mamsl; and
- Due to the low rates of rise the tailings dam will be able to accommodate short term increases in the rate of deposition, subject to the approval of the design engineer.
- The dam could potentially accommodate an additional 72 500 000 m³ (97 700 000 tonnes) of tailings over and above the design capacity for South Deep.

Geotechnical Investigation

- The site is confirmed to be underlain by shales and andesitic lava. Siltstone was also occasionally encountered. In addition, occasionally intrusive dolerite was encountered. Upper soils generally comprise transported Aeolian, colluvium and hillwash soils.
- The footprint of the surface bed for the starter wall must be ripped and re-compacted prior to the placement of the first layer of fill.
- The soils encountered within the footprint of the proposed tailings and return water dam should prove suitable for the construction of the starter wall / return water dam embankment provided that certain precautionary measures are taken during construction.
- A ferricrete layer has been identified as being suitable for the access road which will be constructed around the final perimeter of the footprint of the proposed tailings dam.
- Although not encountered, dolerite dykes and possibly andesite outcrops may transverse the penstock alignment. In these instances hard rock conditions will be encountered. If encountered, the required depth of over-excavation will have to be determined on site during construction.
- It is recommended that the permanent penstock be placed on an engineered rock fill raft and the portion of the penstock outfall pipe closest to the permanent

penstock be placed on a 100m long tapered imported engineered rock fill constructed within the pipe trench. Unacceptable differential settlement is expected to take place between the penstock tower and the outfall pipeline if no precautionary measures are taken.

- It is recommended that the borrow pit operations envisaged in the vicinity of the penstock line, should not come closer than 25m to the pipeline alignment. This is required to ensure that the length of the entire length of the alignment is placed in similar in-situ soils.
- Variable conditions were encountered within the area designated for the return water dam. Residual Andesite is found underlying the higher (north eastern) areas while the lower (south western) areas are underlain by shales near or adjacent to the well defined water course. In addition the area has been intruded by a dolerite feature which is seen to occur on the lower south western portions extending towards the central portions of the return water dam.
- 300 mm of topsoil will be stripped from the footprint of the tailings storage facility and stockpiled until it is needed for covering the sideslopes.
- Box cuts may be required in the construction of the starter and/or return water dam embankments, but this will need to be confirmed during the detailed design phase.
- Water ingress into the test pits away from the water course was minimal, indicating that dewatering of excavations during construction to remove groundwater is unlikely. The return water dam however will be lined with a HDPE liner, which would be affected by any water collecting underneath it. The leakage detection system beneath the liner should be able to handle any seepage occurring, and the soilcrete bags placed on top of the liner will provide resistance to uplift.

Seepage Analysis

- From the analyses it was estimated that less than 3.54×10^{-5} l/s of seepage will be discharged into the in-situ material from the tailings dam;

- The seepage analyses have shown that the combination of main drain, toe and cut-off drains can effectively control the phreatic surface within the tailings dam. A margin of safety should however be incorporated for the main and toe drains to allow for possible wash-a-ways and blinding;
- The phreatic surface is sensitive to the position and size of the main and toe drains. The analyses indicated that main needs to be a minimum of 25 m wide, depending on its location around the dam, and the toe drains needs to be 5 m wide to reduce the risk of toe seepage to a satisfactory level;
- Seepage losses up to the time when the tailings dam breaks ground, while the supernatant pond is in direct contact with natural ground, may exceed the seepage losses calculated in this analysis if the permeability of the underlying soils is significantly higher than that of the tailings;
- Flow rates into the underdrain outlets and total flow into the underdrain collection system would need to cater for a minimum rate;
- It is possible for a large pool to be accommodated if all of the drains are functioning correctly, but a large pool should be avoided; and
- No seepage analysis was conducted on the return water dam as the dam design includes a 2000µm HDPE liner and leakage detection system.

Geochemical Investigation

- The tailings dam may be characterised by two geochemically distinct zones which are expected to be evident throughout the life of the facility but which change in extent depending on the geochemical environment within the tailings dam.
- The outer zone (in the absence of any further controls) will become acidic relatively soon (within a few months or years) and will release seepage characterised by a low pH and high dissolved metal content, should the Sealmac and soil layers prove unsuccessful.

- The inner zone located primarily below the phreatic surface and in areas of the tailings dam that are at or very nearly saturated. The seepage released from this zone will be characterised by neutral drainage and lower dissolved metal concentrations and salt loads.
- Where the flow path crosses from the outer (acid) zone into the inner (neutral) zone, the resulting drainage quality will tend to take on the characteristics of the acid zone within a relatively short distance downstream of the cross over point, primarily because of the limited neutralising capacity of the tailings.
- The two existing dams currently operated by South Deep were used to collect samples of both tailings, underdrain seepage and process water for the prediction of water quality from the proposed Doornpoort Dam.
- The daily salt released from the tailings dam is expected to be 982 kg/day.
- The characteristics of the seepage quality from the inner and outer zones have been described on the basis of test work undertaken.
- The Acceptable Risk Level, as defined in the Minimum Requirements (DWAf 1998), will be exceeded for the following elements:
 - Inner Zone – As, Cu, Mn and Ni.
 - Outer Zone – Al, As, Co, Cr, Cu, Fe, Mn, Ni, Ti and Zn.
- The low air permeability of saturated or near saturated gold tailings will play a key role in limiting ingress of oxygen to the tailings dam during the operational life of the dam, thereby reducing the rate of acid production, particularly in those regions of the tailings dam that are below the phreatic surface, or buried deep below surface and away from points of oxygen ingress.
- On decommissioning of the tailings dam, the air permeability will rise as partially saturated conditions become established within the tailings material, and as the phreatic surface dissipates. Areas that up until decommissioning were prevented from becoming acid generating by virtue of the presence of the

phreatic surface, will gradually contribute to acid generation. The seepage flux from the tailings dam will however also reduce after decommissioning.

- There is a significant risk that in the absence of adequate mitigation, the proposed tailings dam could impact on the surrounding environment through emissions of contaminants as both seepage and surface runoff from the tailings dam and associated infrastructure.

Hydrology

- The proposed Doornpoort tailings dam is located outside of any floodlines and more than 100m from the centreline of any waterway.
- The tailings delivery and return water pipelines will be required to cross streams. The flood lines have been defined at these points.
- Groundwater and surface water protection
- Groundwater protection will be afforded by the following features:
 - A fully lined return water dam incorporating a leakage detection system.
 - A piped seepage collection system
 - A Hyson Cell lined stormwater canal
- Provision for additional groundwater protection has been incorporated in the budget for:
 - A seepage cut-off drain within the starter wall of the tailings dam.
 - A bituminous impregnated (Sealmac) layer between the soil and the tailings to minimise the risk of the tailings going acidic.

Surface water protection will be afforded by the following features:

- Provision of a water treatment plant capable of treating excess process water to a standard suitable for use in the mines refrigeration plant.

- Provision of a return water dam with a capacity sufficient to ensure that the dam will not spill with a frequency exceeding once in fifty years as per Regulation 704 of the National Water Act of 1998.
- Flows into the return water dam are limited to the capacity of the inlet channel (spillway from the silt trap) which in turn is controlled by the tailings dam penstock capacity and stormwater channels. Flow into the stormwater channels comes from runoff from the tailings dam side slopes and catchment paddocks which serve to attenuate the flow. The return water dam spillway capacity requirement is therefore limited to less than the inflow capacity.

Dust Emissions

Dust emissions will be controlled by:

- Soil cladding the side slope concurrently with dam construction.
- Managing deposition cycles to ensure that the beach remains wet during the operational phase.
- Cladding the top surface of the tailings dam with rock/ soil on decommissioning.
- Making use of chemicals such as lignosulphonate, or physical methods such as ploughing wind rows.

Decommissioning, Aftercare and Closure

Decommissioning activities will be focused primarily on the completion of the cover, removal of pipelines, sealing of penstocks, and establishment of vegetation cover to minimise long term erosion and dust emissions. Aftercare will be concerned primarily with monitoring of the cover and seepage quality but may involve treatment of a small quantity of acid water that may emanate from the underdrain collection system during the draw down phase.

Several recommendations have arisen during the design of the tailings facility:

- It is recommended that a trial slope is set up on one of the existing tailings dams in order for the success of the side slope cover to be tested.
- The design criteria should be periodically verified during the operational life of the tailings dam.
- The concrete and structural specialists should be involved during construction.
- Gold Fields to appoint an Approved Professional Person (APP) for the construction and operational stages of the return water dam.
- The water license for South Deep is to be amended.
- The effectiveness of the cover design in modifying the drainage quality should be verified through the monitoring programme.

The return water is equipped with a cutoff drain to enable the dam to be used as a water storage dam (albeit with a much reduced capacity) after the tailings dam is decommissioned and the plastic liner removed. The drain outlets discharge to the natural environment below the downstream toe of the dam. These drains could potentially assist in preventing upliftment of the plastic liner in the event that a high water table occurs in the area during the operational life. They are not required during the operational phase for embankment stability because the liner system has been provided.

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Project No. G001-02

May 2009

Report No. 01: Final

DESIGN REPORT: DETAILED DESIGN OF THE DOORNPOORT TAILINGS DAM COMPLEX AT SOUTH DEEP MINE

1. INTRODUCTION

Metago Environmental Engineers (Pty) Ltd (Metago) in a joint venture with Golder and Associates Africa (GAA) were appointed by South Deep Gold Mine to conduct the detailed design of a new tailings dam for the South Deep operation. In terms of the agreement between GAA and Metago, GAA were responsible for the design of the slurry delivery and return water system, neutralisation plant, thickeners and desilting pump system. Metago were responsible for the design of the tailings dam and its associated earthworks, decant system, silt trap, return water dam and surface water management facilities around the tailings dam. This report documents the design of the tailings dam as per Metago's scope of work.

South Deep Mine is located in South Western Gauteng, about 10km south of Westonaria. The mine currently has 2 tailings dams in operation, a set of cascade ponds and associated infrastructure (Figure 1-1).

South Deep Mine currently operates two slimes dams which are the Old Dam built in 1968 and the New Dam built in 1982. The dams are both approaching the end of their life both in terms of height and expected rate of rise based on the increase tonnage planned. The conceptual design for the new TSF was completed by Metago in 2005 as part of the South Deep Gold Mine Feasibility Study. The design for the dam was based on 330 000 tonnes per month (tpm) less backfill giving a figure of

approximately 220 000 tpm to the slimes dam. The new dam is planned to be commissioned in October 2010 with preparatory works (Phase 1) commencing June 2009.

The detailed design drawings form part of the detailed design report, and are cross referenced in this report.

This design report provides information on the investigation work, design criteria, and detailed design and sizing of the new tailings dam and associated return water dam.

The report should be read in conjunction with the mandatory code of practice (Metago Report G001-02/02) and the operating manual (Metago Report G001-02/03).

2. TERMS OF REFERENCE

The terms of reference for the detailed design of the new tailings dam complex and associated infrastructure are as defined in the GAA contract document of April 2007 as amended. The terms of reference are as per Table 2-1 which also indicates the design reports relevant to each item.

TABLE 2-1: TERMS OF REFERENCE

ITEM	DESCRIPTION	REPORT REFERENCE
1	Tailings Facility	This report
2	Penstocks	This report; Design of Pipe Encasing and Temporary Penstocks Document JN069-NSE-GA-R-800; and South Deep Mine - New Penstock – Investigation into Appropriate Countermeasures Against Heat of Hydration Problems – A Report and Recommendations (Consus Report of November 2007)
3	Catchment Paddocks	This report
4	Blanket, toe and internal drains	This report
5	Trenches and Drains	This report
6	Return Water Dam	This report
7	Return Water Dam Pump Station (hydraulics)	GAA Report 10307/11499/18/S
8	Electrical	GAA report
9	Reverse Osmosis Plant	Subsequently Excluded
10	Tailings Delivery Pipeline	PCCE Report GOL-1033 R01 Rev C
11	Return Water Pipeline	GAA Report 10307/11499/18/S
12	Penstock Pipeline	This report; Design of Pipe Encasing and Temporary Penstocks Document JN069-NSE-GA-R-800; and South Deep Mine - New Penstock – Investigation into Appropriate Countermeasures Against Heat of Hydration Problems – A Report and

ITEM	DESCRIPTION	REPORT REFERENCE
		Recommendations (Consus November 2007)
13	Perimeter Seepage Collection System	This report
14	Pipe Plinths and Anchors	GAA Report 10307/11499/18/S
15	Geotechnical and hydrogeological investigations	GAA Report No. 10307/10319/14/G; and GAA Report No. 10307/10273/13/G
16	Specific Requirements (including the dam closure guide, contingency plans and construction programme)	This report; and GAA Report No. 10307/10452/15/W
17	Code of Practice	Metago Report G001-02/02
18	Tailings Dam Operation	This report (general operation) and the Operating Manual (Metago Report G001-02/03)
19	Operation of all pump stations	Golder Report

The initial design criterion was to design a tailings dam to accept 330 ktpm over 50 years. In December 2007 South Deep requested that Metago provide an alternative design for 220 ktpm. Considerable work had been completed on the 330 ktpm case and the design quantities were scaled from the 330 ktpm case to the 220 ktpm case for the purpose of Board approval. Remeasurement of the Bill of Quantities (BOQ) was carried out prior to tender.

The final construction drawings which have been produced subsequent to December 2007 are for the 220 ktpm case.

Where there is a significant difference, the specialist investigation reports prepared prior to December 2007 refer to both the 330 ktpm and 220 ktpm cases. However, this design report describes only the 220 ktpm case, unless specifically stated otherwise.

3. SCOPE OF WORK

For the above-mentioned terms of reference, the following scope of work was agreed:

3.1.1. TRADE-OFF STUDIES

- Phasing of construction of the tailings dam and return water dam;
- Comparing the option of having one or two paddocks; and
- Selection of the footprint size for the 220 ktpm case.

The comparison of the capital expenditure for the various options is summarised in Section 13.

3.1.2. INVESTIGATION AND FIELD WORK

- Geotechnical investigation of the site including :
 - Identifying the extent, type and characteristics of the near surface soils for construction and rehabilitation specifications, stability, and seepage assessments.
 - Identifying and characterising suitable borrow material (on site) if available for the construction of the tailings dam, return water dam and use as other engineering material (e.g. the cover).
- Geochemical and mineralogical characterisation of the tailings to confirm the quality and chemistry of the slurry water and seepage water, commenting on the potential for, and level of, heavy metal mobilization, acid generating potential, etc. Provision of estimates of seepage qualities for the hydrogeological and contaminant transport model.
- Hydrogeological investigation to confirm the work done during the concept design stage relating to the prediction of the magnitude and extent of the contaminant plume from the tailings dam and the impact on the groundwater.
- Seepage analysis to provide input to the hydrogeological model. To size and position the underdrain system for the tailings dam.
- Probabilistic climatic water balance to confirm the required sizing of the new return water facilities to comply with Regulation 704 of the National Water Act.

- Erosion Study to evaluate alternative side slope profiles and select a design slope that on the basis of current available information will perform best in terms of the closure objectives.

3.1.3. ENGINEERING WORK

- Confirm **design criteria** to determine:
 - The behaviour of the tailings on placement;
 - The method of placement of the tailings;
 - The rate of rise of the tailings;
 - The development and operation of the tailings dam;
 - The long term performance in terms of closure measures; and
 - The capacity of the tailings to adhere to the environmental constraints.
- **Detailed design** of the new tailings dam and return water facilities for the purpose tender letting and construction. The aspects covered in this design report include:
 - Development of the stage capacity relationship for the new TSF;
 - Design of the starter walls;
 - Design of the underdrainage systems and seepage collection system;
 - Design of the decant systems;
 - Design of the side slope and the cover system;
 - Design of the side slope runoff settling and collection system;
 - Design of the civil aspects of the silt trap, located at the outfall to the decant system. The mechanical and electrical aspects are covered elsewhere;

- Design of the earthworks, spillways, liner system and leakage detection system for the return water dam. The structural, mechanical and electrical aspects have been covered by Golder; and
- Design of the clean water management systems.
- Bill of Quantities and Cost Estimate. This design report includes an estimate of the quantities and rates relevant to the construction phase. The cost estimates were developed from the 330 ktpm case and will be re-measured prior to tender letting.

4. AVAILABLE INFORMATION

The following information was available to Metago for the purposes of the detailed design:

- **SRK Consulting, 1988**, Site selection for a Tailings impoundment for the proposed South Deep Mine for Johannesburg Consolidated Investment Co Ltd Report No. MI6131/1
- **Bureau for International Risk Assessments, 2004**, Risk Assessment Slimes Dam Sites for South Deep Mine
- **Metago Environmental Engineers, 2005**, Site Selection Review and Capital Cost Estimate for a New Tailings for South Deep for Placer Dome Western Areas Joint Venture, Metago Report No. 168-006/01
- **South Deep Mine, 2005**, “Mandatory Code of Practice for Mine Residue Deposits (Tailings Facilities Only)”, Revision No. 1, Second Edition, May 2005
- **SRK Consulting, 2003**, South Deep Placer Dome Western Areas Joint Venture Review and reporting on the SRK Report “Site selection for a Tailings impoundment for the proposed South Deep Mine” Report No. Mi 6131, February 1988
- **Metago Environmental Engineers, 2007**, Conceptual Design of the Proposed Doornpoort Tailings Dam Complex at South Deep, Metago Report No. 168-006/08

4.1. SURVEY INFORMATION

The detailed design of the tailings disposal facility was based on survey information supplied by AOC Geomatics (Pty) Ltd. The site was flown during September 2005.

4.2. SEISMIC DATA

The Peak Ground Acceleration (m/s^2) with a 10% Probability of Exceedance in 50 years¹, is less than 0.2m/s^2 which means that this dam falls into the low hazard category. Local deep level mining and blasting activities can also give rise to ground accelerations. Data on these events is not available. Historic experience from similar gold tailings dams indicates that this activity has not given rise to any liquefaction problems.

5. DESIGN CRITERIA

The design criteria for the tailings dam are presented below.

5.1. TONNAGE PROFILE

The conceptual design for the new TSF was done in 2005 as part of the South Deep Gold Mine Feasibility Study. The design for the dam was based on 330 ktpm less backfill giving a figure of approximately 220 ktpm to the slimes dam.

As the land had already been purchased it was felt that maximum use of the footprint should be made so as not to limit the potential throughput of the plant to 330 ktpm. This full footprint has been developed through a phased approach. The additional cost of developing the full footprint compared to the minimum footprint that would otherwise be required, has been evaluated and the results are documented in Section 13.

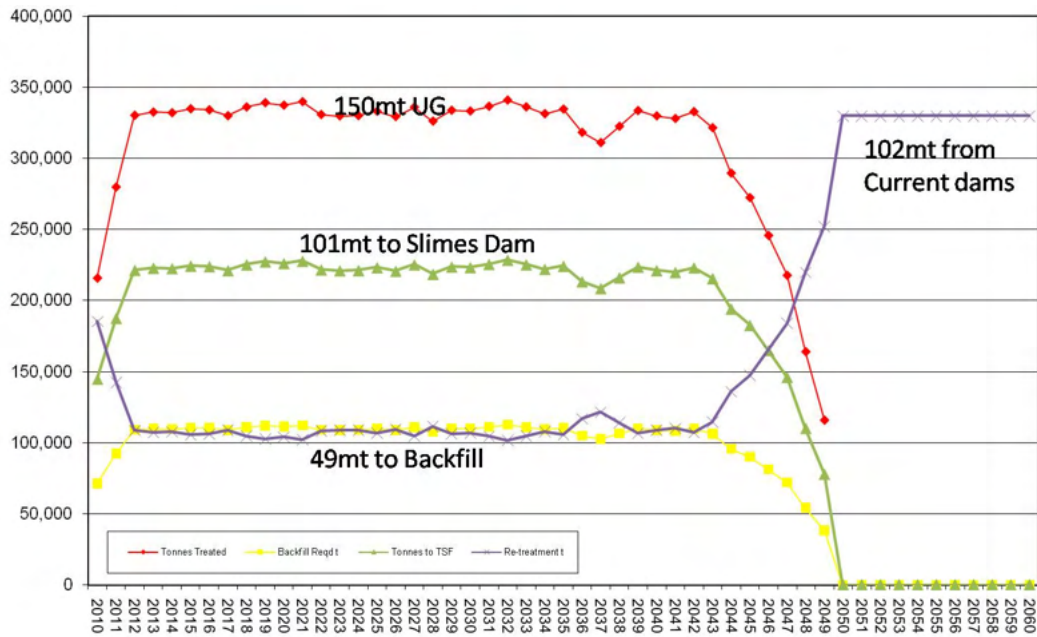
¹ Source: <http://earthquake.usgs.gov/regional/world/africa/gshap.php>

Figure 5-1 shows the projected tonnage based on feasibility study which would be treated at the Gold Plant. The amount removed for backfill is based on performance to date at around 30% to backfill. This figure should increase as the trackless mining becomes more predominant at South Deep but given the risk that additional material might not be used as backfill, a value of 33% was assumed.

The tonnage expected to report to the dam is 101 million tonnes, but the airspace that is potentially available at the site is sufficient for 205 million tonnes. This upside potential would allow the mine to treat the two old slimes dams for gold and / or uranium and deposit them on the new dam.

The design has been changed to accommodate the slow build up of tonnage with capital deferred into at least 3 phases. Infrastructure associated with the upslope part of the dam is delayed to later phases as the footprint is covered. The dam could be modified to physically accommodate an increased tonnage of up to 330 ktpm should this be necessary with relatively small increased expenditure on infrastructure compared to the option of developing the reduced footprint upfront (These modifications and their associated costs have not been determined to date and would require the involvement of the design team at a later stage, should this decision be taken).

This would also enable South Deep to consider treating the envisaged 480 ktpm Kloof South Deep Optimisation (KSDO) Project less backfill giving 330 ktpm to the dams if this option is proven viable in future.

FIGURE 5-1: EXPECTED TONNAGE PROFILE

The design tonnage profile provided by South Deep Mine is as shown in Table 5-1. The design is based on the 220 ktpm scenario.

TABLE 5-1: PLANNED TONNAGE PRODUCTION SCENARIOS

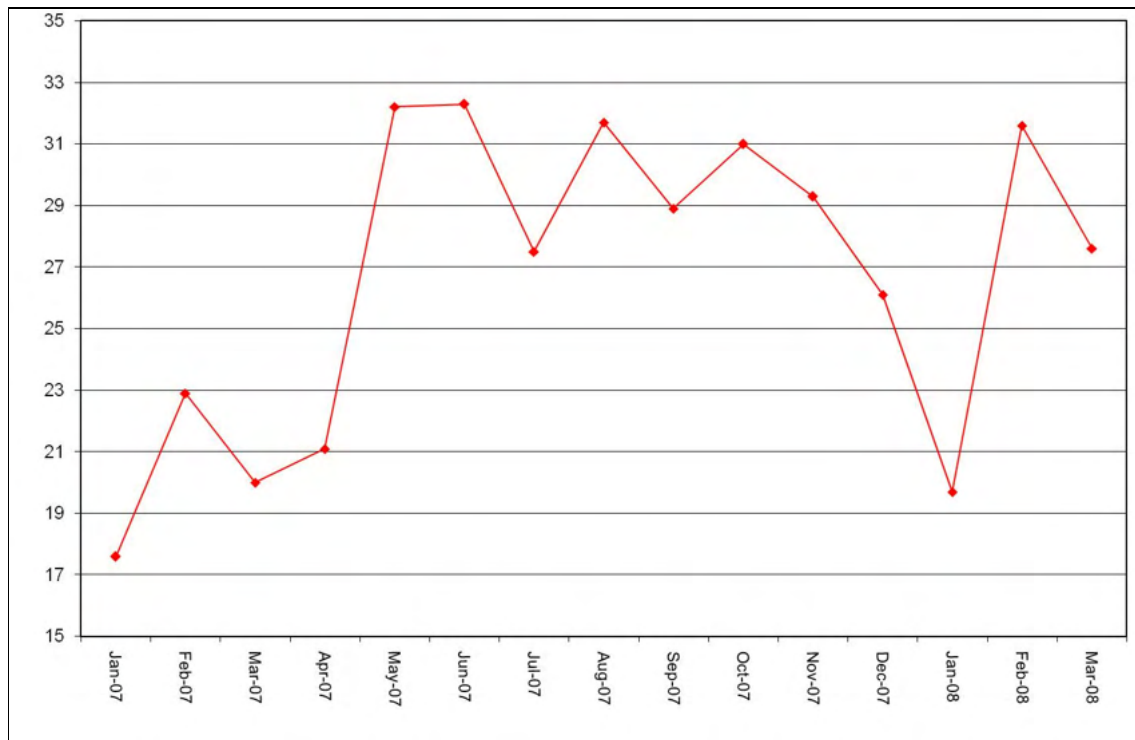
YEAR	TONNAGE PRODUCED DURING PERIOD
	220 KTPM SCENARIO
1	1,411,017
2	1,605,797
3	1,985,285
4	2,402,857
5	2,862,669
6	2,790,682
7	2,790,524
8	2,814,476
9	2,783,519
10	2,797,931
11	2,818,032

YEAR	TONNAGE PRODUCED DURING PERIOD
	220 KTPM SCENARIO
12	2,826,628
13	2,775,934
14	2,857,509
15	2,773,971
16	2,767,122
17	2,745,474
18	2,757,394
19	2,835,884
20	2,868,023
21	2,802,786
22	2,788,083
23	2,863,989
24	2,863,161
25	2,853,817
26	2,766,704
27	2,725,994
28	2,809,884
29	2,806,837
30	2,776,710
31	2,817,737
32	2,723,612
33	2,676,981
34	2,773,366
35	2,781,823
36	2,757,350
37	2,462,669
38	2,319,729
39	1,963,961
40	1,637,306
41	1,219,560
42	708,578
43	0

5.2. BACKFILL PROFILE

Ore is treated at the Gold Plant at Twin Shaft and the tailings pumped to the South Shaft Backfill Plant. At the Backfill Plant the coarse fraction is retained and sent to the shaft for binder addition and placement as backfill. The rest of the material then reports to the current tailings dams. If necessary material can be pumped directly from the Gold Plant to the tailings dams.

The 220 ktpm figure was assumed using the 330 ktpm profile less an allowance for backfill. The maximum theoretical percentage that can be used for void filling is estimated at 50% of the extracted tonnage. The historic backfill record indicates that 30% is typically achieved as shown in Figure 5-2. A design assumption of approximately 33% has been made. The mine depends on backfill to ensure sustainability of the massive and destress mining projects and currently uses a cyclone classified product produced from the tailings from the gold plant. Designs are currently underway to implement a full plant tailings option. If this option is proved to be viable this will improve the quality of material reporting to the new dam significantly.

FIGURE 5-2: HISTORIC PERCENTAGE TAKEOFF TO BACKFILL

5.3. RE-TREATMENT OF CURRENT SLIMES DAMS

The dams at South Deep have not been drilled yet to estimate gold, uranium and sulphur grades but the de-commissioned portion of Dam 4 was drilled recently with fairly promising gold and uranium results ideal for the re-treatment project. The results indicate grades of 0.35g/t Au and 100g/t U_3O_8 . It is believed that the potential for recovery of gold, uranium and sulphur using a flotation / resin plant is excellent and that this material could be re-treated at a rate of 150 ktpm and along with current tailings be used to produce a backfill product and then pumped to the new TSF. This would then change the tonnage reporting to the dam to around 330 ktpm. This would require a possible modification to the starter wall height, depending on the timing of the re-treatment project.

5.4. KLOOF SOUTH DEEP OPTIMISATION (KSDO) PROJECT

Although still in early phase of feasibility study it is important to note that inclusion of these tonnages may result in additional tonnages being treated at South Deep Gold Plant. As can be seen from the figures up to 480 ktpm are expected. With normal backfill take off of 33% this would imply that the additional tailings tonnage would need to be stored on the Doornpoort tailings dam. Although not included in the new design the potential exists to increase the deposition rate to 330 ktpm, resulting in a reduced cost per tonne disposed.

6. TAILINGS CHARACTERISATION

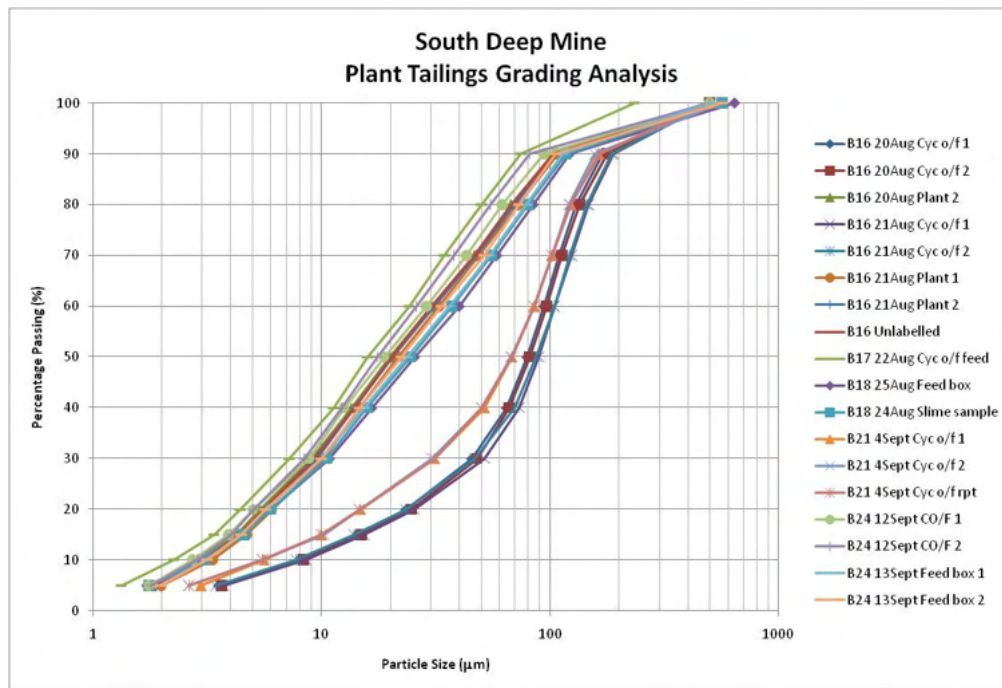
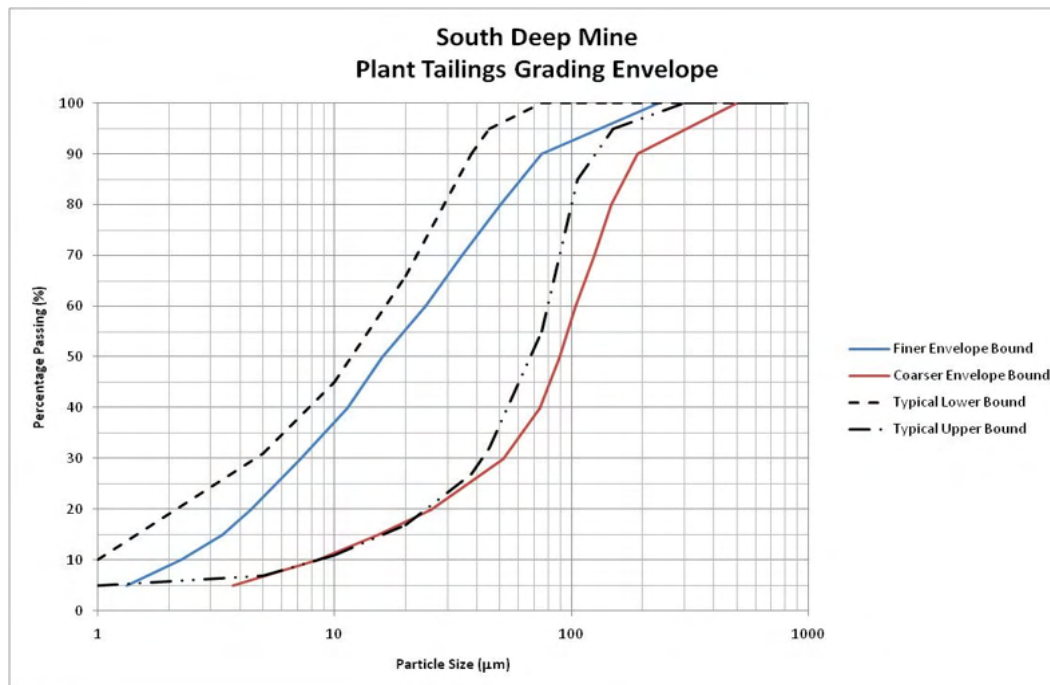
6.1. GEOTECHNICAL CHARACTERISTICS

6.1.1. TAILINGS ORIGIN

The tailings product will be exclusively from underground mining of Ventersdorp contact reef and the Black Reef.

6.1.2. PARTICLE SIZE DISTRIBUTION

The particle size distribution envelope has been derived from a series of particle size distribution test results (Fritsch Particle Sizer for the coarser portion, and a Polydispersive Laser Fraction set of tests for the finer portion) that were supplied by the mine. The samples originally tested are assumed to have been taken from the slurry supply pipes outlets on the current tailings dams. The particle size distribution of the tailings is presented in Figure 6-1 and Figure 6-2.

FIGURE 6-1 : PARTICLE SIZE DISTRIBUTION OF GOLD TAILINGS SAMPLES PROVIDED**FIGURE 6-2: PARTICLE SIZE DISTRIBUTION ENVELOPE FOR SOUTH DEEP GOLD TAILINGS**

It is noted that the particle size grading envelope for the tailings from South Deep is marginally coarser than the grading envelope for typical gold tailings. The tailings has 40% to 90% passing the 75 micron (0.075mm) sieve size while, on average, normal gold tailings exhibits between 55% and 100% passing the 75 micron sieve size i.e. the tailings product from South Deep Gold Mine has slightly more fine sand than average gold tailings.

6.1.3. PARTICLE SPECIFIC GRAVITY

The particle specific gravity was confirmed by the mine to be 2.70 typical of gold tailings.

6.1.4. IN-SITU DENSITY OF TAILINGS

Based on the grading curve for the expected product, the climatic conditions that prevail at the site, the method of disposal and envisaged rates of rise the average dry placed density for the tailings has been estimated as 1.35 t/m³. This is considered to be slightly conservative and could increase to 1.4 to 1.5 t/m³ at low rates of rise.

The dry densities have been calculated on Metago's estimated void ratios (e) for the various products. As a comparison, sand tailings (material >0,075mm) exhibits void ratios of 0.6 to 0.9 while slimes (material less than 0,075mm) exhibit void ratios of 0.7 to 1.3 (Fell et al). Silt sized tailings dried under the climatic conditions in South Africa can exhibit a void ratio of about 0.85. A conservative average void ratio over the entire tailings dam has, at this stage, been taken as 1.0 (which corresponds to a dry density of 1.35 t/m³).

These values will be periodically re-assessed once the facility is in operation.

6.2. SLURRY CHARACTERISTICS

Tailings will be pumped to the tailings dam at a slurry density of 1.40 t/m³, which equates to 55% solids by mass at a particle specific gravity of 2.70.

The characteristics of the tailings slurry are summarised in Table 6-1.

TABLE 6-1: SUMMARY CHARACTERISTICS OF TAILINGS SLURRY

PARAMETER	VALUE	UNIT
Tailings Slurry		
% Solids by Mass	55	%
% Water by Mass	45	%
Particle Specific Gravity (SG)	2.7	
Slurry Density	1.4	t/m ³

6.3. TAILINGS GEOCHEMISTRY AND PROCESS WATER CHEMISTRY

The geochemical characterisation study is documented in Appendix 3. The purpose of the geochemical waste characterisation study was to assess the hazard posed by the proposed tailings dam to the surrounding environment. The geochemistry of the tailings to a large extent dictates the design considerations for liners, covers, water management and water treatment facilities. The impact on the environment is documented in the Environmental impact assessment report and the hydrogeological report (GAA Report 10307/10273/13/G of August 2007).

6.3.1. IMPACT PATHWAYS

A tailings dam typically impacts on the environment through the following pathways:

- Air dispersion of contaminant-bearing dust particles which come into contact with soils or water, resulting in degradation of the resource quality. Erosion of the conventional gold tailings dams through dust emissions is generally considered to equal or exceed erosion through water. The highest percentage of erosion generally occurs from the side slopes and crest of conventional gold tailings facilities.
- Dispersion to air and surface runoff of precipitates that typically form on the top surface and side slopes of a conventional tailings dam as a result of capillary rise.

- Seepage through the footprint of the tailings dam and from associated facilities such as seepage collection trenches, solution trenches, catchment paddocks and the return water dam.
- Runoff from the tailings dam top surface and side slopes that enters the environment and is not captured as process water.

6.3.2. GEOCHEMICAL INVESTIGATION METHOD AND LIMITATIONS

The geochemical study focused only on the characterisation the seepage quality. Surface runoff quality and the effect of dust emissions of runoff qualities from surrounding land were not quantified but these impacts are considered in the design,

The study utilised the existing South Deep tailings dams shown on Figure 1-1 to obtain samples of fresh tailings, partially oxidised tailings, underdrain water and process water. The acid rock drainage potential was assessed using the Acid Base Accounting tests. Mineralogical examinations and leach tests were also conducted.

The radiation hazard posed by the tailings and associated dust, seepage and runoff has not been assessed but would be in line with other similar gold tailings dams associated with the same ore body.

6.3.3. CONCEPTUAL GEOCHEMICAL MODEL

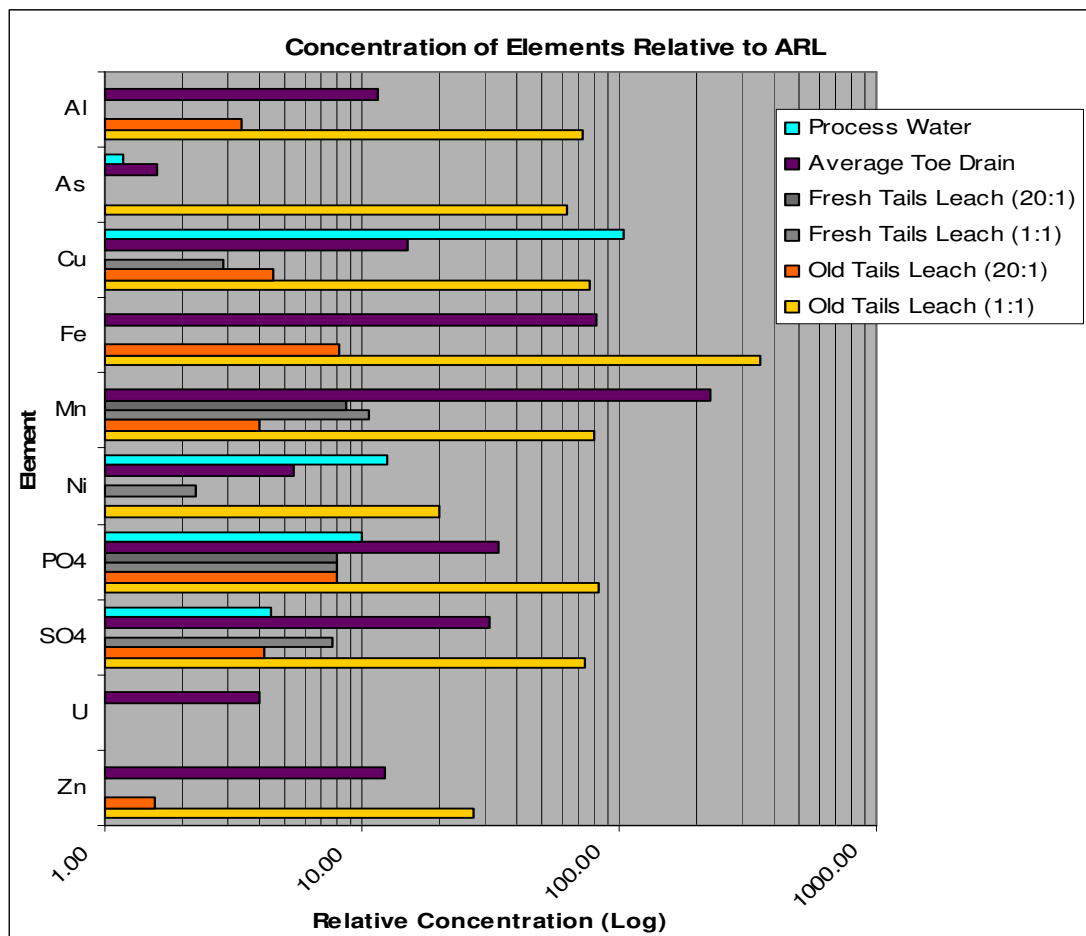
The proposed tailings dam may be characterised by two geochemically distinct zones which exist throughout the life of the facility but which change in size depending on the geochemical environment within the tailings dam. These zones comprise an acidic zone where active sulphide oxidation is occurring (zone 1) and a neutral zone (zone 2) where the environment is not suitable for rapid sulphide oxidation. The characteristics of these zones are further documented in the geochemical report.

6.3.4. ACID GENERATION POTENTIAL

The tailings is acid generating and is expected to release low pH water, characterised by a high TDS and high dissolved metals content if placed in an oxidising environment.

The results are compared in Figure 6-3 below. In order to place the results in perspective in relation to the potential threat that the water could pose to the environment, each concentration has been divided by the acceptable risk level (ARL) as defined in the Minimum Requirements (DWAF 1998). Where the ARL is not defined, the domestic use target water quality standard has been used as a basis for comparison.

Figure 6-3 shows only elements which exceeded the ARL value, or for elements for which no ARL value is quoted in Minimum Requirements, elements which exceeded the target domestic use guideline value as published in the DWAF Domestic Use Guidelines.

FIGURE 6-3: RELATIVE CONCENTRATION OF ELEMENTS THAT EXCEED THE ARL

The expected seepage water quality is shown in Table 6-2 for major cations and anions. Trace element concentrations are presented in the geochemical report.

TABLE 6-2: PREDICTED SPECIES CONCENTRATION IN THE SEEPAGE FROM THE PROPOSED DAM

		MAJOR ANIONS AND CATIONS									
		PH	TD S	CA	CL	F	K	MG	NA	PO4 3-	SO4 2-
Zone 1	Maximum	3.9	-	559	245	0.2	35	660	241	25	-
	Average	2.4	4400	510	8.4	0.2	<0.11	89	2	1	2800
	Minimum	2.2	1100	78	<5	0.15	<0.11	31	0.62	<1.6	840
Zone 2	Maximum	10.6	3900	780	120	0.3	48	72	378	0.1	1530
	Average	6.7	1954	196	73	0.3	27	9	200	0.1	884
	Minimum	5.6	180	130	6.1	0.2	2	1	10	<1.6	78
Guideline	DU	6.0 - 9.0	450	32	100	1	50	30	100	N/A	200
	LW	N/A	1000	1000	1500	2	N/A	500	2000	N/A	1000
	ARL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NA	N/A	N/A

The comparison of the expected seepage quality from the inner and outer zone indicates that the Acceptable Risk Level, as defined in the Minimum Requirements (DWAF 1998), will be exceeded for the following elements:

- Inner Zone – As, Cu, Mn and Ni.
- Outer Zone – Al, As, Co, Cr, Cu, Fe, Mn, Ni, Ti and Zn.

Although trace elements are not included in Table 6-2, it is noteworthy that uranium concentrations in an underdrainage water sample was 4.0 mg/l uranium. Elevated uranium concentrations occur in the seepage from this zone due to uranium's characteristic high solubility under acid conditions. Control measures which limit the sulphide oxidation rate will reduce the concentration of dissolved metals that are emitted from the dam as seepage water and surface water runoff.

Based on the tests conducted on the old tailings dam toe drain seepage, if the tailings are allowed to become acidic, the solubility of uranium is likely to increase significantly to in excess of two orders of magnitude above the DWAF domestic use guideline value.

The salt load (based on total dissolved solids concentration) to the groundwater from the footprint of the tailings dam has been estimated at <1000 kg/day. Of this, in excess of 90% is expected to arise from zone 2 despite the better seepage quality. The higher salt load from zone 2 is ascribed to the higher seepage flux from this zone. Reducing the seepage flux to the foundation will (at least during the operational Phase) significantly reduce the potential impact on the groundwater quality.

6.3.5. MITIGATION OPTIONS

Options to mitigate the potential impact posed by the acid generating tailings were considered to a pre-feasibility level of detail. The options are briefly described in Table 6-3 together with a qualitative rating in terms of their effectiveness in controlling contaminant emissions via the pathways identified:

TABLE 6-3: EMISSION MITIGATION OPTIONS

OPTION	DESCRIPTION	DUST EMISSIONS	RUNOFF EMISSIONS	SEEPAGE EMISSIONS	COST ² /TONNE	COST (R MILLIONS)
1	Scavenger wells located on the perimeter of the tailings dam	Ineffective	Ineffective	Moderate	R0.02	R2.5 to R5
2	Seepage cut-off curtain drain draining to pump sumps	Ineffective	Ineffective	Moderate	R0.02	R2.5 to R5
3	Soil liner to tailings dam- compacted clayey soils	Ineffective	Ineffective	Moderate	R0.12 to R0.31	R25 to R62

² (costs were determined in 2005 terms and are Escalated at 24.3%)

OPTION	DESCRIPTION	DUST EMISSIONS	RUNOFF EMISSIONS	SEEPAGE EMISSIONS	COST ² /TONNE	COST (R MILLIONS)
4	Plastic liner to tailings dam e.g. 1500um HDPE liner	Ineffective	Ineffective	Excellent	R1.86 to R2.50	R375 to R500
5	Convert to thickened tailings disposal method by raising slurry density of the tailings	Possible Moderate improvement	Possible Moderate improvement	Good	R0.06 to R0.37	R12.5 to R75
6a	Apply low air permeability cover to side slopes during operational phase and top surface on decommissioning. Cover low permeability barrier with non ARD generating rock or soil	Excellent	Excellent	Good	R1.50 to R2.37	R300 to R475
6b	As per 6a but plastic cover applied only to outer slope. Basin converted to arable land. Evaporation dam created in centre of basin	Excellent	Excellent	Moderate	R1.38 to R2.30	R275 to R475
7	Addition of 65 kg/tonne limestone during daywall construction and to the final 2 to 3 m of the night wall.	Ineffective	Good but not permanent	Poor to Moderate	R0.93 to R1.55	R186 to R310
8	Apply waste rock cover to the tailings dam and vegetate. (note waste rock required for Option 6)	Excellent	Reduce silt load but runoff quality will be poor	Ineffective	R0.25 to R0.50	R50 to R100

Preferred options are marked in bold in the table.

From the above Table, options 1 and 2 are clearly the lowest cost options but offer moderate protection to groundwater only since the protection is limited to the operational phase as this option is dependent on ongoing pumping and water treatment. This option alone does not offer a long term “walk away” solution.

Conversion to thickened tailings (option 5) offers a significant improvement in terms of seepage loads but the impact on surface runoff quality and dust emissions is very much dependent on the geometric design and operation method. The thickened tailings offers potentially flatter side slopes and a much greater final height, implying that the total footprint of the dam could be significantly reduced. While this option offers excellent benefits during the operational phase, it does not prevent the tailings from going acidic. Thus after decommissioning, the seepage rate through the footprint will be very low but the runoff quality from the surface of the dam is expected to be very poor. This option alone will therefore not satisfy the objective of a “passive aftercare only” solution. This option may achieve certain capital savings for phase 2 of the dam construction attributable:

- Saving in the cost of underdrains
- Saving in the decant tower and penstock costs

These savings have not been included in the cost estimate outlined in Table 6-3.

The capital cost for option 6 is largely incurred over the operational life of the tailings dam which means that this option not only outperforms the plastic lined dam option from an environmental perspective by addressing surface water runoff, erosion, dust and seepage, but also makes this option financially more attractive than the liner option. According to the Rison preliminary hydrogeological study, and as confirmed by the Golder study (GAA Report 10307/10273/13/G of August 2007), the site is considered highly suitable for a tailings dam as there are no aquifers in the area. Protection of seepage quality need therefore be focused primarily on the protection of the Leeuspruit Tributary downstream of the return water dam.

Option 6, possibly in addition to Option 5 best approaches the objective of a “passive care only” solution on closure of the dam. The cost of the combined option is expected to be between R2.14/tonne and R3.77/tonne.

The dam has been designed to accommodate option 6 (cover design) by constructing the outer side slope at a maximum gradient of 1:4. The scavenger wells were considered to not be necessary because of the favourable groundwater conditions associated with this site. No provision is therefore included in the costing for scavenger wells.

Option 5 (thickened tailings) could be considered at a later date by constructing a thickener close to the dam. Given the technical risks associated with this option, implementation of the thickened tailings option would best be considered through trials and implemented over several years. This option is not considered further in this report.

7. CLIMATIC CONDITIONS

The climatic conditions are documented in the Environmental Impact Assessment (Metago Report 168-004/2) and the Floodline Report (Appendix 2).

7.1.1. REGIONAL CLIMATE

The project area is situated on the interior high-plateau of South Africa known as the Highveld. Due to its height above sea-level (1580 m above sea level), the site experiences warm to hot sunny days in the Spring and Summer with temperatures often reaching 30° C. From October to April the area experiences a wet season (The average annual rainfall is 683 mm.) where thunderstorms do occur. The winter season tends to be dry with cold mornings (frost in June and July), although the days are warmer.

The prevailing winds throughout most of the year are north-westerly and north-easterly due to the anti-cyclonic circulation. During winter, particularly July and August, south-westerly winds blow more frequently because of the changing weather conditions (the northward shift of the high pressure belt and enhanced influence of

westerly wave disturbances e.g. cold fronts). Summer months are characterised by the weakening and southward shift of the anti-cyclonic belt, which allows tropical easterly flow to resume its influence over the region. North-easterly winds increase during summer (December to February) with north-westerly winds prevalent during March and April.

The area which is probably the most susceptible to dust fallout is the area to the south and south east of the dam, although the area to the north and north east could also be impacted as a result of strong winds associated with storm events. As described in Section 15.2, the concurrent cover will have significant effect in reducing dust emissions from the side slopes and crest of the facility. Notwithstanding the effect of the sideslope cover, dust emissions could exceed allowable limits, particularly under the following conditions:

- Plant production drops to a level that allows drying of the top surface of the dam to the extent that dust emissions can occur;
- Climatic conditions change resulting in longer, dryer periods or droughts; or
- During construction of the embankment lifts where appropriate measures to manage dust from construction vehicles are not taken.

In the event of temporary cessation of production, or production significantly below the 220 ktpm level, it will be necessary to implement temporary measures to reduce dust emissions over all or part of the top surface of the dam. These measures could include one or combination of the following:

- Raising the outer wall of the embankment and cover, such that it is several metres above the level of the basin;
- Application of chemicals to the surface of the dam such as Dustex or Lignosulphonate; or
- Ridge ploughing of the top surface.

On final decommissioning of the tailings dam, it will be necessary to apply a cover to the top surface of the dam to reduce dust emissions to a level acceptable to the post closure land use.

7.1.2. RAINFALL AND EVAPORATION

Climatic data was obtained for the closest weather stations from the South African Weather Service. The *Westonaria Kloof Goudmyn* station (no 0475174 4), with 37 years of recorded rainfall was selected (rainfall data only) on the basis of proximity and similarity in elevation. The proposed Doornpoort Tailings Dam complex is located at 26° 28' S, Longitude: 27° 39' E with an average elevation of approximately 1560 mamsl, which is closest to the *Westonaria Kloof Goudmyn* station with a similar elevation. The weather stations in the vicinity of South Deep Mine are presented in Table 7-1. The selected station is also geographically co-located with South Deep Mine to the south of the east- west Hillshaven ridge, which may influence rainfall patterns. The evaporation data was sourced from the *Zuurbekom* station, which is the closest to the site. The adopted rainfall and evaporation data is presented in Table 7-2. Average daily temperature data from the *Kroningspark* station, again the closest available data, is also presented.

TABLE 7-1: WEATHER STATIONS IN THE VICINITY OF SOUTH DEEP MINE

STATION NAME	STATION NUMBER	TEMPORAL RANGE (YEARS)	LATITUDE	LONGITUDE	ELEVATION (M.A.M.S.L)
Zuurbekom	0475528 8	1903-2005	-26.30°S	27.80°E	1578
Krugersdorp	0475456 8	1904-2005	-26.10°S	27.77°E	1699
Kroningspark					
Randfontein	0475338 9	1954-2005	-26.13°S	27.70°E	1710
Westonaria Kloof Goudmyn	0475174 4	1966-2005	-26.40°S	27.60°E	1685

**As supplied by the South African Weather Service*

TABLE 7-2: MONTHLY RAINFALL, EVAPORATION DATA AND AVERAGE TEMPERATURES

MONTH	MEAN MONTHLY RAINFALL (MM)	MEAN MONTHLY EVAPORATION (MM)	NET GAIN OR LOSS	AVERAGE NUMBER OF RAIN DAYS (/MONTH)	AVERAGE MAX TEMP	AVERAGE MIN TEMP
STATION	WESTONARIA KLOOF GOUDMYN	ZUURBEKOM (S-PAN)		WESTONARIA KLOOF GOUDMYN	KRUGERSDORP KRONINGSPARK	
January	119	169	-50	10.6	26.1° C	14.6° C
February	86	139	-53	8.4	25.5° C	14.2° C
March	85	131	-45	7.9	24.3° C	12.9° C
April	49	103	-54	5.4	21.3° C	9.4° C
May	13	87	-74	2.5	19.1° C	5.6° C
June	5	70	-65	1.5	16.3° C	2.4° C
July	3	79	-76	1.4	16.9° C	2.4° C
August	9	112	-103	1.7	19.4° C	4.7° C
September	22	148	-127	3.7	22.9° C	8.7° C
October	72	167	-95	8.0	24° C	10.9° C
November	101	166	-65	10.2	24.6° C	12.5° C
December	119	172	-53	11.5	25.7° C	13.7° C
Annual	683	1544	-861	67.3	22.2° C	9.3° C

The site is located in an area where the rate of evaporation exceeds the rate of precipitation. The dam is reliant on the net evaporation rate experienced on the Witwatersrand Highveld and non freezing conditions for strength gain during the drying/ consolidation process.

For the proposed method of construction, the design rate of rise of 1.6m/yr has been set based on the climatic conditions and particle size distributions.

Frost conditions are expected to be common in the winter months and the selection of vegetation species would need to take cognisance of this. Snow and icing conditions are not expected to be a frequent occurrence.

The cover design would need to take cognisance of the low rainfall in winter and the relatively short, sharp storm events, which are common in summer and can lead to erosion.

Lightening protection for workers has to be considered in the operation of the dam.

7.1.3. EXTREME RAINFALL EVENTS

The highest intensity storm recorded in the area at the *Westonaria Kloof Goudmyn* station was 89 mm on 1 Jan 1980 but larger events are possible in the area, illustrated by 129 mm in 24 hours recorded at the *Randfontein Weather* station. The design storm events for specific return periods are shown in Table 7-3. For the 24 hour or 1 day rainfall depths, two divergent values were found or calculated from the two references used. For the purposes of the design the two values for each return period were averaged.

TABLE 7-3: DESIGN STORM EVENTS FOR VARIOUS RETURN PERIODS

RETURN PERIOD (YEARS)	24 HOUR RAINFALL DEPTH	24 HOUR RAINFALL DEPTH	AVERAGE 24 HOUR RAINFALL DEPTH	1 HOUR RAINFALL DEPTH
REFERENCE	(OP TEN NOORD ET AL 1982)	(ADAMSON 1981)		(OP TEN NOORD ET AL 1982)
1:2	53 mm	52 mm	53 mm	31 mm
1:5	70 mm	70 mm	70 mm	41 mm
1:10	86 mm	82 mm	84 mm	51 mm
1:20	106 mm	93 mm	100 mm	62 mm
1:50	140 mm	108 mm	124 mm	82 mm
1:100	172 mm	119 mm	145 mm	101 mm

8. RECEIVING ENVIRONMENT

South Deep's Gold Plants and Shaft Complexes are located to the North of Doornpoort Tailings Dam with the existing tailings dams situated between the South Deep shaft complex and the twin Shafts complex. The area to the south (and down gradient) of the tailings dam is sparsely populated with very few residents expected in the zone of influence of the tailings dam. The area surrounding the tailings dam is characterised by grazing and cultivated land. An Eskom substation is located to the

north east of the dam. All the above Interested and Affected Parties were involved in the Environmental Impact Assessment Process.

The site is located immediately to the east of an unnamed tributary of the Leeuspruit River which drains from north to south. The Leeuspruit drains to the Rietspruit which falls within the Vaal Barrage catchment. The hydrology and floodlines are documented in Appendix 2. All infrastructure has been located outside of the 1:100year floodline, and the 100m buffer zone, as stipulated in Regulation 704 of Act 36 of 1998.

Pipeline river crossings occur where the pipeline crosses the Kariegaspruit and Leeuspruit between South Deep Mine, Twin Shafts, and the Tailings Dam. Measures to protect these rivers are documented in a GAA Report.

Post closure land use will need to tie into the regional development plans applicable to the area. These development plans will probably change significantly over the 50 year design life of the dam. Notwithstanding the possible change, the following assumptions have been made in the design of the dam with respect to post closure land use:

- Increasing population will tend to create additional pressure around the existing urban centres in Gauteng for urban development. The urban fringe is likely to move closer to, and possibly even surround the tailings dam;
- The tolerance for negative impacts from residual gold mining infrastructure will reduce with time as less and less of the population derives benefit from gold mining;
- The more tailings dams that exist in the region, the greater the cumulative impact, and hence the less that each dam will be allowed to impact on the environment overall. This will manifest itself through tightening environmental legislation and environmental performance standards.

Although the detailed planning around post closure land use has not been conducted at this stage, for the purpose of design of the TSF, the post closure land use is assumed to be one, or a combination of the following:

- Establishment of a biodiversity park which creates habitat for a range of indigenous Highveld plants and animals;
- Specific recreational use such as: golf course, driving range, bird watching, hiking and park land.

The following end land uses are specifically not anticipated as they are not likely to satisfy long term sustainability criteria:

- Any use which results in the formation of paths and damage to the proposed cover system such as: grazing, motorcross, crop production on side slopes, etc.;
- Any land use which is susceptible to long term consolidation of the tailings such as residential developments;
- Any land use which is sensitive to radon gas emission which would include residential development.

The final land use will also preclude use of the water stored in the tailings dam as pore water, or use of the water that has seeped out of the tailings dam via underdrains or directly to the groundwater for any use whatsoever unless specifically treated to a standard acceptable for the intended use. The extent of the groundwater plume has been modelled by GAA and is documented in GAA Report No. 10307/10273/13/G of August 2007. The plume is not expected to have a measurable impact on surface water in the stream to the west or south of the site.

9. TOPOGRAPHY

The topography of the proposed site of the tailings dam slopes towards the southwest at an average slope of 1:50. The gradient of the site will necessitate the

construction of a relatively high (and large volume) starter wall embankment. Starter wall heights are documented in Section 16.5.

The topography lends itself to relatively easy operation of the dam since only one penstock system is required and water management prior to breaking ground will be relatively straight forward.

10. GEOTECHNICAL SITE CONDITIONS

GAA and Metago carried out a geotechnical investigation for the proposed tailings storage facility during May 2007 and June 2007.

The fieldwork comprised the excavation of 55 test pits as well as five boreholes. Dynamic Cone Penetrometer (DCP) tests were carried out at selected positions within the formed test pits. Samples taken during test pitting were sent to commercial soil laboratories for testing.

From the investigation undertaken the site is confirmed to be underlain by shales and andesitic lava. Siltstone was also occasionally encountered. In addition, occasionally intrusive dolerite was encountered. Upper soils generally comprise transported Aeolian, colluvium and hillwash soils. Thick alluvium was encountered in the southern portions of the site. Well developed residual andesite lavas as well as limited residual shale were encountered. Outcropping andesite rock was frequently encountered particularly towards the northern portion of the footprint of the proposed tailings dam.

The footprint of the surface bed for the starter wall must be ripped and re-compacted prior to the placement of the first layer of fill.

The soils encountered within the footprint of the proposed tailings dam should prove suitable for the construction of the starter wall provided that certain precautionary measures are taken during construction.

For the access road which will be constructed around the final perimeter of the footprint of the proposed tailings dam, the only suitable soils that have been identified

for the road is the ferricrete layer and the pebble marker present on the site. The ferricrete and pebble marker strata are generally poorly developed on this site, but in some areas this layer has developed sufficiently to make it suitable as a wearing course for the proposed access and perimeter roads.

Although not encountered, dolerite dykes and possibly andesite outcrops may transverse the penstock alignment. In these instances hard rock conditions will be encountered. If these conditions are encountered the required depth of over-excavation (in order to limit the expected differential settlement of the pipe) will have to be determined on site during construction.

It is recommended that the permanent penstock be placed on an engineered rock fill raft and the portion of the penstock outfall pipe closest to the permanent penstock be placed on a tapered imported engineered rock fill constructed within the pipe trench. Unacceptable differential settlement is expected to take place between the penstock tower and the outfall pipeline if no precautionary measures are taken.

It is recommended that the borrow pit operations envisaged in the vicinity of the penstock line, should not come closer than 25m to the pipeline alignment. This is required to ensure that the penstock pipeline benefits from trench conditions along its length.

Variable conditions were encountered within the area designated for the return water dam. Residual andesite is found underlying the higher (north eastern) areas while the lower (south western) areas are underlain by shales near or adjacent to the well defined water course. In addition the area has been intruded by a dolerite feature which is seen to occur on the lower south western portions extending towards the central portions of the return water dam.

Groundwater seepage is expected to occur in the south western portions of the return water dam footprint.

The silt trap and neutralisation plant are located on the northern side of the return water dam and appear to be underlain by andesite.

Shallow box cuts are required in the construction of the starter and return water dam embankments. The final founding elevation of the starter walls and return water embankment is to be confirmed on site by the Engineer after inspection of the boxcut.

For the full details of the investigation, refer to GAA Report 10307/10319/14/G of September 2007.

11. LEGAL PROCESSES AND PERMITTING

11.1. DEPARTMENT OF MINERALS AND ENERGY

Approval of the EMP was required from the Department of Minerals & Energy (DME) in terms of mining legislation. The EIA/EMP process commenced under that Minerals Act (50 of 1991) but will now be completed under the Mineral and Petroleum Resources Development Act (28 of 2002) and supporting regulations.

The EMP for the new tailings dam will become the third amendment to the mine's EMP report.

11.2. DEPARTMENT OF WATER AFFAIRS AND FORESTRY

A **Water use licence** for the new tailings dam needs to be obtained from the Dept of Water Affairs & Forestry (DWAF). This application is an amendment to the Application submitted to DWAF in August 2006. The application was still to be submitted at the time of writing of this report.

Government Notice 704 Regulations were taken into account in the planning of the tailings dam.

In addition to the water use license, the return water dam requires the appointment of an Approved Professional Person for the Design and operational monitoring.

11.3. DEPARTMENT OF AGRICULTURE, CONSERVATION AND ENVIRONMENT

Environmental authorisation from the Department of Agriculture, Conservation and Environment (GDACE) was required for identified listed activities in terms of the Environment Conservation Act (73 of 1989) and supporting regulations.

An application has been submitted to GDACE for consideration. Listed activities identified and applied for include a change in land use from “undetermined” to mining and pipeline routes for tailings delivery and return water.

TABLE 11-1: STAGES OF THE EIA/EMP AMENDMENT PROCESS AND CORRESPONDING ACTIVITIES

PURPOSE	MAIN ACTIVITIES
APPLICATION STAGE	
Application to DACE	When the project commenced, no listed activities in terms of the Environment Conservation Act and supporting regulations were included in the project description therefore no formal application for environmental authorisation was made to DACE. This was decided in consultation with DACE representatives (see minutes of regulatory authority meeting dated 19 November 2003 attached in Section 10.4 of the EIA/EMP Amendment).
Application to DME	Not required as this project does not involve new mining rights.
SCOPING STAGE (NOVEMBER TO DECEMBER 2003)	
Identify regulatory authorities and other interested and affected parties (IAPs) and involve them in the scoping process. Determine the issues on which attention needs to be focused. Input into project planning decisions through the exploration of alternatives. Identify any fatal flaws.	Initial planning with the project team. Updating of the public involvement database for South Deep Mine. Background information document and invitations to meeting sent to regulatory authorities and IAPs (early November 2003). An advertisement was placed in the Randfontein Herald on the 27 November 2003. Posters were erected on the 26 November 2003 at: <u>At the mine:</u> all clocking points, Management Building, Technical Services Building, Stores, Time Office, Personnel Office, Hostels; Clinic; Security. <u>Off Mine:</u> Westonaria – Municipality Offices, Post Office; Fochville – President Sentra, SPAR; Soetdoring Kelders; Glenharvie (Kloof Mine) – SPAR, Butcher; Hillshaven – Supermarket.
<i>Scoping stage continued</i>	Initial meetings with regulatory authorities (19 and 25 November 2003). Meetings with IAPs (10 and 11 December 2003). Compilation of a scoping report (December 2003). Distribution of scoping report to regulatory authorities for review (December 2003). Copies of scoping report were made available for public review at

PURPOSE	MAIN ACTIVITIES
	Westonaria Library, Fochville Library and South Deep Mine (December 2003 and January 2004). Summary of the scoping report was sent out to all IAPs registered on the public involvement database (December 2003). Meeting with regulatory authorities to discuss the findings of the scoping report and the way forward for the EIA/EMP (22 January 2004).
DETAILED INVESTIGATIONS (JANUARY TO MAY 2004)	
Describe the affected environment. Define potential impacts. Give management and monitoring recommendations.	Basic geohydrological study commissioned on all seven alternative sites (February 2004). Detailed geohydrological study (March 2004) and soils study (May 2004) on Site 3 – the preferred site at that stage of the project.
<i>Tailings dam project and EIA process on hold</i> <i>Following discussions by South Deep Mine management, the tailings dam project and EIA process were put on hold in mid 2004. The reason for this was a change in the tonnage profiles for the mine which revealed the urgency of establishing a new tailings dam.</i>	
RE-INITIATION OF THE PROJECT (JANUARY TO NOVEMBER 2005)	
- To update IAPs on the status of the project. - To inform IAPs of revisions to the project description.	- EIA/EMP process re-commissioned (January 2005). - Conceptual design of the tailings dam commissioned (March 2005). - Meetings with various regulatory authorities (Re-initiation meeting with regulatory authorities on 11 August 2005, re-initiation meeting with Department of Agriculture on 6 September 2005). - Distribution of the re-initiation information-sharing document to all IAPs registered on the project's public involvement database (November 2005).
APPLICATION TO DACE (SEPTEMBER 2005)	
To submit a formal application to DACE requesting permission to undertake an activity listed in terms of ECA and the supporting regulations.	- Focused meeting with DACE representatives on 24 August 2005. Minutes of the meeting are attached in Section 10.1 of EIA/EMP Amendment. - Application submitted and scoping report re-submitted to DACE in September 2005.
DETAILED INVESTIGATIONS (OCTOBER 2005 TO FEBRUARY 2006)	
- Describe the affected environment. - Define potential impacts. - Give management and monitoring recommendations.	Specialist investigations of issues identified during the scoping stage and re-initiation stage of the project.
REPORTING (JANUARY 2006 TO PRESENT)	

PURPOSE	MAIN ACTIVITIES
- Compile the EMP report. - Refine the EMP report through consultation with IAPs and authorities.	- Compilation of the draft EIA/EMP amendment (October 2005 to February 2006). - Distribution of the EIA/EMP amendment for review by regulatory authorities and IAPs (March 2006). - Provide IAPs with a summary of the findings (March 2006). - Make the EIA/EMP amendment available to IAPs for review at Westonaria Library, Fochville Library and South Deep Mine (March 2006). - Regulatory authorities review meeting and IAP feedback meetings (April 2006). - Update the final EMP amendment, if necessary (April 2006).
Submit EMP report	Forward final EIA/EMP amendment/comments to regulatory authorities (April 2006). Record of decision still awaited from DEAT.
Approval of document	DME has approved the EMPR 2008.

11.4. CYANIDE CODE

For the purposes of design of tailings dam, Section 4 of the International Cyanide Management Code documents a series of standards of practice relating to management of cyanide process solution and waste streams to protect human health and the environment. The key standards of practice relevant to design of the tailings dam include the following:

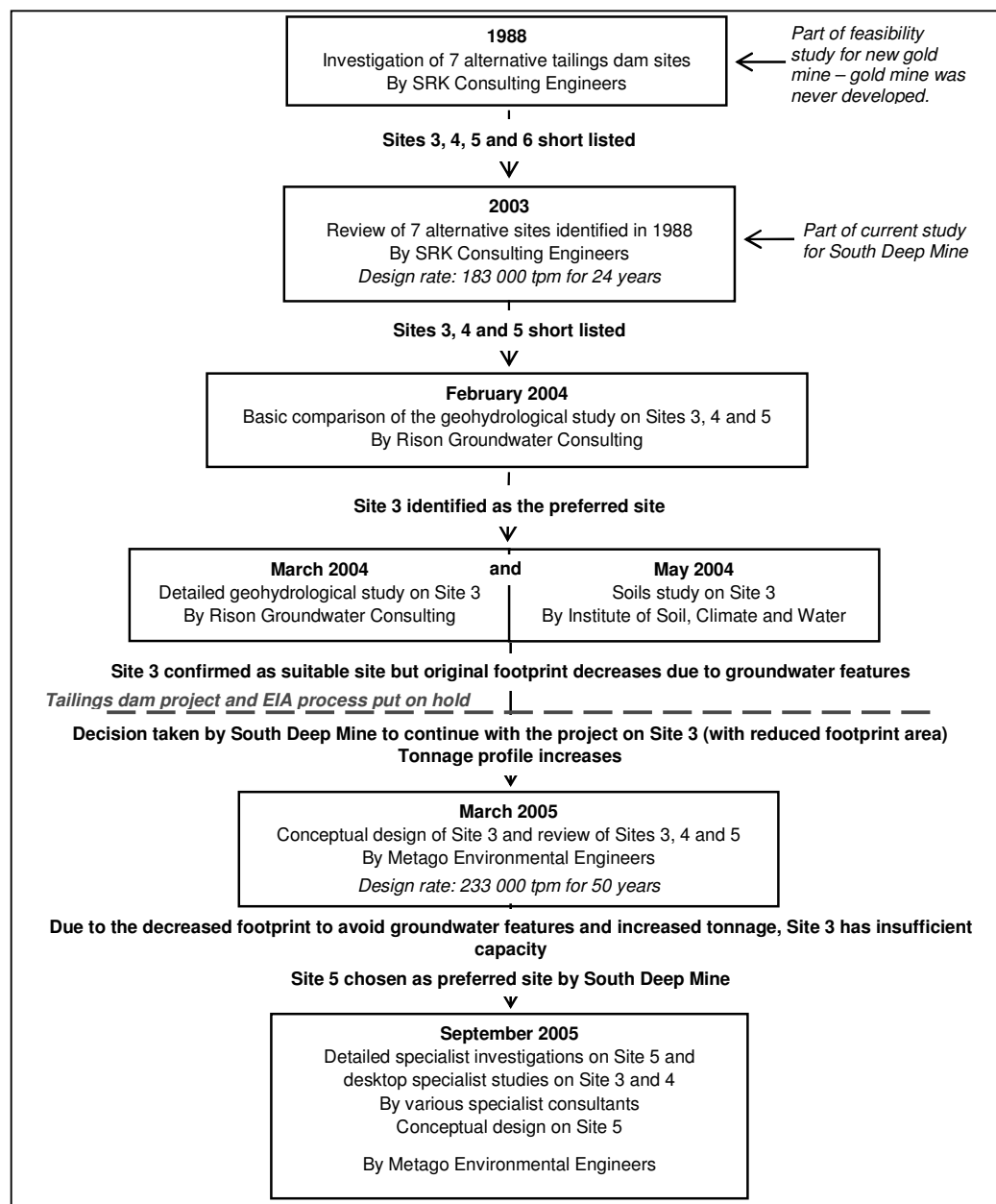
- Implement management and operating systems designed to protect human health and the environment including contingency planning and inspection and preventive maintenance procedures. The management and operating systems are not dealt with in this report.
- Introduce management and operating systems to minimize cyanide use, thereby limiting concentrations of cyanide in mill tailings. This issue is not dealt with in this report.
- Implement a comprehensive water management program to protect against unintentional releases. This issue is dealt with in the sizing and design of facilities and in the operating manual.

- Implement measures to protect birds, other wildlife and livestock from adverse effects of cyanide process solutions. This issue is partially dealt with in this report.
- Implement measures to protect fish and wildlife from direct and indirect discharges of cyanide process solutions to surface water. This issue is dealt with in this report and the water balance report. Protection of fish and wildlife is achieved through the design and sizing of contaminated water management systems.
- Implement measures designed to manage seepage from cyanide facilities to protect the beneficial uses of ground water. This issue is dealt with in a GAA Report.
- Provide spill prevention or containment measures for process tanks and pipelines. This issue is dealt with in a GAA Report and Drawings 10307-212 and 10307-213.
- Implement quality control/quality assurance procedures to confirm that cyanide facilities are constructed according to accepted engineering standards and specifications. This issue is considered in the design.
- Implement monitoring programs to evaluate the effects of cyanide use on wildlife, surface and ground water quality. This issue is address in Section 18 of this report.

12. SITE SELECTION REVIEW

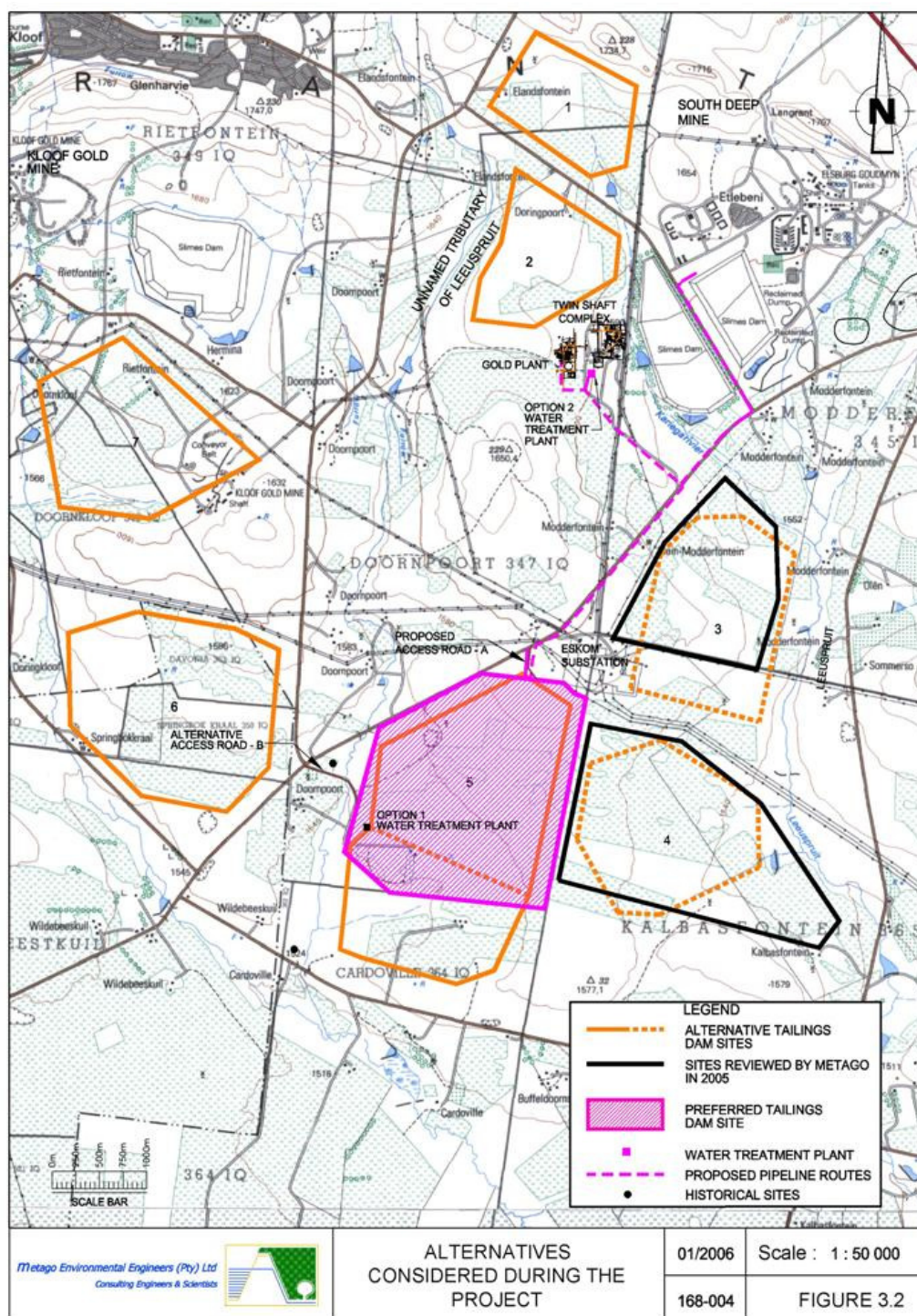
An overview of the site selection process leading up to the selection of the proposed site for Doornpoort is presented in Figure 12-1.

FIGURE 12-1: SITE SELECTION PROCESS (METAGO EIA REPORT 168-004 No. 2 FIGURE 3.1)



The sites considered in the process are shown in Figure 12-2.

FIGURE 12-2: SITES CONSIDERED DURING SITE SELECTION (METAGO EIA REPORT 168-004/2 FIGURE 3.2)



The site selection process for a new tailings dam has been the subject of numerous reports dating back as far 1988 (SRK report MI 6131/1 of February 1988), when a tailings facility was required for several mines in the area that formed part of Johannesburg Consolidated Investments Ltd (JCI). More recently, SRK Consulting reviewed the work done in 1988 (SRK report 225456 of November 2003) with a view to selecting a tailings dam site specifically for South Deep. The report concluded that of the sites originally considered, sites 3, 4 and 5 were most suited to the requirements (Figure 12-1).

In August 2005, the site selection was reviewed by Metago taking cognisance of several possible production and life of mine profiles.

In 2005, Metago was requested to complete a conceptual tailings dam design for South Deep Mine on Site 3. Shortly after commencing with this concept design, South Deep identified the need to increase the production rate to improve the return on investment of the mine. This precipitated the need to re-consider the site selection process in the light of the increased tonnage.

The revised study focused on three sites, namely sites 3, 4 and 5 shown in Figure 12-3 and considered a range of possible production rates varying from 220 ktpm to 330 ktpm giving a range of total life of mine tonnages of between 40 million and 93 million tonnes.

It became apparent at the early stages of the conceptual design for site 3 that this site may no longer be suitable given the total tailings tonnage to be disposed of. The Metago Report (Metago Report No 168-006/01) stated that for the two possible options on Site 3:

The depositional area was limited, which would might limit the mine's production to 220 ktpm less 20% to backfill;

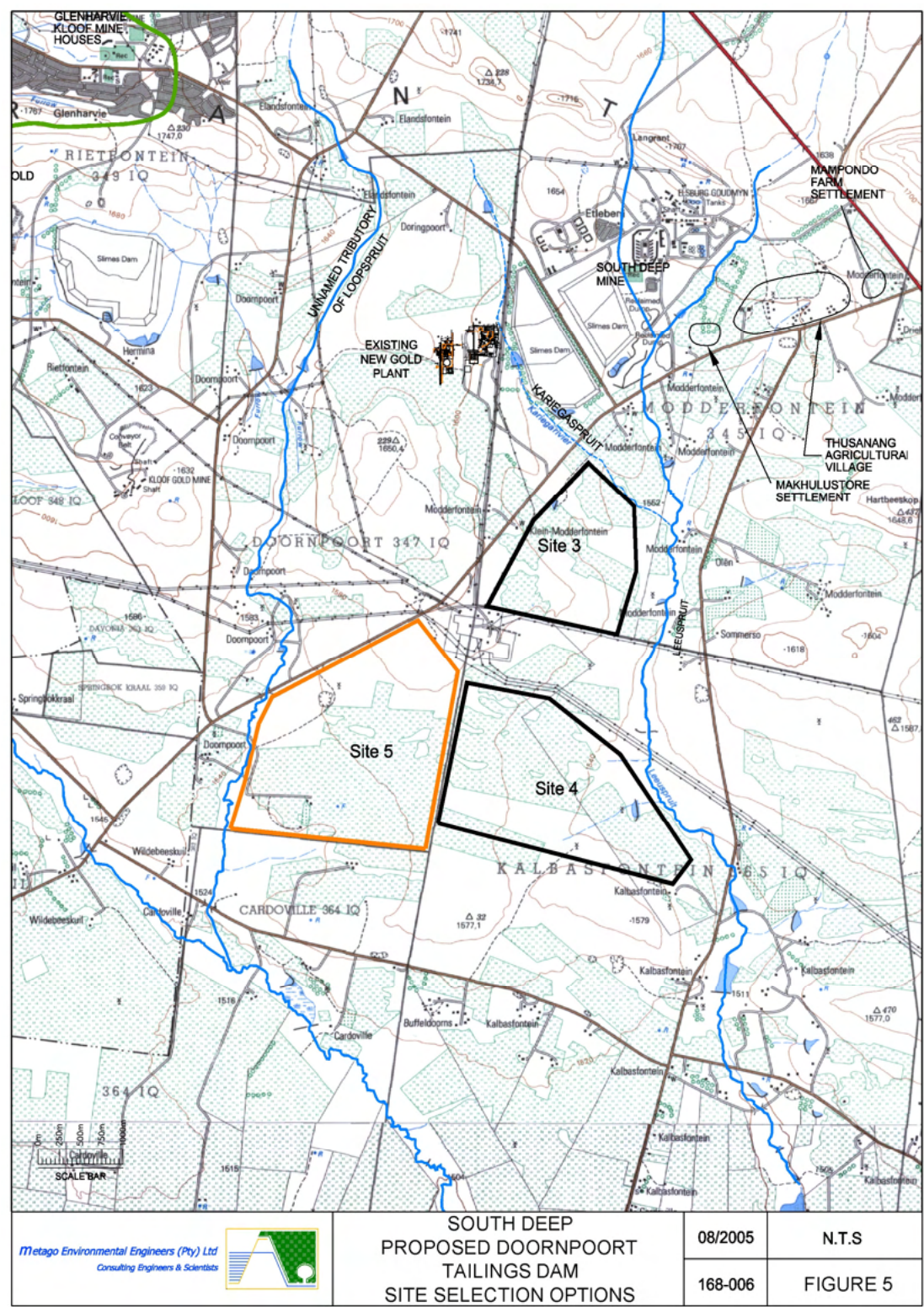
The site also carried a very high risk with respect to environmental permitting issues, as the site would require the permitting of a river diversion;

Site 4 and Site 5 on the other hand had fewer limitations with regard to tonnage and could accommodate in excess of the 93 million tonnes, based on a total plant

production of 330 ktpm less 33% backfill. Site 5 was considered slightly more advantageous from an environmental and cost perspective and was therefore selected for detailed design.

During the period between concept design and detailed design the design tonnage was increased to accommodate 330 ktpm over a 50 year design life giving a total tonnage of 198 million tonnes. This could be accommodated on Site 5 and it was therefore not necessary to revisit site selection. This was later revised downwards to 330 ktpm less backfill, but for a 50 year life of mine. The revised tonnage did not entail reducing the footprint area in order to maintain upside potential for future expansion but involved phasing of capital expenditure and a lowered starter wall.

FIGURE 12-3: PREFERRED SITES 2003 SITE SELECTION REVIEW (METAGO REPORT 168-006 No. 8 FIGURE 5)



13. CONSTRUCTION PHASING TRADE-OFF STUDY

In order to optimise the cash flow for the proposed tailings facility, five trade-off options were considered. All of the options were based on a production rate of 220ktpm, and are summarised below:

- Option 1 consisted of a single compartment, on the maximum footprint, with phased construction of the tailings storage facility;
- Option 2 consisted of a single compartment, on the maximum footprint, with phased construction of both the thickener and the tailings storage facility;
- Option 3 consisted of a single compartment, on a reduced footprint, with phased construction of the tailings storage facility;
- Option 4 consisted of two compartments, on the maximum footprint, with phased construction of the tailings storage facility; and
- Option 5 consisted of two compartments, on the maximum footprint, with no construction phasing of the tailings storage facility.

The costing was based on a simplistic approach which ratio-ed of the quantities, as this was the quickest way to fairly base the comparison. The summarised capital expenditure (Capex) values are summarised in Table 13-1. Contingencies were excluded in the costing of the options.

The following was concluded from the trade-off study:

- The option with the minimum Capex without discounting is Option 2;
- The options with the greatest Capex without discounting, are Options 4 and 5;
- After discounting the Capex, Options 1, 2 and 3 become the most attractive;
- If the discounted Capex is converted to a Rand/m³ or Rand/tonne basis, then Options 1 and 2 become the most attractive.

In order to maximise the footprint potential, it was decided to go with the single compartment, phased construction option, with possible deferment of the thickener. This allows South Deep the opportunity in the future to:

- Increase the production rate;
- Increase the life of mine; or
- Treat the existing dams for gold and/ or uranium and deposit them on the Doornpoort dam.

with a relatively small increased expenditure on infrastructure, compared to the option of developing the reduced footprint upfront.

TABLE 13-1: TRADE-OFF STUDY COSTING OF OPTIONS

		NO. OF COMPARTMENTS	DESIGN TONNAGE	FOOTPRINT UTILISATION	PHASE	TOTAL CAPEX (1 JUNE 2008)	PHASE 2 CAPEX DELAYED (YEARS)	DISCOUNTED CAPEX	MAX POSSIBLE VOLUME	DISCOUNT ED COST PER M ³	MAX POSSIBLE TONNES	DISCOUNTED COST PER Tonne
Options	1	Single Comp	220ktpm	Maximum Footprint	Phase 1	R 428,480,412	0	R 428,480,412	152,135,129	R 3.01	205,382,424	R 2.23
					Phase 2	R 51,843,540	10.5	R 29,081,513				
					Total	R 480,323,953		R 457,561,925				
	2	Single Comp	220ktpm	Maximum Footprint Deferred Thickener	Phase 1	R 355,526,144	0	R 355,526,144	152,135,129	R 2.80	205,382,424	R 2.07
					Phase 2	R 124,797,808	10.5	R 70,005,040				
					Total	R 480,323,953		R 425,531,184				
	3	Single Comp	220ktpm	Reduced Footprint	Phase 1	R 401,796,001	0	R 401,796,001	106,362,772	R 4.12	143,589,743	R 3.05
					Phase 2	R 50,493,632	6	R 36,288,053				
					Total	R 452,289,633		R 438,084,054				
	4	Two Comp Delayed	220ktpm	Maximum Footprint	Phase 1	R 403,809,224	0	R 403,809,224	152,135,129	R 3.15	205,382,424	R 2.33
					Phase 2	R 94,101,579	4	R 75,500,231				
					Total	R 497,910,803		R 479,309,455				
	5	Two Comp Immediately	220ktpm	Maximum Footprint	Phase 1	R 425,560,802	0	R 425,560,802	152,135,129	R 3.14	205,382,424	R 2.32
					Phase 2	R 55,901,264	1.5	R 51,469,908				
					Total	R 481,462,066		R 477,030,710				

14. CLASSIFICATION OF THE TAILINGS DISPOSAL FACILITY

The classification of the Doornpoort Tailings Dam in terms of the requirements of the SANS Code of Practice for Mine Residue Deposits (SANS 10286, previously SABS 0286:1998) is documented below.

14.1. SAFETY CLASSIFICATION

14.1.1. CLASSIFICATION ACCORDING TO SANS10286

The safety classification of the facility has been carried out in accordance with the requirements of SANS 10286. The safety classification system serves to provide a consistent means of differentiating between high, medium and low hazard deposits on the basis of their potential to cause harm to life or property. The classification system furthermore provides a basis for the implementation of safety management practices for specified stages of the life cycle of a tailings dam. The code prescribes the aims, principles and minimum requirements that apply to the classification procedure and the classification in turn gives rise to minimum requirements for investigation, design, construction, operation and decommissioning. The information used in the safety classification is presented in Table 14-1 to Table 14-3.

The approximate area that may be affected by a flow slide originating from the proposed facility is shown in Figure 14-1. The area is based on the guideline values from the Code of Practice and the topography of the area.

Based on the safety classification criteria the tailings dam has been classified as a medium hazard facility. The minimum requirements associated with the design, operation, management and closure of a Medium Hazard Facility are summarised in Table 14-4.

TABLE 14-1: GENERAL INFORMATION REQUIRED FOR SAFETY CLASSIFICATION OF A TAILINGS DAM

1	GENERAL INFORMATION (REF SANS 10286)	
1.1	Name of Mine	South Deep Gold Mine
1.2	Postal Address of the Mine	PO Box 776 Western Area 1780
1.3	Telephone No. of the Mine	011-411-1000
1.4	Magisterial District	Westonaria
1.5	DME Region	Gauteng
1.6	Nearest Town	Westonaria
1.7	Direction and distance to town	About 10 km North
1.8	Name of person responsible for residue deposit	Gordon V. Thompson
1.9	Common name of deposit	Doornpoort Tailings Dam or Site 5
1.10	Name of closest river / stream to the deposit	Unnamed tributary of the Leeuspruit to the east
2	SAFETY CLASSIFICATION (REF SANS 10286)	
2.1	Description of Residue	Gold Tailings (Black Reef and Ventersdorp Contact Reef)
2.2	Is residue deposited hydraulically?	Yes
2.3	Is deposit still active?	N/A
2.4	Time since decommissioning.	N/A
2.5	Ultimate maximum height of deposit on closure (Crest elevation and lowest toe elevation)	80 m
2.6	Current maximum height of deposit	N/A
2.7	When did deposition start?	Currently planned to start October 2010
2.8	What is steepest overall outer slope of the deposit?	1V : 4H, 14° from horizontal
2.9	Steepest ground slope gradient measured on downstream perimeter of the deposit over a distance of 200m	5m over 200m (2.5%)
2.10	Is deposit located on undermined ground?	No
2.11	What is the shallowest depth to underground excavations?	
2.12	Line diagram of the deposit showing : Outline of deposit, approximate	

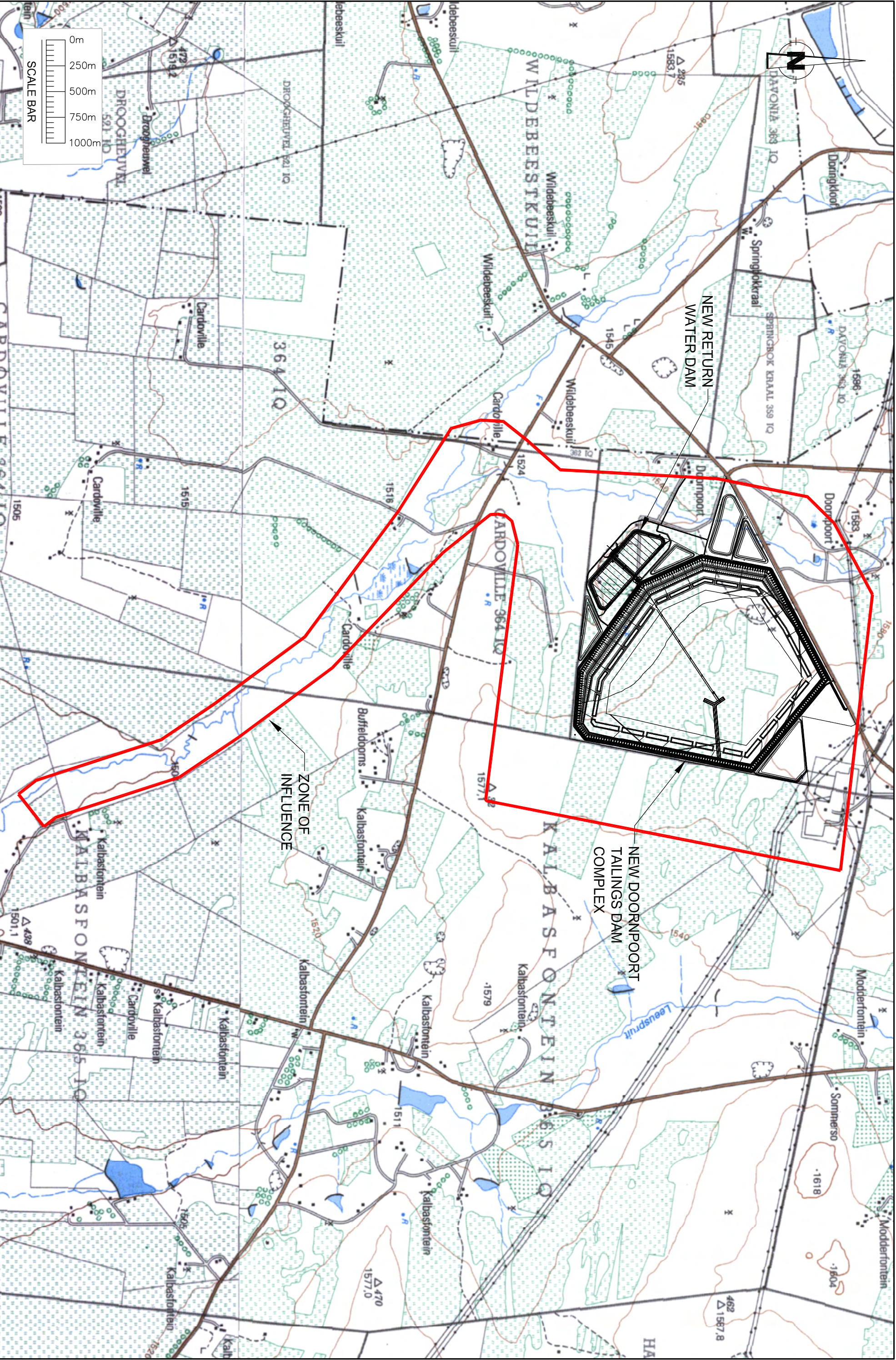
	ground contours for a distance around deposit as defined section A.2 of classification system; Zone of potential influence of a failure of the deposit (ref section A.2) Property / Infrastructure / Services located within the zone of influence	Refer Figure 14-1
A.2	DETERMINATION OF ZONE OF INFLUENCE	
Step 1	Deposition is hydraulic, go to step 2	
Step 2	Deposit will shortly be active, go to step 4	
Step 3	NA	
Step 4	Zone of influence defined by : (Ref. Figure 14-1) Upstream (Southern Side) Sides (Eastern and Western Sides) Downstream (Southern Side)	5H from upstream toe = 5 x 80m = 400m 10H = 800m 100H = 100 x 80m = 8 000m
Step 5	NA	

TABLE 14-2: SAFETY CLASSIFICATION CRITERIA

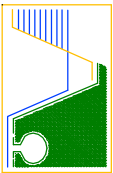
1	2	3	4	5
NO. OF RESIDENTS IN ZONE OF INFLUENCE	NO. OF WORKERS IN ZONE OF INFLUENCE ¹	VALUE OF 3 RD PARTY PROPERTY IN ZONE OF INFLUENCE ²	DEPTH TO UNDERGROUND MINE WORKINGS ³	CLASSIFICATION
0 1 – 10 > 10	< 10 11 – 100 > 100	0 – R 2 m R2 m – R 20 m > R20 m	> 200 m 50 m – 200 m < 50 m	Low Hazard Medium Hazard High Hazard
Not including workers employed solely for the purpose of operating the deposit The value of third party property should be in the replacement value in 1996 terms. The potential for collapse of the residue deposit into the underground workings effectively extends the zone of influence to below ground level. Source : SABS 0286:1998, Table 2 – Safety Classification Criteria				

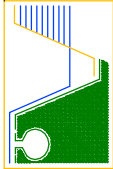
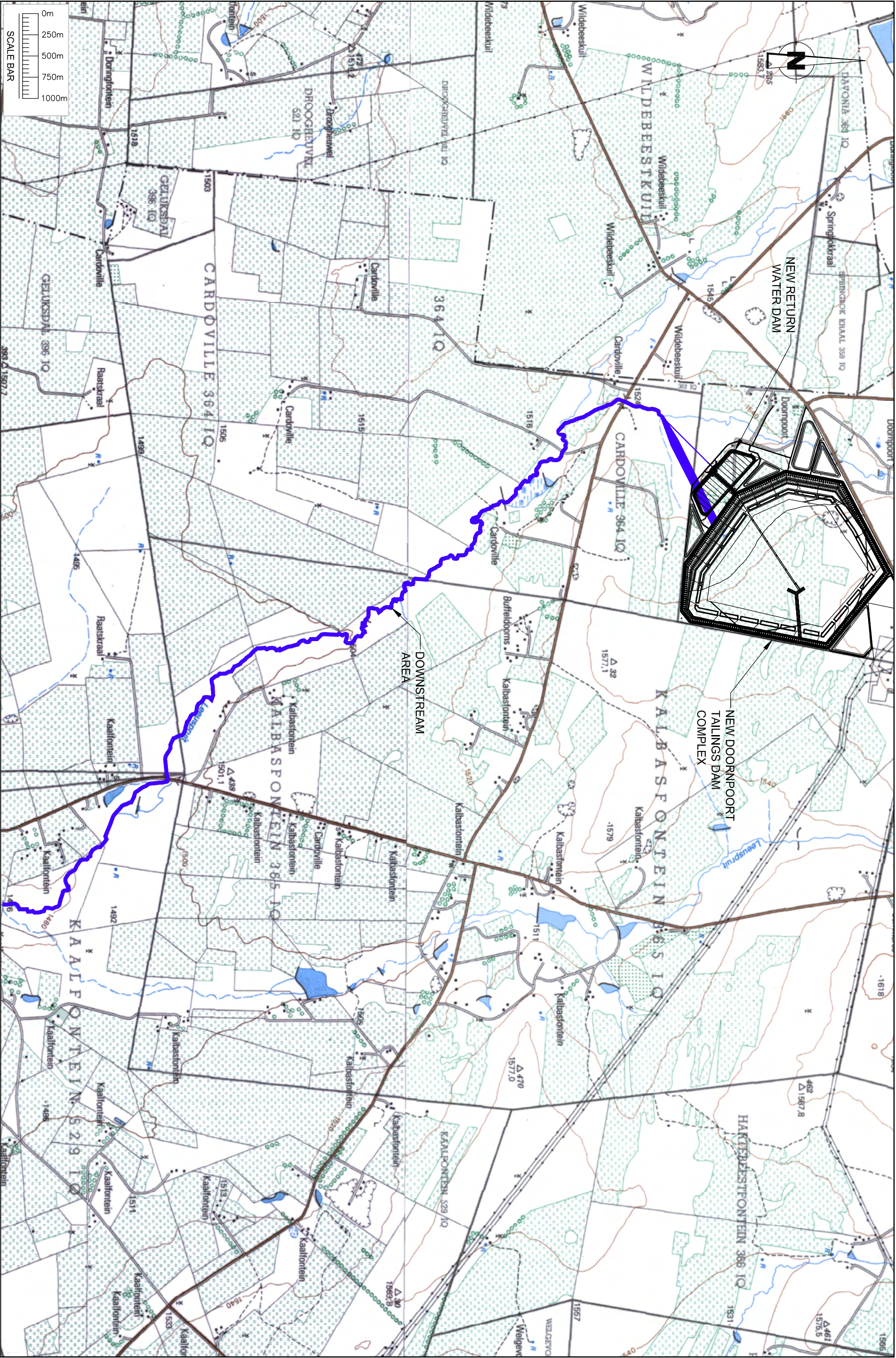
TABLE 14-3: SAFETY CLASSIFICATION

CRITERIA No.	CRITERIA	COMMENT	SAFETY CLASSIFICATION
1	No. of Residents in Zone of Influence	While no formal settlements are indicated on the 1 : 50 000 topographical maps of the zone of influence it is possible that small informal settlements may have been established in the area since the production of these maps	Medium Hazard
2	No. of Workers in Zone of Influence	The tailings dam is located up gradient of farm land. It is unlikely that there would be more than 10 workers (other than those involved in the operation of the facility) in the zone of influence	Low Hazard
3	Value of 3 rd party property in zone of influence	No formal assessment of the value of property has been done in the zone of influence as it is felt that the replacement value would be comfortably less than the R 20 m necessary to change the classification to High Hazard.	Medium Hazard
4	Depth to underground mine workings	There are no mine workings beneath the Proposed Tailings Dam Site	Low Hazard



DOORNPPOORT TAILINGS DAM
ZONE OF INFLUENCE
ACCORDING TO SANS CLASSIFICATION





14.1.1. CLASSIFICATION OF TAILINGS DAM ACCORDING TO DWAF DAM SAFETY OFFICE

The safety classification of the tailings dam has been carried out in accordance with the requirements of the Department of Water Affairs and Forestry (DWAF), form DW 692 E. It is only necessary to classify the dam if the maximum wall height of the dam exceeds 5 metres and the gross storage capacity is more than 50 000 cubic metres.

Appendix 8 contains the safety classification forms submitted to DWAF, and the correspondence received from DWAF. According to DWAF, the proposed Doornpoort Tailings Dam is not regarded as a dam with a safety risk on condition that the Dam will not store more than 50 000 m³ of water under normal operating conditions. In Metago's opinion, 50 000 m³ of water will be stored on the tailings dam at frequent intervals. In addition to this, the dam contains interstitial water which exceeds the 50 000 m³ limit set by DWAF by several orders of magnitude.

14.1.2. CLASSIFICATION OF RETURN WATER DAM ACCORDING TO DWAF DAM SAFETY OFFICE

The safety classification of the return water dam has been carried out in accordance with the requirements of the Department of Water Affairs and Forestry (DWAF), form DW 692 E. It is only necessary to classify the dam if the maximum wall height of the dam exceeds 5 metres and the gross storage capacity is more than 50 000 cubic metres.

Appendix 8 contains the safety classification forms submitted to DWAF, and the correspondence received from DWAF. According to DWAF, the return water dam is classified as a Category II dam, with a Significant Potential Hazard rating.

14.2. ENVIRONMENTAL CLASSIFICATION

The environmental classification of the facility has been carried out in accordance with the requirements of SANS 10286. All mine residue deposits should be classified into one of the following two environmental categories:

- Residue deposits that have a potentially significant impact on any environmental component; or

- Residue deposits that have no potentially significant impact on the environment.

A geochemical and mineralogical characterisation of the tailings has been carried out during the preliminary design of the facility – refer to Appendix 3. The results of the characterisation and water sampling of the underdrains have indicated that the leachate from the tailings storage facility could adversely impact on the quality of the groundwater in the vicinity of the facility.

In addition to the above, the release of tailings dust from the top surface and non-rehabilitated side slopes of the tailings dam poses a potential risk to the surrounding environment in the absence of suitable mitigation measures.

The above factors indicate that the future Doornpoort Tailings Dam should be classified as having a potentially significant impact on groundwater and air quality.

14.3. REQUIREMENTS ARISING FROM CLASSIFICATION OF TAILINGS DISPOSAL FACILITY

14.3.1. SANS REQUIREMENTS FOR MINE RESIDUE FACILITIES

The Doornpoort Tailings Dam can be classified as having a medium safety hazard in terms of the requirements of the SANS Code of Practice for Mine Residue Deposits (Table 14-3). A summary of the minimum requirements associated with a medium hazard safety classification is shown in Table 14-4.

TABLE 14-4: SUMMARY OF MINIMUM REQUIREMENTS ASSOCIATED WITH A MEDIUM HAZARD SAFETY CLASSIFICATION

PLANNING STAGE	DESIGN STAGE	OPERATION/ COMMISSIONING STAGE	DECOMMISSIONING STAGE
1. Conceptualisation by owner 2. Preliminary site selection by appropriate specialist 3. Geotechnical investigation by suitably qualified person	1. Geotechnical report required 2. Residue characterisation by laboratory analyses 3. Design by Pr. Eng. 4. Risk Analysis (optional) 5. Construction supervision by suitably qualified person	1. Risk analysis (optional) 2. Suitably qualified person responsible for operation 3. Pr. Eng. appointed to monitor 4. Pr. Eng. to audit every two years	1. Pr. Eng. appointed to monitor 2. Pr. Eng. to audit every two years

14.3.2. DWAF REQUIREMENTS IN TERMS OF DAM SAFETY CLASSIFICATION

There are no additional requirements over and above the requirements mentioned in Section 14.3.1 for the Tailings Dam. The requirements for the Return Water Dam are stipulated in Regulations 2 and 3 of the regulations published in Government Notice R1560 of 5 July 1986 of chapter 12 of the National Water Act, 1998.

The regulations require the following:

1. Appointment of an Approved Professional Person (APP);
2. Submission of an application for a license to construct;
3. Submission of an application for a license to impound after completion of the dam; and
4. Registration of the dam with the Dam Safety Office within 120 days of the date on which the dam becomes capable of storing water.

15. CLOSURE AND REHABILITATION PLAN AND AFTERCARE ISSUES

The closure and rehabilitation plan comprise a series of activities both during and after the operational phase. The aim of concurrent closure is to have long term evidence that the closure measures are successful in terms of meeting the closure objectives, and if they are not, provide sufficient time for them to be remedied.

15.1. CLOSURE OBJECTIVES

The closure objectives for the tailings dam and its associated infrastructure are as follows:

- To achieve chemical and physical stability for an indefinite time period;
- To protect surface, groundwater, soils and other natural resources from loss of utility value or environmental functioning;
- To limit the rate of emissions to the atmosphere of particulate matter and salts to the extent that degradation of the surrounding properties land value and land capability does not occur;
- To achieve visual 'harmony' within the surrounding landscape, and

- To create a final land use that has economic, environmental and social benefits for future generations that outweigh the long term aftercare costs associated with the facility.

15.2. CLOSURE ACCEPTANCE PARAMETERS AND TARGETS

Closure targets comprise a set of measurable, defined indicators that together, evaluate the performance of the facility against the closure objectives. The closure acceptance parameters and targets will need to be reviewed from time to time over the life of the facility. The following closure acceptance parameters and targets have been identified at this stage as a provision set of closure acceptance parameters and targets:

15.2.1. SURFACE WATER QUALITY

The quality of standing water measured within any of the catchment paddocks should satisfy the DWAF livestock watering standards as amended.

15.2.2. GROUNDWATER QUALITY

The groundwater quality measured in the monitoring boreholes around the perimeter of the tailings dam should satisfy the requirements for Class 3 water or better as defined by DWAF.

15.2.3. DUST EMISSIONS

The dust emissions from the tailings dam should meet the legal standards as amended.

15.2.4. LAND CAPABILITY AND LANDSCAPE FUNCTION

The catchment paddocks, side slope and top surface cover of the tailings dam should support a level of vegetation cover and biodiversity that is commensurate with natural undisturbed land in the same climatic region and on similar slopes. The specific indicators and targets will be developed over a period of time using a trial slope developed on one of the existing tailings dams at South Deep. According to

Hoffman, et al. (January 1999), an erosion rate of 0.02 to 0.75 t/Ha/annum is typical of ungrazed veld and this target is envisaged (subject to testing using the trial slope) for the tailings dam.

15.2.5. MANAGEMENT AND MAINTENANCE FUNDING - ECONOMIC SUSTAINABILITY

Ongoing income generated from economic activities established on the property, specifically to generate income to cover the aftercare maintenance costs of the tailings dam, together with the closure insurance, bond and guarantees must cover all reasonably anticipated future maintenance and aftercare costs in perpetuity. A reasonable demonstration period for the economic sustainability of the tailings is probably in the region of 10 to 20 years. Options to generate income include development of the land into botanical gardens, park lands, sports fields, golf course and/or driving range development etc.

15.3. REHABILITATION DURING OPERATIONS

GAA put together a closure framework in order to allow the proposed tailings dam to comply with closure requirements and be in visual 'harmony' with the surrounding landscape (Refer to GAA Report No. 10307/10462/15/W). Figure 15-1 gives an indication as to the target visual appearance of the slope. The following concurrent rehabilitation activities have been provided for in terms of the budget and are assumed to be carried during the operational life of the facility:

- Covering of the side slope with a bituminous impregnated layer and a 3.1m wide (horizontal measurement) layer of subsoil, with an additional 1.0m wide (horizontal measurement) layer of topsoil. This equates to a 1.0m thick soil cover, measured perpendicular to the slope;
- Installation of Drainex pipes within the protective layer to provide of drainage of water down the slope;
- Vegetation of the topsoil clad tailings side slopes with trees, shrubs and grasses that will provide additional long term erosion resilience. Species should be selected on the basis of frost resistance, ability to provide erosion resistance

through the root zone structure, habitat creation/ biodiversity, aesthetics, fire resistance, root penetration depth, drought resistance, nitrogen fixation, etc. It is proposed that the combination of species be confirmed and proven on the basis of field trials; and

- Although the dam is designed without step-ins on the side slopes, for practical reasons, access ramps will have to be constructed on the slopes. When some of the ramps become redundant at closure, they will be dozed and rehabilitated to blend in with the surrounding vegetated slope.

FIGURE 15-1: FUTURE APPEARANCE OF THE OUTER SLOPE AT CLOSURE

15.4. DECOMMISSIONING ACTIVITIES AT CESSATION OF OPERATIONS

At the end of the operational life of the facility several activities will be required in for the tailings dam to be closed. The following activities are likely to be necessary, although improvements to the final closure design may be made during the concurrent closure based on the monitored success of the existing design (Refer to Figure 15-2):

- Tailings Dam:
 - Top Surface: Structures that could lead to physical instability as a result of long term degradation include the penstock towers, the penstock outfall pipe, and the return water dam embankment. Concrete structures will be grouted and sealed appropriately on decommissioning under professional supervision.
 - Remove pipelines and pipe supports;

- Seal penstock intakes and decant pipelines;
 - Construct a perimeter berm on the crest, 2 m high which is clad with vegetated topsoil or possibly waste rock;
 - Create a topographical low to make sure that all surface water does not drain onto the sideslopes. It may be necessary to provide a suitable liner to the pool in order to prevent it from becoming a driving head for contaminated tailings water along the footprint area to the local shallow groundwater;
 - Conduct a long-term water balance to confirm that overtopping under extreme and/or prolonged rainfall events;
 - 1 m of soil/ topsoil cover over the remainder of the tailings dam top surface;
 - Vegetation of the top surface; and
 - The addition of lime to neutralise any acidic soil conditions.
- Side Slopes:
 - With the exception of the access ramps, all side slopes would have been covered and rehabilitated as described in Section 15.3 and illustrated in Figure 15-2. Access ramps that do not form part of the final land use plan, will be rehabilitated;
 - Side slopes dozed to 1V : 4H continuous slope, where the slope has not been attained during normal operations; and
 - Any old access ramps dozed over and covered with soil and vegetation to fit in with the surrounding slope area.
 - Toe and Surrounding Area: Seepage from the tailings dam is expected to reduce with time, thus reducing the overall impact of the dam on the surrounding environment. The groundwater plume is expected to spread

and dissipate with time. Runoff from the both the top surface and sideslopes is expected to be of an acceptable quality to discharge to the groundwater as seepage or natural surface water streams.

- Remove delivery and return water pipelines and pipe supports
- Reshape and clean out the paddocks and stormwater canal
- Vegetation cover all around and inside paddocks
- Conduct groundwater monitoring to confirm that any possible groundwater contamination from the tailings dam has been arrested
- Once the flow from the underdrains is negligible, the underdrainage collection pipes are to be grouted to prevent an ingress of oxygen into the tailings.

- Water Dams:

The fate of the return water dam is unknown at this stage, but it is assumed that the embankment crest will be lowered so as to classify the dam as a dam without a safety risk, and the plastic liner removed. The dam would serve no purpose in terms of pollution control, and it is envisaged that it will no longer be required for pollution control. The dam may however serve some function in terms of agriculture or recreation.

- Demolish and dispose of all pump stations and associated infrastructure at the return water dam;
- Eventual demolition and disposal of silt traps, neutralisation plant, desilting pump station and other concrete infrastructure once the underdrains have stopped releasing water. Concrete footings to be removed to 1m below the final surface topography;
- Widening and/or cleaning out of return water dam spillway;

- Lowering the embankment crest so as to classify the dam as a dam without a safety risk; and
- Eventual removal and disposal of HDPE liner after any sediment has been removed and placed on the tailings dam, prior to the covering of the top tailings surface.

15.5. AFTERCARE REQUIREMENTS

On completion of the final decommissioning and rehabilitation measures an aftercare programme has to be implemented to ensure that the closure measures are robust, have performed adequately and that no further liabilities arise. The aftercare period would be indefinite. The typical aftercare requirements would include:

- The monitoring of closure measures and the sustainability indicators to ascertain whether the landscape function targets, water quality and dust emission targets have been successfully achieved over the entire facility. These targets will include values for erosion loss, vegetation cover, biodiversity, soil chemistry and health, runoff quality, etc;
- Monitoring of the decrease in the phreatic surface and the quantity and quality of the seepage from the underdrains over a period of 10 to 20 years to confirm that the phreatic surface dissipates in accordance with the predicted rate, and monitoring of the underdrain quality for as long as possible to ensure that it remains in line with expectations. Once the flow rate from the underdrains ceases they should be grouted to prevent the ingress of oxygen to the tailings dam which will accelerate acid generation;
- Erosion management. The catchment paddocks serve to settle topsoil and humus material prior to discharge of the surface water to the environment. The topsoil that accumulates in catchment paddocks can be used to repair any erosion gullies that form on the side slopes of the cover. (anticipated interval every 2-5years)
- Revenue generating and management activities associated with the final land use which will serve amongst other requirements to generate revenue to offset the cost of aftercare. Revenue streams could be derived from:
 - Income generated from final land use such as recreational activities;

- Funding set up during the operational life of the mine to fund in perpetuity after care and monitoring costs.
- The magnitude of the required funding which would need to be set aside would be determined through detailed closure planning drawing on the data provided by the ongoing monitoring of sustainability indicators and cost data that is to be acquired during the operational life of the dam.

16. DESIGN SUMMARY

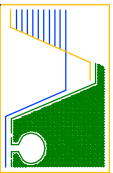
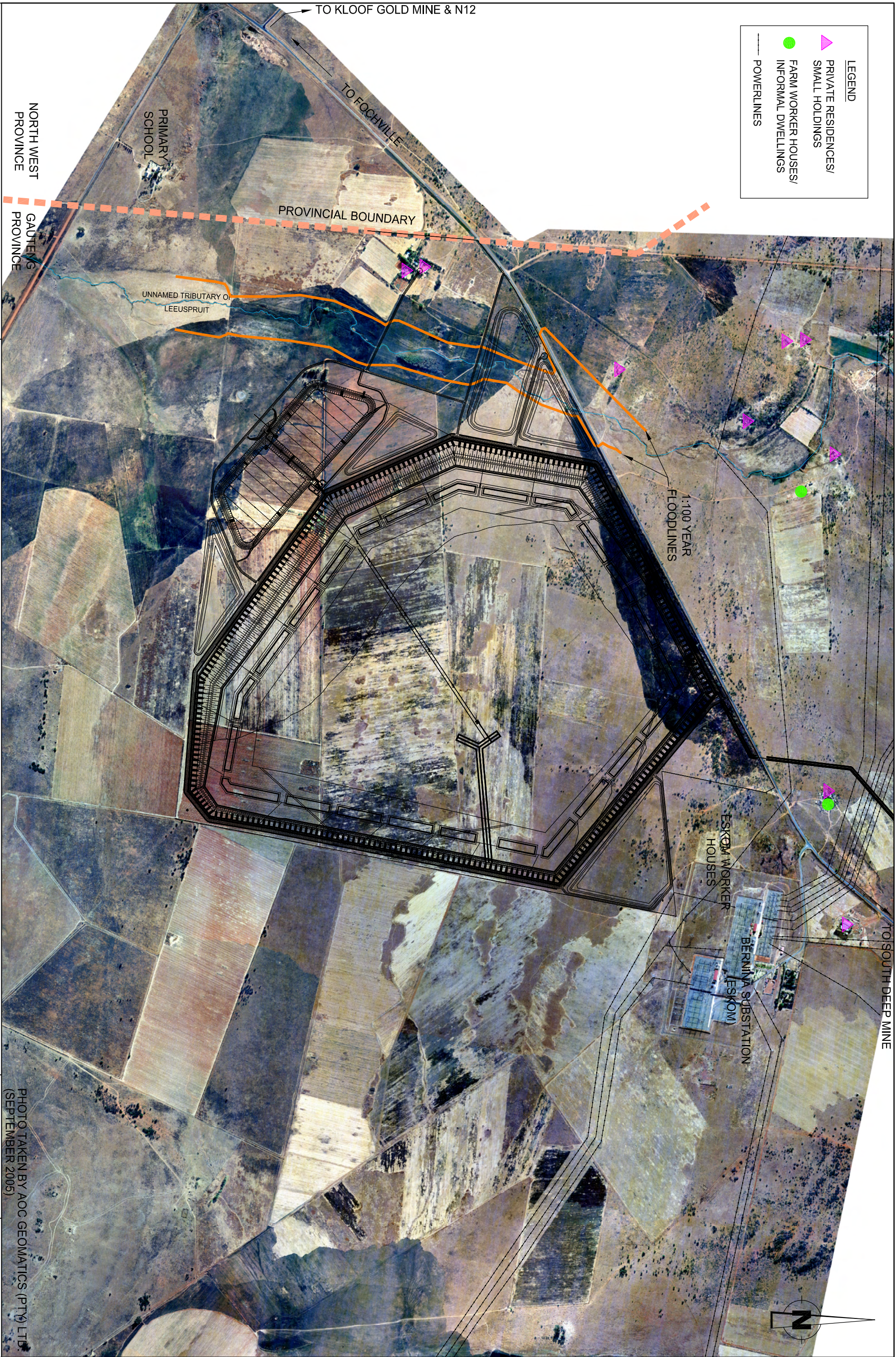
Summaries of the various design aspects carried out in the detailed design of the facility are presented below. More detailed discussions and information is presented in the appendices.

16.1. SIZING AND LAYOUT

The key features of the sizing and layout of the facility are:

- The footprint area of the tailings dam is 348.2 ha (386.5 ha including perimeter road and cut off bund) with approximately an additional 24ha surface area of the return water dam; and
- The final elevation of the tailings dam is planned to be 1591.4 mamsl (designated as the planned production height) for the planned mine production but can be extended to 1624 mamsl (design height) with the current design elements, which results in a maximum height of the tailings dam of 78.4m at the lowest side.

A layout of the tailings dam and associated infrastructure showing the major components of the system is presented in Figure 16-1. The components of the facility are described briefly below.



16.2. TAILINGS DELIVERY AND RETURN WATER PIPELINE ROUTE

The water and slurry pipelines are routed together as far as practical and unlined earth bunding has been allowed underneath the pipelines to assist with spillage containment and cleanup.

The tailings delivery and return water pipeline route is shown in Drawing 10307-002. There is a river crossing across the Kariegaspruit and the Leeuspruit. The location of the river crossing is shown on Drawing 10307-093.

The steel pipelines will be supported on concrete plinths and placed between two earth berm walls to contain spillage.

16.3. WALL RAISING PROCEDURE

The height of the starter wall is dependent on the selection of the method of operation of the tailings dam. Construction of the composite cover concurrently as the dam rises is an essential part of the management of many of the impacts that arise from the dam. Ensuring that the composite cover does not become contaminated with acid tailings at any stage during the life of the facility, is crucial to the performance of the cover. Concurrent rehabilitation can only be achieved by raising the tailings embankment in lifts of 2m or more measured vertically, in a series of construction campaigns which would take place every one to two years, using conventional construction equipment. This approach has the advantage (over the conventional daywall system) that except for the short period during construction of the wall raise, (probably 3 months) the tailings is always below the level of the composite cover, thus runoff from the tailings cannot contaminate the soil cover.

Construction of the tailings dam lifts would generally take place during the dry season when trafficability over the tailings is at its best. In order to reduce costs, the bulk of the material used in the wall raise will comprise tailings excavated from the basin of the dam, sourced immediately adjacent to the raised embankment.

Instead of the conventional daywall system of tailings deposition, a spigotted day wall, combined with an open ended night time system has been chosen. The daywall crest will be maintained approximately 2m above the basin level. The procedure for wall raising is illustrated in Drawing 10307-021 and described in the Operating Manual. The approach requires however that the rate of rise be kept slightly below the rate of rise that can be achieved on a conventional daywall system in order to ensure that the tailings is trafficable when the lift is done and the cover constructed. The maximum rate of rise for this type of construction is estimated to be 1.6m/yr. The starter wall embankment crest levels have therefore been determined as the point at which the rate of rise is reduced to 1.6m/yr. Construction by the upstream method is made possible by the material characteristics and the local climatic conditions which result in rapid drying and consolidation of the tailings and the resulting attainment of good tailings shear strengths within a short period of time after placement.

The side slopes have been specified at a slope of (1V : 4H) to reduce the erosion rate, which will assist in preserving the composite cover. The conventional daywall dams are constructed with much steeper slopes (1 : 2.7) which have unacceptable erosion rates.

16.4. TAILINGS DELIVERY

The slurry system comprises three slurry pumps stations.

- Pump Station No. 1 is located at Twin Shafts Gold Plant and transfers the slurry to the existing Backfill Plant where the backfill product is removed for underground support.
- Pump Station No. 2 is located at the Backfill Plant and transfers the remaining portion of slurry not disposed as backfill product to Pump Station No. 3
- Pump Station No. 3 is located at the Twin Shafts Gold Plant and transfers the slurry to the TSF.

All slurry pump stations consist of a single delivery line, but a duty and standby set of pumps are allowed for at the pump stations.

The pump and pipeline systems have been designed to deliver a minimum of 233 ktpm and a maximum of 330 ktpm. This operating envelope is required to accommodate periods when the backfill plant is not in use.

The existing pipeline that delivers the slurry from the Twins Shafts Gold Plant to the Backfill Plant is routed through a residential/ living area and allowance has been made for a new pipeline that is routed away from the living area and around the South of the existing tailings dams. New pipelines have been provided for the transfer of the slurry from Pump Station No. 2 to Pumps Station No. 3 and to the new tailings dam. The pipelines have been specified as 350NB mild steel pipelines with 8mm HDPE liners. This allows for low friction losses, whilst offering excellent abrasive resistance which will reduce wear and the risk of slurry spillages from the pipelines.

Provision has been made for differential flow measurement to assist with the detection of catastrophic pipe failure. This will reduce the time that tailings spillage will occur.

The steel slurry delivery line location is presented in Drawing 10307-002. From the perimeter access road, the 350mm NB riser pipes branch of the ring main at approximately 200m spacings. The riser pipes cross the stormwater canal, before running along the top of the catchment paddock wall and then up the slope of the tailings dam. At the crest of the dam, the riser pipe connects to the spigot delivery pipe and basin delivery pipe. The spigots discharge pipes run approximately 100 m in either direction and are controlled by valves. The basin delivery pipe is controlled by a valve and runs across the There are no internal riser pipes on the dam. All pipes run on surface, except where the pipes cross the road at the crest of the tailings dam, where they are temporarily buried to enable vehicles to run along the crest wall.

16.5. DECANT SYSTEM

The decant system consists of the following:

- A single reinforced concrete encased outfall pipeline with six temporary or intermediate penstocks (comprising 2 No. 0.9 m internal diameter penstock ring towers each) and a single permanent decant tower which supports 4 penstock ring structures at three different levels. The temporary penstocks are decommissioned as the pond advances up the hill towards the permanent penstock. The permanent penstock ring systems are decommissioned in a similar way as the height limit for each penstock ring cluster is reached.
- The outfall pipeline is made up of class 100D concrete sewer pipe with a sacrificial layer to increase the life of the pipeline;
- Temporary side inlets at the intermediate intake structures are provided to assist in minimising the pond size on the tailings dam and maximise water recovery. Once the tailings level exceeds the operational level of the side inlets, the inlet at the top of the intake structure is commissioned with the use of standard 0.9m internal diameter concrete rings. When the pool has reached a level of approximately 2m above the intake the side inlets of the next upstream intake is commissioned. The side inlets of decommissioned intermediate intakes will be blocked with steel plates and grout;
- Side inlet feeder trenches which divert water to the side inlets; and
- The penstock outlet flows directly into the energy dissipater at the silt trap.

16.5.1. OUT FALL PIPE CAPACITY

The outfall pipe capacity is based on decanting the 1:50 year storm event in addition to the slurry water off the top of the dam within 10 days. The decant system is comprised of two distinct components:

- A cluster of vertical shafts/pipes consisting of stacked concrete rings, which convey the water from the pond of supernatant water on top of the dam to roughly ground level; where it conveyed by a:
- A concrete sewer pipe with a sacrificial layer encased in reinforced concrete in a trench below natural ground level.

Table 16-1 presents the capacity calculations for both components of the system.

The concrete encased penstock outfall pipe was designed to be able to convey the full flow entering the permanent penstock tower under supercritical (open channel) flow conditions, and flow less than two thirds full when all 4 penstock rings are decanting at their full design capacity. Since only 3 rings should be in use for decanting at any one time, the pipe will safely flow under open channel conditions. This criterion was set in order to minimise the chances of any transient surge pressures.

The penstock outfall pipeline terminates in the energy dissipater at the silt trap.

TABLE 16-1: TAILINGS DAM DECANT SYSTEM CAPACITY

DESIGN FLOOD DISCHARGE	
1:50 Year flood (mm)	140
Drainage period (days)	10
Flood volume (m ³)	347,490
DESIGN SLURRY WATER DISCHARGE	
Dry tailings production rate (tpm)	330,000
Water pumped to dam (tpm)	428,108
Interstitial lockup of water (tpm)	117,333
Evaporation (m ³ /day)	2,895
VERTICAL PERMANENT PENSTOCK PIPE FLOW CAPACITY	
Standard penstock ring internal diameter (m)	0.9
Single Pipe Capacity (m ³ /s)	0.5
Number of pipes required to convey air and water	4

HORIZONTAL OUTFALL PIPE CAPACITY		
	UPPER SECTION	LOWER SECTION
Pipe length (m)	1000	325
Height difference (m)	20.12	3.60
Slope	1:50	1:90
Internal diameter (m)	0.843	1.089
Water depth (as % of diameter)	66%	48%
Flow area (m ²)	0.45	0.56
Wetted perimeter (m)	2.21	2.85
Hydraulic radius (m)	0.25	0.32
Manning's n	0.013	0.013
Design discharge for pipe (m ³ /s)	2	2

16.6. RETURN WATER SYSTEM

The return water system will consist of the following:

- A silt trap that is fed by the penstock outfall pipe, stormwater channel and neutralisation plant;
- A neutralisation plant that is fed by the underdrainage collection pipe;
- Two HDPE lined return water dam compartments (fed by the silt trap);
- The return water pumping station; and
- The return water pipeline.

The silt trap is designed to remove (or “settle out”) particles from the decant water. The design criteria for the silt trap are summarised in Table 16-5.

The return water dam has been sized to ensure compliance with Regulation 704 of the National Water Act (Act 36 of 1998) and has a storage volume of 1 million m³, determined using the probabilistic climatic water balance. The return water pump system is capable of pumping a maximum of approximately 1,160 m³/hr to the Twin Shafts Plant and Backfill Plant simultaneously. This allows for water to be delivered to the Twin Shafts Gold Plant at a maximum rate of approximately 770 m³/hr, which is sufficient to provide the plant with its full demand at a throughput of 330 ktpm.

Alternatively the system can deliver a maximum of 389 m³/hr to the Backfill Plant. The pipelines have been optimised by considering the optimal diameter and lining relative to the associated friction loss. As a result of this the water pipelines are all mild steel units with epoxy lining. The return water pumping system utilises three vertical spindle pumps of which a maximum of two units will be operational at any time. This amount of water will only be available during wet periods. During dry periods, water from other sources, including underground water will be used as makeup water to the metallurgical plant. This approach satisfies the water re-use philosophy adopted by the Department of Water Affairs and Forestry as part of their usual water license conditions.

The advantage of the proposed water management system is that the maximum possible use is made of the water at the tailings dam by keeping the clean and dirty water separate which allows for only the contaminated water to be treated.

Furthermore, the groundwater pollution risk is minimised through the provision of a 2000µm HDPE liner and leakage detection system.

The return water dam's two HDPE lined compartments can be operated independently. Each compartment can be accessed and maintenance performed during the dry season when the demand on the return water dam is reduced sufficiently to empty one compartment completely. Water enters the return water dam through the silt trap, and can flow from the upper to lower compartment via a spillway. There is an emergency spillway on the lower compartment, which allows water to be released equivalent to the inflow rate. Water can be abstracted from either compartment through two return water pump station suction pipes, with the intakes located at the lowest corners of each compartment.

A level indicator sensor has been incorporated near the intake point in each compartment to allow the level to be monitored remotely. A measuring rope has been placed in each compartment which indicates the capacity of the dam in 10% intervals to allow for a quick on site check of the capacity.

16.7. STAGE CAPACITY RELATIONSHIPS AND SIZING OF STARTER EMBANKMENT

The stage capacity curves for the Doornpoort Tailings Dam are presented in Appendix 1. The information presented in these curves may be summarized as follows for the 233 ktpm deposition rate:

- The tailings dam has a volumetric capacity (up to 1624 mamsl) of approximately 152 000 000 m³ (205 000 000 tonnes) which is more than the 79 500 000 m³ (107 300 000 tonnes) required according to the mine planning schedule provided (Table 5-1);
- Based on the production ramp up provided by the Mine, the required elevation of the starter wall is 1562.1 mamsl, which equates to a maximum starter wall height of 16.6 m*;
- The maximum elevation of the crest of the tailings dam corresponding to an airspace volume of 79 500 000 m³ is 1591.4 mamsl, which equates to a maximum height of 45.9 m*;
- The rate of rise at the final planned elevation of 1591.4 mamsl will be 0.2 m/yr;
- The construction of the TSF may be completed in two preparatory phases referred to as Phase 1, comprising the lower portion and Phase 2 comprising the upper portion of the tailings dam. Phase 2 must be completed within 12.5 years (149 months) from the date of first deposition;
- Coverage of the entire tailings dam footprint will be achieved at a crest elevation of 1584 mamsl; and
- Due to the low rates of rise the tailings dam will be able to accommodate short term increases in the rate of deposition, subject to the approval of the design engineer.

* All heights are measured as the difference between the lowest point along the toe and the crest elevation.

- The dam could potentially accommodate an additional 72 500 000m³ (97 700 000 tonnes) of tailings over and above the design capacity for South Deep's planned production.

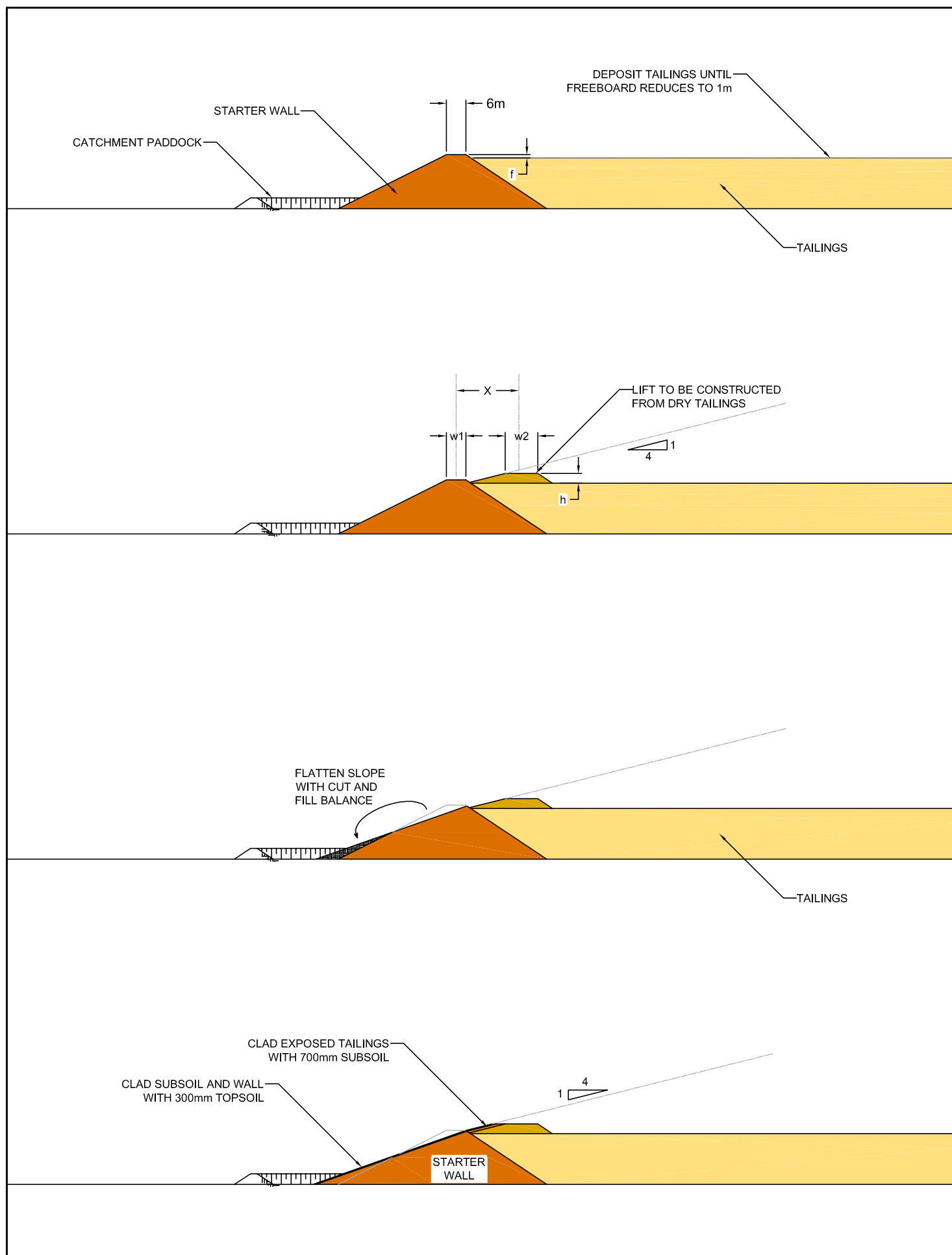
16.8. STARTER WALL DESIGN

16.8.1. DESIGN PARAMETERS

TABLE 16-2: DESIGN CRITERIA FOR STARTER EMBANKMENTS

	233 000 TPM
Crest width	6m
Inner slope of embankment	1:1.5 (V:H)
Outer slope of embankment (Constructed)	1:2 (V:H)
Outer slope of embankment (Rehabilitated)	1:4 (V:H)

The final constant outer slope of 1 : 4 would be achieved by stepping back the tailings once the starter wall height is reached. The starter wall material would then be excavated and placed on the sideslope as illustrated in Figure 16-2. Based on the maximum wall height of 16.6m, the maximum step back from the outer crest of the starter wall will be 26.2 m, which occurs at the highest point of the TSF starter wall. The step back required to achieve the design outer slope of 1 : 4 has been calculated in the Wall Raising Procedure Section in the Operating Manual.



16.8.2. GEOMETRY

The height of the embankment is such that the maximum rate of rise will should not be exceeded once the tailings level has reached the embankment crest level. This equates to an elevation of 1562.1 mamsl and a maximum starter wall height of 16.6m between the crest of the wall and the lowest point on the outer toeline.

The crest width of 6m will be sufficient for vehicle access and deposition pipes. The inner and outer slopes have been set as 1:1.5 and 1:2 (vertical: horizontal) respectively, which results in the wall being stable, while minimising the earth volume required.

It will be necessary to incorporate a box-cut in the construction of the starter wall, to an estimated depth of 300mm. This will however need to be confirmed during construction.

Along the toeline where a starter wall elevation of 1562.1mamsl would result in a wall of less than 3m in height, a 3m high starter wall, with a crest of 1m width, and outer slopes of 1 : 2.5 (vertical: horizontal) is to be constructed.

16.9. SURFACE WATER MANAGEMENT

The surface water management for the Doornpoort tailings facility entails limiting any pollution that erosion caused by surface water of the deposited tailings may cause, and separating storm water runoff that is possibly contaminated, from any runoff that could be protected from being contaminated by the tailings or process water.

The storm water management is separated into the following distinct areas:

- The depositional area;
- The side slopes of the depositional area;
- The catchment paddocks;

- The services area, which includes the stormwater channel, the pipe servitude and the access road, all of which surround the depositional area;
- The area where the return water system is situated;
- Other areas within the complex fence; and
- Areas outside of the complex that drain towards the facility.

Storm water that falls on the depositional area reports to the supernatant pool, there it mixes with process water and is handled as such, through the return water system, described in Section 16.6.

During any rainfall event, storm water on the side slopes presents two design challenges:

- The volume of water, which is classed as clean water as it is in contact with rehabilitated slope; and
- The volume of topsoil eroded by the storm water.

The volume of water that falls on the side slopes is retained, together with the eroded solids, in catchment paddocks that run around the outer toe of the dam. Storm water will be drained from the catchment paddocks via a decant structure that discharges slowly into the storm water channel. The decant structure consists of a vertical, slotted HDPE pipe encased by gabions.

The catchment paddocks are designed to attenuate and discharge the storm runoff and trap any topsoil eroded from the side slope cover, which will have be routinely removed from the paddocks and used to repair any erosion gullies that form.

Water falling on other areas within tailings dam complex is either:

- Excluded from the depositional area by the bund wall located on the outside of the access roads, in which case it is diverted around the facility and discharged directly to the environment outside of the fenced area; or

- Captured via the penstocks and underdrains and drained to the return water dam, from where it is returned to the plant as process water makeup;
- Captured in the catchment paddocks, which discharge to the stormwater canal which may either discharge either to the return water dam or be discharged to the environment bypassing the return water dam. Water entering the catchment paddocks is regarded as “clean” runoff as it has not come into contact with tailings or process water.

Storm water that would normally flow through the area from upstream catchments is diverted towards the east or west in a temporary storm water diversion channel within the basin of the tailings dam during the first construction phase, and then by a bund running around the perimeter. The temporary storm water diversion trenches in the basin of the tailings dam are specified as an unlined trapezoidal earth channels.

16.10. WATER BALANCE

An overall monthly water balance assessment (refer to Appendix 7) has been undertaken to determine the following:

- The required storage capacity of the return water dam to satisfy the requirements of Regulation 704;
- The volume of water on a monthly basis that will be available to be pumped back to the process plant; and
- The number of spillages and the spillage volume from the return water dam to the environment.

The water balance model, which uses a probabilistic approach to determine monthly rainfall and evaporation, has been used to define the required return water dam storage capacity and to determine the volume of water that will be available to the plant for reuse on a monthly basis.

The return water dam is sized to satisfy the requirements of Regulation 704 of the National Water Act of 1998 No. 56, which states that the facilities should be designed to “not spill more than once in every 50 years”.

The results of the water balance simulations indicate that:

- The return water dam must have a design capacity of 1 000 000 m³ (Full Supply Level);
- Spillages to the environment will occur once every 62.9 years (The mean expected value for 50 years is 0.80);
- The expected mean spillage volume is calculated to be 2 662 m³;
- The volume of water stored in the return water dam is between 26.2% and 28.2% for 90% of the operational life of the dam, with a mean value of 27.2%;
- There will be sufficient water, on average, only 10% of the time for the plant's requirements; and
- When there is a short fall, the maximum amount of make up water for the plant from another source is expected to be 330 000 m³ per month.

16.11. RETURN WATER DAM

16.11.1.DESIGN PARAMETERS

As mentioned in Section 16.10, the return water dam was sized to satisfy Regulation 704 of the National Water Act of 1998 No. 56, which states that the dam may “not spill more than once every 50 years”. See Appendix 7. The results of the water balance simulations indicate that:

- The return water dam must have a design capacity of 1 000 000 m³ (Full Supply Level);

- Except when there is insufficient water in the return water dam, all water requirements of the plant should be taken from the available water stored in the return water dam. This is expected to occur roughly 90% of the time. Failure to adhere strictly to this rule will result in more water being brought into the system than is required, increasing the risk of non conformance with Regulation 704.

The catchment paddock water (stormwater canal) should be discharged to the environment when the volume of water in the dam exceeds 90% of the full supply capacity. The ability to discharge clean water offers the benefit of allowing the system to be designed such that maximum re-use of water from the tailings dam is possible, without increasing the risk of spillage.

The return water dam compartments are lined with a 2000µm HDPE liner. The liner has a design life of 20 to 25 years and will need to be replaced at least once during the operational life of the tailings dam. The liner is not required after decommissioning.

Each compartment of the dam is equipped with a narrow access ramp to enable pedestrian access to the dam. The liner over the length of the ramp is equipped with roughened HDPE to reduce the risk of slipping.

The return water dam embankment is constructed of earthfill. The earthfill will be excavated from the return water dam basin and /or the tailings dam basin and compacted in layers in accordance with the drawings and specifications.

The crest of the return water dam embankment is to be provided with a gravel wearing course. The crest must be kept free of vegetation at all times to reduce the risk of fire damage to the liner.

TABLE 16-3: SUMMARY OF RETURN WATER DAM DESIGN PARAMETERS

Maximum height of RWD wall*	8.87m
Maximum height of the spillway**	7.87m
Crest width	5m
Total volume of fill in the embankment	195 000 m ³

Inner slope of embankment	1 : 3
Outer slope of embankment	1 : 2

*Measured from the lowest point along the downstream toe to the crest

**Measured from the lowest point along the downstream toe to the invert level of the spillway

16.11.2. LEAKAGE DETECTION

A leakage system is present below the liner to check that there are no holes or tears in the liner. It consists of slotted HDPE pipes at 50m centres running below the liner, with a collection pipe running around the inner toeline. There are riser pipes up the side of the dam to allow the use of dip meters to detect if there is any leakage through the liner.

In the event that a leakage is detected, a sump is provided at the lowest point of the dam, adjacent to the pump intake sump but below the liner. A borehole pump can be lowered into the sump and the sump pumped to minimise the impact of the leak on the environment until the dam can be emptied and the hole or tear repaired.

The pipes under the liner also serve as an air release to allow any air trapped under liner to escape.

No seepage analysis was undertaken for the return water dam as a result of the HDPE liner. The overall stability of the return water dam embankment could be negatively affected in the event that the plastic liner fails. Catastrophic or sudden immediate failure of the dam embankment would not occur in the event that the liner punctures or tears. Liner failure and possible associated stability problems are indicated by the cutoff drain outlets starting to flow or the toe of the embankment becoming saturated and sodden. A leakage detection system is provided to assess the integrity of the liner on a regular (quarterly) basis. Monitoring of the leakage detection system is required to be undertaken as part of the routine tailings complex monitoring. In the event that a leak is detected, the leak would need to be repaired during the next dry season by emptying the relevant compartment.

16.11.3. CUTOFF DRAIN

The return embankment is equipped with a vertical cutoff drain as shown on drawing 10307-407. The drain extends along the entire length of the downstream embankment. Drain outlets are provided at 100m centres. Monitoring of the flow from the outlets will form part of the normal monitoring.

16.11.4. RETURN WATER DAM EMERGENCY SPILLWAY

The return water dam has been sized to not spill more than once in every 50 years in accordance with the requirements of R704. An emergency spillway has however been provided to discharge water from paddock 2 should the need arise. The spillway has a capacity of 5.3 m³/s which may be compared to the maximum inflow rate of 3.4 m³/s. The spillway discharges to the natural environment.

The two dam compartments are joined by an intermediate spillway which has a maximum capacity of 9.5 m³/s.

The spillways are lined with HDPE as a continuation of the dam lining. The emergency spillway lining is protected with a layer of concrete as the spillway also serves under normal operating conditions as an access roadway along the dam crest.

16.11.5. OUTLET TO PUMP STATION

An outlet sump is provided to each compartment in accordance with the details on drawing 10307-047. The outlet pipe comprises a concrete encased, bitumen wrapped, steel pipe with an outer diameter of 711 mm. Wedge Gate Valves are provided to each outlet pipe to enable water to be abstracted from either compartment 1 or compartment 2 or both compartments and to allow one compartment to be kept empty to facilitate maintenance of the liner or cleaning of the dam basin.

16.11.6. PUMP STATION DESIGN

The details of the pump station are shown on drawings 10307-050 to 10307-053. The pump station is located within a widened portion of the dam embankment to

accommodate the vertical spindle pumps required to be used by Gold Fields. The structural design of the pump station was undertaken by Mr Wulf Toussaint Pr Eng.

16.11.7.MISCELLANEOUS DESIGN INCLUSIONS

Soilcrete bags are placed on the liner to hold the liner down during periods of low water storage and high winds.

The risk of drowning and safety risks are reduced through the provision of the following:

- Manilla ropes (or equivalent) fastened to anchor blocks at 20 m centres around the dam compartments for humans to catch and assist themselves in getting up the smooth HDPE side slopes;
- Nylon rope nets fastened at the top and bottom of the embankment that will serve as an escape route for any animals trapped in the dam; and
- A high security fence around the perimeter of the dam.

The general arrangement for the return water dam is shown on drawing No. 10307-007.

16.12. SEEPAGE ANALYSES

Seepage analyses were carried out on the final profile of the proposed Doornpoort Tailings Dam to:

- Estimate the maximum likely seepage flux from the underlying foundation soils;
- Size and position the underdrains; and
- To check if the underdrains would be able to adequately control the phreatic surface in order to prevent daylighting of the phreatic surface on the outer slope.

The seepage analyses were undertaken using the program SEEP/W (2004). The analyses are described in detail in Appendix 4.

The drains were modelled as being located as follows:

- The toe drain is offset from the inside toeline of the starter wall by a 6m wide roadway, and is coincident with the inside toeline when the starter wall is closer to 3m high;
- The main drain which runs parallel to the starter wall, 180 m from the outer toeline along the southern side of the dam, and 90 m from the outer toeline along the other sides of the dam, towards the centre of the dam; and
- The 0.4 m wide, 3.1 m high cut off drain, which runs within the starter wall, below the crest.

The following can be concluded from the analyses:

- Less than 3.54×10^{-3} m³/day of seepage will be discharged into the in-situ foundation material from entire footprint the tailings dam, once the entire footprint has been covered with tailings;
- The seepage analyses have shown that the combination of main drain, toe and cut-off drains can effectively control the phreatic surface within the tailings dam. A margin of safety should however be incorporated for the main and toe drains to allow for possible wash-a-ways and blinding;
- The phreatic surface is sensitive to the position and size of the main and toe drains. The analyses indicated that the main drain needs to be a minimum of 25 m wide, depending on its location around the dam, and the toe drains needs to be 5 m wide to reduce the risk of toe seepage to a satisfactory level;
- Seepage losses up to the time when the tailings dam breaks ground, while the supernatant pond is in direct contact with natural ground, may exceed the seepage losses calculated in this analysis if the permeability of the underlying soils is significantly higher than that of the tailings; and
- Flow rates into the underdrain outlets and total flow into the underdrain collection system would need to cater for a minimum rate as shown in Table 16-4.

TABLE 16-4: UNDERDRAIN OUTFLOW PIPE DESIGN FLOW RATES

DRAIN	MAXIMUM OUTFLOW PER OUTLET	ESTIMATED TOTAL OUTFLOW FROM DRAINS
Main Drain Outlets	0.102 l/s	3.063 l/s
Toe Drain Outlets	0.005 l/s	0.198 l/s
Cut-off Drain Outlets	2.754×10^{-6} l/s	4.307×10^{-5} l/s
Total inflow to Underdrain collection system		3.261 l/s

16.13. STABILITY ANALYSIS

The slope stability was quantified using a safety factor calculated using SLOPE/W version 6.22, which is a Windows based software that uses a variety of 2-Dimensional user selected limit equilibrium methods. The slope stability modelling was undertaken for representative sections through the impoundment, and assesses the intrinsic stability of the slope under selected operating conditions. The model was used to predict the stability of the proposed tailings storage facility based on the information concerning material strength parameters and soil profiles as documented in the geotechnical report (GAA Report No. 10307/10319/14/G). The Chamber of Mines Guideline (1996) was used to benchmark the modelled safety factors against published guideline values. The stability analysis is documented in Appendix 5.

The modelling uses the results of the seepage analyses to determine the likely location of the phreatic surface under various conditions considered. The seepage analyses are documented in Appendix 4.

From the analyses, it can be concluded that:

- The results indicate that the slope is stable with respect to the guidelines, i.e. a safety factor greater than 1.3, (Chamber of Mines 1996) under normal operating conditions;
- Under normal operating conditions, the factor of safety is at least 1.64;

- Provided that the phreatic surface does not daylight as a result of a combination of drain failures with a large supernatant pond, the phreatic surface does not significantly affect the slip surface which means that the factor of safety is still above the recommended factor of safety of 1.3 as stated in the Chamber of Mines Guidelines; and
- Provided that the dam is operated correctly, the stability of the slopes will not affect the integrity of the dam.

16.14. UNDERDRAINAGE SYSTEM

The design of the underdrainage system is based on three sets of drains:

- The toe drain is offset from the inside toeline of the starter wall by a 6m wide roadway, and is coincident with the inside toeline when the starter wall is closer to 3m high;
- The main drain which runs parallel to the starter wall, 180 m from the outer toeline along the southern side of the dam, and 90 m from the outer toeline along the other sides of the dam, towards the centre of the dam; and
- The 0.4 m wide, 3.1 m high cut off drain, which runs within the starter wall, below the crest.

The function of the drains is to 1) maintain or improve the stability of the tailings dam slopes and 2) prevent seepage from emanating through the toe of the facility, which would result in damage to the cover and contamination of the catchment paddocks.. The placement and performance of the drains with respect to the functioning has been modelled as part of the seepage analysis (Appendix 4).

Based on the design and analysis, the preferred approach to construction of an underdrainage system is to make use of:

- A 5 m wide toe drain constructed at the inside edge of the starter wall;

- A 25m to 35m wide inner elevated main drain constructed on top of a compacted earth platform varying between 2,0 and 4,0 m above the base level of tailings 5 m to 25 m wide slots every 200 m to allow tailings and water to migrate through to the inside area of the tailings dam basin during initial deposition; and

This approach is intended to eliminate the need for further elevated drains construction during the life of the tailings dam, i.e. there are no additional costs associated with installing drains continually over a number of years. The only operational control would be that of removing a portion of the mounded coarse tailings and Bidim above the elevated drains just prior to covering with the spigotted tailings.

All three of the drains have separate outlet pipes which allow for the individual flow rates and water qualities of each drain to be determined independently to check that the drains are functioning properly. These outlet pipes are discharged into manholes, where it is possible to differentiate between the flows from each drain based on the size and location of the outlet pipes. The main collection pipes (one from each side of the dam) which connect the manholes, are conveyed to the neutralisation plant, where it is treated before being discharged into the silt trap.

The seepage from the underdrains has been kept separate from the storm water because of its potential to be acidic, which would have an adverse affect on the clean surface runoff from the sideslopes, and concrete lining in the storm water canal.

Correct commissioning of the drains is critical to there success in operation.

During commissioning of each drain, it is critical that the tailings material deposited on the drains be carefully motivated to ensure that the drains are not blinded. The underdrain commissioning procedure is documented in the Operating Manual.

16.15. PENSTOCK ANALYSIS AND DESIGN

The six intermediate penstocks are offset a short distance from the penstock outfall pipeline to minimise the potential damage to the pipeline, should any of the inlets fail due to differential settlement. Side inlets at the intermediate intake structures

facilitate easy migration of the pool to the centre of the tailings dam. Once the tailings level exceeds the operational level of the side inlets, the inlet at the top of the intake structure is commissioned with the use of concrete rings. When the pool has reached a level of approximately 2m above the intake the side inlets of the next upstream intake is commissioned. The side inlets of decommissioned intermediate intakes will be blocked with steel plates and grout as part of the operation. Side inlet feeder trenches will be excavated to divert water to the side inlets.

The permanent penstock tower consists of three tiers of rings. This is based on the practical safety constraint of penstock rings failing above a height of around 20 m. The difference between the first and second level is 15 m while the difference is 18 m between the second and third level.

In terms of the operation of the penstock tower, the lower level is used until the penstock rings exceed the elevation of the intermediate level. Once both levels are operating, the rings of the lower level are grouted. Similarly, the penstock rings from the intermediate level increase are grouted when they exceed the elevation of the higher level.

16.15.1.HYDRAULIC DESIGN

The permanent penstock tower was designed to be able to decant the water released from the deposited tailings plus the 24 hour, 1 in 50 year storm event, within a period of 10 days. Each level of the permanent penstock tower has 4 penstock rings with internal diameters of 900mm. The hydraulic design of the tower allows for a maximum of 3 rings to be used for decanting at any one time, with the fourth ring kept above the supernatant pond to allow for air to flow down the penstock tower in order to prevent negative pressures forming in the pipe.

Once the decanted water has entered the tower through the rings, the individual pipes from each of the rings join a vertical pipe, where the water then falls down to the chamber at the bottom of the tower. In order to prevent large scale scouring by the falling water, energy dissipaters were incorporated into the vertical pipes of the two higher levels. They consist of angles which are welded to the vertical steel pipe each rotated on the way down, giving a plan view similar to a six pointed star. The

idea is that the falling water will collide with the angles multiple times and consequently not hit the chamber with the full force if the water had been free falling from the penstock rings.

Horizontal pipes have been included between the vertical pipes to allow air flow to further prevent negative pressures.

In a brief literature investigation into the formation of plunge pools, it was found that the depth of a naturally forming plunge pool could be in the region of a third of the height from which the water falls. As it was not practical to include a 12 m deep plunge pool below the ground level, an epoxy coated, steel lined, smaller plunge pool with a depth of 500 mm has been designed. A complex steel contraction allows the water to flow out of the chamber, into the penstock outfall pipe. The outlet has been designed to force the flow to be highly supercritical as it leaves the chamber. Supercritical flow is necessary to prevent any possible silting up of the pipe which may result in cementation and a partial to full blockage of the outfall pipe.

To prevent waves in the chamber creating a surge wave down the outfall pipe, a slotted steel plate has been placed just upstream of the chamber outlet to dissipate wave energy. The vertical slots in the plate allow air to pass through to the outlet when the maximum decant rate occurs. It was not possible to include sufficient openings for the air in the plate, so 4 PVC bypass pipes have been incorporated which go around the plate. Table 16-1 summarises the permanent penstock tower pipe flow capacity.

16.15.2.STRUCTURAL DESIGN

The key risk which was identified during the analysis of the penstock system was thermal cracking.

The outcomes from this key risk include the following:

- A special concrete mix was designed by Consus (Pty) Ltd (Consus Report of November 2007);
- The concrete encasing around the penstock outfall pipe is poured in a single lift;

- The concrete for the temporary penstocks should not be placed in three approximate equal lifts to allow heat of hydration to escape. No construction joint should be within the middle third of the pipe;
- The open ends of the pipes are to be sealed and the concrete is to be insulated with polystyrene shortly after casting;
- Thermocouples should be installed for measuring the development of temperatures in the concrete;
- The concrete encasement has been reinforced (NSE Report No. JN069-NSE-GA-R-800); and
- A method statement has been drawn up which needs to be followed during construction.

It is recommended that the concrete and structural specialists are involved during construction as part of the quality assurance team.

16.16. ENERGY DISSIPATER AND SILT TRAP

A silt trap was incorporated into the TSF design to reduce sediment loading in the return water dam, which in turn reduces the chance of damage to the liner in the return water dam as cleaning is less frequent and intensive.

16.16.1. HYDRAULIC DESIGN

The water from the penstock pipe enters the silt trap through the Energy Dissipater. The Energy Dissipater was designed so that the water from the penstock pipe will plunge into the water below the pipe which consequently reduces the decanted water's velocity substantially.

The silt trap was designed as an upflow system, with the option of operating one (or both) of the compartments at any point in time, to allow for cleaning (or unusually high flow periods). From the Energy Dissipater, the water can be directed towards the main (larger) silt trap compartment or the service (smaller) silt trap compartment

through the use of manually operated sluice gates. After passing through the sluice gate, the water enters a distribution box which has openings at the base level into the silt trap compartment. The main silt trap has been sized to accommodate the peak flow rate of the storm water canal, combined with the full design flowrate of the penstock pipe (3.4 m³/s). The service silt trap has been sized for the low flow condition from the penstock pipe (assumes that only 1 penstock ring is operational).

TABLE 16-5: DESIGN CRITERIA FOR SILT TRAP

	MAIN SILT TRAP COMPARTMENT	SERVICE SILT TRAP COMPARTMENT
Maximum Design Flowrate	3.4 m ³ /s	0.5 m ³ /s
Design Particle Diameter	78 µm	84 µm

Each of the compartments can be cleaned independently by draining the water to a sump, through the use of a portable pump. In the main silt trap, a ramp has been incorporated to allow a front end loader to clean the compartment if necessary. The loose silt can however be pumped out of the compartment through the use of a desilting pump, directly onto the tailings dam. The desilting system is documented in a GAA Report and shown on Drawings 10307-208 and 10307-209)

The service silt trap can be accessed via a narrow ramp. This allows men and wheel barrows to clean the compartment manually if necessary. Under normal circumstances, the silt would be pumped out using the same method as the main silt trap.

16.16.2.STRUCTURAL DESIGN

The silt trap is provided with a series of subsoil drains around the perimeter of the silt trap to control the ground water and prevent the silt trap from floating upwards in the event that the groundwater table level rises.

16.17. CATCHMENT PADDOCKS

The catchment paddocks are located around the outer toe of the starter wall and are designed to attenuate the storm runoff and trap any topsoil eroded from the side slopes, which will have to be routinely removed from the paddocks and placed back on the side slopes as part of the ongoing maintenance of the cover. In the event that the soil becomes contaminated with tailings (e.g. in the event of a pipe burst), the contaminated soil will be used to construct the wall lifts. The catchment paddock details are shown on Drawing 10307-006

16.17.1.SIZING

The paddocks have been sized to hold the 1 in 50 year, 24 hour storm event. The paddocks in each section or “Zone” of the tailings dam were set to have the same dimensions. The distance between the outer toeline and the centreline of the catchment paddock outer wall was set at 26 m, and the distances between the centrelines of the cross walls vary between 43.2 m and 49.2 m, based on the length of the toeline in each section. The heights of the walls were calculated to be able to contain the storm event with an additional 700 mm freeboard.

16.17.2.OUTLET DESIGN

Storm water will be drained from the catchment paddocks via a decant structure that discharges slowly into the stormwater channel. Each decant structure is located in the lowest corner of each paddock and consists of a vertical slotted HDPE pipe encased by gabions.

Based upon testing done by Metago, it was found that the limiting factor in allowing the water to flow out of the paddocks would not be the vertical pipe section, but rather the nearly horizontal section between the decant structure and the stormwater channel. The grade of the horizontal section was consequently set to be between 1:100 and 1:50 in order to reduce the required stormwater channel dimensions.

In the areas where the access ramps reach the paddocks from the crest of the tailings dam, there is an additional concentration of run-off from the side slopes. In

order to prevent the paddocks at these points from potentially failing, Hyson Cell lined spillways have be sized to allow the excess volume in each paddock to spill to the paddocks below it. When the flow is too small to justify a lined spillway, an overflow pipe has been incorporated.

In the event that the outlets become clogged up with sediment, it is possible to backwash the outlet using a bowser by blocking the outlet pipe and filling the Drainex pipe with water. Backwashing of the outlets is documented in the operating manual.

16.18. STORMWATER CANAL

The decanted water from the catchment paddocks flows into the stormwater channel, which is located along the perimeter of the tailings dam, between the access road and catchment paddocks.

The trapezoidal channel is constructed from concrete filled Hyson Cells which allows for small deflections of the channel due to consolidation to be accommodated. The Hyson Cells are more resistant to scouring and are consequently more durable and require less maintenance in terms of cleaning than an earth channel. The channel dimensions vary per zone as a result of the flow rate in the channel increasing after every catchment paddock outlet. The majority of the channel is in cut; however a certain volume of fill is required in the lower sections.

The eastern and western sections of the channels join near the penstock outlet pipe, and the combined flow then enters the large distribution box of the silt trap.

16.19. SIDE SLOPE COVER DESIGN

The objectives of the cover design are as follows:

- To ensure that the quality of water entering the catchment paddocks is not detrimental to the environment;
- Minimise erosion on the side slopes;

- Promote long term physical stability;
- Maximise long term environmental quality; and
- Provide an effective store and release cover.

Concurrently to the mechanical raising of the outer wall with tailings, a Sealmac layer is to be placed on the outside of the tailings, with a 1m thick layer of soil. The soil layer prevents the tailings from oxidising or contaminating the clean surface runoff. This soil layer also serves to reduce dust emissions.

16.19.1. EROSION RATE PREDICTIONS

The Revised Universal Soil Loss Equation (RUSLE) has been used to predict erosion rates from different slopes. The analysis is documented in Appendix 6 to this report. The results indicate erosion rates as summarised in Table 16-6.

TABLE 16-6: EROSION RESULTS FROM RUSLE

CANDIDATE SLOPE	A (TONS PER ACRE PER YEAR)		
	BARREN TAILINGS	VEGETATED TAILINGS	VEGETATED SOIL
1	43.5	27.2	21.7
2	50.5	31.6	25.3
3	45.8	28.6	22.9
Conventional	129.7	81.1	64.9

The table indicates that natural soil covers outperform the conventional directly vegetated tailings and slope geometry by a significant margin. This is primarily due to the flatter side slopes of the proposed geometry but also to the expected higher clay content of the natural soil compared to the tailings. It is important to note that

while the erosion rate is dependent on the slope length and the slope angle, it is more sensitive to slope angle than slope length, particularly on the flatter slopes.

The RUSLE approach has the limitation that it fails to predict where erosion and deposition take place. Metago have made use of a landscape evolution model SIBERIA to predict how a range of candidate slope profiles compare with one another in terms of long term performance. The candidate slope profiles considered are shown in Figure 16-3 to Figure 16-6. The analysis is documented in Appendix 6 to this report.

SIBERIA is a long term erosion model developed by Willgoose et al in 1989 to explore the linkages between the time evolving geomorphic form of natural landscapes and the hydrology and erosion processes occurring on them, and how these processes, in turn, determine the future evolution of the natural landform.

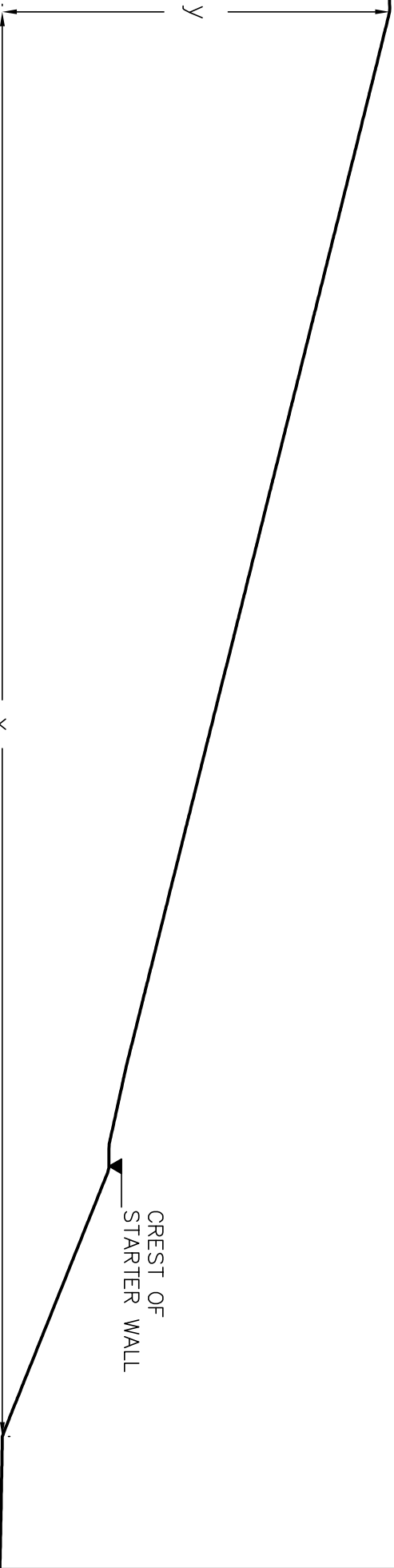
Erosion parameters derived from erosion testing of soil covers at other mines have been applied in the simulations. From the results, an indication of the potential performance of the decommissioning proposals has been obtained. The results are documented in Appendix 6.

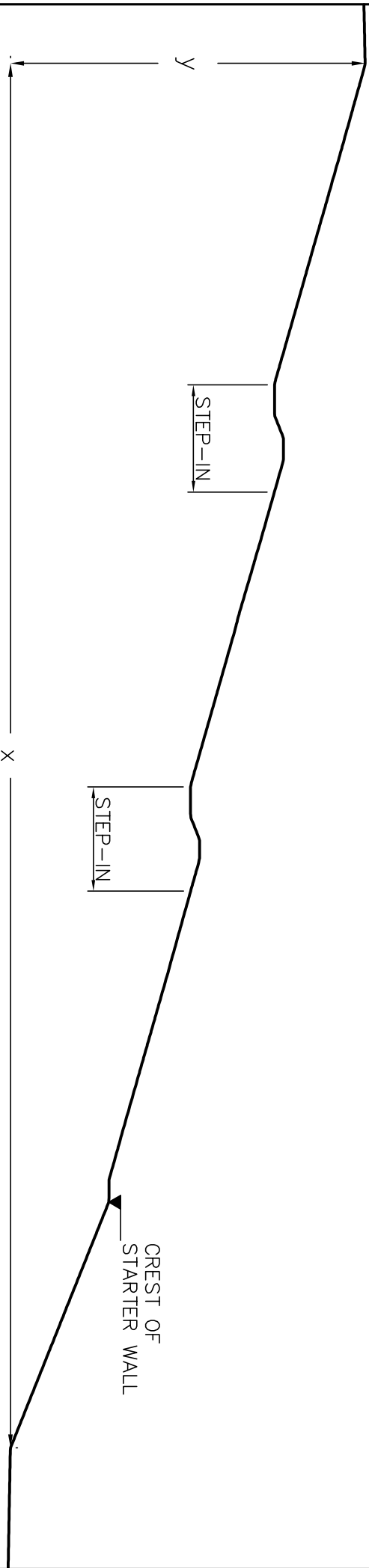
Of the candidate slope profiles considered, the straight slope profile with a constant 1:4 slope was selected as the preferred slope profile as the other profiles would tend to concentrate large quantities of water on the terraces. Deposition of sediment on the terraces would ultimately result in probable overtopping of the terraces which could result in complete and rapid failure of a portion of the cover.

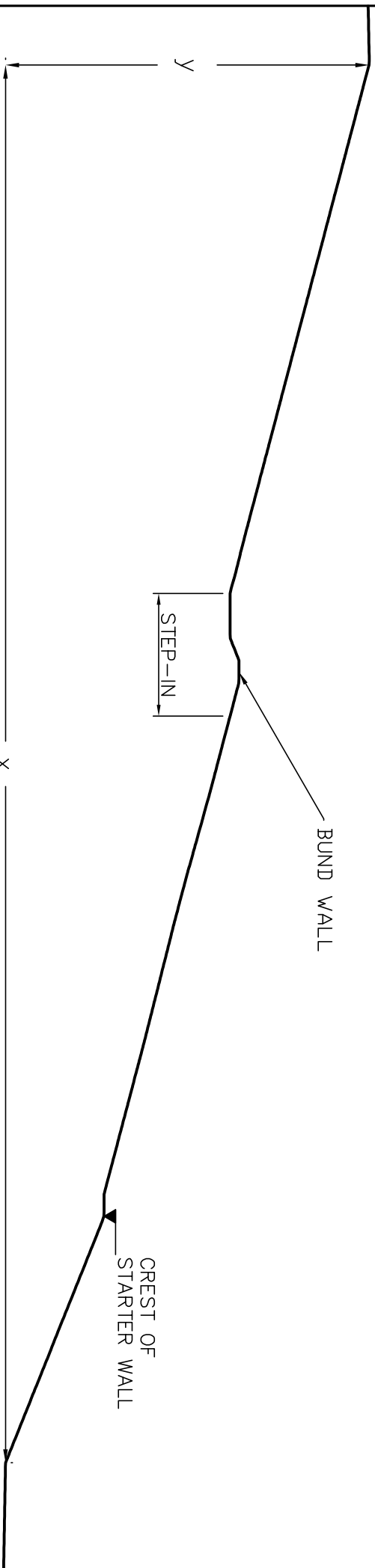
The major disadvantage of the step-ins is that the berms have to be very large to be able to contain the runoff behind them. If and when the water breaches the berms, dramatic erosion occurs in the form of deep gulleys which would destroy the cover in the vicinity of the berm, thereby exposing tailings.

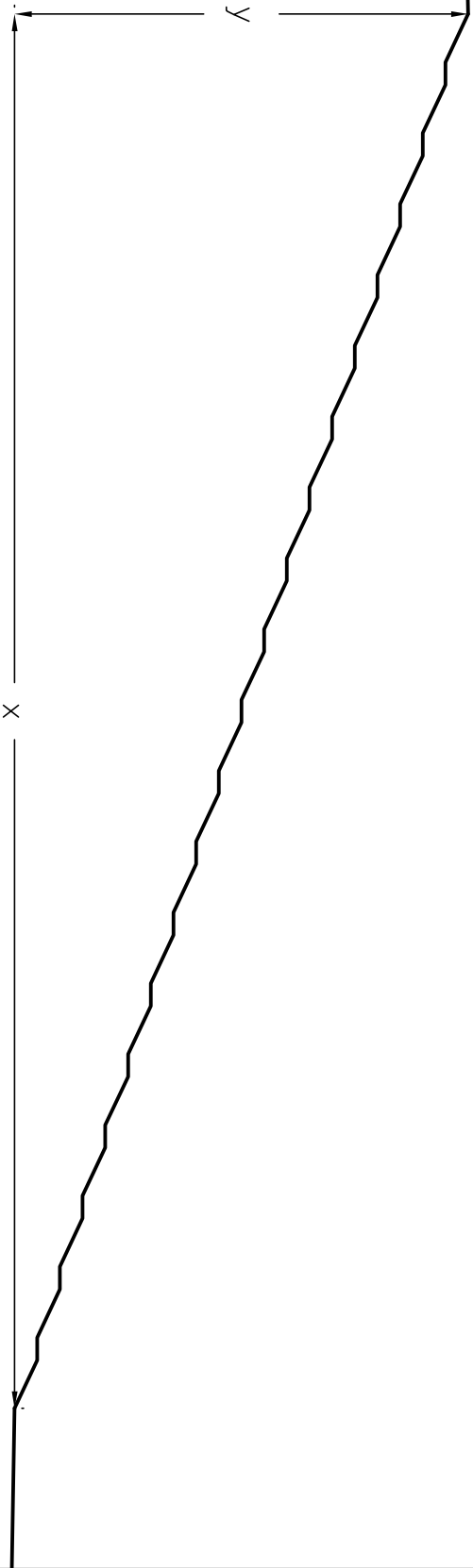
TABLE 16-7: SLOPE GEOMETRY OF CANDIDATE SLOPES

CANDIDATE SLOPE	HEIGHT (Y)	HORIZONTAL LENGTH (X)	OVERALL SLOPE	INTERMEDIATE SLOPE	WIDTH OF STEP-INS
1	80m	320m	1 : 4	N/A	N/A
2	80m	320m	1 : 4	1 : 3.5	25m
3	80m	320m	1 : 4	1 : 3.8	25m
Conventional	80m	240m	1 : 3	1 : 2.125	4m









**CANDIDATE SLOPE 4
CONVENTIONAL SLOPE**

Date :	05/2009	Scale :	N.T.S
Project No :	G001-02	FIGURE	16-6

16.19.2. VADOSE ZONE MODELLING

The predicted seepage for the store and release cover of the tailings dam was modelled using the Vadose/W (Geoslope, 2004) software. The predicted seepage fluxes were used as comparative instead of quantitative predictions.

“The intent of a store and release cover system is for the cover to store water during wet periods and releasing it back to the atmosphere during dry periods. The water retentivity of a material determines the success of a store and release cover system since the water retentivity determines the water storage capacity and the ability of the material to sustain evaporation during dry periods.”

The slope was modelled over a hydrological year (October to September) and used various meteorological and geotechnical input data sourced from a nearby rain gauge, the ARC-Institute for Soil, Climate and Water, and the geotechnical report (Golders Report No 10307/10319/14G, September 2007).

The vadose zone modelling indicated that the water storage capacity for the 1.0 m and 0.8 m thick covers was sufficient, but was too small for the 0.6 m cover.

Refer to Appendix B of Golder Report 10307/10462/15/W, April 2008 for the full technical memorandum of the modelling.

16.19.3. VEGETATION SPECIES

The vegetation cover on the side slopes will require frequent monitoring to ensure that a high level of sustainable biodiversity is achieved. The recommended plant species are listed in Table 16-8.

TABLE 16-8: VEGETATION SPECIES FOR THE COVER DESIGN

SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
<i>Acacia caffra</i>	Common hookthorn	Tree
<i>Acacia karroo</i>	Sweet-thorn	Tree
<i>Aristida congesta subsp. Barbicollis</i>	Spreading Three-Awn	Grass

SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
<i>Cymbopogon plurinoides</i>	Narrow-leaved Turpentine Grass	Grass
<i>Cyanotis speciosa</i>	Doll's powderpuff	Forb
<i>Eragrostis curvula</i>	Weeping love grass	Grass
<i>Eragrostis superba</i>	Saw tooth love grass	Grass
<i>Eragrostis racemosa</i>	Narrow Heart Love Grass	Grass
<i>Euclea crispa</i>		Tree
<i>Helichrysum rugulosum</i>		Forb
<i>Hyparrhenia hirta</i>	Common thatching grass	Grass
<i>Hypoxis rigidula</i>	Silver-leaved Star-flower	Geophyte
<i>Ledibouria spp.</i>		Geophyte
<i>Lippia scabberima</i>		Shrublet
<i>Melinis repens</i>	Natal Red Top	Grass
<i>Panicum maximum</i>	Guinea Grass	Grass
<i>Raphionacme hirsute</i>	False Gentian	Forb
<i>Rhus rigida</i>		Shrub
<i>Setaria sphacelata var. sericea</i>	Golden Bristle Grass	Grass
<i>Solanum panduriforme</i>	Bitter Apple	Forb
<i>Stoebe vulgaris</i>	Bankrupt Bush	Shrub
<i>Themeda triandra</i>	Red Grass	Grass
<i>Vernonia oligocephae</i>		Forb
<i>Ziziphus zeyheriana</i>	Dwarf buffalo-thorn	Shrublet
<i>Ziziphus mucronata</i>	Buffalo-thorn	Tree

Slope trials are intended to assist in further refining this list.

16.19.4. TOPSOIL AND SUBSOIL SOURCING OF MATERIALS

Based on the geotechnical investigation it has been determined that the average topsoil thickness is about 300 mm. Prior to the commencement of construction activities; topsoil needs to be removed and stockpiled. It is currently estimated that the total volume of topsoil to be stripped within the Doornpoort Tailings Dam facility (from tailings dam, return water dam, and return water sump etc. footprints) is approximately 985 000m³.

Topsoil stockpiles exceeding 1 to 2m in height normally results in chemical effect such as accumulation of ammonium and anaerobic conditions at the base of the pile (Harris et al, 1989). Therefore to minimise the decrease in the quality of the stockpiled topsoil, five stockpile areas will be used. This allows for the outer slopes of the stockpiles to be 1:3 and their maximum heights to be less than 2 m. The surface of the topsoil stockpile is also to be shaped in such a way that rain water will not pond on top of the stockpile. Refer to Drawing 10307-084 for the layout of the topsoil stockpiles.

The subsoil required for the concurrent raising procedure will also be sourced from the basin of the tailings dam and nearby sites.

16.19.5. IRRIGATION AND FERTILISER APPLICATION

Immediately after the topsoil cladding has been vegetated, irrigation will be required to sustain the vegetation until it has reached a point where the natural mean annual precipitation is sufficient.

Fertiliser will be applied in the first few years in order to improve the vegetation growth rate, thereafter no fertiliser is anticipated.

17. DESCRIPTION OF PREPARATORY WORKS

The preparatory works required for the tailings dam and associated water dams and infrastructure are shown on Drawings 10307-004 and 10307-005 and are described briefly below.

17.1. CONSTRUCTION PHASING

The construction of the tailing storage facility has been phased in order to defer capital. The phasing has been scheduled to prevent interruptions to the deposition of tailings.

17.2. TAILINGS DAM

The tailings dam preparatory works will include:

- A compacted residual andesitic starter wall with a maximum height of approximately 16.6 m including an internal cut off drain of 0.4 m width and 3.1 m height;
- Toe drains offset 6 m from the inner toeline of the starter wall which are 5m wide comprising suitably graded sand and stone with drain pipes;
- The installation of main drains (25 m to 35 m wide) located between 180 m and 90 m from the outer toeline of the starter wall;
- Drain outlets which comprise a backfilled trench with pipes (slotted HDPE Drainex or approved similar) to direct the seepage water from the drains (cut off, toe and main drains) out to the seepage collector pipes;
- Two seepage collector pipes (unslotted HDPE Drainex DN160 or approved similar) that accept effluent from the toe drains and blanket drains separately;
- A neutralisation plant that receives seepage water for treatment;
- Concrete sewer outfall pipes with a sacrificial layer and nominal diameters of 900 mm and 1200 mm for the lower and upper sections of the outfall pipeline respectively with full concrete encasement buried in a trench, which discharges into the energy dissipater at the silt trap;
- Associated with the penstock outfall are the temporary penstocks;
- Wooden catwalk extending from the first to the third temporary penstock;
- A Hyson Cell lined storm water canal around the perimeter of the starter embankment which accepts the decanted water from the catchment paddocks;
- A silt trap immediately upstream of the return water dam, accepting water from the storm water canal, neutralisation plant and penstock outfall pipe;

- Two HDPE lined return water dam compartments;
- A return water pump station;
- A compacted ferricrete road around the perimeter of the tailings dam and towards the public road;
- A barbed wire perimeter fence with gates around the perimeter of the whole tailings dam facility and around the perimeter of the return water sump and associated infrastructure;
- A 1.8 m high security fence and access gate around the return water dam facility; and
- A cut-off berm around the tailings dam that directs external surface run off away from the tailings and water dams, and to contain possible spillages caused by pipe bursts.

17.2.1. BORROW MATERIAL

The starter walls are to be constructed of material from the proposed Return Water Dam area, and the basin of the tailings dam. The material from the basin of the dam is to be excavated to a depth not exceeding 2m from natural ground level, from the area immediately upstream of the starter walls.

In order to comply with recommendation made in the geotechnical report regarding the borrow area, no excavation of borrow material will take place closer than 25m either side of the penstock pipeline.

17.3. SOURCING OF CONSTRUCTION MATERIALS (EARTH) FOR TAILINGS DAM CONSTRUCTION

Based on the geotechnical investigation and laboratory testing it has been determined that the residual andesitic material is suitable for the construction of the following:

- Starter walls;

- Dam walls; and
- Berms.

The depths of such materials and the depths to refusal are variable throughout the site. Excavation conditions are expected to be variable and may in some cases be difficult, with blasting expected to be required to form parts of the penstock and the drain outlet trenches as outcrops of intact hard rock andesite are evident over the entire area of the site.

All material will be sourced from a borrow pit that would have to be established in the basin area. The borrow pit area is not to encroach within 25m of the penstock outfall pipe. The floor of the tailings dam must be left with a minimum of 0.5m residual andesitic material after borrowing. Ferricrete may be used for road construction. Blasted rock may be used for the lining of spillways and filling of gabions and Reno mattresses. Sand and stone sources for the construction of the drains and for use in concrete will be sourced from commercial sources in the area. Should additional material be required for the construction of roads and lining of the spillways, suitable rock may be sourced from the existing waste rock dump at South Deep.

17.4. METHOD OF OPERATION AND DAM DEVELOPMENT

The major part of the tailings facility operations relates to the delivery and placement of tailings onto the dam and formation of the outer walls. The deposition operation comprises of two distinct sub-operations, namely start up/drain covering and routine operations.

The covering of the drains with suitable material while at the same time preventing the washing away or damage of the filter sand drain is vital to the successful operation and integrity of the tailings dam in the longer term. The tailings dam operator will be required to take extra care of drain covering at all times. In order to improve the long term integrity of the drains, they have been designed with a geotextile covering and mounded coarse tailings which are both to be removed just prior to covering by the deposited tailings.

Deposition is to commence at the lowest point of the tailings dam directly against the starter wall and rise up contour as the level of the tailings in the basin rises with time. The tailings is to be placed in a manner to ensure that a beach is formed which results in the formation of supernatant/decant water around the decant inlets and away from the sides of the starter wall. Decant water is not allowed to pond or pool within 20m of the toe drain or the main drain at any time during the dam commissioning, start up and routine operations.

Once the tailings has reached the crest of the starter wall the deposition will cycle around the tailings dam to allow the formation of the day walls for the continual raising of the spigot pipeline.

Decanting will be via the temporary penstocks during the initial stages of dam development as the pool migrates from the starter wall up-contour towards the main intake. The intermediate intakes will be sealed as the pool migrates past to the next (higher) penstock. The decanted pool water will discharge via the penstock pipeline into an energy dissipater at the silt trap which will in turn discharge into the HDPE lined return water dam.

Water collected in the return water dam will be pumped back to the plant via the pump station at the return water dam should water be required. The return water dam will need to be managed such that the dam has capacity to absorb the 1:50 year storm event at all times. In the event of the design capacity of the storm water dam being exceeded, excess water will be released via a lined spillway.

18. MONITORING REQUIREMENTS

In order for the tailings storage facility to reach all long term design aims, it is necessary to monitor various aspects of the facility. These are briefly summarised in Table 18-1, but are by no means exhaustive.

18.1. MONITORING

During the life of the facility, various elements will be monitored to ensure the integrity of the tailings dam complex. Monitoring elements will include:

Tailings dam:

- Dam safety, which includes the location of the phreatic surface, slope stability adequacy of freeboard, presence of seepage, functioning of underdrains and the incidence of layering, results of which would be included in quarterly reports and annual audits.
- Groundwater pollution, which entails the measurement of pH, EC, Ca, Mg, Fe, Mn, Na, Cl, K, SO₄, HCO₃, PO₄, Cr, Cr(VI) and piezometric level in 5 or more boreholes located around the perimeter of the tailings dam complex to quantify upstream and downstream groundwater levels and quality including. The frequency of measurements would be as follows:
 - Major cations and anions: quarterly, recorded in the quarterly reports;
 - Minor constituents: annually (recorded in the annual reports) after 2 years of quarterly monitoring (recorded in the quarterly reports).
- Dust monitoring programme included in Section 6 of the EIA amendment.
- Erosion damage and general condition of catchment paddocks, solution trench, erosion gullies, penstocks and catwalks etc. (Quarterly report)

Return water dam:

- Daily monitoring to include:
 - Water levels; and
 - Operation of pumps and pump motor control system.
- Monthly monitoring to include:

- Dipping of leak detectors to determine water level and electrical conductivity (EC);
 - Pump line flow rates; and
 - Physical inspection for damage to liner from animals, etc.
- Quarterly monitoring includes upstream and downstream borehole monitoring as per tailings dam borehole monitoring. Monitoring of drain outlets and seepage along the toe.
- Pump line flow monitoring (m^3/month) on a quarterly basis.

TABLE 18-1: PROPOSED LIFE CYCLE MONITORING

	CONSTRUCTION PHASE	OPERATIONAL PHASE	AFTER CARE PHASE	MONITORING	FREQUENCY	TARGET	RESPONSIBILITY	CORRECTIVE ACTION
Tailings Dam								
Piezometers		✓		Visual inspection. Phreatic surface not corresponding to underdrain outflow rate.	Daily check Monthly record	Good overall condition of piezometers Enable dipping Anticipate raising of piezometer tube Early identification of high phreatic surface within tailings dam and associated stability problems	Tailings Dam Operator	Raise piezometer. Install new piezometer.
Freeboard		✓		Survey data	Daily check Monthly record	Satisfy freeboard requirements of 0.85m to reduce the risk of dam overtopping	Tailings Dam Operator	Reduce or temporarily cease deposition. Raise outer wall.
Penstock Pipeline Damage	✓	✓		Camera inspection. Debris entering the silt trap from the penstock outfall pipe.	Monthly	No damage to penstock pipeline which may result in structural failure. No damage which may allow tailings to ingress into decant system. No blockages of penstock outfall pipe.	Tailings Dam Operator	Repair pipeline similar to a sewer line repair. Unblock as appropriate.
Starter Wall	✓	✓	✓	Visual inspection along wall of dam to check for excessive erosion Low spots or accumulation of water on crest Adequate erosion protection General wall condition Seepage visible Vegetation on side slopes in good condition	Daily check	Acceptable rate of erosion (< 0.75 t/ha/yr) Good condition Negligible seepage Vegetation growth	Tailings Dam Operator	Repair slopes Fill in low spots
Dam Stability		✓		Visual inspection along wall of dam to check for excessive erosion Low spots or accumulation of water on crest Adequate erosion protection General wall condition Seepage visible Vegetation on side slopes in good condition Visual inspection along toe of dam to check for sloughing, wet areas and discharge from cutoff drain outlets Bulging of underlying foundations at the toe	Monthly	Achieve a stable slope with no daylighting of the phreatic surface. No vegetation die off due to saturation of the soil.	Tailings Dam Operator	Repair slopes Fill in low spots
Catwalks	✓	✓		Visual inspection to check suitability of catwalks (in terms of stability, width, height above tailings, etc.)	Daily check Monthly Record	Safety signage in place Safe to use and in good condition Penstock cages and safety belts in place Level of tailings and water sufficiently below the catwalk Provides access to penstocks Enabling raising of penstock rings and safety cage, and decanting of pool water Condition of spare penstock rings	Tailings Dam Operator	Repair or replace relevant aspects
Beach Profile		✓		Survey of slope Characteristics of deposited tailings	Deposition Area- Daily check Monthly record	Pool controlled to be as close to the penstock inlet as possible. The pool should not be allowed to get close to the TSF outer walls.	Tailings Dam Operator	Investigate grading curve of tailings. Look at method of deposition.

	CONSTRUCTION PHASE	OPERATIONAL PHASE	AFTER CARE PHASE	MONITORING	FREQUENCY	TARGET	RESPONSIBILITY	CORRECTIVE ACTION
Access Roads	✓	✓		Visual inspection of the integrity of the road surface (e.g. Potholes, low points which allows water to pond, etc.)	Monthly record	No vegetation or obstruction No ponding of water General good condition and maintenance Effective storm water drainage	Tailings Dam Operator	Remove obstructions Repair road Grade road Develop effective drainage system
Pipe and Pipeline Route	✓	✓		Visual inspection to check for any leakage from the pipe, degradation of the route, etc.	Daily check Monthly Record	Route clear of vegetation/ debris No tailings from spillages	Tailings Dam Operator	Vegetation cleared along the route Leaking or defective pipes or valves Valves greased and in working order General condition of pipelines and valves Plinths in adequate condition
Supernatant Pond		✓		Visual inspection and survey	Daily Check Monthly record	< 50 000 m ³ stored on the dam except immediately after storm events Pond to be located as close to the centre of the dam as possible	Tailings Dam Operator	Decant water off rapidly after a storm event Using deposition to control the location of the pond
Penstock	✓	✓		Visual inspection	Penstock Inlet and Outlet - Daily check Monthly record	Vertical development of penstock rings Good maintenance and stability Correct decanting of dam water	Tailings Dam Operator	Replaced damages rings (if possible) Correct vertical alignment of rings Sleeve and grout if necessary
Rate of rise		✓		Comparison of survey results at different points in time.	Monthly record	Ensure even deposition and stability Ensure compliance with design criteria	Tailings Dam Operator	Change deposition cycle times per section Adhere to design rate of rise by controlling deposition rate
Return Water Dam								
Return Water Dam		✓		Visual and remote monitoring of the volume of water stored in the dam	Continuous monitoring of water levels using pressure meter	Correct operation of dam with regards to capacity and spilling of clean water to the environment. The RWD should not spill more frequently than once in 50years on average (R704)	Metallurgical Plant Manager	
Liner	✓	✓		Vacuum and weld testing during construction Visual liner inspection Leakage detection system monitoring using dip meter Wet area at downstream toe Flow from cutoff drain	During construction - all welds During operation - Quarterly	No liner leakage No vegetation in close proximity to liner Good condition with no visible leaks, tears or burns	During construction - Lining Contractor During operation - Tailings Dam Operator	Repair or replace liner Pump water from under liner prior to repair, using a borehole pump
Leakage Detection		✓		Dip meters down riser pipes Vacuum and weld testing during construction Wet area at downstream toe Flow from cutoff drain	Quarterly	No leakage detected.	Tailings Dam Operator	Check for damage to liner. Pump out leakage
Water Quality		✓		Water sampling	Monthly	Neutral water with cyanide < cyanide code requirement.	Tailings Dam Operator	Determine source of water quality degradation Check operation of Neutralisation Plant if pH is out Add lime to neutralise pH

	CONSTRUCTION PHASE	OPERATIONAL PHASE	AFTER CARE PHASE	MONITORING	FREQUENCY	TARGET	RESPONSIBILITY	CORRECTIVE ACTION
								Check cyanide concentration of deposited tailings.
RWD wall and downstream protection		✓	✓	Visual inspection along wall of dam to check for excessive erosion Low spots or accumulation of water on crest Adequate erosion protection General wall condition Seepage visible Vegetation on side slopes in good condition Spillway condition	Quarterly	Acceptable rate of erosion (< 0.75 t/ha/yr) Good condition Negligible seepage Vegetation growth	Tailings Dam Operator	Repair slopes Fill in low spots Check liner Repair spillway
Dam Stability		✓	✓	Visual inspection along toe of dam to check for sloughing, wet areas and discharge from drain outlets Bulging of underlying foundations at the toe Spillway condition	Monthly	Dam safety maintained through integrity of liner No vegetation die off due to saturation of the soil. No flow from outlets and no wet areas	Tailings Dam Operator	Repair slopes Fill in low spots Check liner Repair spillway
Safety nets and ropes		✓		Visual Inspection	Daily check Monthly record	8 safety nets installed in position as shown on Drawing 10307-007, in good condition at all times 140 safety ropes as shown on Drawing 10307-007 at 20m spacing maximum, in good condition at all times	Tailings Dam Operator	Replace safety ropes Repair or replace safety nets
Pumps, pipes and valves	✓	✓		Visual inspection	Daily	No leakage Working condition - valves close and open correctly, pumps operate correctly	Tailings Dam Operator	Repair or replace damaged items
Cover								
Erosion rate		✓	✓	Survey of side slopes Measurement of sediment in catchment paddocks	Every 5 years	Erosion rate < soil formation rate Erosion rate < 0.75 t/ha/yr	Tailings Dam Operator	Improve vegetation cover. Additional soil retention methods. Repair slopes through replacing lost topsoil.
Vegetation		✓	✓	Landscape function analysis	Monthly record	95% vegetation cover Long term ecological and environmental sustainability Minimise erosion Improve stability	Tailings Dam Operator	Improve vegetation cover Improve biodiversity Aim to mimic the natural surrounding flora.
Nutrients		✓		Landscape function analysis tools	Quarterly	Rate of gain of nutrients ≥ rate of loss over measured area	Tailings Dam Operator	Investigate soil enrichment. Investigate effect of biodiversity
Dust Emissions	✓	✓		Fallout buckets and dust analysis if necessary	Monthly	Negligible dust emissions from side slopes.	Tailings Dam Operator	Improve vegetation cover Increase moisture content of topsoil
Groundwater								
Underdrainage Collection Flow rate		✓		Bucket hung into manhole and timed.	At neutralisation plant - Continuous Check if there's flow - Weekly Measure flow - Quarterly	Adjacent outlets to have comparable flow rates, otherwise there is a problem with some portion of the underdrains or underdrainage collection system.	Tailings Dam Operator	Rod any blocked pipes

	CONSTRUCTION PHASE	OPERATIONAL PHASE	AFTER CARE PHASE	MONITORING	FREQUENCY	TARGET	RESPONSIBILITY	CORRECTIVE ACTION
Underdrainage Collection Quality		✓		Sample taken from bucket lowered in to manhole	Monthly	Water quality record to check if Neutralisation Plant is required. Acidic water quality may indicate the ingress of oxygen into the tailings which could be linked to damage of the composite cover	Tailings Dam Operator	Investigate possible ingress of oxygen below Sealmac.
Borehole water quality		✓	✓	Sampling and testing	Bi-annually during construction After construction- quarterly	Non polluted water with regards to an increase in levels of pH, sulphates, nitrates, aluminium, etc. in relation to the baseline water quality	Tailings Dam Operator	Investigate source of contamination and remedy appropriately (e.g. phytoremediation)
Surface Water								
Water quality		✓		pH and EC recorders located in stormwater channels	Monthly record	Clean water to be within guidelines for recreational use	Tailings Dam Operator	Treat (neutralise) water
Water volume		✓		Flowmeters located in the stormwater channels and penstock outfall pipe	Continuous (hourly) measuring	Record off runoff	Tailings Dam Operator	Change frequency of measuring based on numerical requirements Repair flowmeter
Stormwater Canals	✓	✓	✓	Visual inspection of lining, presence of sedimentation, vegetation, etc.	Monthly	No siltation Good condition No obstacles	Tailings Dam Operator	Clear obstructions Remove silt Repair canal lining
Culverts	✓	✓	✓	Visual inspection of culverts, presence of sedimentation, vegetation, etc.	Monthly	No siltation Good condition No obstacles	Tailings Dam Operator	Clear obstructions Remove silt Repair culverts
Silt Trap		✓		Visual inspection of concrete, presence of sedimentation, vegetation, etc.	Monthly	Sediment level which does not hinder the operation of the silt trap No damage to concrete	Tailings Dam Operator	Remove silt and debris through the use of high pressure hoses, desilting pump station, etc.
Catchment Paddocks	✓	✓		Visual inspection of earth, vegetation, catchment paddock outlet structures	Monthly	Reduce erosion and dust pollution Anticipate raising of paddocks Detect stability problems Outlets not blocked or damaged No saturation at toe of TSF embankment	Tailings Dam Operator	Removal of sediment and debris Repair or unblocking of outlet structures
General								
Weather conditions	✓	✓		Use appropriate temperature, wind speed and rainfall gauges Weather station at South Deep	Continuous	NA	Tailings Dam Operator	NA
Deposition data	✓	✓		Density and flow measurements - SCADA	Continuous	< 230ktpm	South Deep Mine	Repair measuring devices
Air Quality	✓	✓		Fall out buckets.	Monthly	Air Quality Act - Dust emission standard for PM ₁₀ : - a 24 hour average of 180µg/m ³ and the 24 hour may not be exceeded more than 3 times in 1 year; - an annual average of 60µg/m ³ . Air Quality Act - Dust emission standard for ambient concentration of total suspended solids may not exceed: - a 24 hour average of 300µg/m ³ and the 24 hour limit may not be exceeded more than 3 times in 1 year; - an annual average of 100µg/m ³ .	Tailings Dam Operator	Adopt dust reduction measures on the depositional areas of the TSF (ploughing windrows, constructing berms, application of lignosulphonate, etc)
Additional Pollution	✓	✓	✓	Visual inspection of the following: Any dumping of metal, refuse or hazardous material Oil leakages Adequate dust control Clearing of vegetation/ burning	Weekly	No pollution Dust control Removal of overgrowth	Tailings Dam Operator	Removal and/ or cleaning up of any dumping, oil leakages, etc. Improve dust control Clear vegetation/ burn firebreaks

	CONSTRUCTION PHASE	OPERATIONAL PHASE	AFTER CARE PHASE	MONITORING	FREQUENCY	TARGET	RESPONSIBILITY	CORRECTIVE ACTION
				firebreaks				
Fences, signage and gates	✓	✓	✓	Visual inspection	Safety Signs - Daily check Fences signage and gates- monthly record	Maintain fences and signage in working condition Maintain controlled access Sufficient signage and positioning Public awareness should be clear from signage	Tailings Dam Operator	Repair fences and gates Replace damaged signage
Daily Log Book	✓	✓		Sign off log book	Monthly record	Ensure correct operation Rainfall data Survey Data Deposition programme Production tonnages Report on defects and deviations Instruction ex Operations Manager Other operating happenings	Tailings Dam Operator	Improve procedure for recording information

18.2. CONTINGENCY PLANS

Contingency plans are envisaged for the following situations:

- Leakage because of a breach in the return water dam liner; and
- A monitoring borehole showing an increase in groundwater pollution.

A leakage in the return water dam liner would be identified by the increase in water reporting to the manholes that are part of the leak detection system. In the event that a leakage does occur, the leakage water would be pumped from the appropriate manhole(s) back to the return water dam.

In the event that increased pollution is indicated by one or more of the monitoring boreholes, the source would need to be identified and appropriate measures put in place to prevent further pollution and to remove the pollution plume if necessary.

A matrix for the Life Cycle Monitoring has been drawn up which incorporates various potential problematic situations. See Table 18-1 in Section 18.1.

19. CONCLUSIONS

The following conclusions arise from this study:

Site Selection

The Doornpoort Site (Site 5 in Figure 12-3) is the preferred site from the point of view of environmental impacts (see Environmental Impact Assessment Metago Report 168-006 No. 2). Although the capital cost of site 5 is relatively high compared to sites 3 and 4, the size of the site facilities a much longer life of dam and/ or higher production rates. The cost per tonne of tailings disposed is thus lower than for the other sites considered.

Stage Capacity

- The tailings dam has a volumetric capacity (up to 1624 mamsl) of approximately 152 000 000 m³ (205 000 000 tonnes) which is more than the 79 500 000 m³ (107 300 000 tonnes) required according to the mine planning schedule provided;
- Based on the production ramp up provided by the Mine, the required elevation of the starter wall is 1562.1 mamsl, which equates to a maximum starter wall height of 16.6 m^{*};
- The maximum elevation of the crest of the tailings dam corresponding to an airspace volume of 79 500 000 m³ is 1591.4 mamsl, which equates to a maximum height of 45.9 m^{*};
- The rate of rise at the final planned elevation of 1591.4 mamsl will be 0.2 m/yr;
- The construction of the TSF may be completed in two preparatory phases referred to as Phase 1, comprising the lower portion and Phase 2 comprising the upper portion of the tailings dam. Phase 2 must be completed within 12.5 years (149 months) from the date of first deposition;
- Coverage of the entire tailings dam footprint will be achieved at a crest elevation of 1584 mamsl; and
- Due to the low rates of rise the tailings dam will be able to accommodate short term increases in the rate of deposition, subject to the approval of the design engineer.
- The dam could potentially accommodate an additional 72 500 000m³ (97 700 000 tonnes) of tailings over and above the design capacity for South Deep.

^{*} All heights are measured as the difference between the lowest point along the toe and the crest elevation.

Geotechnical Investigation

- The site is confirmed to be underlain by shales and andesitic lava. Siltstone was also occasionally encountered. In addition, occasionally intrusive dolerite was encountered. Upper soils generally comprise transported Aeolian, colluvium and hillwash soils.
- The footprint of the surface bed for the starter wall must be ripped and re-compacted prior to the placement of the first layer of fill.
- The soils encountered within the footprint of the proposed tailings dam should prove suitable for the construction of the starter wall provided that certain precautionary measures are taken during construction.
- A ferricrete layer has been identified as being suitable for the access road which will be constructed around the final perimeter of the footprint of the proposed tailings dam.
- Although not encountered, dolerite dykes and possibly andesite outcrops may transverse the penstock alignment. In these instances hard rock conditions will be encountered. If encountered, the required depth of over-excavation will have to be determined on site during construction.
- It is recommended that the permanent penstock be placed on an engineered rock fill raft and the portion of the penstock outfall pipe closest to the permanent penstock be placed on a 100m long tapered imported engineered rock fill constructed within the pipe trench. Unacceptable differential settlement is expected to take place between the penstock tower and the outfall pipeline if no precautionary measures are taken.
- It is recommended that the borrow pit operations envisaged in the vicinity of the penstock line, should not come closer than 25m to the pipeline alignment. This is required to ensure that the length of the entire length of the alignment is placed in similar in-situ soils.
- Variable conditions were encountered within the area designated for the return water dam. Residual Andesite is found underlying the higher (north eastern)

areas while the lower (south western) areas are underlain by shales near or adjacent to the well defined water course. In addition the area has been intruded by a dolerite feature which is seen to occur on the lower south western portions extending towards the central portions of the return water dam.

- 300 mm of topsoil will be stripped from the footprint of the tailings storage facility and stockpiled until it is needed for covering the sideslopes.
- Box cuts may be required in the construction of the starter and/or return water dam embankments, but this will need to be confirmed during the detailed design phase.
- Water ingress into the test pits away from the water course was minimal, indicating that dewatering of excavations during construction to remove groundwater is unlikely. The return water dam however will be lined with a HDPE liner, which would be affected by any water collecting underneath it. The leakage detection system beneath the liner should be able to handle any seepage occurring, and the soilcrete bags placed on top of the liner will provide resistance to uplift.

Seepage Analysis

- From the analyses it was estimated that less than 3.54×10^{-5} l/s of seepage will be discharged into the in-situ material from the tailings dam;
- The seepage analyses have shown that the combination of main drain, toe and cut-off drains can effectively control the phreatic surface within the tailings dam. A margin of safety should however be incorporated for the main and toe drains to allow for possible wash-a-ways and blinding;
- The phreatic surface is sensitive to the position and size of the main and toe drains. The analyses indicated that main needs to be a minimum of 25 m wide, depending on its location around the dam, and the toe drains needs to be 5 m wide to reduce the risk of toe seepage to a satisfactory level;
- Seepage losses up to the time when the tailings dam breaks ground, while the supernatant pond is in direct contact with natural ground, may exceed the

seepage losses calculated in this analysis if the permeability of the underlying soils is significantly higher than that of the tailings;

- Flow rates into the underdrain outlets and total flow into the underdrain collection system would need to cater for a minimum rate; and
- It is possible for a large pool to be accommodated if all of the drains are functioning correctly, but a large pool should be avoided.

Geochemical Investigation

- The tailings dam may be characterised by two geochemically distinct zones which are expected to be evident throughout the life of the facility but which change in extent depending on the geochemical environment within the tailings dam.
- The outer zone (in the absence of any further controls) will become acidic relatively soon (within a few months or years) and will release seepage characterised by a low pH and high dissolved metal content, should the Sealmac and soil layers prove unsuccessful.
- The inner zone located primarily below the phreatic surface and in areas of the tailings dam that are at or very nearly saturated. The seepage released from this zone will be characterised by neutral drainage and lower dissolved metal concentrations and salt loads.
- Where the flow path crosses from the outer (acid) zone into the inner (neutral) zone, the resulting drainage quality will tend to take on the characteristics of the acid zone within a relatively short distance downstream of the cross over point, primarily because of the limited neutralising capacity of the tailings.
- The two existing dams currently operated by South Deep were used to collect samples of both tailings, underdrain seepage and process water for the prediction of water quality from the proposed Doornpoort Dam.
- The daily salt released from the tailings dam is expected to be 982 kg/day.
- The characteristics of the seepage quality from the inner and outer zones have been described on the basis of test work undertaken.

- The Acceptable Risk Level, as defined in the Minimum Requirements (DWAF 1998), will be exceeded for the following elements:
 - Inner Zone – As, Cu, Mn and Ni.
 - Outer Zone – Al, As, Co, Cr, Cu, Fe, Mn, Ni, Ti and Zn.
- The low air permeability of saturated or near saturated gold tailings will play a key role in limiting ingress of oxygen to the tailings dam during the operational life of the dam, thereby reducing the rate of acid production, particularly in those regions of the tailings dam that are below the phreatic surface, or buried deep below surface and away from points of oxygen ingress.
- On decommissioning of the tailings dam, the air permeability will rise as partially saturated conditions become established within the tailings material, and as the phreatic surface dissipates. Areas that up until decommissioning were prevented from becoming acid generating by virtue of the presence of the phreatic surface, will gradually contribute to acid generation. The seepage flux from the tailings dam will however also reduce after decommissioning.
- There is a significant risk that in the absence of adequate mitigation, the proposed tailings dam could impact on the surrounding environment through emissions of contaminants as both seepage and surface runoff from the tailings dam and associated infrastructure.

Hydrology

- The proposed Doornpoort tailings dam is located outside of any floodlines and more than 100m from the centreline of any waterway.
- The tailings delivery and return water pipelines will be required to cross streams. The flood lines have been defined at these points.
- Groundwater and surface water protection
- Groundwater protection will be afforded by the following features:
 - A fully lined return water dam incorporating a leakage detection system.

- A piped seepage collection system
- A Hyson Cell lined stormwater canal
- Provision for additional groundwater protection has been incorporated in the budget for:
 - A seepage cut-off drain within the starter wall of the tailings dam.
 - A bituminous impregnated (Sealmac) layer between the soil and the tailings to minimise the risk of the tailings going acidic.

Surface water protection will be afforded by the following features:

- Provision of a water treatment plant capable of treating excess process water to a standard suitable for use in the mines refrigeration plant.
- Provision of a return water dam with a capacity sufficient to ensure that the dam will not spill with a frequency exceeding once in fifty years as per Regulation 704 of the National Water Act of 1998.

Dust Emissions

Dust emissions will be controlled by:

- Soil cladding the side slope concurrently with dam construction.
- Managing deposition cycles to ensure that the beach remains wet during the operational phase.
- Cladding the top surface of the tailings dam with rock/ soil on decommissioning.
- Making use of chemicals such as lignosulphonate, or physical methods such as ploughing wind rows.

Decommissioning, Aftercare and Closure

Decommissioning activities will be focused primarily on the completion of the cover, removal of pipelines, sealing of penstocks, and establishment of vegetation cover to

minimise long term erosion and dust emissions. Aftercare will be concerned primary with monitoring of the cover and seepage quality but may involve treatment of a small quantity of acid water that may emanate from the underdrain collection system during the draw down phase.

20. RECOMMENDATIONS

It is recommended that a trial slope is set up on one of the existing tailings dams in order for the success of the side slope cover to be tested.

The design criteria should be periodically verified during the operational life of the tailings dam.

The concrete and structural specialists should be involved during construction.

Gold Fields to appoint an Approved Professional Person (APP) for the construction and operational stages of the return water dam.

The water license for South Deep is to be amended.

The effectiveness of the cover design in modifying the drainage quality should be verified through the monitoring programme.

21. REFERENCES

Adamson P T, 1981, Southern African Storm Rainfall, Department of Water Affairs and Forestry, Technical Report No. TR 102.

Chamber of Mines of South Africa, 1996, Guidelines for Environmental Protection Volume 1/1979 (Revised 1983 and 1995) "The Engineering Design, Operation and Closure of Metalliferous, Diamond and Coal Residue Deposits".

CONSUS (Pty) Ltd, 2007, South Deep Mine - New Penstock – Investigation into Appropriate Countermeasures Against Heat of Hydration Problems – A Report and Recommendations.

Department of Water Affairs and Forestry, 1996, South African Water Quality Guidelines (second edition). Volume 1: Domestic Use and Volume 5: Agricultural Use: Livestock Watering.

Dorman S and McPhail G, 1988, Site selection for a Tailings impoundment for the proposed South Deep Mine for Johannesburg Consolidated Investment Co Ltd Report No. MI6131/1.

Fell R, MacGregor, P and Stapeldon, D, 1992, “Geotechnical Engineering of Embankment Dams”, Balkema

Golder Associates Africa, 2007, Hydrogeological Investigation and Impact Assessment for Proposed Tailings Storage Facility No.5 – South Deep Gold Mine, Report No. 10307/10273/13/G.

Golder Associates Africa, 2007, South Deep Gold Mine Geotechnical Investigation for the Proposed Tailings Storage Facility, Report No. 10307/10319/14/G.

Golder Associates Africa, 2008, South Deep Gold Mine New Doornpoort Tailings Storage Facility Closure Framework, Report No. 10307/10462/15/W.

Harris J.A, Birch P and Short K C, 1989, “Changes in Microbial Community and Physio-Chemical Characteristics of Top soils Stockpiled during Opencast Mining”, Soil Use and Management Journal 5 (4): pp 161-168

Hoffman T, Todd S, Ntshona Z and Turner S, 1999, “Land Degradation in South Africa”: Chapter 6, pp 77-84

Hydrological Research Unit, 1972, Design Flood Determination in South Africa, University of the Witwatersrand Department of Civil Engineering, Report No. 1/72

Metago Report No. 168-004/02, 2007, Environmental Impact Assessment/ Environmental Management Programme for a New Tailings Dam (First Amendment to the Mine’s Updated EMP).

Metago Report No. 168-006/01, 2005, Site Selection Review and Capital Cost Estimate for a New Tailings for South Deep for Placer Dome Western Areas Joint Venture. Unpublished report by Metago Environmental Engineers.

Minnaar H, 2004, Risk Assessment Slimes Dam Sites for South Deep Mine. Unpublished report by Bureau for International Risk Assessments.

NSE Report No. JN069-NSE-GA-R-800, 2008, Design of Pipe Encasing and Temporary Penstocks.

Op Ten Noort and Stephenson D, 1982, “Flood Peak Calculation in South Africa”, Water Systems Research Programme, Wits University, Report 2/1982

SANRAL, 2006, Drainage Manual, 5th Edition – Fully Revised.

SANS 10286, 1998, SANS Code of Practice for Mine Residue Deposits.

SEEP/W, 2004, “Finite Element Seepage Analysis”, Version 6.22, Geo-Slope International Ltd., Calgary, Alberta, Canada

Smithers JC and Schulze RE, 2000, “Long Duration Design Rainfall Estimates for South Africa”, WRC Report No. 811/1/00, Water Research Commission, Pretoria, South Africa

South Deep Mine, 2005, “Mandatory Code of Practice for Mine Residue Deposits (Tailings Facilities Only)”, Revision No. 1, Second Edition, May 2005.

Stanford K and Meintjies H, 2003, South Deep Placer Dome Western Areas Joint Venture Review and reporting on the SRK Report “Site selection for a Tailings impoundment for the proposed South Deep Mine” (Report No. Mi 6131 – Dated February 1988). Unpublished report by SRK Consulting.

USGS Earthquake Hazards Program, Website Accessed May 2008, <http://earthquake.usgs.gov/regional/world/africa/gshap.php>

Van Biljon M, 2005, Placer Dome Western Areas Joint Venture – South Deep Mine Geohydrological Investigation at the Proposed New Tailings Site Disposal Site 5. Unpublished report by Rison Ground Water Consulting.

Willgoose G R, Bras R L and Rodriguez-Iturbe I. 1989. "A physically based channel network and catchment evolution model", TR 322, Ralph M. Parsons Laboratory, Dept. of Civil Engineering, MIT, Boston, MA.



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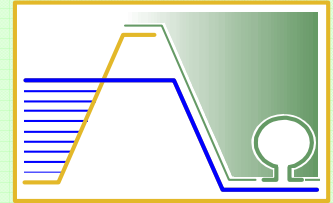
APP

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**APPENDIX 1: STAGE CAPACITY CALCULATION FOR THE PROPOSED DOORNPOORT TAILINGS
DAM AT SOUTH DEEP MINE**



Environmental Engineers (Pty) Ltd



**STAGE CAPACITY CALCULATION FOR THE
PROPOSED DOORNPOORT TAILINGS DAM AT
SOUTH DEEP MINE**

Prepared For

South Deep Gold Mine

METAGO PROJECT NUMBER G001-02

REPORT NO. A1

May 2008

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STAGE CAPACITY CALCULATION FOR THE PROPOSED DOORNPPOORT TAILINGS DAM AT SOUTH DEEP MINE

1. INTRODUCTION

The Stage Capacity Calculation Report forms part of the detailed design of the proposed Doornpoort Tailings Storage Facility (TSF) for South Deep Mine.

Stage capacity curves are presented for 233 000tpm and 330 000tpm. The 330 000tpm case has been included as Gold Fields are currently considering options to optimise their operations which may involve deposition of tailings from other operations on the proposed Doornpoort tailings dam.

The nominal 233 000tpm case has been determined based on a production of 330 000tpm passing through the mill but with the balance being used as underground backfill.

2. TERMS OF REFERENCE

The terms of reference for the development of the stage capacity curves are to develop representations of:

- The relationship between the height (elevation) of the facility and the volume of tailings deposited;



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- Variations in the active depositional area of the facility corresponding elevations and dates;
- Variations in the rates of rise at corresponding elevations and dates; and
- The rate at which tailings will be produced and disposed of to the facility.

The graphical plots are then used, in conjunction with the rate of rise limitations specified in the design criteria, to define the height of the starter wall required to enable the development of the facility to the point where raising of the walls can be achieved using dried, consolidated tailings.

3. DESIGN CRITERIA

The design criteria applicable to the development of the graphs, which define the stage capacity relationships applicable to the tailings disposal facility are defined by the physical area available for the development of the facility and the following:

- The maximum extent of the available site (referred to as Site 5 in the site selection Metago Report 168-004 No.2, March 2007, Chapter 3) was utilised for both the 233 000 tpm and 330 000tpm cases. It is however possible to dispose of 233 000tpm on a smaller footprint area of 250Ha. South Deep has however chosen to develop the full site using a phased approach to maximise upside mining potential;
- The average dry density of the hydraulically placed tailings, which is a function of the particle specific gravity and the assumed final void ratio of the deposited tailings. This has been found through experience to average 1.35 tonnes/m³ for Witwatersrand Gold Tailings;
- The estimated beach profile of the deposited tailings, which is a function of the particle size distribution, slurry water content and method of placement. The gold tailings beach profile is expected to be relatively flat and the beach slope has therefore been disregarded in the stage capacity relationship estimation;
- The planned rate of tailings production and the total mass of tailings that will be produced during the mine's life. The assumed annual tailings production rate is documented in Table 1 for two design cases, namely 233 000tpm and 330 000tpm.

It should be noted that the airspace provision is based on a total tailings production of 330 000tpm. Operation of the backfill plant is expected to reduce this to 233 000tpm on average. The backfill plant does not however run continuously and so the peak instantaneous delivery of 330 000tpm may be expected;

- The rate of rise at which it is possible for tailings to dry and consolidate sufficiently to be used for the construction of walls for the facility. A maximum rate of raise to allow for mechanical wall building of ~1.6m/yr was assumed on the basis of historic experience with Witwatersrand gold tailings and after consideration of the grading curve. This rate of rise would allow for access onto the beach using a high floatation excavator or similar equipment. A ramp up production profile was provided by the mine which was based on the mine plan. This ramp up production profile was used to determine the required starter wall heights; and
- Slide slopes above the starter wall are assumed to average 1V:4H.

4. METHODOLOGY

The methodology used to develop the graphs comprising the stage capacity relationships is as follows:

- The area available for the development of the facility was defined based on the topographical and cadastral constraints relating to the Doornpoort site, which are outlined in the main report;
- The position of the starter walls is defined based on the topography of the site;
- The area of the tailings dam basin accessible from the starter and perimeter walls is measured for different heights of starter wall;
- The areas available for the deposition of tailings are calculated up to an assumed final elevation of the tailings dam with the incremental volumes also being calculated;
- The total volume of the facility is calculated and the final surface area is checked to ensure that the volume and final rate of rise criteria are satisfied;
- If the volume or final rate of rise criteria are not satisfied the process is repeated with an amended footprint;

- Once the volume and rate of rise criteria are satisfied the rates of tailings deposition are used to calculate the rates of rise throughout the life of the facility;
- Based on the rate of rise curves, the elevation of the facility at which the target rate of rise for self construction is achieved is then defined;
- A multi-axial plot of the various relationships is then developed which allows the various parameters to be determined at various times in the development of the facility; and
- From the stage capacity curves, it can be seen that the upper portion can be constructed at a later stage as the tailings take a number of years to cover the lower portion. The lower and upper portions have been labelled as Phase 1 and Phase 2 respectively (Figure 1). The division of the footprint between Phase 1 and Phase 2 has been set at an elevation of 1570m to allow the construction of the final reinforced penstock tower to be delayed for as long as possible.

5. RESULTS

5.1. CASE 1: 233 000TPM

The results of the stage capacity calculations for the nominal 233 000tpm case are presented in the form of a multi-axial plot shown in

Figure 2 and in Table 2. It may be concluded that:

- The tailings dam has a volumetric capacity (up to 1624 mamsl) of approximately 152 000 000 m³ (205 000 000 tonnes) which is more than the 79 500 000 m³ (107 300 000 tonnes) required according to the mine planning schedule provided in Table 1;
- Based on the production ramp up provided by the Mine, the required elevation of the starter wall is 1562.1 mamsl, which equates to a maximum starter wall height of 16.6 m*;

* All heights are measured as the difference between the lowest point along the toe and the crest elevation.

- The maximum elevation of the crest of the tailings dam corresponding to an airspace volume of 79 500 000 m³ is 1591.4 mamsl, which equates to a maximum height of 45.9 m*;
- The rate of rise at the final planned elevation of 1591.4 mamsl will be 0.2 m/yr;
- The construction of the TSF may be completed in two preparatory phases referred to as Phase 1, comprising the lower portion and Phase 2 comprising the upper portion of the tailings dam. The phasing is shown in Figure 1. Phase 2 must be completed within 12.5 years (149 months) from the date of first deposition;
- Coverage of the entire tailings dam footprint will be achieved at a crest elevation of 1584 mamsl; and
- Due to the low rates of rise the tailings dam will be able to accommodate short term increases in the rate of deposition, subject to the approval of the design engineer.
- The dam could potentially accommodate an additional 72 500 000m³ (97 700 000 tonnes) of tailings over and above the design capacity for South Deep.

5.2. CASE 2: 330 000TPM

The results of the stage capacity calculations for the nominal 330 000tpm case are presented in the form of a multi-axial plot shown in Figure 3 and in Table 3. It may be concluded that:

- The tailings dam has an ultimate volumetric capacity (up to 1624 mamsl) of approximately 152 000 000 m³ (205 000 000 tonnes). Above this height, the rate of rise exceeds 1.6m/yr;
- Based on the assumed production provided by the Mine, the required elevation of the starter wall is 1567.2 mamsl, which equates to a maximum starter wall height of 21.7 m*;
- The maximum elevation of the crest of the tailings dam corresponding to an airspace volume of 146 700 000 m³ is 1621.2 mamsl, which equates to a maximum height of 75.6 m*;

- The rate of rise at the final planned elevation of 1621.2 mamsl will be 1.5 m/yr;
- The commissioning of the upper portion of the facility can be deferred by approximately 7.8 years (94 months) from the date of first deposition; and
- Coverage of the entire tailings dam footprint will be achieved at a crest elevation of 1584 mamsl.

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FIGURE 1: LAYOUT AND LOCATION OF PHASING

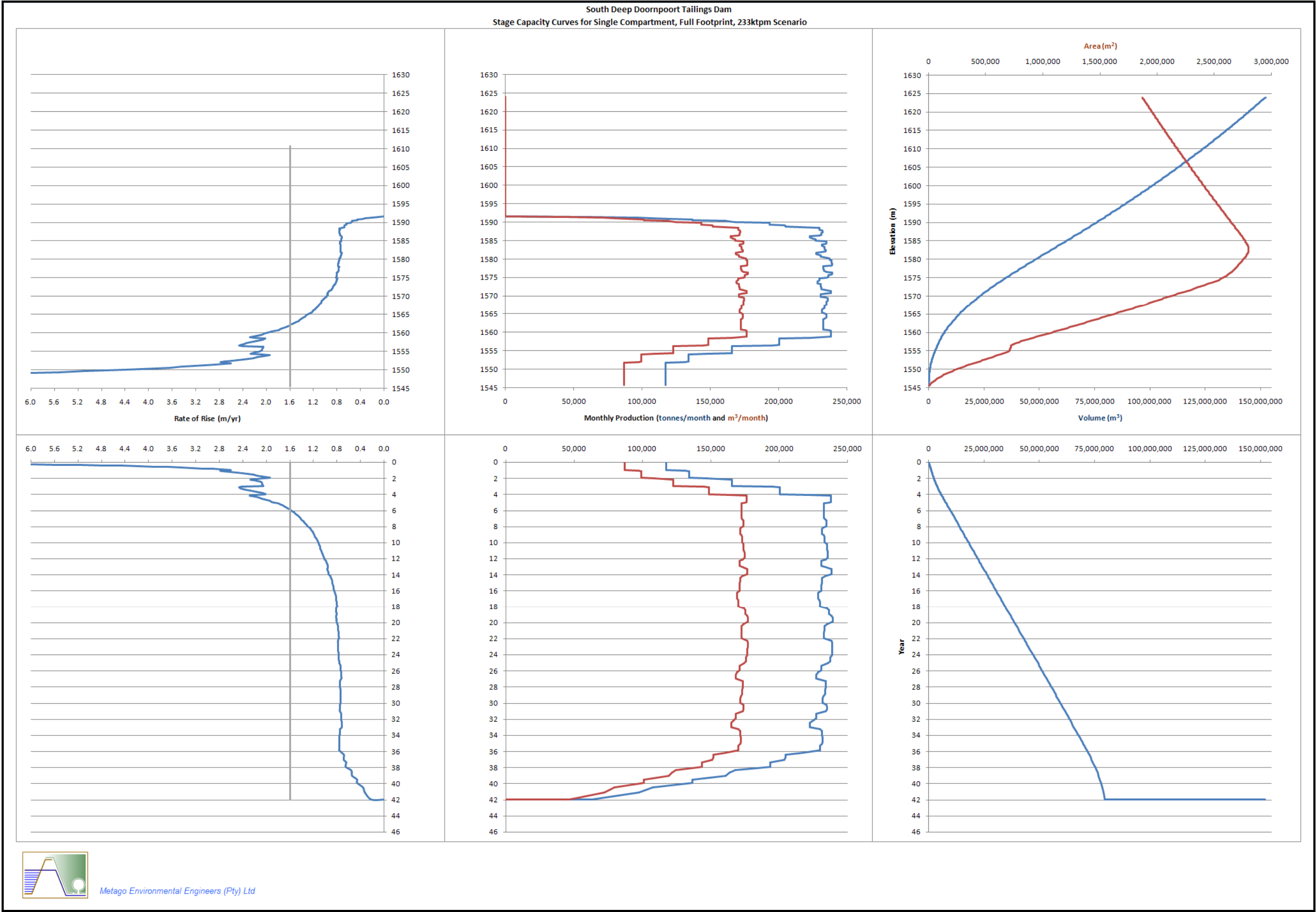


FIGURE 2: STAGE CAPACITY RELATIONSHIP FOR THE 233KTPM SCENARIO

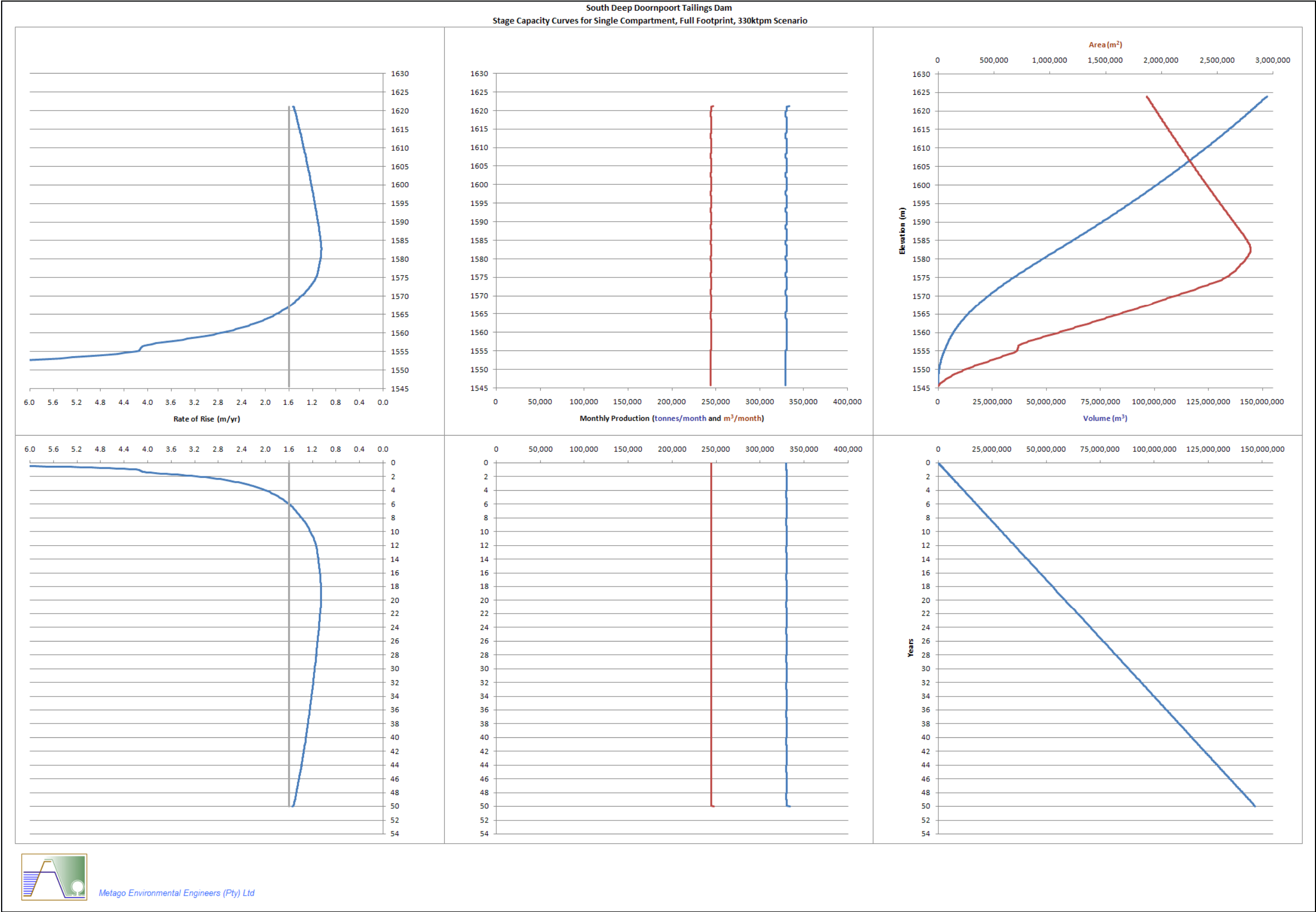


FIGURE 3: STAGE CAPACITY RELATIONSHIP FOR THE 330KTPM SCENARIO

TABLE 1: TONNAGE PRODUCTION SCENARIOS

YEAR	TONNAGE PRODUCED DURING PERIOD	
	233KTPM SCENARIO	330KTPM SCENARIO
1	1,411,017	3,960,000
2	1,605,797	3,960,000
3	1,985,285	3,960,000
4	2,402,857	3,960,000
5	2,862,669	3,960,000
6	2,790,682	3,960,000
7	2,790,524	3,960,000
8	2,814,476	3,960,000
9	2,783,519	3,960,000
10	2,797,931	3,960,000
11	2,818,032	3,960,000
12	2,826,628	3,960,000
13	2,775,934	3,960,000
14	2,857,509	3,960,000
15	2,773,971	3,960,000
16	2,767,122	3,960,000
17	2,745,474	3,960,000
18	2,757,394	3,960,000
19	2,835,884	3,960,000
20	2,868,023	3,960,000
21	2,802,786	3,960,000
22	2,788,083	3,960,000
23	2,863,989	3,960,000
24	2,863,161	3,960,000
25	2,853,817	3,960,000
26	2,766,704	3,960,000
27	2,725,994	3,960,000
28	2,809,884	3,960,000
29	2,806,837	3,960,000
30	2,776,710	3,960,000
31	2,817,737	3,960,000
32	2,723,612	3,960,000
33	2,676,981	3,960,000
34	2,773,366	3,960,000
35	2,781,823	3,960,000
36	2,757,350	3,960,000
37	2,462,669	3,960,000

YEAR	TONNAGE PRODUCED DURING PERIOD	
	233KTPM SCENARIO	330KTPM SCENARIO
38	2,319,729	3,960,000
39	1,963,961	3,960,000
40	1,637,306	3,960,000
41	1,219,560	3,960,000
42	708,578	3,960,000
43	0	3,960,000
44	0	3,960,000
45	0	3,960,000
46	0	3,960,000
47	0	3,960,000
48	0	3,960,000
49	0	3,960,000
50	0	3,960,000

TABLE 2: STAGE CAPACITY DATA FOR THE 233KTPM SCENARIO

ELEVATION (M)	CORRESPONDING AREA (M ²)	VOLUME (M ³)	CUMULATIVE VOLUME (M ³)	CORRESPONDING YEAR (FOR VOLUME)	AVERAGE RATE OF RISE (M/YR)
1545.5	3,015	0	0	0.00	
1546	13,388	4,101	4,101	0.00	96.6
1547	52,675	33,032	37,132	0.03	21.7
1548	104,021	78,348	115,480	0.11	10.6
1549	166,160	135,091	250,571	0.24	6.6
1550	242,875	204,518	455,088	0.43	4.4
1551	330,906	286,891	741,979	0.71	3.2
1552	429,543	380,225	1,122,203	1.06	2.8
1553	524,542	477,043	1,599,246	1.46	2.3
1554	621,606	573,074	2,172,320	1.94	1.9
1555	705,667	663,637	2,835,956	2.41	2.1
1556	715,997	710,832	3,546,788	2.89	2.1
1557	751,657	733,827	4,280,615	3.32	2.4
1558	852,941	802,299	5,082,914	3.77	2.1
1559	964,116	908,529	5,991,443	4.23	2.2
1560	1,076,130	1,020,123	7,011,566	4.71	2.0
1561	1,185,268	1,130,699	8,142,265	5.25	1.8
1562	1,296,607	1,240,938	9,383,202	5.85	1.6
1563	1,403,790	1,350,199	10,733,401	6.51	1.5
1564	1,509,663	1,456,727	12,190,127	7.21	1.4
1565	1,615,910	1,562,787	13,752,914	7.96	1.3
1566	1,720,307	1,668,109	15,421,022	8.77	1.2
1567	1,827,735	1,774,021	17,195,043	9.62	1.1
1568	1,924,517	1,876,126	19,071,169	10.53	1.1
1569	2,014,951	1,969,734	21,040,903	11.47	1.0
1570	2,114,826	2,064,889	23,105,792	12.46	1.0
1571	2,222,589	2,168,708	25,274,499	13.50	1.0
1572	2,319,476	2,271,033	27,545,532	14.59	0.9
1573	2,410,348	2,364,912	29,910,444	15.74	0.9
1574	2,506,926	2,458,637	32,369,081	16.95	0.8
1575	2,575,390	2,541,158	34,910,239	18.19	0.8
1576	2,625,254	2,600,322	37,510,561	19.43	0.8
1577	2,664,414	2,644,834	40,155,395	20.69	0.8
1578	2,696,637	2,680,526	42,835,920	21.98	0.8
1579	2,725,676	2,711,157	45,547,077	23.26	0.8
1580	2,754,419	2,740,048	48,287,124	24.55	0.8
1581	2,777,539	2,765,979	51,053,103	25.89	0.7

ELEVATION (M)	CORRESPONDING AREA (M ²)	VOLUME (M ³)	CUMULATIVE VOLUME (M ³)	CORRESPONDING YEAR (FOR VOLUME)	AVERAGE RATE OF RISE (M/YR)
1582	2,794,385	2,785,962	53,839,065	27.26	0.7
1583	2,796,935	2,795,660	56,634,725	28.61	0.7
1584	2,785,868	2,791,402	59,426,127	29.96	0.7
1585	2,765,858	2,775,863	62,201,990	31.30	0.7
1586	2,745,901	2,755,880	64,957,869	32.68	0.7
1587	2,721,291	2,733,596	67,691,465	34.02	0.8
1588	2,696,526	2,708,909	70,400,374	35.34	0.8
1589	2,671,662	2,684,094	73,084,468	36.73	0.7
1590	2,646,903	2,659,283	75,743,750	38.31	0.6
1591	2,622,248	2,634,576	78,378,326	40.46	0.4
1591.4	2,622,248	1,048,899	79,427,225	42.00	0.2

TABLE 3: STAGE CAPACITY DATA FOR THE 330KTPM SCENARIO

ELEVATION (MAMSL)	CORRESPONDING AREA (M ²)	VOLUME (M ³)	CUMULATIVE VOLUME (M ³)	CORRESPONDING YEAR (FOR VOLUME)	AVERAGE RATE OF RISE (M/YR)
1545.5	3,015	0	0	0.00	0.0
1546	13,388	4,101	4,101	0.00	271.2
1547	52,675	33,032	37,132	0.01	60.9
1548	104,021	78,348	115,480	0.04	29.6
1549	166,160	135,091	250,571	0.09	18.4
1550	242,875	204,518	455,088	0.16	12.5
1551	330,906	286,891	741,979	0.25	9.1
1552	429,543	380,225	1,122,203	0.38	7.0
1553	524,542	477,043	1,599,246	0.55	5.7
1554	621,606	573,074	2,172,320	0.74	4.8
1555	705,667	663,637	2,835,956	0.97	4.2
1556	715,997	710,832	3,546,788	1.21	4.1
1557	751,657	733,827	4,280,615	1.46	3.9
1558	852,941	802,299	5,082,914	1.73	3.5
1559	964,116	908,529	5,991,443	2.04	3.1
1560	1,076,130	1,020,123	7,011,566	2.39	2.8
1561	1,185,268	1,130,699	8,142,265	2.78	2.5
1562	1,296,607	1,240,938	9,383,202	3.20	2.3
1563	1,403,790	1,350,199	10,733,401	3.66	2.1
1564	1,509,663	1,456,727	12,190,127	4.16	2.0
1565	1,615,910	1,562,787	13,752,914	4.69	1.8
1566	1,720,307	1,668,109	15,421,022	5.26	1.7
1567	1,827,735	1,774,021	17,195,043	5.86	1.6
1568	1,924,517	1,876,126	19,071,169	6.50	1.5
1569	2,014,951	1,969,734	21,040,903	7.17	1.5
1570	2,114,826	2,064,889	23,105,792	7.88	1.4
1571	2,222,589	2,168,708	25,274,499	8.62	1.3
1572	2,319,476	2,271,033	27,545,532	9.39	1.3
1573	2,410,348	2,364,912	29,910,444	10.20	1.2
1574	2,506,926	2,458,637	32,369,081	11.03	1.2
1575	2,575,390	2,541,158	34,910,239	11.90	1.1
1576	2,625,254	2,600,322	37,510,561	12.79	1.1
1577	2,664,414	2,644,834	40,155,395	13.69	1.1
1578	2,696,637	2,680,526	42,835,920	14.60	1.1
1579	2,725,676	2,711,157	45,547,077	15.53	1.1
1580	2,754,419	2,740,048	48,287,124	16.46	1.1
1581	2,777,539	2,765,979	51,053,103	17.40	1.1
1582	2,794,385	2,785,962	53,839,065	18.35	1.1

ELEVATION (MAMSL)	CORRESPONDING AREA (M ²)	VOLUME (M ³)	CUMULATIVE VOLUME (M ³)	CORRESPONDING YEAR (FOR VOLUME)	AVERAGE RATE OF RISE (M/YR)
1583	2,796,935	2,795,660	56,634,725	19.31	1.0
1584	2,785,868	2,791,402	59,426,127	20.26	1.1
1585	2,765,858	2,775,863	62,201,990	21.21	1.1
1586	2,745,901	2,755,880	64,957,869	22.14	1.1
1587	2,721,291	2,733,596	67,691,465	23.08	1.1
1588	2,696,526	2,708,909	70,400,374	24.00	1.1
1589	2,671,662	2,684,094	73,084,468	24.92	1.1
1590	2,646,903	2,659,283	75,743,750	25.82	1.1
1591	2,622,248	2,634,576	78,378,326	26.72	1.1
1592	2,597,698	2,609,973	80,988,299	27.61	1.1
1593	2,573,253	2,585,476	83,573,774	28.49	1.1
1594	2,548,912	2,561,083	86,134,857	29.36	1.2
1595	2,524,677	2,536,795	88,671,651	30.23	1.2
1596	2,500,546	2,512,612	91,184,263	31.09	1.2
1597	2,476,520	2,488,533	93,672,796	31.93	1.2
1598	2,452,598	2,464,559	96,137,355	32.77	1.2
1599	2,428,782	2,440,690	98,578,045	33.61	1.2
1600	2,405,070	2,416,926	100,994,971	34.43	1.2
1601	2,381,463	2,393,267	103,388,237	35.25	1.2
1602	2,357,961	2,369,712	105,757,949	36.05	1.2
1603	2,334,563	2,346,262	108,104,211	36.85	1.3
1604	2,311,271	2,322,917	110,427,128	37.65	1.3
1605	2,288,083	2,299,677	112,726,805	38.43	1.3
1606	2,264,999	2,276,541	115,003,346	39.21	1.3
1607	2,242,021	2,253,510	117,256,856	39.97	1.3
1608	2,219,147	2,230,584	119,487,440	40.73	1.3
1609	2,196,378	2,207,763	121,695,203	41.49	1.3
1610	2,173,714	2,185,046	123,880,249	42.23	1.3
1611	2,151,155	2,162,435	126,042,683	42.97	1.4
1612	2,128,700	2,139,928	128,182,611	43.70	1.4
1613	2,106,350	2,117,525	130,300,136	44.42	1.4
1614	2,084,105	2,095,228	132,395,363	45.13	1.4
1615	2,061,965	2,073,035	134,468,398	45.84	1.4
1616	2,039,929	2,050,947	136,519,345	46.54	1.4
1617	2,017,999	2,028,964	138,548,309	47.23	1.5
1618	1,996,173	2,007,086	140,555,395	47.92	1.5
1619	1,974,451	1,985,312	142,540,707	48.59	1.5
1620	1,952,835	1,963,643	144,504,350	49.26	1.5
1621	1,931,323	1,942,079	146,446,429	49.92	1.5
1621.12	1,931,323	231,759	146,678,188	50.00	1.5

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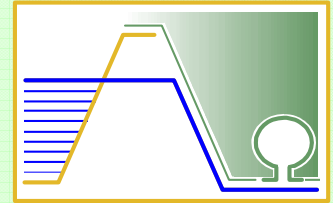
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APPENDIX 2: HYDROLOGY AND FLOODLINES AFFECTING THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE



Environmental Engineers (Pty) Ltd



**HYDROLOGY AND FLOODLINES AFFECTING THE
PROPOSED DOORNPOORT TAILINGS DAM AT
SOUTH DEEP MINE**

Prepared For

South Deep Gold Mine

METAGO PROJECT NUMBER G001-02

REPORT NO. A2

May 2008

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HYDROLOGY AND FLOODLINES AFFECTING THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

1. INTRODUCTION

This report comprises an Appendix report (Appendix A2) to the detailed design of the proposed Doornpoort Tailings Dam complex on Site 5 for South Deep Mine and documents the catchment characteristics, flood discharges for a range of statistical return periods and location of flood lines.

This study is part of the detailed design for the proposed Doornpoort Tailings Dam which is located as shown in Figure 1 to the East of the an unnamed tributary of the Leeu Spruit¹, on Site 5, which was identified during the site selection stage (referred to as Site 5 in the site selection Metago Report 168-004 No.2, March 2007, Chapter 3).

2. TERMS OF REFERENCE

The terms of reference for the study are as follows:

- To determine the hydrological characteristics of the stream catchment for the Leeu Spruit Tributary that flows to the west of the proposed tailings dam site;

¹ Referred to as the Leeu Spruit Tributary



- To determine the flood discharges for the 20, 50 and 100 year return periods for the same stream;
- Ensure that the tailings complex is outside the specified 100m from any water courses ; and
- Calculate the position of the 1 in 100 year floodline.

3. CLIMATIC DATA

3.1.1. REGIONAL CLIMATE

The project area is situated on the interior high-plateau of South Africa known as the Highveld. Due to its height above sea-level (1580 m above sea level), the site experiences warm to hot sunny days in the Spring and Summer with temperatures often reaching 30° C. From October to April the area experiences a wet season (The average annual rainfall is 683 mm) where thunderstorms do occur. The winter season tends to be dry with cold mornings (frost in June and July), although the days are warmer.

The prevailing winds throughout most of the year are north-westerly and north-easterly due to the Southern African anti-cyclonic circulation. During winter, particularly July and August, south-westerly winds blow more frequently because of the changing weather conditions (the northward shift of the high pressure belt and enhanced influence of westerly wave disturbances e.g. cold fronts). Summer months are characterised by the weakening and southward shift of the anti-cyclonic belt, which allows tropical easterly flow to resume its influence over the region. North-easterly winds increase during summer (December to February) with north-westerly winds prevalent in March and April.

3.1.2. RAINFALL AND EVAPORATION

Climatic data was obtained for the closest weather stations from the South African Weather Service. The *Westonaria Kloof Goudmyn* station (no 0475174 4), with 37 years of recorded rainfall was selected on the basis of proximity and similarity in elevation (rainfall data only). The site for the proposed Doornpoort Tailings Dam complex is located at 26.467° S, Longitude: 27.65° E with an average elevation of

approximately 1580 mamsl, which is closest to the *Westonaria Kloof Goudmyn* station with a similar elevation (Table 1). The selected station is also geographically co-located with South Deep Mine to the south of the east- west Hillshaven ridge, which may influence rainfall patterns. The evaporation data was sourced from the *Zuurbekom* station, which is the closest station with evaporation data to the site. The adopted rainfall and evaporation data is presented in Table 2. Average daily temperature data from the *Kroningspark* station, again the closest available data, is also presented.

TABLE 1: WEATHER STATIONS IN THE VICINITY OF SOUTH DEEP MINE

STATION NAME	STATION NUMBER	TEMPORAL RANGE (YEARS)	LATITUDE	LONGITUDE	ELEVATION (mamsl)
Zuurbekom	0475528 8	1903-2005	26.30° S	27.80° E	1578 m
Krugersdorp Kroningspark	0475456 8	1904-2005	26.10° S	27.77° E	1699 m
Randfontein	0475338 9	1954-2005	26.13° S	27.70° E	1710 m
Westonaria Kloof Goudmyn	0475174 4	1966-2005	26.40° S	27.60° E	1685 m

**As supplied by the South African Weather Service*

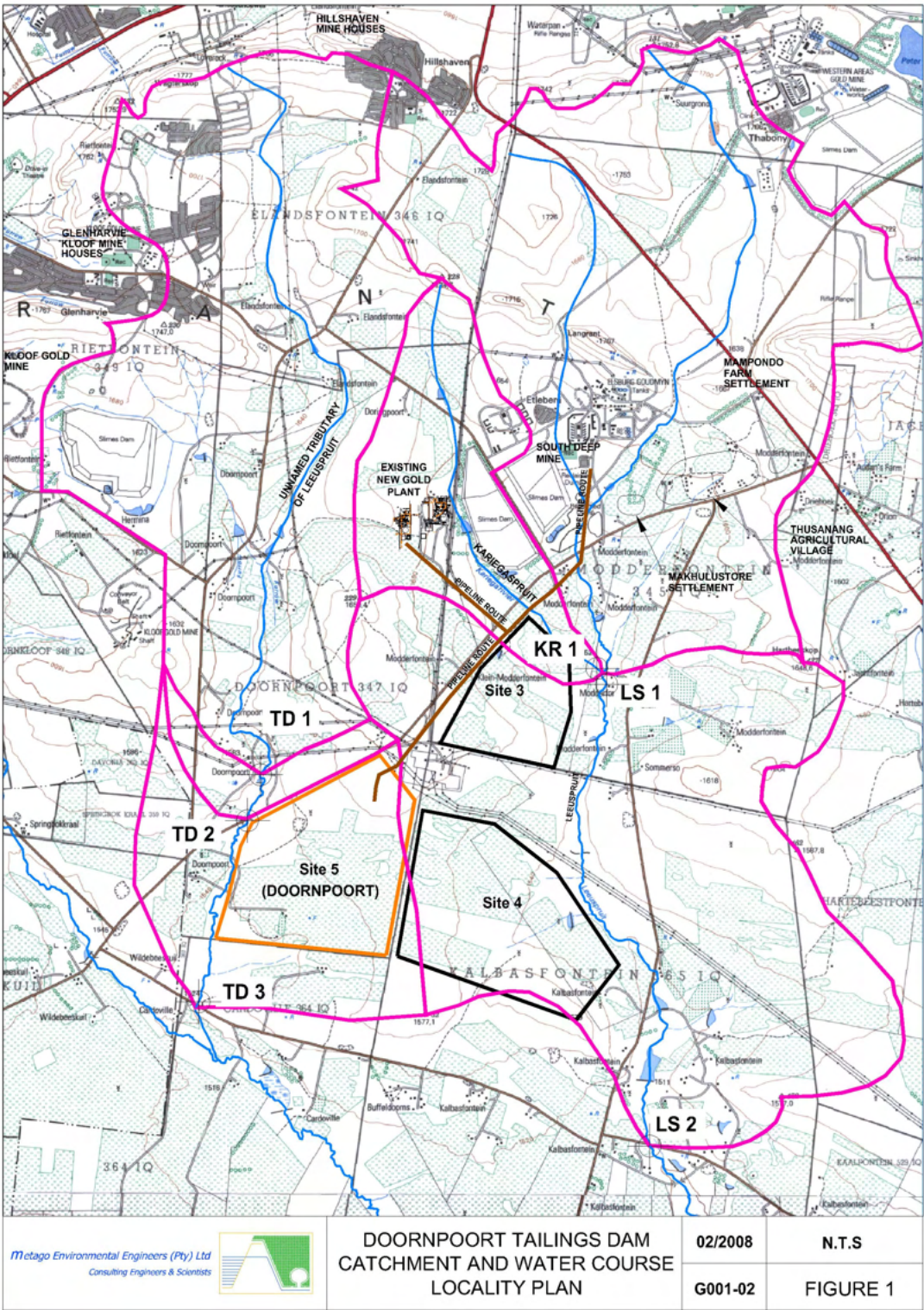


FIGURE 1: LOCALITY PLAN WITH THE CATCHMENTS AND TAILINGS DAM SITE

TABLE 2: MONTHLY RAINFALL, EVAPORATION DATA AND AVERAGE TEMPERATURES

MONTH	MEAN MONTHLY RAINFALL (MM)	MEAN MONTHLY EVAPORATION (MM)	NET GAIN OR LOSS	MAXIMUM DAILY RAINFALL (MM)	CORRESPONDING DATE	AVERAGE NUMBER OF RAIN DAYS (/MONTH)	AVERAGE MAX TEMP	AVERAGE MIN TEMP
Station	Westonaria Kloof Goudmyn	Zuurbekom (S-pan)				Westonaria Kloof Goudmyn	Krugersdorp Kroningspark	
January	119	169	-50	89	07 January 1980	10.6	26.1° C	14.6° C
February	86	139	-53	63.5	12 February 1994	8.4	25.5° C	14.2° C
March	85	131	-45	86.7	13 March 2000	7.9	24.3° C	12.9° C
April	49	103	-54	67	04 April 1971	5.4	21.3° C	9.4° C
May	13	87	-74	46	19 May 1969	2.5	19.1° C	5.6° C
June	5	70	-65	22.5	12 June 1983	1.5	16.3° C	2.4° C
July	3	79	-76	19	16 July 1970	1.4	16.9° C	2.4° C
August	9	112	-103	47	29 August 1986	1.7	19.4° C	4.7° C
September	22	148	-127	87	26 September 1987	3.7	22.9° C	8.7° C
October	72	167	-95	85.5	11 October 1993	8.0	24° C	10.9° C
November	101	166	-65	68.7	12 November 1997	10.2	24.6° C	12.5° C
December	119	172	-53	81.5	15 December 1987	11.5	25.7° C	13.7° C
Annual	683	1544	-861	89	07 January 1980	67.3	22.2° C	9.3° C

3.1.3. EXTREME EVENTS

The highest intensity storm recorded in the area at the *Westonaria Kloof Goudmyn* station was 89 mm on 7 Jan 1980 but larger events are possible in the area, illustrated by 129 mm in 24 hours recorded at the *Randfontein* Weather station. The design storm events for specific return periods are shown in Table 3. For the 24 hour or 1 day rainfall depths, two divergent values were found or calculated from the two references used. For the purposes of the detailed design the two values for each return period were averaged.

TABLE 3: DESIGN STORM EVENTS FOR VARIOUS RETURN PERIODS

RETURN PERIOD (YEARS)	24 HOUR RAINFALL DEPTH	24 HOUR RAINFALL DEPTH	AVERAGE 24 HOUR RAINFALL DEPTH	1 HOUR RAINFALL DEPTH
Reference	(Op Ten Noord et al 1982)	(Adamson 1981)		(Op Ten Noord et al 1982)
1:2	53 mm	52 mm	53 mm	31 mm
1:5	70 mm	70 mm	70 mm	41 mm
1:10	86 mm	82 mm	84 mm	51 mm
1:20	106 mm	93 mm	100 mm	62 mm
1:50	140 mm	108 mm	124 mm	82 mm
1:100	172 mm	119 mm	145 mm	101 mm

4. CATCHMENT HYDROLOGY

The catchment area, situated about 10km south of Westonaria, is covered mainly by natural vegetation (grasslands) and farms (cultivated fields and pasture). The catchment extends from the east west Hillshaven ridge in the north to the Leeu Spruit water course, south of South Deep Mine and the site for the proposed tailings dam. Kloof Gold Mine is bisected by the western catchment boundary and the Randfontein Estates No 4 shaft complex in the East.

For the flood discharge determination, the catchments were delineated incrementally using six salient points (Figure 1) on the various water courses that would be affected by the proposed tailings storage facility.

4.1. SURFACE WATER QUANTITY

South Deep Mine and the proposed project area is located in the Riet Spruit Quaternary Catchment (C22J) WR90 (WRC 1990) of the Vaal Barrage Catchment.

There are three water courses draining South Deep Mine and the proposed project area. The location of the water courses are illustrated in and include:

- The Leeu Spruit;
- The Kariega River (tributary of the Leeu Spruit); and
- The Leeu Spruit Tributary¹.

The Leeu Spruit originates north-east of South Deep Mine and flows in a southerly direction to the east of the old South Shaft complex. The Kariega River, a tributary of the Leeu Spruit, flows in a south easterly direction between the existing tailings dam and the Twin Shaft Complex to its confluence with the Leeu Spruit 3 km south of the mine. The Leeu Spruit Tributary runs in a southerly direction, west of the proposed tailings dam site as illustrated in Figure 1. The confluence of the Leeu Spruit and the Leeu Spruit Tributary is approximately 9.5km downstream of the proposed tailings dam complex. The Leeu Spruit flows into the Riet Spruit which ultimately flows into the Vaal River via the Vaal Barrage. The Vaal Barrage is approximately 32.5km downstream of the proposed tailings dam complex.

The Leeu Spruit contributes about 4.8% (WR90) of the flow to the Riet Spruit (WR90 catchments C22H and C22J), which has a MAR of approximately $25 \times 10^6 \text{ m}^3/\text{year}$. In comparison the flow at the barrage is approximately $4300 \times 10^6 \text{ m}^3/\text{year}$. The contribution to the Vaal River is therefore small.

No drainage lines occur on the proposed tailings dam site. A section of the proposed pipeline route crosses the non-perennial Kariega River in the vicinity of one of the mine's existing tailings dams (Figure 1).

4.2. SURFACE WATER USE

Of the two mines affecting the Leeu Spruit catchment, South Deep Mine and Kloof Gold Mine, neither are using a significant amount of the limited surface water

resources for their water requirements, leaving domestic and agricultural use as the major abstractions.

4.2.1. DOMESTIC

Informal abstraction of water from the watercourses is taking place. The communities settled along the streams abstract the water for drinking and domestic purposes. This is difficult to control or prevent and domestic use can be considered a potential use of the water sources.

4.2.2. AGRICULTURAL

Due to cattle farming in the area, livestock watering is considered a potential use of water sources. The livestock drink from streams on properties where they graze. Water for livestock drinking is supplemented by borehole water.

Water from the streams is used by farmers downstream of the mine, for irrigation of their lands. Extensive irrigation systems have been installed to utilise the water in the streams for irrigation purposes. Flowers, mielies and fruit are grown on the surrounding farms.

4.3. AFFECTED SUB-CATCHMENTS

Three catchments have been identified in the project area, namely the Leeu Spruit, the Kariega River and the Leeu Spruit Tributary. Catchment boundaries are shown on Figure 1 and the catchment areas presented in Table 4. The catchment names correspond with the names of the water courses.

TABLE 4: CATCHMENTS AREAS

WATER COURSE	CATCHMENT	AREA (KM ²)
Leeu Spruit Tributary	TD 1	30.97
	TD 2	32.86
	TD 3	43.86
Kariega River	KR 1	8.69
Leeu Spruit	LS 1	44.39
	LS 2	78.37

A description of each catchment and the type of infrastructure located within the catchment is provided below.

4.3.1. LEEU SPRUIT CATCHMENT

The Leeu Spruit catchment, the largest of the three catchments, comprises of natural grassland, South Deep mining infrastructure including the old South Shaft, processing plants, waste site, rock dumps, tailings dams and return water dams, Eskom substation, agricultural land (including small holdings) and residential areas (formal and informal settlements, mine hostels).

The Leeu Spruit:

- Receives overflow from the new return water dams at the tailings dams;
- Receives surplus water from underground;
- Receives storm water runoff from Randfontein Estates Ltd. No 4 shaft (old Western Areas Gold Mine - North Shaft upstream of South Deep Mine).

A section of the proposed pipeline route and a corner of the proposed tailings dam complex are located within the Leeu Spruit catchment.

4.3.2. KARIEGA RIVER CATCHMENT

The Kariega River catchment, the smallest of the three catchments, comprises of South Deep mining infrastructure such as Twin Shaft Complex shafts, gold processing plant, rock dump, tailings dam and return water dam; agricultural land and a residential area (mine hostel). The Kariega River:

- Drains part of the run-off from the existing tailings dam, should the existing return water dams overflow; and
- Receives water originating from the dolomite aquifer through which the shaft is sunk and which leaks into the shaft.

The majority of the proposed pipeline route and the water treatment plant fall within this catchment.

4.3.3. LEEU SPRUIT TRIBUTARY CATCHMENT

The catchment comprises of mining infrastructure (Kloof Gold Mine tailings dam and a small portion of South Deep's waste rock dump); agricultural land (including small holdings) and residential areas (sections of Glenharvie and Hillshaven). The Leeu Spruit Tributary:

- Drains a very small portion of the waste rock dump at the Twin Shaft Complex.

The proposed tailings dam complex, access road and small section of the pipeline route fall within this catchment. The tailings dam complex is located in the southern parts of this catchment.

4.4. MEAN ANNUAL RUNOFF

The mean annual runoff (MAR) for the water courses has been estimated on a surface-area proportional basis using the MAR for Quaternary Catchment C22J (WR90). Table 5 summarises the MAR for the catchment areas associated with the project.

TABLE 5: MEAN ANNUAL RUNOFF (WR90)

WATER COURSE	CATCHMENT	MAR (m ³)
Leeu Spruit Tributary	TD 1	681 000
	TD 2	723 000
	TD 3	965 000
Kariega river	KR 1	191 000
Leeu Spruit	LS 1	977 000
	LS 2	1 724 000

4.5. BASE FLOW

Significant flow only occurs in the water courses following rainfall events. There is little or no flow during the dry period.

4.6. DRAINAGE DENSITY

The drainage density for each of the catchments is presented in Table 6.

TABLE 6: DRAINAGE DENSITY

WATER COURSE	CATCHMENT	DRAINAGE DENSITY (KM/KM ²)
Leeu Spruit Tributary	TD 1	0.37
	TD 2	0.37
	TD 3	0.35
Kariega river	KR 1	0.71
Leeu Spruit	LS 1	0.23
	LS 2	0.23

5. FLOOD DETERMINATION

The Rational method was used to calculate the peak flow rates in the river, which makes use of the equation:

EQUATION 1 RATIONAL METHOD EQUATION

$$Q = cIA$$

(Hydrological Research Unit, 1972)

Where: Q is the peak flow rate

c is the catchment runoff coefficient which takes various factors into account

I is the rainfall intensity

A is the area of the catchment

The Flood discharge calculation was based on the methods presented in the report: “Design Flood Determination in South Africa” published by the Hydrological research unit at the University of the Witwatersrand. The report recommends a catchment runoff coefficient of 0.35 (Hydrological Research Unit, 1972). The value is deemed to be conservative presently (Other methods suggest that the value could be lower than 0.2) but is used because the catchment could be subject to suburban or urban development during the life of the tailings facility.

The rainfall intensity was found by using the time of concentration (t_c) for each of the catchments (Table 7). The t_c value represents the shortest time which it takes for the entire catchment to contribute to the flood discharge, i.e. the time it takes for the flow from the farthest point within the watershed to get to the point on the river.

The time of concentration, t_c , was calculated by using the formula (Hydrological Research Unit, 1972):

EQUATION 2 TIME OF CONCENTRATION

$$t_c = \left\{ \frac{0.87L^3}{H} \right\}^{0.385}$$

Where: L is the length of the river; and

H is the elevation difference between the start and end points of the river

TABLE 7: TIME OF CONCENTRATION CALCULATION

WATER COURSE	CATCHMENT	AREA (KM ²)	LENGTH OF RIVER (KM)	ΔH (M)	T _c (HRS)
Leeu Spruit Tributary	TD 1	30.97	11.6	227	1.98
	TD 2	32.86	12.3	232	2.11
	TD 3	43.86	15.3	257	2.62
Kariega River	KR 1	8.69	6.2	184	1.05
Leeu Spruit	LS 1	44.39	10.2	211	1.77
	LS 2	78.37	17.7	251	3.12

The mean annual precipitation (MAP) of 683mm was obtained from the South African Weather Bureau data for *Westonaria Kloof Goudmyn station*, which is the only weather station in the catchment area.

The rainfall intensities and depths for the six catchments were calculated using Op ten Noord et al (1982), using the following parameters (Table 8 and Table 9):

- The MAP value is 683mm;
- The durations are the same as the t_c values (Table 7);
- The recurrence intervals (1 in 2, 5, 10, 20, 50, 100 and 200 years); and
- The area experiences summer rain.

TABLE 8: RAINFALL DEPTHS CORRESPONDING TO TIME OF CONCENTRATION (MM)

WATER COURSE	CATCHMENT	RAINFALL DEPTHS CORRESPONDING TO TIME OF CONCENTRATION (MM)						
		Recurrence Interval						
		1:2	1:5	1:10	1:20	1:50	1:100	1:200
Leeu Spruit Tributary	TD 1	37	49	60	74	97	119	147
	TD 2	37	49	60	74	98	121	149
	TD 3	39	51	63	78	102	126	155
Kariega River	KR 1	32	42	51	63	83	102	126
Leeu Spruit	LS 1	36	47	58	72	94	116	143
	LS 2	40	53	65	80	105	130	160

TABLE 9: RAINFALL INTENSITY CORRESPONDING TO TIME OF CONCENTRATION (MM/HR)

WATER COURSE	CATCHMENT	RAINFALL INTENSITY CORRESPONDING TO TIME OF CONCENTRATION (MM/HR)						
		Recurrence Interval						
		1:2	1:5	1:10	1:20	1:50	1:100	1:200
Leeu Spruit Tributary	TD 1	18.57	24.44	30.09	37.04	48.76	60.03	73.91
	TD 2	17.67	23.26	28.63	35.25	46.40	57.13	70.33
	TD 3	14.84	19.54	24.05	29.62	38.98	48.00	59.09
Kariega River	KR 1	30.18	39.73	48.91	60.21	79.27	97.59	120.14
Leeu Spruit	LS 1	20.31	26.73	32.91	40.52	53.34	65.67	80.85
	LS 2	12.85	16.92	20.83	25.64	33.76	41.56	51.17

Using Equation 1, the Rational Method Equation, the flood discharges for the six catchments were calculated, which are presented in Table 10 and the flood volumes presented in Table 11. The flood volumes were calculated using the unit hydrograph method (Hydrological Research Unit, 1972).

TABLE 10: FLOOD DISCHARGES

WATER COURSE	CATCHMENT	FLOOD DISCHARGES (M ³ /S)							
		Recurrence Interval (years)							
		1:2	1:5	1:10	1:20	1:50	1:100	1:200	RMF
Leeu Spruit Tributary	TD 1	56	74	91	112	147	181	223	369
	TD 2	56	74	91	113	148	183	225	377
	TD 3	63	83	103	126	166	205	252	421
Kariega River	KR 1	26	34	41	51	67	82	102	227
Leeu Spruit	LS 1	88	115	142	175	230	283	349	423
	LS 2	98	129	159	195	257	317	390	525

TABLE 11: FLOOD VOLUMES

WATER COURSE	CATCHMENT	FLOOD VOLUMES (M ³)							
		Recurrence Interval (years)							
		1:2	1:5	1:10	1:20	1:50	1:100	1:200	RMF
Leeu Spruit Tributary	TD 1	285 000	375 000	461 000	568 000	748 000	921 000	1 133 000	1 877 000
	TD 2	287 000	378 000	466 000	574 000	755 000	930 000	1 145 000	1 920 000
	TD 3	322 000	424 000	522 000	643 000	847 000	1 042 000	1 283 000	2 143 000
Kariega River	KR 1	130 000	171 000	211 000	259 000	341 000	420 000	517 000	1 159 000
Leeu Spruit	LS 1	446 000	588 000	723 000	891 000	1 173 000	1 444 000	1 777 000	2 153 000
	LS 2	499 000	657 000	808 000	995 000	1 310 000	1 613 000	1 986 000	2 672 000

6. FLOODLINE DETERMINATION

6.1. RIVER GEOMETRY

The river was modelled using the contours and an aerial image from the aerial photo survey that was used for the engineering design of the tailings dam facility, which was completed by AOC Geomatics in November 2005. In the absence of more accurate data, the cross sectional geometry of the river channel, was assumed to be a trapezoidal, unlined channel that was 1.2m deep, 1.2 wide at its base and 2 m wide at its maximum level, coincident with the base of the flood plain. The geometry is based on observations made on site.

For the river analysis software (HEC-RAS), cross-sections were measured at selected points, perpendicular to the water course. The geometry and the position (chainage) of each cross section were then used in HEC-RAS to model the 3 dimensional geometry of the length of river and flood plain adjacent to the tailings dam complex, shown in Figure 2.

6.2. RIVER ANALYSIS

The flood modelling was done using the software package HEC-RAS, which models the topography of the river by means of cross sections of known position and either data for or assumptions made on the following:

- The flow regime, which was assumed to mixed (super- and sub critical);
- The flow was modelled in a steady state, with a known water surface being used for the boundary conditions. The known water levels were determined by a series of iterations, which sought similar flow regimes to adjacent cross sections up- and downstream of the boundaries;
- The road bridge and culverts were modelled using geometric data collected in the field

The model was then run using the 1 in 100 year flood discharges for the three known points on the watercourse.

The results from the model comprised water levels for each cross section that were then plotted on the topographical survey data. The floodlines were then inferred by connecting points derived from the water levels on each cross section on the left and right banks of the water course. The floodlines are presented in Figure 2 and are represented by point in Table 12. It should be noted that although the 1:50 year floodline was not calculated, it would be situated within the 1: 100 year floodline, leaving the 1:100 year floodline as a design criterion.

7. CONCLUSIONS

The proposed tailings dam and associated return water facility is located well outside of the 1:100 year recurrence interval floodline and the 100m buffer zone associated with the water course to the west of the proposed site.

8. REFERENCES

Hydrological Research Unit 1972, Design Flood Determination in South Africa, University of the Witwatersrand Department of Civil Engineering, Report No. 1/72

Op Ten Noort and Stephenson D, 1982, "Flood Peak Calculation in South Africa", Water Systems Research Programme, Wits University, Report 2/1982

Water Research Commission 1994, Surface Water Resources of South Africa 1990, Volume 2 with Appendices, WRC Report No 298/2.X/94. (Referred to as WR90)

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FIGURE 2: 1 IN 100 YEAR FLOODLINES FOR THE WATER COURSE WEST OF THE PROPOSED DOORNPOORT TAILINGS DAM

TABLE 12: FLOODLINE COORDINATES

CHAINAGE (M)	SECTION NUMBER	LEFT BANK		RIGHT BANK	
		X - COORDINATE	Y - COORDINATE	X - COORDINATE	Y - COORDINATE
0	30	63765.0	-2927230.0	63727.5	-2927142.5
62	29.5	63742.5	-2927260.0	63585.0	-2927195.0
168	28.5	63730.0	-2927292.5	63465.0	-2927315.0
285	27	63713.8	-2927315.0	63185.0	-2927587.5
299	26.5 U	63700.0	-2927335.0	63225.0	-2927587.5
311	26.5 D	63732.5	-2927337.5	63300.0	-2927561.3
340	26	63575.0	-2927432.5	63512.5	-2927468.8
370	24.5	63587.5	-2927465.0	63420.0	-2927512.5
565	23	63535.0	-2927582.5	63395.0	-2927550.0
795	21.5	63460.0	-2927695.0	63350.0	-2927682.5
920	21	63437.5	-2927765.0	63320.0	-2927750.0
1085	20	63420.0	-2927870.0	63375.0	-2927862.5
1143	19	63445.0	-2927935.0	63270.0	-2927885.0
1149	18	63435.0	-2927937.5	63280.0	-2927895.0
1167	17.5	63437.5	-2927952.5	63272.5	-2927910.0
1323	16.5	63425.0	-2928050.0	63250.0	-2928035.0
1638	15	63355.0	-2928287.5	63160.5	-2928262.5
1773	14	63355.0	-2928410.0	63157.5	-2928310.0
1775	13	63355.0	-2928412.5	63170.0	-2928322.5
1828	12.5	63340.0	-2928457.5	63147.5	-2928360.0
2165	11	63272.5	-2928585.0	63065.0	-2928543.8
2493	10	63242.5	-2928765.0	63032.5	-2928722.5
2788	9	63220.0	-2929000.0	63037.5	-2928942.5
2895	8	63207.5	-2929055.0	63037.5	-2929037.5
2897	7	63212.5	-2929060.0	63037.5	-2929042.5
2938	6.5	63225.0	-2929092.5	62977.5	-2929070.0
3200	5	63190.0	-2929285.0	62940.0	-2929327.5

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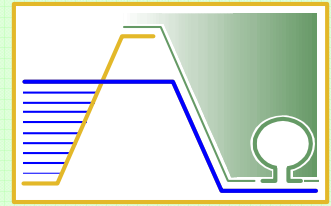
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APPENDIX 3: GEOCHEMICAL WASTE CHARACTERISATION FOR THE PROPOSED TAILINGS STORAGE FACILITY AT SOUTH DEEP MINE



Environmental Engineers (Pty) Ltd



**GEOCHEMICAL WASTE CHARACTERISATION FOR
THE PROPOSED TAILINGS STORAGE FACILITY
AT SOUTH DEEP MINE**

Prepared For

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May 2008

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EXECUTIVE SUMMARY

Introduction

This report documents the findings of the geochemical characterisation at South Deep Gold Mine ("South Deep"). The findings of the geochemical characterisation have been used to assist in the design of the proposed new South Deep gold tailings dam and, in conjunction with the seepage analyses, has been used to quantify emissions to environment as seepage water.

Waste Characterisation Method

The characterisation of the waste has been carried out to satisfy Section 73(2) of Regulation R527 of the Mineral and Petroleum Resources Development Act No 28 of 2002 ("MPRDA"). This section calls for the characterisation of waste materials to address a number of inherent properties of the material so as to determine how it may behave in the environment for many years into the future. A range of laboratory tests were carried out on tailings material and water as follows:

- Acid Base Accounting (ABA);
- South African Acid Rain Leach Procedure (ARLP) tests;
- Mineralogical analyses; and
- Determination of the chemical composition of the water samples.

There are two separate tailings dams at South Deep. The "New Dam" is an operational dam is used for the regular deposition of tailings material and the "Old Dam" (an older facility) is only used occasionally for tailings deposition. Samples of freshly deposited tailings material, old tailings material (deposited several years earlier), process water and underdrain water were collected by Metago on 11 November 2005.

Leach tests were carried out on the material under the conditions of that prescribed in the Minimum Requirements (DWAF 1998), where a the liquid to solids ratio is at 20:1, as well as using a lower liquid to solids ratio of 1:1 which is considered more representative of that actually encountered in the tailings dam. The underdrain water was also sampled as this should provide the best indication of the seepage quality from the dam.

Conceptual Geochemical Model

The results of analysis carried out on the samples were used to predict the potential seepage quality from a conceptual geochemical developed for the proposed new South Deep tailings dam. The geochemical model describes expected conditions during both the operational phase of the facility, while deposition is taking place on the dam, and the decommissioned phase as the phreatic surface elevation gradually decreases. The conceptual model characterised the dam as having two

geochemically distinct zones, comprising the unsaturated oxidising zone (Zone 1) and the saturated zone which is oxygen deficient (Zone 2). The exact extent of each zone will vary from one location in the tailings dam to another through the life of the facility.

Conclusions

The following conclusions have been drawn from the investigation:

- The characteristics of Zone 1 and Zone 2 are as follows:
 - Zone 1 (in the absence of any further controls) will become acidic relatively soon (within a few months or years) and will release seepage characterised by a low pH and high dissolved metal content.
 - Zone 2 which is beneath the phreatic surface and is at or very nearly saturated. The seepage released from this zone will be characterised by neutral drainage and lower dissolved metal concentrations and salt loads.
- Drainage from the outer (acid) zone into the inner (neutral) zone, will tend to take on the characteristics of the acid zone within a relatively short distance downstream of the cross over point, primarily because of the limited neutralising capacity of the tailings.
- This study has made use of a several laboratory tests to understand and characterise the tailings and seepage quality characteristics. The characteristics of the seepage from the proposed tailings dam are most accurately predicted by measuring the water quality from underdrain outlets from the existing gold tailings dams.
- The results of seepage modelling (as documented in Metago report 168-006/08 dated February 2006) were used to apportion seepage rates to Zone 1 and Zone 2. These seepage rates, together with the estimates of contaminant concentrations, were used to estimate the contaminant loads from the tailings dam as summarised in Table 1.

TABLE 1: SEEPAGE RATES AND ESTIMATED ENVIRONMENTAL LOAD FROM TSF

ZONE	SEEPAGE FLUX (L/S)	SEEPAGE FOR ENTIRE FOOTPRINT (M ³ /DAY)	TDS (KG/M ³)	ENVIRONMENTAL LOAD (KG/DAY)
Zone 1	0.69	5.36	4371	261
Zone 2	4.27	0.87	1954	721
Total Environmental Load				982

- The characteristics of the seepage quality from Zone 1 and Zone 2 were derived from the results of the leach tests carried out and the water analyses and are summarised in Table 2 and Table 3 below.

TABLE 2: PREDICTED SPECIES CONCENTRATION IN THE SEEPAGE FROM THE PROPOSED DAM

		MAJOR ANIONS AND CATIONS									
		PH	TDS	CA	CL	F	K	MG	NA	PO ₄ ³⁻	SO ₄ ²⁻
Zone 1	Maximum	3.9	-	559	245	0.2	35	660	241	25	-
	Average	2.4	4400	510	8.4	0.2	<0.11	89	2	1	2800
	Minimum	2.2	1100	78	<5	0.15	<0.11	31	0.62	<1.6	840
Zone 2	Maximum	10.6	3900	780	120	0.3	48	72	378	0.1	1530
	Average	6.7	1954	196	73	0.3	27	9	200	0.1	884
	Minimum	5.6	180	130	6.1	0.2	2	1	10	<1.6	78
Guideline	DU	6.0 - 9.0	450	32	100	1	50	30	100	N/A	200
	LW	N/A	1000	1000	1500	2	N/A	500	2000	N/A	1000
	ARL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NA	N/A	N/A

TABLE 3: PREDICTED TRACE ELEMENT CONCENTRATIONS EXCEEDING GUIDELINE VALUES

		TRACE ELEMENTS										
		AL	AS	CO	CR	CU	FE	MN	NI	SR	TI	ZN
Zone 1	Maximum	720	27	11	13	7.7	3200	34	23	0.12	0.84	19
	Average	38	2	2	0.7	0.7	367	24	2.0	1.02	0.06	2.87
	Minimum	34	0.04	1	0.7	0.45	73	1.2	1	0.04	0.02	1.1
Zone 2	Maximum	2	0.5	1.6	0.05	10	2.6	3.2	2.6	0.8	<0.02	<0.17
	Average	<0.08	0.5	1.0	0.03	0.3	0.6	2.6	14.4	0.6	<0.02	<0.17
	Minimum	<0.08	<0.07	<0.12	0.01	<0.02	0.4	0.1	0.38	0.1	<0.02	<0.17
Guideline	DU	0.15	0.01	N/A	N/A	1	0.1	0.05	N/A	N/A	N/A	3
	LW	5	1	1	N/A	0.5	10	10	1	N/A	N/A	20
	ARL	10	0.43	6.9	4.7	0.1	9	0.3	1.14	1	0.73	0.7

- The guideline values presented in Table 2 and Table 3 are for comparison. The expected seepage quality from Zone 1 and Zone 2 indicates that the Acceptable Risk Level, will be exceeded for the following elements:
 - Zone 1 – As, Cu, Mn and Ni.
 - Zone 2 – Al, As, Co, Cr, Cu, Fe, Mn, Ni, Ti and Zn.
- The low air permeability of saturated or near saturated gold tailings (such as below the phreatic surface) will play a key role in limiting ingress of oxygen to the tailings dam during the operational life of the dam, thereby reducing the rate of acid production.
- On decommissioning of the tailings dam, the air permeability will rise as the phreatic surface dissipates. Areas that air penetrates will gradually contribute to acid generation. The seepage flux from the tailings dam will however reduce after decommissioning.
- There is a significant risk that in the absence of adequate mitigation, the proposed tailings dam could impact on the surrounding environment through emissions of contaminants as both seepage and surface runoff from the tailings dam and associated infrastructure.

Recommendations

The following recommendations arise from this study:

- The seepage flux during the drawdown phase should be quantified through detailed seepage analysis during the detailed design phase.
- Measures to prevent oxygen ingress to underdrains, in the form of upturns or P-traps should be incorporated into the design of the tailings dam.
- Water from the blanket drain outlets should be separated from toe drain water as the blanket drain water is likely to be neutral whereas the toe drain will become strongly acidic over time.
- It is recommended that a numerical groundwater contaminant transport model be used to predict the impact of the seepage released from the proposed tailings dam on the surrounding aquifer quality. The model should simulate the behaviour of a SO₄ plume under a range of scenarios including:
 - An unlined tailings dam; and
 - The application of scavenger wells.
- The elemental and salt loads should be used together with the seepage fluxes to determine the spatial impact of the tailings dam on the long term groundwater quality.
- Once the impact has been quantified for both the operational and post operational phases it will be necessary to assess which mitigation measures or combination of measures that offer the best practical benefit in terms of environmental protection.
- The challenge of decommissioning the tailings dam needs to be further considered during the detailed design phase. The option of constructing a low air permeability cover to the tailings dam as part of the operational phase to limit the acid generation from the material exposed to the outer side slope should be incorporated into the design and cost provisions. The low air permeability cover would then be extended during the decommissioning phase to the top surface of the tailings dam.
- The thickened tailings technology should be considered and tested in the early phases shortly after commissioning of the tailing dam with a view to converting the dam to thickened tailings deposition method.

The relevant studies to evaluate the impact on the seepage flux of converting to the thickened tailings should be commissioned.

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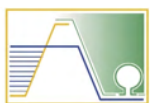
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GEOCHEMICAL WASTE CHARACTERISATION FOR THE PROPOSED TAILINGS STORAGE FACILITY AT SOUTH DEEP MINE

1. INTRODUCTION

Metago Environmental Engineers (Pty) Ltd ("Metago") have been appointed by South Deep Gold Mine ("South Deep") to carry out the design of the proposed new South Deep gold tailings dam. This report comprises an Appendix report to the tailings dam design report and documents the chemical characteristics of the gold tailings and associated process and seepage water. This report, in conjunction with the seepage analyses, has been used to quantify emissions to environment as seepage water. The impacts of these emissions on groundwater have been assessed elsewhere by Rison Groundwater Consulting using contaminant transport modelling as documented in their report contained in Appendix 10.8 to the EIA.

1.1. OBJECTIVE

Chemical characterisation of the tailings is required to predict the impact of the proposed tailings dam on the surrounding environment and to satisfy Section 73(2) of Regulation R527 of the Mineral and Petroleum Resources Development Act No 28 of 2002 ("MPRDA"). This section calls for the characterisation of waste materials to identify any potentially significant health or safety hazards and environmental impacts that may be associated with the residue when stockpiled or deposited at the site under consideration. Residue stockpiles and deposits must be characterised in terms of their physical and chemical characteristics. Chemical characterisation must address the following:

- The toxicity;
- The propensity to oxidize and decompose;
- The propensity to undergo spontaneous combustion;
- The pH and chemical composition of the water separated from the solids;



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- Stability and reactivity and the rate thereof; and
- Neutralizing potential.

The evaluation has been conducted using a range of laboratory tests on the same tailings material that will be disposed of at the new tailings dam. The process water and seepage water associated with the existing facilities was also sampled and analysed. Laboratory tests have included:

- Acid Base Accounting (ABA);
- South African Acid Rain Leach Procedure (ARLP) tests; and
- Mineralogical analyses.

The laboratory analyses included tests on newly deposited tailings material at New Dam 4 ("new TSF") as well as tailings material from Old Dam 2 ("old TSF") that was deposited several years earlier, to evaluate how the material will weather with time and how this will affect the seepage quality.

Spontaneous combustion is not a concern for gold tailings as the sulphide content is too low and is not considered further.

The pH and chemical composition of the water separated from the solids from both the new TSF and the old TSF has been evaluated by analysing the leachate quality discharging from the TSF underdrains. The leachate quality from the new TSF will be indicative of that expected throughout the operational phase of the tailings dam that is to be constructed. The composition of the leachate from the old TSF is indicative of how the leachate from the new and proposed tailings facilities will change after the operational phase.

The chemical composition of the water samples and the geochemical characteristics of the tailings material were used to model the seepage quality from the proposed TSF and hence the potential environment load.

1.2. LIMITATIONS AND ASSUMPTIONS

The tailings material was collected as grab samples from a single point on the each TSF. Water samples were collected from two underdrains on the new TSF (on opposite sides of the TSF) and from the only accessible running drain at the old TSF. Despite the limited number of samples and single sampling event, the results are considered be representative of the seepage and process water quality for the purpose of this study.

Radiation emissions have not been considered as part of this study.

2. WASTE AND SEEPAGE CHARACTERISATION

2.1. ACID ROCK DRAINAGE POTENTIAL

Acid Rock Drainage (ARD) results from the oxidation of sulphide minerals and is ultimately characterised by elevated acidity, sulphate and dissolved metals concentrations in the leachate and runoff from the waste facilities. Acid conditions may lead to further dissolution of other minerals, potentially resulting in high concentrations of metals being released into the environment.

2.1.1. LABORATORY TESTS

Laboratory tests to characterise ARD are generally grouped into two categories; static and kinetic tests. Static tests are relatively simple, inexpensive and rapid, whereas kinetic tests may take many months. Kinetic tests are often carried out if the results of the static tests are not conclusive. In the case of South Deep, kinetic tests are not required since the existing tailings dams provide the equivalent information to that which could be obtained from a kinetic test.

ABA Tests

While evidence from the existing tailings dams clearly indicates that the South Deep tailings is acid generating, Acid Bas Accounting (“ABA”) tests have been conducted to provide a comparison with generally accepted assessment criteria. In the ABA test, the acid neutralising potential (NP) and the acid generating potential (AP) of rock samples are determined, and the balance between the two gives an indication of the likely potential for ARD. The overall assessment may be expressed as a difference (net neutralising potential (NNP), where $NNP = NP - AP$) or as a ratio (neutralisation potential ratio (NPR) where $NPR = NP/AP$). The general assessment criteria are given in Table 1 and

Table 2 below.

TABLE 1: CRITERIA 1: NET NEUTRALISING POTENTIAL (NP – AP)

POTENTIAL FOR ARD	NNP	COMMENTS
Likely	0 or less	Likely to generate ARD, except if the sulphide content is very low and/or there is a significant slow release of non-carbonate sources of alkalinity
Prediction Difficult	0 to 15	Zone of uncertainty
Unlikely	15 or more	Unlikely to generate ARD

TABLE 2: CRITERIA 2: NP/AP RATIO

POTENTIAL FOR ARD	NP/AP	COMMENTS
Likely	<1:1	Likely to generate ARD
Possibly	1:1 to 2:1	Possibly ARD generating if NP is insufficiently reactive or depleted at a faster rate than sulphides
Low	2:1 to 4:1	Not potentially ARD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	>4:1	No further ARD testing required unless materials are to be used as a source of alkalinity

The Modified EPA ABA (Lawrence) method was used for acid base accounting. The concentration of total sulphur, sulphide, sulphate, and carbonate are determined.

Mineralogy

The type and abundance of the sulphide mineral phases and their relative reactivity's are important as not all sulphide minerals will generate acid. Similarly, not all carbonate minerals consume acid. Thus static tests do not account for the variation in reactivity of the different sulphide and carbonate minerals, and so the actual degree of acid neutralisation in the field may differ from that derived from ABA test results. The mineralogical examination also provides an indication of the major elements likely to be released from the material during leaching.

Mineralogical examination was carried out using XRD scan and petrographic analysis. Two samples were submitted for X-ray Diffraction (XRD) and petrographic examination to determine their bulk mineral assemblage. A polished thin section was prepared from each sample and examined under a polarising microscope to ascertain the nature and mode of occurrence of sulphides, neutralising minerals and secondary minerals.

Acid Rain Leach Procedure

The Acid Rain Leach Procedure ("ARLP") provides some indication of the metals and salts that will be leached from the TSF. The procedure has the disadvantage that the chemical conditions of the test do not correspond to the chemical conditions in the tailings dam so the results cannot be directly extrapolated to predict the leachate quality in the field.

The test does not adequately take cognisance of various factors that arise in a large scale facility, such as ARD, solubility constraints, liquid to solids ratio's etc. but the results are still useful for purposes of predicting the seepage quality. A more detailed analysis is usually required to assess the actual leachate quality or runoff quality from the waste facility. In this case, the leachate quality was determined by sampling the underdrain quality from two existing tailings dams at the site and the standard ARLP together with a modified ARLP were used and compared with the actual seepage quality from the existing tailings dams.

The ARLP test is a standard test that is commonly used to evaluate a wide range of wastes and so it can be used to provide a relative indication of the contaminants likely to be present in the seepage or runoff across a wide range of waste materials.

The Acid Rain Leach Procedure (ARLP) was used as a first order assessment as documented in the Minimum Requirements Series (2nd Edition, Department of Water Affairs and Forestry (of South Africa), 1998). A modified ARLP was also used in which the liquid to solids ratio used was changed from 20:1 (used in the standard test) to 1:1. The lower L:S ratio is more representative of the tailings environment.

Paste pH

The paste pH is measured as part of the ABA procedure, and is useful to determine if acid generation has occurred prior to analysis. In non-acid generating materials, it is indicative of the natural long term pH of the material. Paste pH values of less than 5 indicate the presence of stored acidity (i.e. stored oxidation products), whereas high paste pH values suggest the presence of reactive neutralising minerals.

2.1.2. FIELD TESTS

The presence of any existing tailings dams that have been used for deposition of the same or a similar ore and have been in existence for several years, provides an ideal opportunity to characterise both the short and long term seepage quality from the proposed tailings dam. For this reason, considerable emphasis has been placed on the results of water quality analyses performed on the underdrainage samples collected from the dams. Notwithstanding the above, Metago recognises that the water samples collected in the underdrains are unlikely to be representative of the seepage quality from the entire footprint of the tailings dam. A significant change in the geochemical environment from the outer portion of the dam (which is characterised by unsaturated and oxidising conditions) to the central portion of the dam is expected. The characteristics of these zones is further described in this report.

2.2. SAMPLE COLLECTION AND ANALYSIS

The tailings originate from the Ventersdorp Contact Reef/Black Reef ore bodies. The gold tailings from this orebody is a well recognised acid generating material so only two ABA tests were conducted

for the purpose of characterising the acid potential and neutralising potential of the material. The samples were collected by Metago in disposable plastic bags from newly deposited fresh tailings (labelled "Fresh Tailings") and from the older material that had been deposited several years earlier (labelled "Old Tailings"). The Fresh Tailings were grey in appearance, whereas the Old Tailings were a yellow/orange colour as shown in Figure 1 and Figure 2. There was brown staining on the rock used to clad parts of the old TSF, providing visual evidence that acid drainage was already occurring.

The new TSF is being used regularly whereas the old TSF is being used for disposal of tailings on an infrequent basis.



FIGURE 1: DEPOSITION OF FRESH TAILINGS AT THE OPERATIONAL TSF



FIGURE 2: OLDER (PARTIALLY OXIDISED) TAILINGS MATERIAL COLLECTED FROM THE SIDE SLOPE OF THE OLD TSF

Four water samples were also collected on 11 November 2005 from the following locations:

- Two from the underdrains of the new TSF;
- One from the process water being used to deposit the waste on the new TSF; and
- One from the underdrains of the old TSF.

The water collected from the underdrains of the operational TSF was colourless as shown in Figure 3. The sample contained some orange particulates and had a slight odour. The sample collected from the underdrain to old TSF was orange/brown in colour as shown in Figure 4. There was a strong ammonia odour coming from the water and there was scum on the surface of the stream at the point of discharge. The pH and electrical conductivity (EC) of the water samples was recorded at the time of sampling. The sample locations are shown in Appendix 1.

The tailings material was submitted to SGS Lakefield Laboratories in Johannesburg for assessment of their pollution potential. The water samples were submitted to Waterlab in Pretoria for assessment of their trace metal concentration and macro chemistry.



FIGURE 3: UNDERDRAIN 51 AND 52 AT THE NEW TSF



FIGURE 4: UNDESIGNATED UNDERDRAIN AT THE OLD TSF

2.3. GEOTECHNICAL CHARACTERISTICS OF THE TAILINGS

The geotechnical characteristics of the tailings material are documented in Metago report 168-006/08 of February 2006. The geotechnical characteristics have a significant influence on the seepage quality. Parameters that are significant from a seepage quality perspective include:

- The degree of saturation of the tailings material which typically varies over tailings dam from 1.0 below the phreatic surface to potentially as low as 0.4 on the dry surface of the outer slope of the tailings dam. In general however, the degree of saturation is above 0.8, which corresponds approximately to the field capacity of gold tailings.
- The water permeability of the tailings material which decreases as the degree of saturation decreases. Typically the saturated water permeability for the tailings is in the range 1.6×10^{-7} m/s to 0.9×10^{-7} m/s.
- The air permeability of the tailings. Dry tailings has the highest air permeability and the oxygen flux through dry tailings is several orders of magnitude higher than that through saturated tailings. The air permeability and water permeability are therefore inversely related.
- The propensity, depth, size and connectivity of desiccation cracks. Desiccation cracks form during consolidation of the tailings primarily as a direct result of evaporation of pore water. Desiccation crack can play a significant role in assisting in the transfer of oxygen to greater depths in the tailings thereby accelerating the rate of acid generation.

3. RESULTS

The analytical certificates of the laboratory test work are included in Appendix 2 of this report.

3.1. MINERALOGY OF SAMPLES SUBMITTED FOR ANALYSIS

The results of the X-Ray diffraction and Petrographic examination are shown in Table 3 below.

TABLE 3: RESULTS OF MINERALOGICAL TESTING OF TAILINGS AT SOUTH DEEP

MINERAL	APPROXIMATE FORMULA	FRESH TAILINGS	OLD TAILINGS
Quartz	SiO ₂	±90%	±90%
Chlorite	(Mg,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈	5%	5%
Mica (muscovite/sericite)	KMg ₃ (Si ₃ Al)O ₁₀ (OH) ₂	3%	3%
Pyrophyllite	Al ₂ (OH) ₂ Si ₄ O ₁₀	<3%	<3%
Gypsum	CaSO ₄ ·2H ₂ O	n.d.	<2%
Jarosite	KFe ₃ (SO ₄) ₂ (OH) ₆	n.d.	3%
Fe-oxide	Fe-O	n.d.	trace

MINERAL	APPROXIMATE FORMULA	FRESH TAILINGS	OLD TAILINGS
Carbonate (calcite)	$\text{Ca}(\text{CO}_3)_2$	<2%	n.d.
Pyrite	FeS_2	2%	<2%
Chalcopyrite	CuFeS_2	trace	n.d.

n.d. = not detected (note: no carbonates were observed in the Old Tailings sample)

Fresh Tailings

The sample comprises predominantly quartz with small amounts of mica (muscovite/sericite), chlorite, and pyrophyllite also present. There are approximately 2% sulphides present in the sample, comprising mainly pyrite with trace amounts of chalcopyrite observed scattered throughout the sample. The sulphide grains generally measure 20-30µm in size and liberation is ±85%, with the remainder being occluded in gangue. A small amount of carbonate (<2%) is present in the sample.

Old Tailings

The sample of Old Tailings material was much coarser than the Fresh Tailings sample. It also contains approximately 90% quartz with small amounts of chlorite, muscovite/sericite, pyrophyllite, Secondary minerals including gypsum, jarosite, and trace amounts of Fe-oxide are also present. Pyrite is still present and makes up <2% of the sample. The sulphide grains are ±90% liberated and are generally about 30-50µm in size, but may be up to 100µm.

3.2. ACID BASE ACCOUNTING

A summary of the ABA results is given in Table 4 below.

TABLE 4: SUMMARY RESULTS OF ABA FOR THE TAILINGS AT SOUTH DEEP

	FRESH TAILINGS	OLD TAILINGS
Paste pH	9.42	2.40
Total S (%)	1.24	1.58
Sulphide S (%)	0.96	0.93
SO ₄ (%)	0.83	1.96
CO ₃ (%)	0.33	<0.05
NP	13.3	<0.1
AP	30.0	29.1
Net NP	-16.7	-29.0
NP/AP	0.44	<0.1

Using the criteria presented in Table 1 and

Table 2 the predicted acid generation potential for the samples is shown in Table 5 below.

TABLE 5: POTENTIAL FOR ACID ROCK DRAINAGE FROM SOUTH DEEP SAMPLES

	FRESH TAILINGS	OLD TAILINGS
NNP	-16.7	-29.0
NP/AP	0.44	<0.1
Potential for ARD	Likely	Likely
Acid Generation Potential	Medium acid generation potential	Strong acid generation potential

The ABA test confirms that the neutralising potential of the tailings becomes depleted long before the acid generating potential of the tailings is depleted giving rise to the acid generating conditions as evidenced at the site.

3.3. ACID RAIN LEACH PROCEDURE, TOE DRAINAGE AND PROCESS WATER QUALITY

The results of the laboratory tests are presented in Table 6 to Table 8 together with several selected water quality standards for comparative purposes, including:

- The South African Water Quality Guidelines (SAWQG) for domestic use (DU);
- The South African Water Quality Guidelines (SAWQG) for livestock watering (LW); and
- The Minimum Requirements for Disposal of Hazardous Waste to Landfill Acceptable Risk Level (ARL).

TABLE 6: LABORATORY TEST RESULTS FOR ELEMENTS EXCEEDING GUIDELINE VALUES

SAMPLE	Al	As	Ca	Cd	Co	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Na	Ni	NO ₃	P
STANDARD ARLP																
Fresh Tailings	<0.08	0.064	130	0.00055	<0.12	0.01	0.02	0.44	<0.003	8.6	2.6	<0.05	10	0.38	ND	<0.53
Old Tailings	34	0.04	78	0.0031	0.68	0.7	0.45	73	<0.003	31	1.2	<0.05	0.62	1.1	ND	<0.53
MODIFIED ARLP																
Fresh Tailings (L:S =1:1)	<0.08	0.29	780	<0.0005	1	0.026	0.29	0.58	0.0031	72	3.2	0.06	200	2.6	ND	<0.53
Old Tailings (L:S= 1:1)	720	27	510	0.065	11	13	7.7	3200	<0.003	660	24	<0.05	1.2	23	ND	8.3
BLANK	<0.08	<0.001	0.28	<0.0005	<0.12	<0.001	<0.02	0.12	<0.003	0.03	<0.01	<0.05	0.56	<0.05	ND	<0.53
TOE DRAIN WATER QUALITY																
7520 New TSF	0.240	0.62	557	0.0	0.63	0.019	0.0	36.3	0.009	48	14.09	0.047	275	0.0	0.4	<2
7521 New TSF	2.41	0.69	553	0.0	1.02	0.028	0.0	86.9	0.007	63	15.97	0.071	268	0.92	0.7	<2
7523 Old TSF	112	5.15	690	0.01	2.97	1.466	1.5	648	0.004	110	51.57	0.003	185	5.2	<0.2	2.4
PROCESS WATER QUALITY																
7522 Process Water	1.64	0.5	253	0.0	1.56	0.049	10.5	2.61	0.006	1	0.092	0.098	399	14.4	13	<2
Domestic Use	0.15	0.01	32	0.005	N/A	N/A	1	0.1	0.001	30	0.05	N/A	100	N/A	6	0.01
Livestock Watering	5	1.0	1000	0.010	1	N/A	0.5	10	0.001	500	10	0.01	2000	1	100	0.1
ARL	10	0.43	N/A	0.031	6.9	4.7	0.1	9	0.022	N/A	0.3	N/A	N/A	1.14	N/A	0.1

ND = Not Determined

N/A = Not Available

TABLE 7: LABORATORY TEST RESULTS FOR ELEMENTS EXCEEDING GUIDELINE VALUES (CONTINUED)

SAMPLE	Pb	Se	SO ₄	Sr	Ti	TDS	U	V	Zn	pH	CONDUCTIVITY (mS/m)
STANDARD ARLP											
Fresh Tailings	0.015	<0.020	78	0.13	<0.02	ND	ND	<0.07	<0.17	5.56	ND
Old Tailings	0.065	<0.020	840	0.04	0.02	ND	ND	<0.07	1.1	2.56	ND
MODIFIED ARLP (L:S =1:1)											
Fresh Tailings (1:1)	<0.002	<0.020	1530	0.83	<0.02	ND	ND	<0.07	<0.17	6.74	ND
Old Tailings (1:1)	0.024	0.180	14700	0.12	0.84	ND	ND	0.28	19	2.22	ND
BLANK	<0.002	<0.020	<1.8	<0.02	<0.02	ND	ND	<0.07	<0.17	3.74	ND
TOE DRAIN WATER QUALITY											
7520 New TSF	0.003	0.02	2045	1.312	0.011	3116	0.003	0.002	0.055	5.6	474
7521 New TSF	0.004	0.02	2094	1.248	0.007	3236	0.08	0.002	1.033	3.7	488
7523 Old TSF	0.005	0.03	4164	0.513	0.164	6782	3.9	0.123	7.512	2.5	1045
PROCESS WATER QUALITY											
7522 Process Water	0.065	0.03	884	0.624	0.019	1954	0.031	0.011	0.126	10.6	308
Domestic Use	0.010	0.02	200	N/A	N/A	450	0.015	0.1	3	6-9	N/A
Livestock Watering	0.1	0.05	1000	N/A	N/A	1000		1	20		N/A
ARL	0.1	0.26	N/A	1	0.73	N/A		1.3	0.7		N/A

ND = Not Determined

N/A = Not Available

TABLE 8: LABORATORY TEST RESULTS FOR SPECIES BELOW GUIDELINE VALUES AND METHOD DETECTION LIMIT

SAMPLE	Ag	B	Ba	Be	Bi	Cl	Cr ⁶⁺	F	K	Li	Sb	Si	Sn	Zr
STANDARD ARLP														
Fresh Tailings	<0.005	<0.07	0.04	<0.02	<0.2	6.1	<0.005	0.19	2.3	<0.02	<0.31	12	<0.34	<0.05
Old Tailings	<0.005	<0.07	0.03	<0.02	<0.2	<5	<0.005	0.15	<0.11	<0.02	<0.31	1	<0.34	<0.05
MODIFIED ARLP														
Fresh Tailings (1:1)	<0.005	0.43	0.09	<0.02	<0.2	120	<0.005	0.16	27	<0.02	<0.31	35	<0.34	0.13
Old Tailings (1:1)	<0.005	0.45	0.05	<0.02	<0.2	8.4	-	<0.1	<0.11	0.48	<0.31	42	<0.34	<0.05
BLANK	<0.005	<0.07	0.02	<0.02	<0.2	<5	<0.005	<0.1	<0.11	<0.02	<0.31	<0.3	ND	<0.05
TOE DRAIN WATER QUALITY														
7520 New TSF	<0.005	0.447	0.073	0.0	<0.2	208	ND	0.2	37.0	0.029	0.001	7.8	ND	0.025
7521 New TSF	<0.005	0.446	0.069	0.0	<0.2	210	ND	0.2	35.9	0.025	0.001	6.5	ND	0.025
7523 Old TSF	<0.005	0.356	0.055	0.002	<0.2	318	ND	<0.2	30.8	0.216	0.001	42.7	ND	0.032
PROCESS WATER QUALITY														
7522 Process Water	<0.005	0.363	0.089	0.0	<0.2	73	ND	0.3	44.3	0.002	0.007	13.5	<0.34	0.024
DU	N/A	N/A	N/A	N/A	N/A	100	0.05	1	50	N/A	N/A	N/A	N/A	N/A
LW	N/A	5	N/A	N/A	N/A	1500	1.0	2	N/A	N/A	N/A	N/A	N/A	N/A
ARL	2	N/A	7.8	N/A	N/A	N/A	0.02	N/A	N/A	N/A	0.07	N/A	N/A	2

ND = Not Determined

N/A = Not Available

4. DISCUSSION

4.1. INTERPRETATION OF TEST RESULTS

4.1.1. MINERALOGY

Fresh Tailings

A significant amount (2%) of pyrite and chalcopyrite occurred in the Fresh Tailings sample. Significant amounts of carbonate species (<2%) were also present. Chlorite also contributes to the neutralisation of the acid produced, but since chlorite is a relatively slow weathering mineral and present in such small amounts, its effect will be negligible. The acid generation potential is expected to be medium.

Old Tailings

The Old Tailings sample contains similar amounts of pyrite (<2%) but no carbonates. The presence of Fe-oxides, gypsum, and jarosite is an indication that the material has been subjected to sulphuric acid solutions in the past. Since some pyrite still remains, sulphuric acid will continue to be produced from this material over time. Other minerals such as chlorite will only buffer at low pH range and tend to weather too slowly to be of much use in the neutralisation of the acid produced from the more rapidly oxidising sulphides. The acid generation potential is expected to be medium to high.

From the mineralogical examination, elements that are most abundant in the tailings (and would therefore be expected to contribute significantly to seepage quality, subject to favourable pH conditions) include Al, C, Ca, Cu, Fe, K, Mg, S and Si.

4.1.2. ACID BASE ACCOUNTING

The paste pH for the Fresh Tailings was alkaline (pH 9.42) and the paste pH of the old tailings was strongly acid (pH 2.4). Thus initially, during the early stages of sulphide oxidation, the arising acid would be neutralised by the carbonate present in the sample until such time that the neutralising capacity is depleted.

The acid generation potential (AGP) has been determined by the laboratory for each sample based on a review of the sulphur species concentration, carbonate values, the AP, NP and NNP values and the NP/AP ratio. The tailings is classified as having a medium to high acid generation capacity.

4.2. COMPARISON OF LEACH TEST RESULTS WITH ACTUAL TOE DRAINAGE QUALITY

The drainage quality has been estimated on the basis of three different approaches namely:

- The standard ARLP as documented in the Minimum Requirements which specifies a liquid to solids ratio of 20:1

- A modified ARLP which is the same as the above test, except that the liquid to solids ratio is reduced to 1:1, which is more in line with that which arises in the tailings facility.
- Direct measurement of the process water and seepage water from the two existing tailings dams. While the ARLP tests provide useful information, the samples of underdrain water provide the most accurate data for the prediction of the long term seepage from the proposed new tailings dam.

The results are compared in Figure 5 below. In order to place the results in perspective in relation to the potential threat that the water could pose to the environment, each concentration has been divided by the ARL as defined in the Minimum Requirements. Where the ARL is not defined, the domestic use target water quality standard has been used as a basis for comparison.

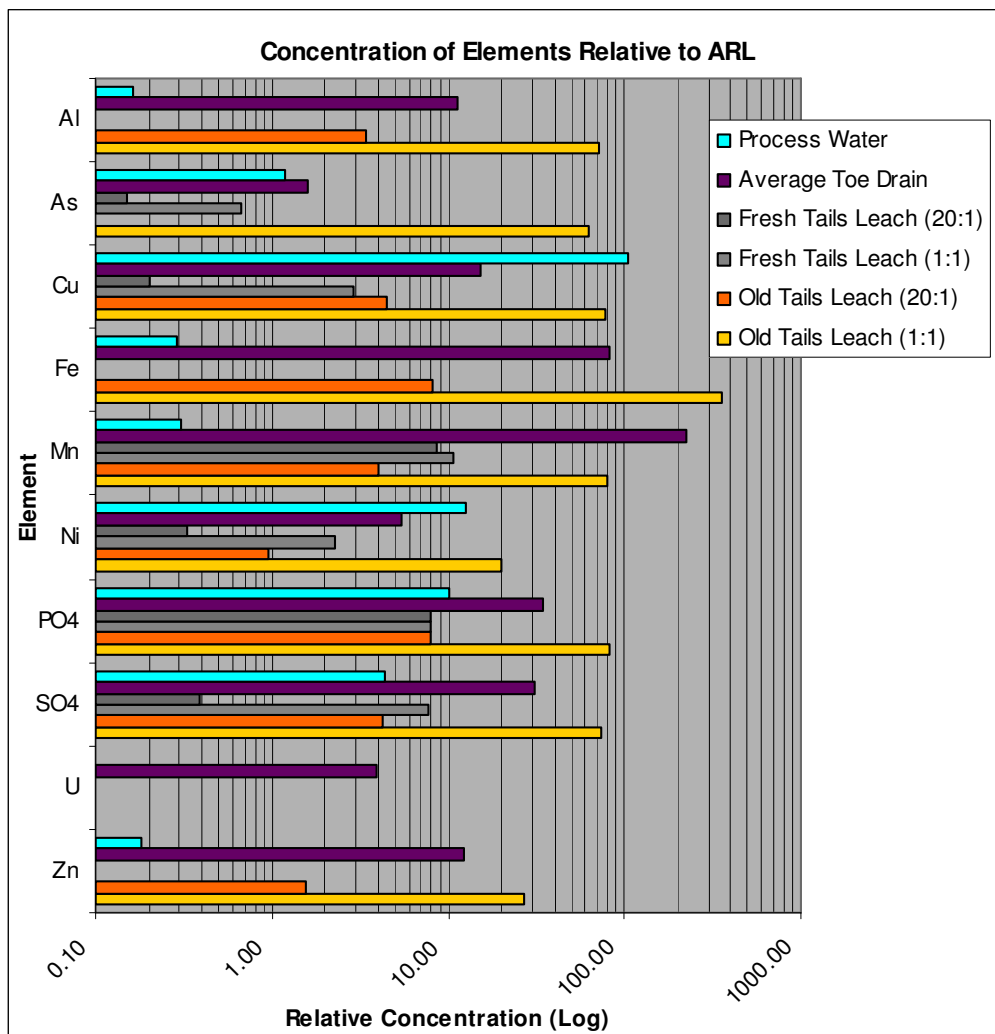


FIGURE 5: RELATIVE CONCENTRATION OF ELEMENTS THAT EXCEED THE ARL

The following trends are observed from the graph:

- There is a significant difference between the ARLP test results for tests conducted on old partially oxidized tailings and those conducted fresh tailings with the old partially oxidized tailings given much higher leachate concentrations. With the possible exception of uranium (not determined in the ARLP tests), the leachate from the old tailings had a higher concentration than that from the new tailings.
- The ARLP tests conducted on fresh tailings consistently under-predicted the concentration in the toe seepage.
- With the exception of manganese, the ARLP test conducted on partially oxidized tailings at a liquid to solids ratio of 1:1 consistently over estimated the concentration in the toe seepage.
- In all cases the ARLP test using the 1:1 liquid to solids ratio gave the worst result compared to the standard 20:1 liquids to solids ratio test.
- With the exception of Mn, the actual toe seepage concentration was between the concentrations measured in the (L:S=1:1) leach test conducted on the old tailings and the (L:S=20:1) test on old tailings.
- There is a wide range of results for the different tests which is typical for elements for which their solubility is strongly pH dependent.

A comparison between the fresh and old tailings ARLP test result for the liquid to solids ratio of 1:1 is presented in Figure 6 below. From this Figure it can be seen that the average toe drain concentration was closer to the ARLP test conducted on fresh tailings than that conducted on partially oxidised tailings. This may be indicative of the fact that zone of the tailings dam that has been partially oxidised is small and limited in extent primarily to the outer side slope of the dam.

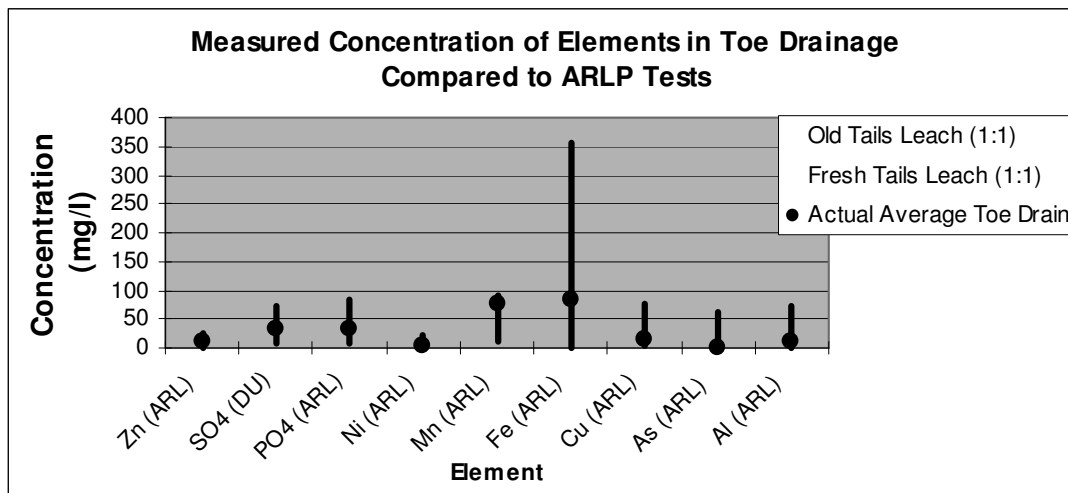


FIGURE 6: COMPARISON OF ARLP TEST RESULTS FOR FRESH AND OXIDISED TAILINGS WITH AVERAGE TOE DRAIN SEEPAGE QUALITY

4.3. CONCEPTUAL GEOCHEMICAL MODEL

Based on the results of the tests undertaken on the existing operational and old tailings dams at South Deep, the following conceptual geochemical model is proposed for the new South Deep tailings dam.

The model is described for two stages during the life of the facility, namely:

- The operational phase, when tailings is continually being deposited on the dam resulting in the development of a supernatant pond and phreatic surface: and
- The drawdown phase, after cessation of tailings deposition when the phreatic surface elevation gradually reduces.

The conceptual geochemical models are illustrated with the aid of Figure 7 (operational phase) and Figure 8 (drawdown phase).

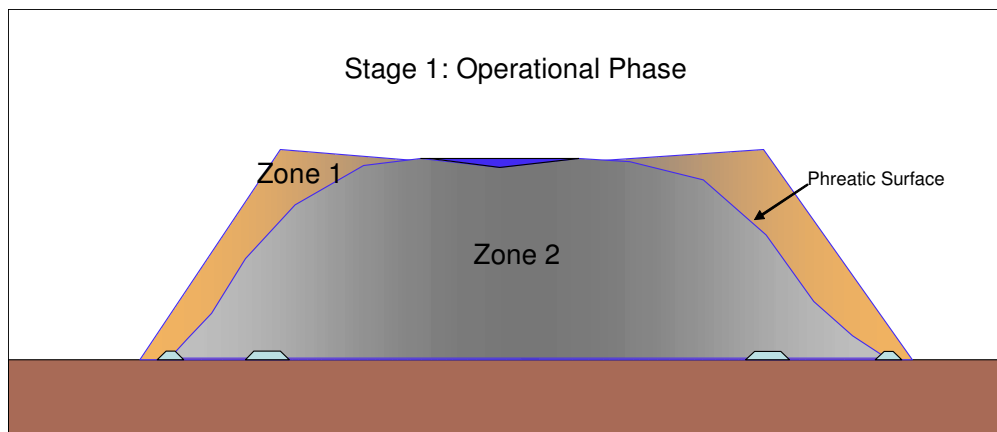
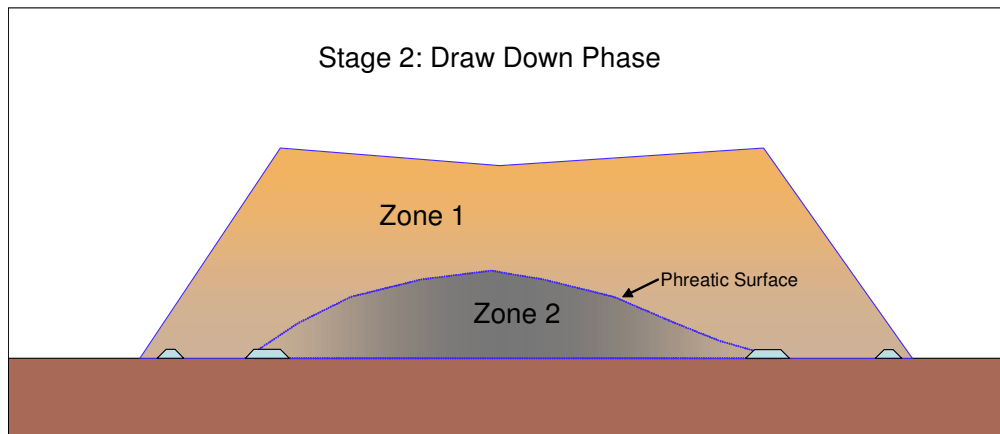


FIGURE 7: STAGE 1: OPERATIONAL PHASE

**FIGURE 8: STAGE 2: DRAW DOWN PHASE**

The tailings dam may be characterised by two geochemically distinct zones which exist throughout the life of the facility but which change in size depending on the geochemical environment within the tailings dam. These zones referred to in the figures as Zone 1 and Zone 2 are described in Table 9 below.

TABLE 9: DESCRIPTION OF ZONES IN THE TAILINGS DAM

PARAMETER	ZONE 1	ZONE 2
SEEPAGE QUALITY	Low pH, high dissolved metals and high TDS largely attributable to Ca, SO ₄ , Mg etc.	Neutral to alkaline pH Moderate TDS depending largely on quality of process water Low concentrations of dissolved metals
DEGREE OF SATURATION	Slightly less than 1	Typically saturated throughout zone
OXYGEN FLUX	Orders of magnitude higher than Zone 2 as air can enter the material by diffusion through air filled voids, barometric pumping, etc.	Limited by the solubility of oxygen in water
BACTERIAL OXIDATION OF SULPHIDES	Conditions are near optimal for sulphide oxidising bacteria	Conditions not ideal and sulphide oxidising bacteria largely inactive Sulphate reducing bacteria may be present but lack of carbon source likely to inhibit activity
REDOX POTENTIAL	Typically higher – oxidising conditions prevail with respect to sulphides	Typically lower – reducing conditions may apply with respect to sulphides
DRAWDOWN PHASE BEHAVIOUR	Tends to get larger and larger as more of the dam becomes unsaturated	Reduces in size as Zone 1 increases

The exact extent of each zone will vary from one location in the tailings dam to another through the life of the facility. While the phreatic surface does not form an exact boundary it provides the best practical guide for the interface between the two geochemically distinct zones. Note that underdrains can also receive mixed water and could therefore report a mixed water quality.

4.4. PROPOSED DOORNPOORT TAILINGS DAM SEEPAGE QUALITY

The seepage characteristics of the proposed tailings dam has been estimated for the two zones on the basis of the water quality results obtained from the existing operational and old tailings dams at South Deep and the results of the leach tests.

In terms of a practical cutoff between Zone 1 and Zone 2, the location of the blanket drain (which is supposed to draw the phreatic surface down) has been selected as the most likely transition point between Zone 1 and Zone 2 for the operational phase of the tailings dam.

The future water quality of Zone 1 of the proposed tailings dam may best be informed on the basis of the water quality from the underdrain samples taken from the existing operational tailings dams. The water quality of Zone 2 is best informed on the basis of the water quality taken from the supernatant pond.

The predicted water qualities of Zone 1 and Zone 2 of the new tailings dam are as shown in Table 10 for the pH, TDS and major cations and anions. The concentration of the species are in units of mg/l, except for pH and EC (mS/m).

TABLE 10: PREDICTED SPECIES CONCENTRATION IN THE SEEPAGE FROM THE PROPOSED DAM

		MAJOR ANIONS AND CATIONS									
		pH	TDS	CA	CL	F	K	MG	NA	PO ₄ ³⁻	SO ₄ ²⁻
Zone 1	Maximum	3.9	-	559	245	0.2	35	660	241	25	-
	Average	2.4	4400	510	8.4	0.2	<0.11	89	2	1	2800
	Minimum	2.2	1100	78	<5	0.15	<0.11	31	0.62	<1.6	840
Zone 2	Maximum	10.6	3900	780	120	0.3	48	72	378	0.1	1530
	Average	6.7	1954	196	73	0.3	27	9	200	0.1	884
	Minimum	5.6	180	130	6.1	0.2	2	1	10	<1.6	78
Guideline	DU	6.0 - 9.0	450	32	100	1	50	30	100	N/A	200
	LW	N/A	1000	1000	1500	2	N/A	500	2000	N/A	1000
	ARL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NA	N/A	N/A

The range of likely concentrations in the seepage from zone 1 and zone 2 of trace elements is shown in Table 11 and Table 12.

TABLE 11: PREDICTED TRACE ELEMENT CONCENTRATIONS

		TRACE ELEMENTS										
		AL	AS	B	BA	CO	CR	CU	FE	HG	LI	MN
Zone 1	Maximum	720	27	0.45	0.07	11	13	7.7	3200	<0.005	0.5	34
	Average	38	2	0.4	0.05	2	0.7	0.7	367	<0.005	0.1	24
	Minimum	34	0.04	<0.07	0.03	1	0.7	0.45	73	<0.005	<0.02	1.2
Zone 2	Maximum	2	0.5	0.4	0.1	1.6	0.05	10	2.6	0.003	<0.02	3.2
	Average	<0.08	0.5	0.1	<0.02	1.0	0.03	0.3	0.6	0.006	<0.02	2.6
	Minimum	<0.08	<0.07	0.1	<0.02	<0.12	0.01	<0.02	0.4	0	<0.02	0.1
Guideline	DU	0.15	0.01	N/A	N/A	N/A	N/A	1	0.1	0.001	N/A	0.05
	LW	5	1	5	N/A	1	N/A	0.5	10	0.001	N/A	10
	ARL	10	0.43	N/A	7.8	6.9	4.7	0.1	9	0.022	N/A	0.3

TABLE 12: PREDICTED TRACE ELEMENT CONCENTRATIONS - CONTINUED

		TRACE ELEMENTS										
		MO	NI	PB	SB	SE	SI	SR	TI	V	ZN	ZR
Zone 1	Maximum	0.04	23	0.07	<0.31	0.18	42	0.12	0.84	0.28	19	<0.05
	Average	<0.05	2.0	0.02	<0.31	0.02	19	1.02	0.06	0.04	2.87	0.03
	Minimum	<0.05	1	<0.004	<0.31	<0.02	1	0.04	0.02	<0.07	1.1	<0.05
Zone 2	Maximum	0.06	2.6	0.015	<0.31	<0.02	35	0.8	<0.02	<0.07	<0.17	0.13
	Average	0.1	14.4	0.1	<0.31	<0.02	13	0.6	<0.02	<0.07	<0.17	<0.05
	Minimum	<0.05	0.38	<0.002	<0.31	<0.02	12	0.1	<0.02	<0.07	<0.17	<0.05
Guideline	DU	N/A	N/A	0.01	N/A	0.02	N/A	N/A	N/A	0.1	3	N/A
	LW	0.01	1	0.1	N/A	0.05	N/A	N/A	N/A	1	20	N/A
	ARL	N/A	1.14	0.1	0.07	0.26	N/A	1	0.73	1.3	0.7	2

The contribution to the environmental load from the different zones will vary according to the seepage flux through the footprint of the dam. The seepage flux through the inner zone will be greater than the outer zone due to the head of water in the pond on the top of the dam. The environmental load from the facility is shown in Table 13.

TABLE 13: TOTAL ENVIRONMENTAL LOAD FROM PROPOSED TSF

ZONE	SEEPAGE FLUX (L/S)	SEEPAGE FOR ENTIRE FOOTPRINT (M ³ /DAY)	TDS (KG/M ³)	ENVIRONMENTAL LOAD (KG/DAY)
Zone 1	0.69	5.36	4371	261
Zone 2	4.27	0.866	1954	721
Total Environmental Load				982

Zone 1 leachate contains a higher concentration of species than Zone 2, but the environmental load will be lower as less water is seeping through this zone. To assess the impact that this seepage will have on the environment, it will be necessary to run a numerical groundwater model to simulate the development and movement of contaminant plumes.

5. MITIGATION OPTIONS

Mitigation options have been identified to reduce the impact on the tailings dam on the environment. The need for and final selection of the preferred combination of mitigation options will depend largely on the environmental impact assessment and in particular on the results of the contaminant transport modelling documented in the Geohydrological Investigation at the Proposed New Tailings Disposal Site 5, February 2006, carried out by Rison Groundwater Consulting.

The mitigation options identified are summarised and briefly compared in Table 14.

TABLE 14: COMPARISON OF CONCEPTUAL MITIGATION MEASURES

OPTION	DESCRIPTION	MODUS OPERANDI	RELIABILITY AND EFFECTIVENESS	COST
1	Scavenger wells located on the perimeter of the tailings dam	Abstract contaminated seepage from the groundwater and return it to process	Moderate – but dependent on ongoing pumping and treatment even after decommissioning	Low
2	Seepage cutoff curtain drain draining to pump sumps	Intercepts seepage and drains to series of sumps	Also requires active pumping and treatment even after decommissioning. Effectiveness depends on founding and aquifer conditions	
3	Soil liner to tailings dam	Reduces seepage flux from tailings dam into underlying soils	Low – risk of desiccation of clayey soil liner is high as it takes several years before liner is covered by tailings. Permeability of clayey soils are generally similar to that of tailings	Moderate
4	Plastic liner to tailings dam	Reduces seepage flux from tailings dam into underlying soils	Good- but risk of theft of plastic liner and damage during covering phase	Very high initial capital expense
5	Convert thickened tailings disposal method	Reduces the amount of water deposited with the tailings thereby virtually eliminating the supernatant pond	Metago have proven the technology in Australian operations. The long term reliability of the technology is considered good but requires additional work to operate on the scale of the South Deep Operation. An immediate transition to this technology is considered by Gold Fields to be high risk	Low for thickened tailings Moderate for paste disposal
6	Apply low air permeability cover to sideslopes during operational phase and top surface on decommissioning	Reduces ingress of both water and oxygen resulting in reduced seepage flux and improved seepage quality	High – but difficult to construct. Cover requires protection from roots, vandalism, wind, Abrasion etc.	High but spread over life of TSF
7	Addition of lime during daywall construction and to the final 2 to 3 m of the nightwall	Increases the neutralising potential (NP) of the material in Zone 1	Moderate – lime likely to seep out before acid generating material in Zone 1 is oxidised	Moderate- cost spread over life of TSF

Based on consideration of the above table and subject to the outcome of the solute transport modelling, the preferred strategy is as follows:

Initial Operating Phase

- Install the seepage collection wells and/or seepage collection cutoff drain to protect surrounding water resources including groundwater and surface water.
- Design and implement a low (air and water) permeability cover system to side slopes of the tailings dam. This cover will reduce the rate of generation of acid and help in maintaining the seepage and runoff quality from the tailings dam in line with that of Zone 2, rather than Zone 1. The cover would probably comprise an HDPE membrane plus protective layers of sand and waste rock.

Final Operating Phase

- Within a period of 2 to 4 years (depending on the development and reliability in the technology), change the tailings deposition method to the thickened tailings technology. This option provides for the possibility of developing and proving the thickened tailings technology at smaller scale before implementing the technology over the entire tailings dam, without effecting a delay in commissioning of the new dam or risk of loss of production.
- Continue to apply a modified low permeability barrier to the side slopes and ultimately top surface of the tailings dam.

Decommissioning Phase

- Continue to apply the low permeability cover to the top surface of the tailings dam.
- Decommission the scavenger well and/or curtain drain system.

6. CONCLUSIONS

The following conclusions have been drawn from the investigation:

- The tailings dam may be characterised by two geochemically distinct zones which are expected to be evident throughout the life of the facility but which change in extent depending on the geochemical environment within the tailings dam.
 - The outer zone (in the absence of any further controls) will become acidic relatively soon (within a few months or years) and will release seepage characterised by a low pH and high dissolved metal content.

- The inner zone located primarily below the phreatic surface and in areas of the tailings dam that are at or very nearly saturated. The seepage released from this zone will be characterised by neutral drainage and lower dissolved metal concentrations and salt loads.
- Where the flow path crosses from the outer (acid) zone into the inner (neutral) zone, the resulting drainage quality will tend to take on the characteristics of the acid zone within a relatively short distance downstream of the cross over point, primarily because of the limited neutralising capacity of the tailings.
- This study has made use of a several laboratory tests to understand and characterise the tailings and seepage quality characteristics. The characteristics of the seepage from the proposed tailings dam are most accurately predicted by measuring the water quality from underdrain outlets from the existing gold tailings dams, both of which were constructed several years ago. The two dams currently operated by South Deep referred to as the Old Dam and New Dam were used to collect samples of both tailings, underdrain seepage and process water.
- The results of seepage modelling, which takes cognisance of the tailings permeability, extent of the supernatant pond and position of underdrains as documented in Metago report 168-006/08 dated February 2006 were used to apportion seepage rates to the inner and outer zone. These seepage rates, together with the estimates of contaminant concentrations, were used to estimate the contaminant loads from the tailings dam as summarised in Table 15.

TABLE 15: SEEPAGE RATES AND ESTIMATED ENVIRONMENTAL LOAD FROM TSF

ZONE	SEEPAGE FLUX (L/S)	SEEPAGE FOR ENTIRE FOOTPRINT (M ³ /DAY)	TDS (KG/M ³)	ENVIRONMENTAL LOAD (KG/DAY)
Zone 1	0.69	5.36	4371	261
Zone 2	4.27	0.87	1954	721
Total Environmental Load				982

- The characteristics of the seepage quality from the inner and outer zones may be summarised in Table 16 and Table 17 below. A number of predictive tools were used to obtain these ranges including:
 - The standard ARLP conducted on both fresh tailings and oxidised tailings;
 - A modified ARLP conducted on both fresh tailings and oxidised tailings;

- Samples of process water taken at the point of tailings deposition; and
- Samples of underdrain water taken from both tailings dams.

TABLE 16: PREDICTED SPECIES CONCENTRATION IN THE SEEPAGE FROM THE PROPOSED DAM

		MAJOR ANIONS AND CATIONS									
		pH	TDS	CA	CL	F	K	MG	NA	PO ₄ ³⁻	SO ₄ ²⁻
Zone 1	Maximum	3.9	-	559	245	0.2	35	660	241	25	-
	Average	2.4	4400	510	8.4	0.2	<0.11	89	2	1	2800
	Minimum	2.2	1100	78	<5	0.15	<0.11	31	0.62	<1.6	840
Zone 2	Maximum	10.6	3900	780	120	0.3	48	72	378	0.1	1530
	Average	6.7	1954	196	73	0.3	27	9	200	0.1	884
	Minimum	5.6	180	130	6.1	0.2	2	1	10	<1.6	78
Guideline	DU	6.0 - 9.0	450	32	100	1	50	30	100	N/A	200
	LW	N/A	1000	1000	1500	2	N/A	500	2000	N/A	1000
	ARL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NA	N/A	N/A

TABLE 17: PREDICTED TRACE ELEMENT CONCENTRATIONS EXCEEDING GUIDELINE VALUES

		TRACE ELEMENTS										
		AL	AS	CO	CR	CU	FE	MN	NI	SR	TI	ZN
Zone 1	Maximum	720	27	11	13	7.7	3200	34	23	0.12	0.84	19
	Average	38	2	2	0.7	0.7	367	24	2.0	1.02	0.06	2.87
	Minimum	34	0.04	1	0.7	0.45	73	1.2	1	0.04	0.02	1.1
Zone 2	Maximum	2	0.5	1.6	0.05	10	2.6	3.2	2.6	0.8	<0.02	<0.17
	Average	<0.08	0.5	1.0	0.03	0.3	0.6	2.6	14.4	0.6	<0.02	<0.17
	Minimum	<0.08	<0.07	<0.12	0.01	<0.02	0.4	0.1	0.38	0.1	<0.02	<0.17
Guideline	DU	0.15	0.01	N/A	N/A	1	0.1	0.05	N/A	N/A	N/A	3
	LW	5	1	1	N/A	0.5	10	10	1	N/A	N/A	20
	ARL	10	0.43	6.9	4.7	0.1	9	0.3	1.14	1	0.73	0.7

- Several guideline values are presented in Table 16 and Table 17 for comparison. The comparison of the expected seepage quality from the inner and outer zone indicates that the Acceptable Risk Level, as defined in the Minimum Requirements (DWAF 1998), will be exceeded for the following elements:

- Inner Zone – As, Cu, Mn and Ni.
- Outer Zone – Al, As, Co, Cr, Cu, Fe, Mn, Ni, Ti and Zn.
- The low air permeability of saturated or near saturated gold tailings will play a key role in limiting ingress of oxygen to the tailings dam during the operational life of the dam, thereby reducing the rate of acid production, particularly in those regions of the tailings dam that are below the phreatic surface, or buried deep below surface and away from points of oxygen ingress.
- On decommissioning of the tailings dam, the air permeability will rise as partially saturated conditions become established within the tailings material, and as the phreatic surface dissipates. Areas that up until decommissioning were prevented from becoming acid generating by virtue of the presence of the phreatic surface, will gradually contribute to acid generation. The seepage flux from the tailings dam will however also reduce after decommissioning.
- There is a significant risk that in the absence of adequate mitigation, the proposed tailings dam could impact on the surrounding environment through emissions of contaminants as both seepage and surface runoff from the tailings dam and associated infrastructure.

7. RECOMMENDATIONS

The following recommendations arise from this study:

- The seepage flux during the drawdown phase should be quantified through detailed seepage analysis during the detailed design phase.
- Measures to prevent oxygen ingress to underdrains, in the form of upturns or P-traps should be incorporated into the design of the tailings dam.
- Water from the blanket drain outlets should be separated from toe drain water as the blanket drain water is likely to be neutral whereas the toe drain will become strongly acidic over time.
- It is recommended that a numerical groundwater contaminant transport model be used to predict the impact of the seepage released from the proposed tailings dam on the surrounding aquifer quality. The model should simulate the behaviour of a SO_4 plume under a range of scenarios including:
 - An unlined tailings dam; and
 - The application of scavenger wells.

- The elemental and salt loads should be used together with the seepage fluxes to determine the spatial impact of the tailings dam on the long term groundwater quality.
- Once the impact has been quantified for both the operational and post operational phases it will be necessary to assess which mitigation measures or combination of measures that offer the best practical benefit in terms of environmental protection.
- The challenge of decommissioning the tailings dam needs to be further considered during the detailed design phase. The option of constructing a low air permeability cover to the tailings dam as part of the operational phase to limit the acid generation from the material exposed to the outer side slope should be incorporated into the design and cost provisions. The low air permeability cover would then be extended during the decommissioning phase to the top surface of the tailings dam.
- The thickened tailings technology should be considered and tested in the early phases shortly after commissioning of the tailing dam with a view to converting the dam to thickened tailings deposition method.
- The relevant studies to evaluate the impact on the seepage flux of converting to the thickened tailings should be commissioned.

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APPENDIX 1: SAMPLE LOCATIONS AND PHOTOGRAPHS

DETAILS	SAMPLE NUMBER					
	SAMPLE 1 & 2	SAMPLE 3 & 4	SAMPLE 5 & 6	SAMPLE 7 & 8	NEW TAILS	OLD TAILS
Type	Water	Water	Water	Water	Solids	Solids
Location	Underdrain at new slimes dam Point 51	Unlabelled underdrain at new slimes dam (opposite side to Point 51)	Process water at discharge of slimes (new dam)	Underdrain to the old dam	Tailings sample from new tailings dam	Tailings sample from old tailings dam
GPS Co Ords	S26° 25' 6.7" E027° 40' 27.3"	S26° 25' 6.8" E027° 40' 27.2"	S26° 25' 10.8" E027° 40' 13.6"	S26° 25' 8.5" E027° 40' 34.4"	S26° 25' 10.8" E027° 40' 13.6"	S26° 24' 43.6" E027° 40' 21.0"
pH	6.8	6.4	11.3	2.2	N/A	N/A
EC (ms/cm)	3.4	3.4	2.6	5.3	N/A	N/A
Comments	Sample location smelt slightly, but fluid flowing almost colourless but contained small particulates	As per sample 1 & 2	Water may contain some slimes and scum was noted on the surface	Water smelt strongly (ammoniacal) Water was orange and lots of scum was at discharge point	Freshly deposited 2 samples collected	Sample collected from side slope of old dam



Samples 1 & 2



Samples 3 & 4



Samples 5 & 6



Freshly Deposited Tailings



Samples 7 & 8



Side slope of old dam



Location of Collected Sample from Side Slope

APPENDIX 2: LABORATORY TEST DATA

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APPENDIX 4: SEEPAGE ANALYSIS FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

Metago

Environmental Engineers (Pty) Ltd



SEEPAGE ANALYSIS FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

Prepared For

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SEEPAGE ANALYSIS FOR THE PROPOSED DOORNPORST TAILINGS DAM AT SOUTH DEEP MINE

1. INTRODUCTION

Metago Environmental Engineers (Pty) Ltd (Metago) in a joint venture with Golder and Associates Africa (GAA) were appointed by South Deep Gold Mine to conduct the detailed design of a new tailings dam for the South Deep operation. The site selected for the new dam is referred to as Site 5 and is located on the farm Doornpoort. This report comprises an Appendix report to the detailed design report and documents the seepage analyses conducted to:

- Estimate the maximum likely seepage flux from the underlying foundation soils;
- Size and position the underdrains as shown on Figure 1;
- Check if the drains will function adequately in terms of controlling the phreatic surface and preventing daylighting of the phreatic surface on the outer slopes of the tailings dam and starter walls. This is important to ensure that hydrostatic pressure build up does not take place below the composite cover.

The seepage analyses were based on a design which assumed an average production rate of 330 000 tonnes per month (tpm) and a total tailings capacity of approximately 152 000 000 m³. This was subsequently revised downwards to 220 000 tpm which would not represent a worse case than the assumed design case. The tailings dam layout is presented in Figure 1.

The seepage analyses were undertaken using a finite element analysis program SEEP/W (2004). This model is capable of analysing two dimensional flow through porous media.

The analyses were limited to the period after the tailings dam has broken ground, once the supernatant pond is no longer in direct contact with the underlying soils. The period prior to this and the period after decommissioning (draw down phase) have not been analysed.

The seepage analysis has also been used to estimate the proportion of the total seepage flux likely to emanate from what could potentially become the acid generating zone. The geochemical model documented in Appendix A3 describes the expected formation of an outer zone and an inner zone. Seepage from the outer zone has a greater potential to become acidic during the operational life of the dam whereas seepage from the inner zone is expected to be characterised by neutral conditions throughout the operational life. After decommissioning, depending on the long term performance of the composite cover, the entire tailings dam footprint could release acidic seepage, although the seepage rate is expected to reduce with time as a result of the draw down of the phreatic surface and evapo-transpiration.

2. TERMS OF REFERENCE

The terms of reference for the seepage analyses were as follows:

- To ensure that the proposed size and position of the underdrains is such that seepage does not arise on the outer side slope of the tailings dam under normal operating conditions;
- To estimate the maximum seepage flux likely to occur through the tailings dam footprint after ground has been broken;
- To estimate the proportion of the total seepage flux likely to emanate from the tailings dam through the outer, potentially acid generating zone. The outer and inner zones are described in Appendix A3.

3. AVAILABLE INFORMATION AND REFERENCES

The following reports are relevant to this investigation and have been used as a source of Information for this study:

- **Metago Environmental Engineers (Pty) Ltd 2008**, Geochemical Waste Characterisation for the Proposed Doornpoort Tailings Storage Facility at South Deep Mine **G001-02/01, Appendix A3**, May 2008.
- **Golders Report No. 10307/10273/13/G**, Hydrogeological Investigation and Impact Assessment for Proposed Tailings Storage Facility No. 5 – South Deep Gold Mine, August 2007.
- **Golders Report No. 10307/10319/14/G**, South Deep Gold Mine Geotechnical Investigation for the Proposed Tailings Storage Facility, September 2007.

4. SEEPAGE MODEL

The tailings dam was modelled using SEEP/W version 6.22 (Seep/W 2004), which is capable of analysing seepage through a two dimensional section using a finite element solution to the differential equation (Equation 1) that states the sum of the rates of change of flows in the x- and y- directions plus the external applied flux is equal to the rate of change of the volumetric water content with respect to time. Under steady state conditions, the flux entering and leaving an elemental volume is the same at all times, reducing the right hand side of the equation to zero (Seep/W User's Guide 2004).

EQUATION 1: DIFFERENTIAL EQUATION FOR SEEPAGE MODELLING

$$\frac{\partial}{\partial x} \left(k_x \cdot \frac{\partial H}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \cdot \frac{\partial H}{\partial y} \right) + Q = \frac{\partial \Theta}{\partial t}$$

Where:

H is the total Head;

k_x is the permeability in the x- direction;

k_y is the permeability in the y- direction;

Q is the applied boundary flux;

Θ is the volumetric water content; and

t is time.

The locations of the sections chosen for the analysis (shown in Figure 1) are as follows:

- Section 1 passes through the embankment at the point where the outer slope will ultimately be at its highest, to the location of the final penstock tower (Figure 2);
- Section 2 was taken from the final penstock tower to the closest point on the outer toeline (Figure 3); and
- Section 3 passes from the final penstock tower to the northern side of the dam (Figure 4).

The sections through the tailings were divided into regions based on experience, to more realistically model the variation of permeability resulting from the depositional profile.

A pond area covering 10% of the total top surface area of the tailings dam has been assumed for the normal operating condition of the dam. This equates to a supernatant pond of 270m from the penstock tower.



FIGURE 1: LAYOUT AND LOCATION OF SECTIONS FOR SEEPAGE MODELLING

The model has been run to simulate seepage assuming that the dam has grown to its final height and has been analysed under steady state seepage conditions. The starter wall material was assumed to be isotropic. Anisotropic permeability parameters have been assigned to the gold tailings on the basis of our experience and calibration of seepage models against piezometer levels for similar gold tailings dams.

The model boundary was set to the base of the subsoil located at a depth of approximately 5 m beneath the tailings dam.

The following boundary conditions have been assumed:

TABLE 1: FLOW BOUNDARIES

BOUNDARY	TYPE OF BOUNDARY CONDITION	EXPLANATION
Supernatant Pond	Fixed Head Boundary	<i>Elevation corresponds to elevation of the pond</i>
Tailings Beach	None	<i>Evaporation is assumed to be roughly equal to rainfall and beach infiltration</i>
Side slopes	Review flux nodes	<i>This allows the model to identify the daylight point</i>
Underdrains	Review flux nodes	<i>The seepage has the ability to be drained away by the outlet pipes</i>
Contact below the subsoil	Undrained case: no flow boundary	<i>Flow is as if the tailings dam is fully lined with a low permeability barrier</i>
	Drained case: Review flux nodes	<i>Flow is as if the dam is completely drained by an underlying drainage system</i>

The tailings dam is expected to have limited seepage occurring downwards through the subsoil to the fractures rock horizon. Dykes and faults may also play a role in determining the extent to which material underlying the tailings dam is effective in draining the dam. These effects have been ignored in the model by assigning a no flow boundary to the base of the subsoil layer in order to size the drains.

In order to estimate the maximum likely seepage to the environment, the subsoil layer has been assumed to be completely drained by the underlying material.

An unstructured triangular mesh of varying sizes was used for the element grid spacing. An unstructured triangular mesh has the advantages of being quicker and easier to model, and has the ability to fit to irregularly shaped regions relatively easily.

Since the model is a two dimensional model but the seepage practically takes place over the entire footprint (3 dimensional problem) the results from the 2 dimensional model were extrapolated to the 3 dimensional problem using an area correction factor. The area correction factor is calculated as follows for each section:

EQUATION 2: SHAPE FACTOR CALCULATION

$$\text{Shape Factor} = \frac{\text{Depositional Area}}{\text{Base area of CrossSection}}$$

Thus the seepage flux determined from the model was multiplied by their respective shape factors to estimate the seepage flux from the entire footprint.

TABLE 2: SHAPE FACTORS

	DEPOSITIONAL AREA (M ²)	BASE AREA OF CROSS SECTION (M ²)	SHAPE FACTOR
Section 1	2,270,000	1,200	1,892
Section 2	517,000	640	808
Section 3	418,000	750	557

Geotechnical parameters have been assigned to the model as described in Section 5.

The tailings were assumed to be anisotropic, and varying in permeability based on the depositional practice employed. The vertical to horizontal permeability ratio of the tailings was assumed based on experience with similar dams.

The tailings was divided into four regions:

- Average Tailings. This region exists as a result of the full slurry product being deposited into the outer paddock created by the spigotted day-wall configuration;
- Coarse Tailings. A depositional profile occurs due to the end of pipe discharge which results in the coarsest particles settling out first, i.e. near the point of deposition. This region is the most permeable region of the tailings;
- Medium Tailings. The next region resulting from the depositional profile is less permeable than the coarse tailings, and is taken to be equal to the average tailings; and
- Fine Tailings. This region occurs in the central region of the tailings dam and has the lowest permeability.

Flux lines were specified to determine the proportion of flow through the outer (potentially acidic) zone.

A series of alternate drain sizes and positions were analysed to compare the efficiency of different configurations. The final position of the drain is determined not only by the seepage analysis, but also by practical considerations relating to construction of the tailings dam and operational issues.

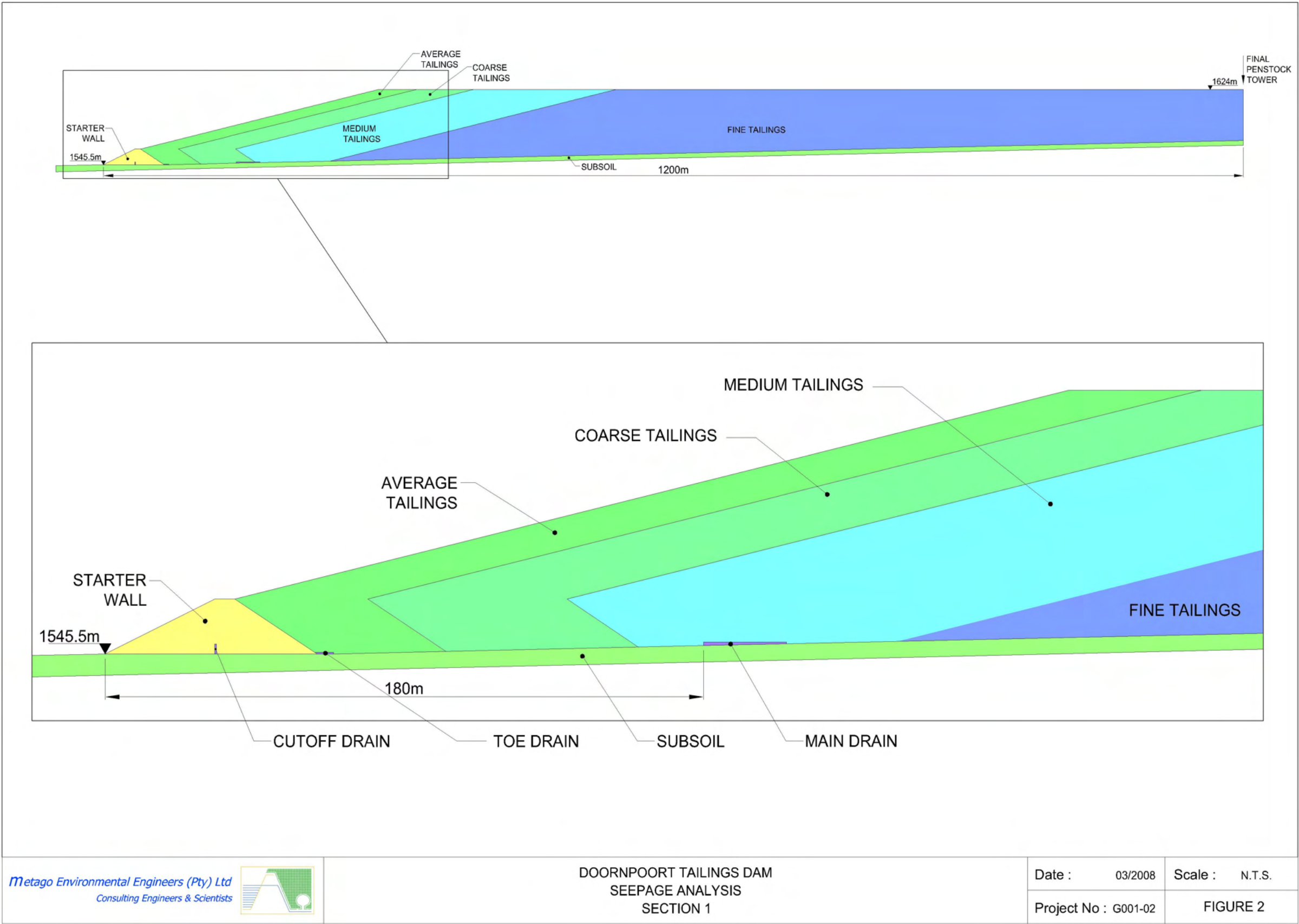


FIGURE 2: SECTION 1

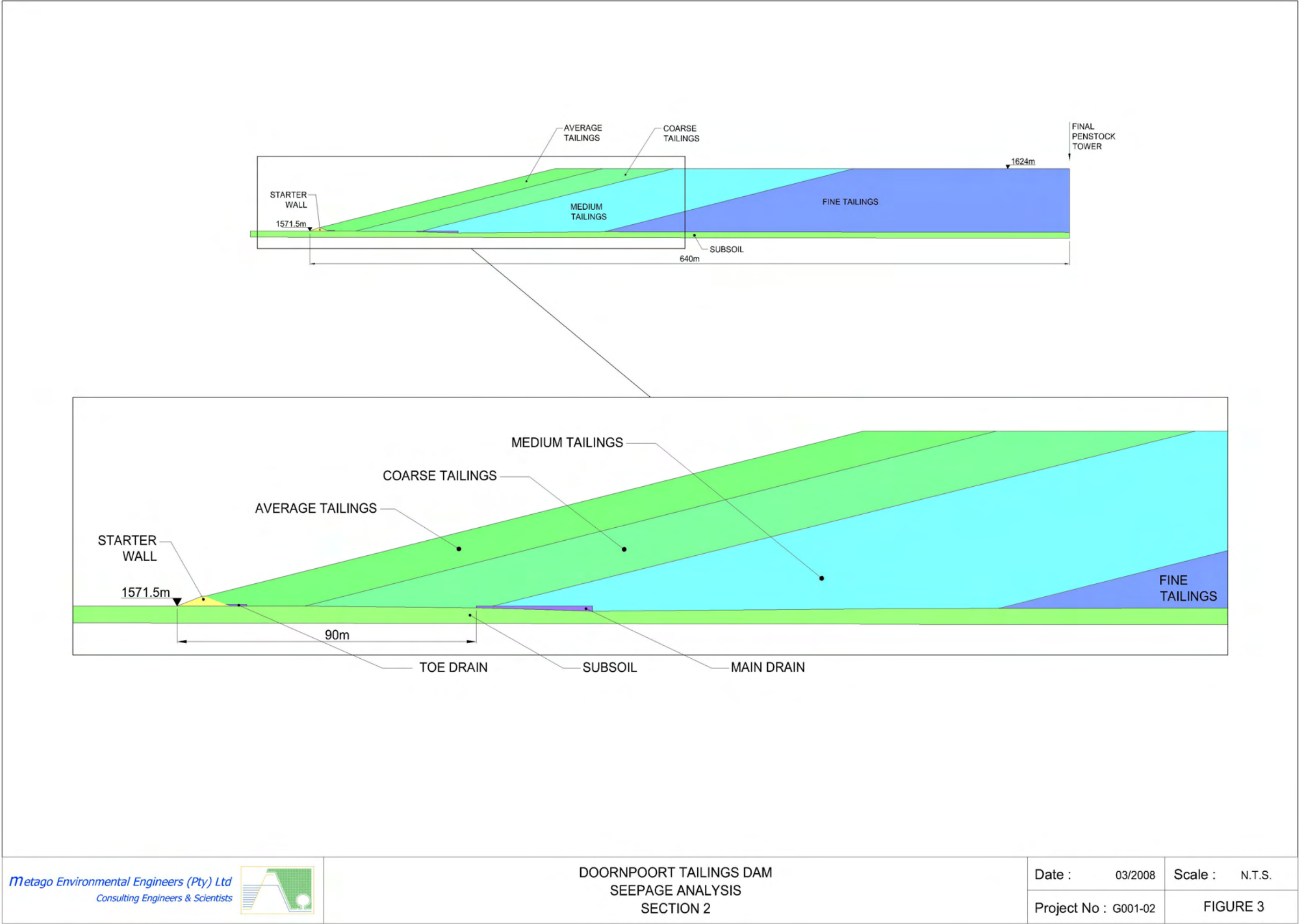


FIGURE 3: SECTION 2

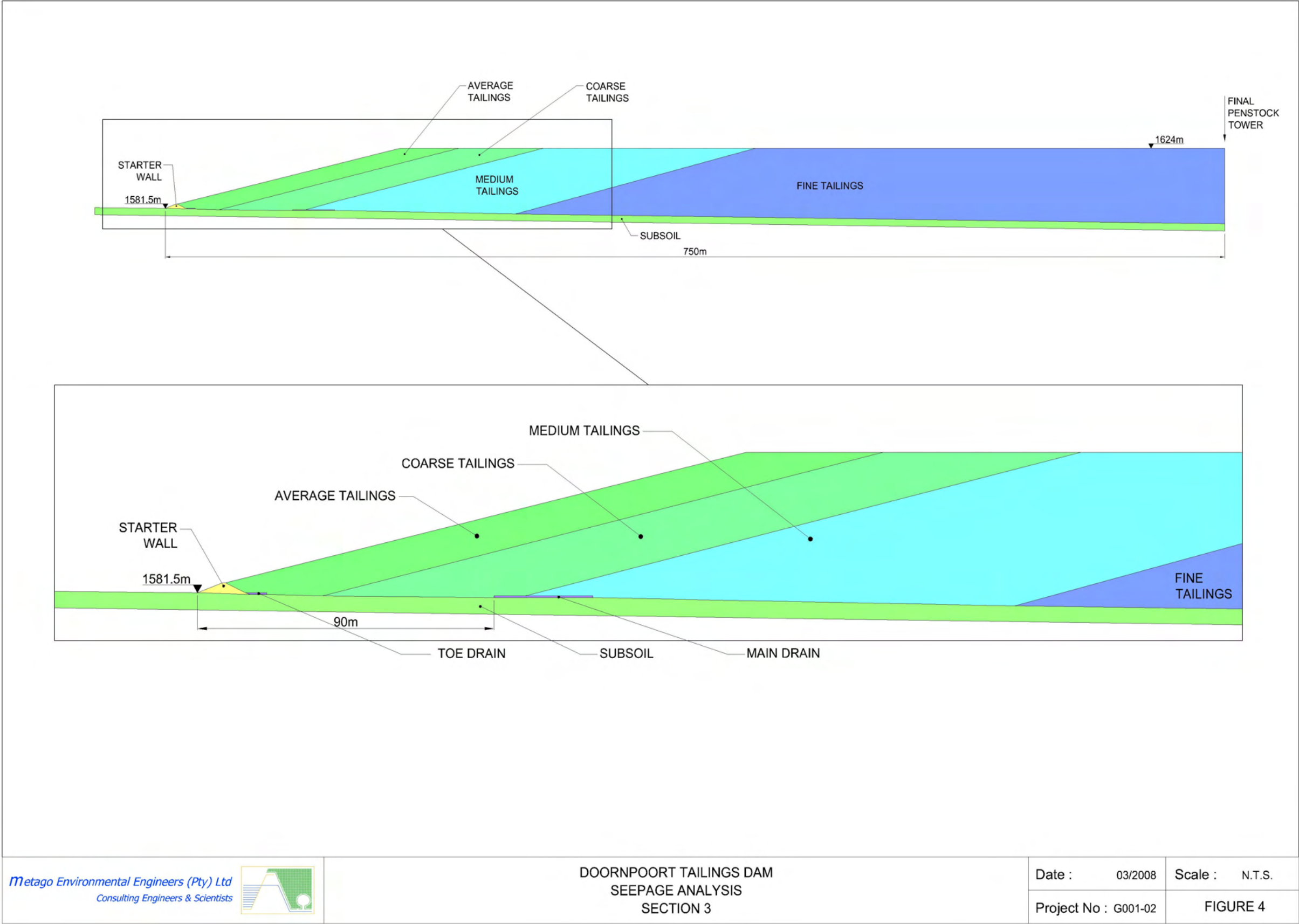


FIGURE 4: SECTION 3

5. GEOTECHNICAL PARAMETERS

Foundation Materials

While the model does not include analysis of seepage through the full extent of the foundations this section provides comment on the relative permeability of the tailings compared to the underlying near surface soils and underlying aquifer.

Information on the permeability of the underlying aquifer has been obtained through borehole pump testing and is documented in the Geohydrological Report (**Golders Report No. 10307/10273/13/G**, August 2007). These results are summarised in Table 3.

TABLE 3: INSITU MATERIAL PERMEABILITY FROM HYDROGEOLOGICAL INVESTIGATION

AQUIFER	PERMEABILITY (M/DAY)	PERMEABILITY (M/S)
Dyke	0.0143	1.655×10^{-7}
Dyke Contact	0.114	1.319×10^{-6}
Weathered Aquifer	0.0095	1.100×10^{-7}
Fractured Aquifer	0.0095	1.100×10^{-7}

The borehole pump tests reflect only the permeability of the aquifer but are not necessarily a good reflection of the near surface soils above the aquifer. In order to assess the permeability of the near surface soils, the particle size distributions documented in the Geotechnical Report (**Golders Report No. 10307/10319/14/G**, September 2007) have been used.

From the laboratory test results documented in the geotechnical report, the permeabilities of the tailings dam foundation materials for each sample were determined through the use of a falling head permeameter test, as presented in Table 4.

TABLE 4: INSITU MATERIAL PERMEABILITY, CALCULATED FROM GEOTECHNICAL INVESTIGATION RESULTS

TEST PIT	SAMPLE DEPTH (M)	PERMEABILITY (M/S)
TTP04	1	2.80×10^{-10}
TTP05	1.8	4.70×10^{-10}
TTP20	3.3 - 3.5	2.90×10^{-9}
ETP03	3.3 - 4.4	1.30×10^{-9}
Average		1.24×10^{-9}
Standard Deviation		1.19×10^{-9}
Minimum		2.8×10^{-10}
Maximum		2.90×10^{-9}
COV		96%

The permeability valued used in the seepage modelling was an average of only TTP04 and TTP05 for the following reasons:

- The results for drain sizing are conservative; and
- The samples were taken at the point where the starter wall is the highest.

A comparison of the permeability values for the underlying fractured aquifer shown in Table 3, with those for the tailings dam subsoils as shown in Table 4, indicates that in general the permeability of the near surface soils are between one and two orders of magnitude lower than that of the underlying fractured aquifer.

Tailings Dam Parameters

Hazen (1919) proposed that the permeability of a silt/ sand can be estimated from Equation 3.

EQUATION 3: HAZEN FORMULA

$$k = (D_{10})^2$$

Where:

k is the calculated permeability (m/s); and

D_{10} indicates 10 percent of the particles are finer than this diameter (cm).

The results using Equation 3 have been found historically to compare well with results from laboratory (small scale) permeameter tests.

TABLE 5: GOLD TAILINGS PERMEABILITY

	D₁₀ VALUE (CM)	PERMEABILITY (M/S)
Average or spigotted tailings	5.35×10^{-4}	2.86×10^{-7}
Coarse fraction near discharge point	8.50×10^{-4}	7.23×10^{-7}
Medium fraction along beach	5.35×10^{-4}	2.86×10^{-7}
Fine fraction near pool	2.20×10^{-4}	4.84×10^{-8}

A comparison of the results in Table 3 (underlying soils) - with Table 5 (tailings material) suggests that the tailings may be more or is less permeable than the underlying soils, implying that the unit head loss for seepage through the underlying materials will be lower or higher than that for the tailings material.

Embankment parameters

The embankments were assumed to be constructed from the subsoil material taken from the basin of the tailings dam.

Parameters adopted in the seepage model

The material parameters used in the seepage model were as shown in Table 6.

Given the natural variability in the subsoil permeability parameters likely to be encountered, for the purpose of sizing the drains, the underlying subsoil materials have been assumed to be far less permeable than the tailings and the values of subsoil and starter wall permeabilities shown in Table 6 have been used for the purpose of drain sizing and the assessment of the effect of upset conditions on the risk of daylighting of the phreatic surface.

For the purpose of assessing the pollution potential of the tailings dam, the upper and lower bound subsoil permeability values documented Table 6 have been used.

TABLE 6: ADOPTED PERMEABILITY VALUES USED FOR SEEPAGE MODEL

	K_{MEAN} (M/S)	K_x (M/S)	K_y (M/S)	K_y/K_x
Starter Wall	3.75×10^{-10}	3.75×10^{-10}	3.75×10^{-10}	1/1
Subsoil	3.75×10^{-10}	3.75×10^{-10}	3.75×10^{-10}	1/1
Tailings Average	2.86×10^{-7}	5.61×10^{-7}	1.12×10^{-8}	1/50
Tailings Coarse	7.23×10^{-7}	1.42×10^{-6}	2.83×10^{-8}	1/50
Tailings Medium	2.86×10^{-7}	5.61×10^{-7}	1.12×10^{-8}	1/50
Tailings Fine	4.84×10^{-8}	9.49×10^{-8}	1.90×10^{-9}	1/50
Filter Sand	1.00×10^{-2}	1.00×10^{-2}	1.00×10^{-2}	1/1

6. RESULTS

The results are derived for the cross-sections in Figure 2, Figure 3 and Figure 4, which are implicitly 1m wide i.e. the results are per meter width.

6.1. NORMAL CONDITIONS- SEEPAGE TO FOUNDATIONS

The results of the analysis of the normal operating conditions shows that for the given section, a maximum of 1.5×10^{-8} l/s per meter width discharges into the insitu (subsoil) material below. The total discharge emanating from the tailings into the subsoil is 2.668×10^{-5} l/s. The results are presented in Table 7, with the zones and flow paths presented in Figure 5, Figure 6 and Figure 7.

TABLE 7: SUBSOIL SEEPAGE RESULTS FOR NORMAL CONDITIONS

SECTION	ZONE	CALCULATED SEEPAGE FOR ENTIRE FOOTPRINT (SHAPE FACTOR APPLIED) (M ³ /DAY)	
		LOWER BOUND	UPPER BOUND
1	Inner	8.5×10^{-13}	51.5
	Outer	3.1×10^{-3}	1.3
	Total	3.1×10^{-3}	52.8
2	Inner	5.5×10^{-7}	29.8
	Outer	2.3×10^{-6}	0.0
	Total	2.8×10^{-6}	29.8
3	Inner	9.3×10^{-10}	1.3
	Outer	2.7×10^{-9}	0.0
	Total	3.7×10^{-9}	1.3
Combined	Inner	5.5×10^{-7}	82.6
	Outer	3.1×10^{-3}	1.3
	Total	3.1×10^{-3}	83.9

The drains were placed and sized based on an iterative approach which consisted of guessing a drain size and location, running the seepage model, and checking if the phreatic surface was drawn down sufficiently to prevent daylighting of the phreatic surface against the tailings dam surface, during normal operating conditions. The drain widths and location from the outer toeline are summarized in Table 8. The seepage which emanates from the drains is summarized in Table 9.

TABLE 8: DRAIN SIZING AND LOCATION

SECTION	DRAIN	LOCATION	DRAIN WIDTH (M)
1	Main	180m from outer toe line	25
	Toe	At inner toe line of starter wall	5
	Cutoff	In starter wall	0.4
2	Main	90m from outer toe line	35
	Toe	At inner toe line of starter wall	5
3	Main	90m from outer toe line	30
	Toe	At inner toe line of starter wall	5

TABLE 9: DRAIN SEEPAGE RESULTS FOR NORMAL CONDITIONS

SECTION	DRAIN	CALCULATED FLOW PER DRAIN TYPE PER SECTION (M ³ /DAY)
1	Main	34.7
	Toe	9.9
	Cutoff	0.003
2	Main	66.2
	Toe	0.255
3	Main	14.3
	Toe	0.000
Combined	Main	115.1
	Toe	10.1
	Cutoff	0.003
	Total	125.3

The design flow rates for the seepage collection pipes are summarised in Table 10 below:

TABLE 10: UNDERDRAIN DESIGN FLOW RATES FOR NORMAL OPERATING CONDITIONS

DRAIN	OUTFLOW /200M DRAIN SECTION (M ³ /DAY)
Main Drain Outlets	8.82
Toe Drain Outlets	0.53
Cutoff Drain Outlets	2.33×10^{-4}
Total inflow to Underdrain collection system	9.35

6.2. UPSET CONDITIONS

Various upset conditions were run to allow the implications of a combination of drain failures, a large supernatant pond, etc. to be predicted. Table 11 summarises the numerical results of the various scenarios completed. Failure of both the main and toe drains, or failure of the main drain and a large supernatant pond, would result in daylighting of the phreatic surface. Stability of the composite cover the associated

rehabilitation measures would be severely affected with any such daylighting. The effect of upset conditions (and the associated phreatic surface) on the tailings dam stability is documented in Appendix Report A5.

With the drains included in the model, only a supernatant pond encroaching within 30m of the crest for Section 1 (Figure 8) would result in the phreatic surface daylighting. With complete failure of the main drain in Section 2 (Figure 12), also resulting in daylighting.

It can also be seen that while it is not advisable, a large pool can be accommodated for an extended period on Section 2 (Figure 9) and Section 3 (Figure 10), so long as all of the drains are functioning correctly. However, if it suspected that any of the drains have failed due to blinding, blocked outlet pipes, etc., then the pond will need to be carefully restricted to the immediate area around the final penstock tower, especially for Section 2.

TABLE 11: RESULTS FROM UPSET CONDITIONS

UPSET CONDITION	SECTION 1		SECTION 2		SECTION 3	
	DAYLIGHTING OF PHREATIC SURFACE	FIGURE NUMBER	DAYLIGHTING OF PHREATIC SURFACE	FIGURE NUMBER	DAYLIGHTING OF PHREATIC SURFACE	FIGURE NUMBER
Large Pool	Yes	Figure 8	No	Figure 9	No	Figure 10
Main Drain failure	No	Figure 11	Yes	Figure 12	No	Figure 13
Toe Drain failure	No	-	No	-	No	-
Cutoff Drain failure	No	-	-	-	-	-
Main and Toe Drain failure	Yes	-	Yes	-	Yes	-
Main and Cutoff Drain failure	No	-	-	-	-	-
Toe and Cutoff Drain failure	No	-	-	-	-	-
Large Pool and Main Drain failure	Yes	-	Yes	-	Yes	-
Large Pool and Toe Drain failure	Yes	-	Yes	-	Yes	-
Large Pool and Cutoff Drain failure	Yes	-	-	-	-	-

7. CONCLUSIONS

The following can be concluded from the analyses:

- From the analyses it was estimated that between 3.05×10^{-3} and $83.9 \text{ m}^3/\text{day}$ of seepage will be discharged into the subsoil material from the tailings dam;
- The seepage analyses have shown that the combination of main drain, toe and cutoff drains can effectively control the phreatic surface within the tailings dam during normal operating conditions;
- The phreatic surface is sensitive to the position and size of the main and toe drains. The analyses indicated that main drain needs to be a minimum of 25 m wide, depending on its location around the dam, and the toe drains needs to be 5 m wide to reduce the risk of toe seepage to a satisfactory level;
- In the event of an extreme rainfall event, or failure of the operators to decant the supernatant pond, it is possible for a large pool to be accommodated if all of the drains are functioning correctly, but a large pond should be avoided as the daylighting of the phreatic surface will result in vegetation die back;
- Seepage losses up to the time when the tailings dam breaks ground, while the supernatant pond is in direct contact with natural ground, may exceed the seepage losses calculated in this analysis if the permeability of the underlying soils is significantly higher than that of the tailings; and
- Flow rates into the underdrain outlets and total flow into the underdrain collection system would need to cater for a minimum rate as shown in Table 10.

8. RECOMMENDATIONS

The following recommendations arise from this study:

- The drain configuration shown on Figure 1 is considered suitable in terms of controlling the position of the phreatic surface;
- A quality assurance procedure needs to be drawn up and strictly enforced with regards to the grading curve of the tailings covering of the drains, removal of any vegetation just prior to covering, etc;
- Piezometers to be installed in the tailings dam side slope to monitor the position of the phreatic surface during the operational life of the tailings dam. Drain flows to be monitored as a means to check on their operation; and
- The drains should be covered straight after being constructed, and then exposed just prior to commissioning, to allow for possible wash-aways and blinding.

9. REFERENCES

Hazen A, 1911, Discussions of dams on sand foundations, Transactions, No 73, American Society of Civil Engineers, New York.

Seepage Modeling with SEEP/W, An Engineering Methodology, John Krahn, First Edition, May 2004

SEEP/W User's Guide 2003, Finite Element Seepage Analysis User's Guide, Geo-Slope International Ltd., Calgary, Alberta, Canada.

SEEP/W 2003, "Finite Element Seepage Analysis", Version 5.20, Geo-Slope International Ltd., Calgary, Alberta, Canada.

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APPENDIX 1: NORMAL OPERATING CONDITIONS FOR ALL SECTIONS

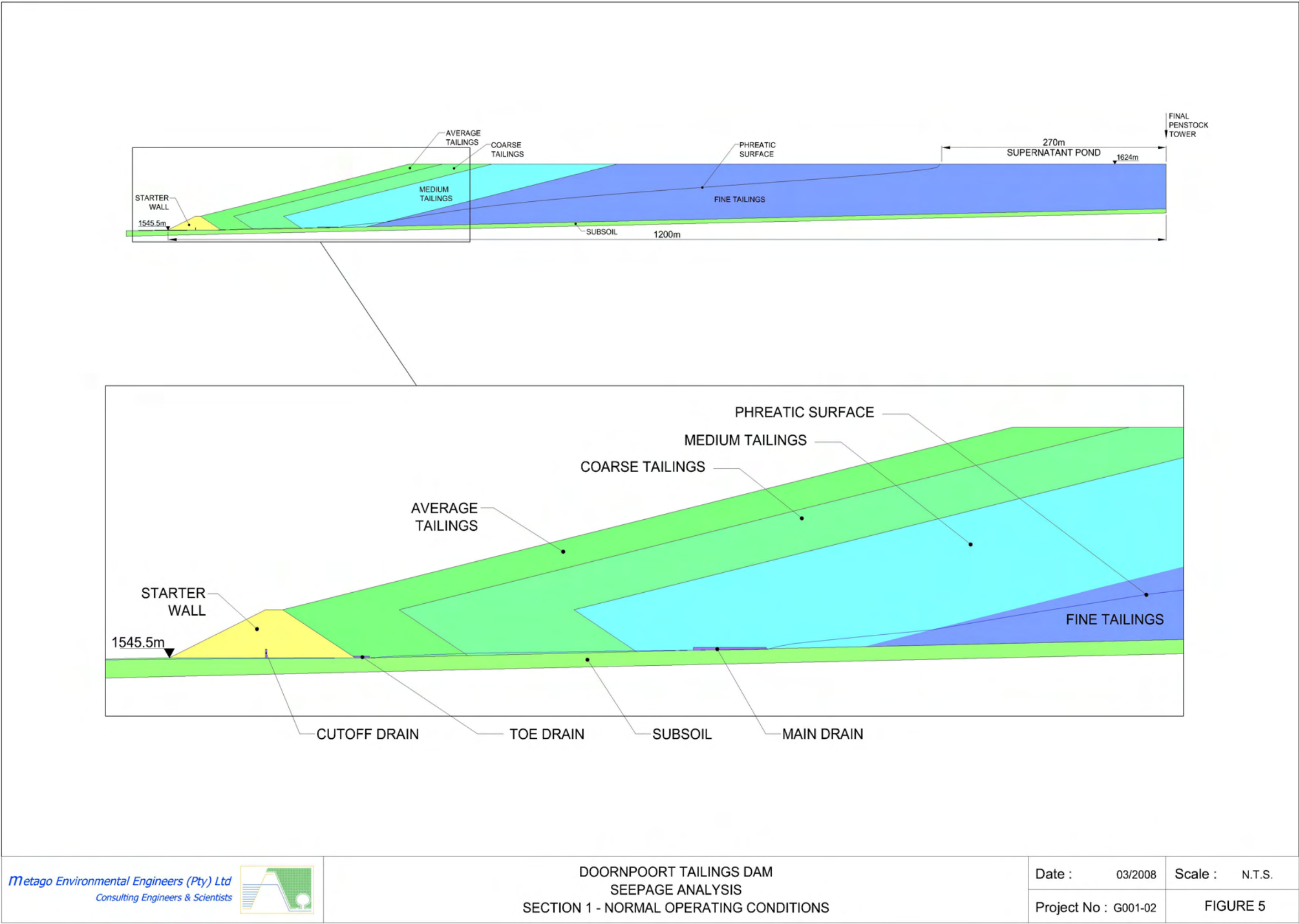


FIGURE 5: SECTION 1 - NORMAL OPERATING CONDITIONS

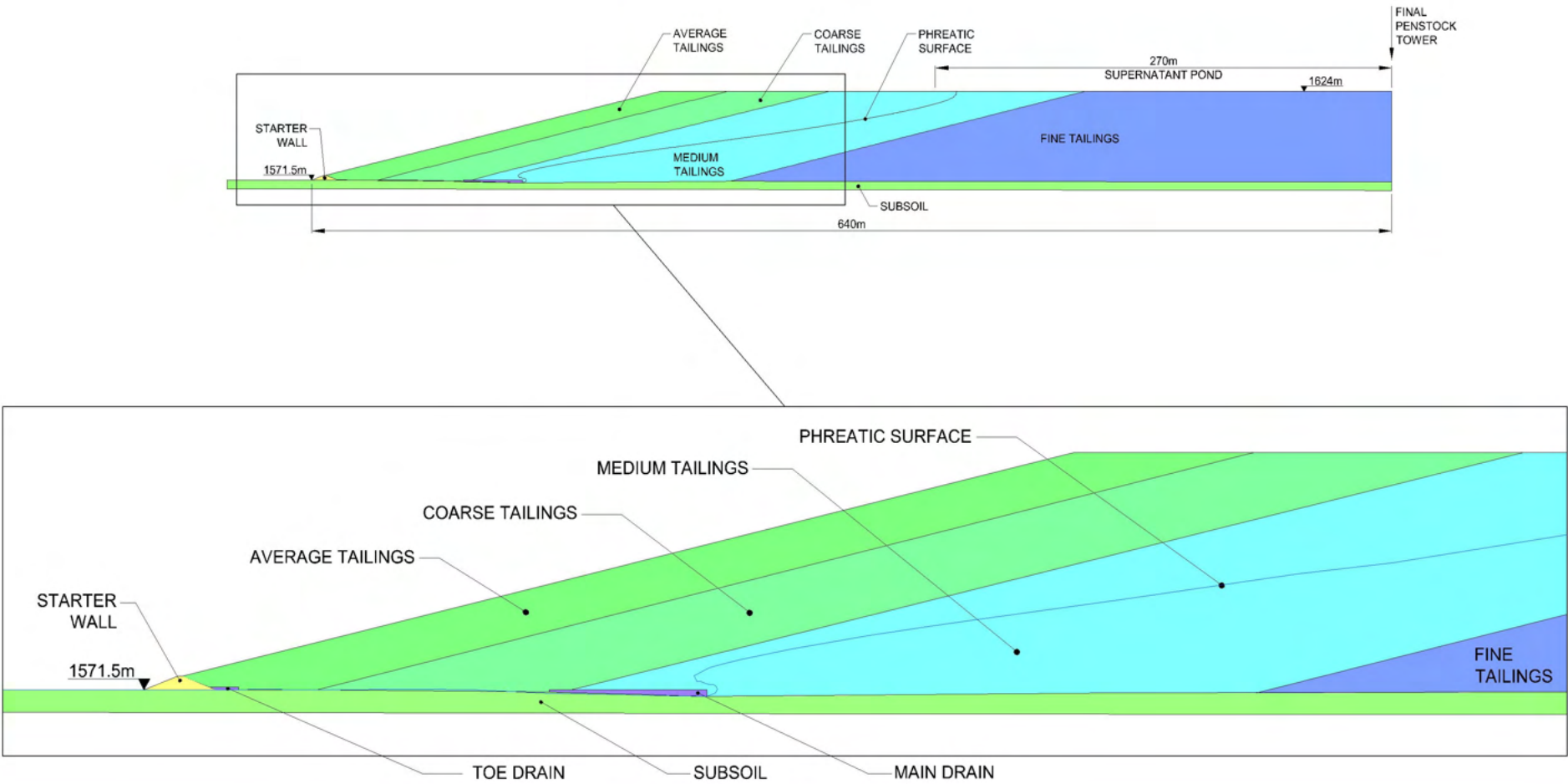
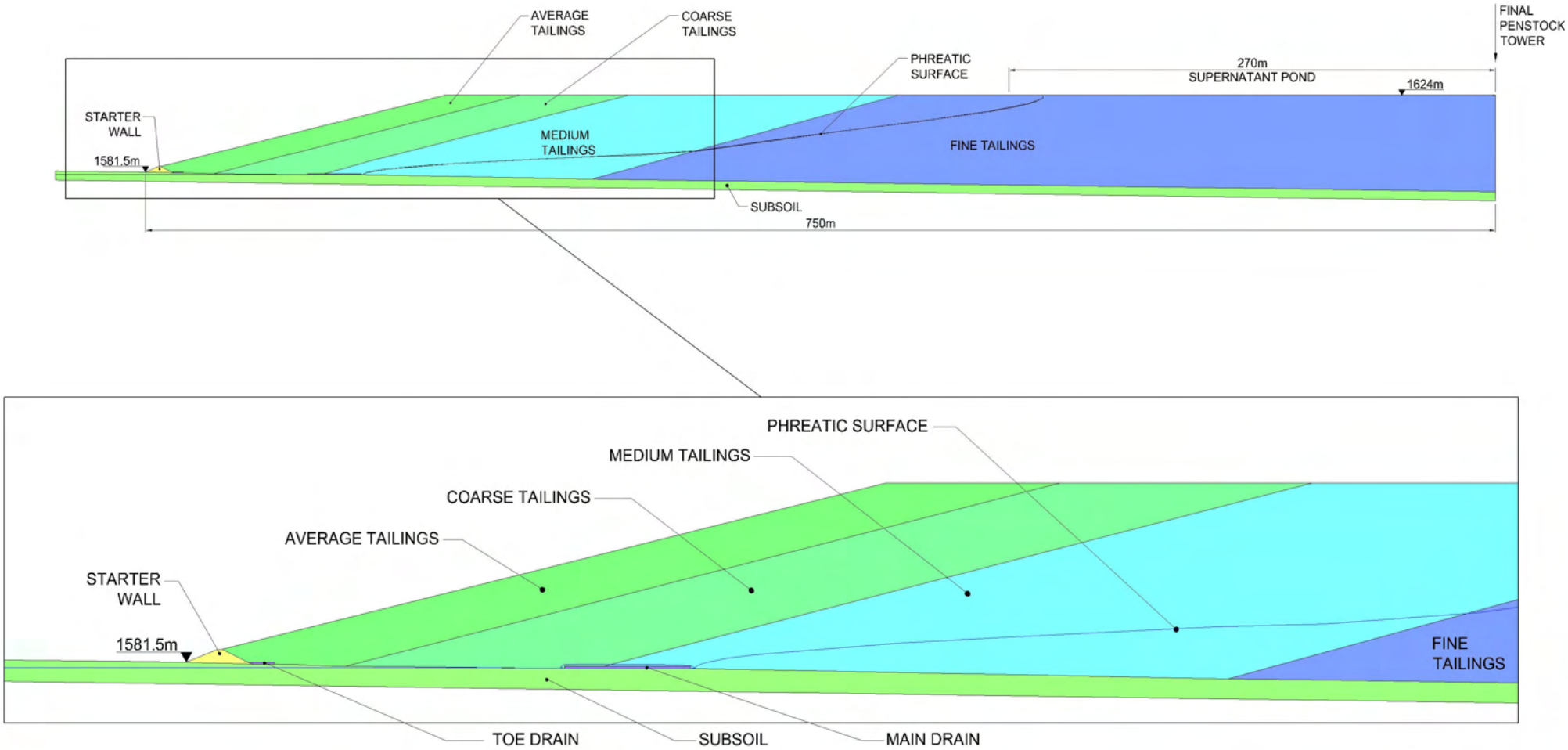
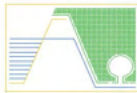


FIGURE 6: SECTION 2 - NORMAL OPERATING CONDITIONS



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DOORNPOORT TAILINGS DAM
SEEPAGE ANALYSIS
SECTION 3 - NORMAL OPERATING CONDITIONS

Date :	03/2008	Scale :	N.T.S.
Project No :	G001-02	FIGURE 7	

FIGURE 7: SECTION 3 - NORMAL OPERATING CONDITIONS

APPENDIX 2: UPSET CONDITION - LARGE SUPERNATANT POND FOR ALL SECTIONS

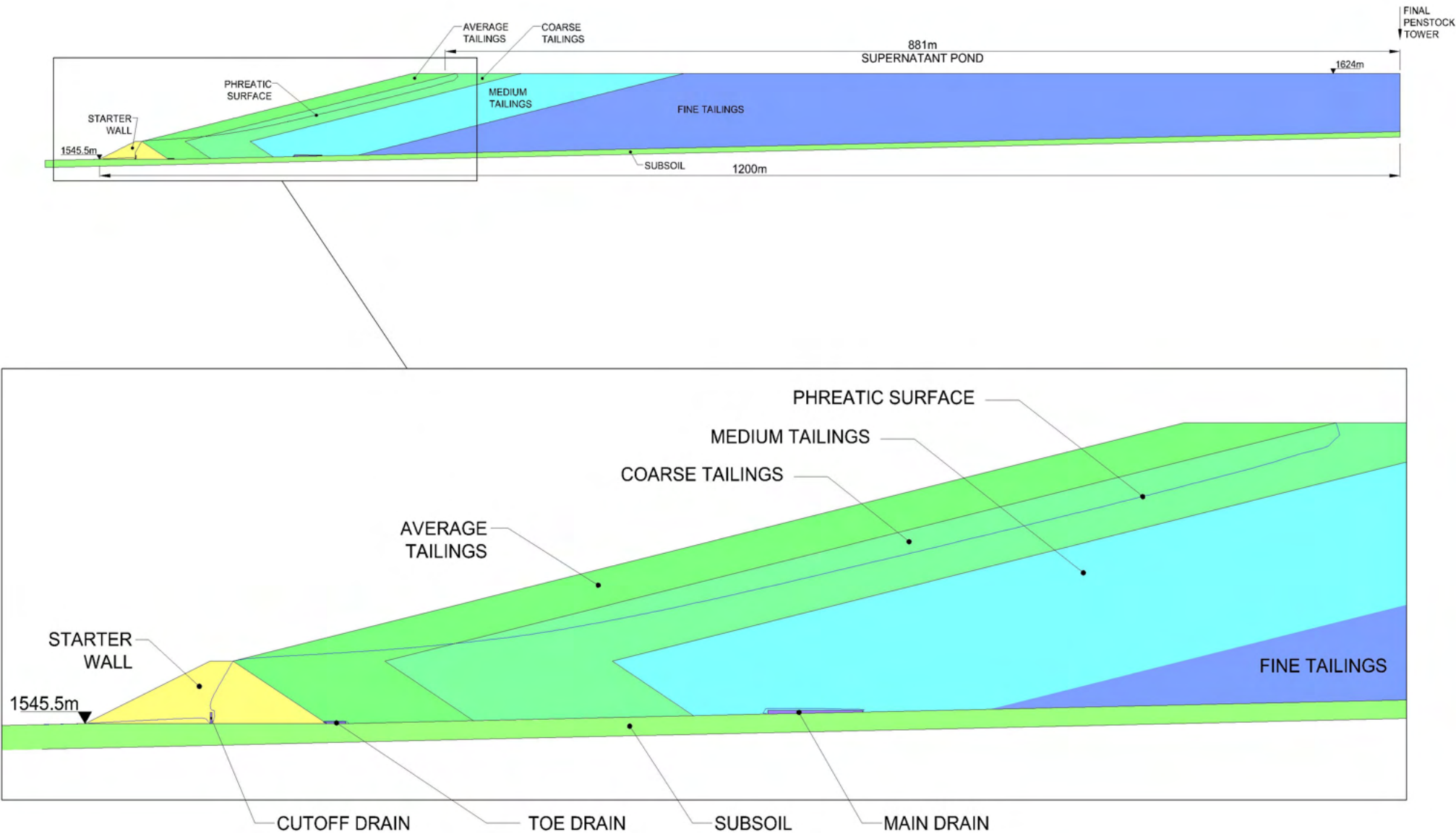


FIGURE 8: SECTION 1 - LARGE SUPERNATANT POND

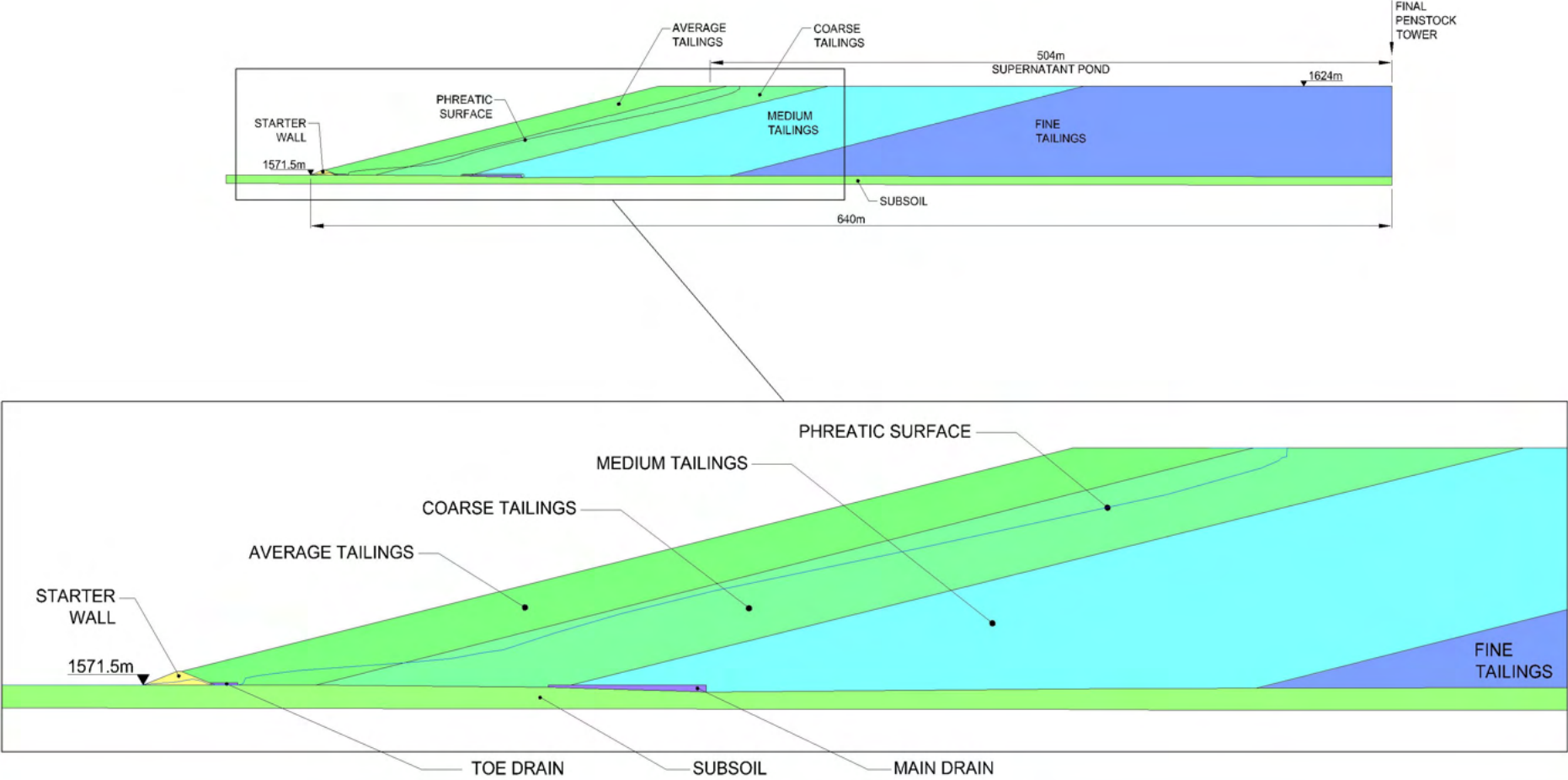


FIGURE 9: SECTION 2 - LARGE SUPERNATANT POND

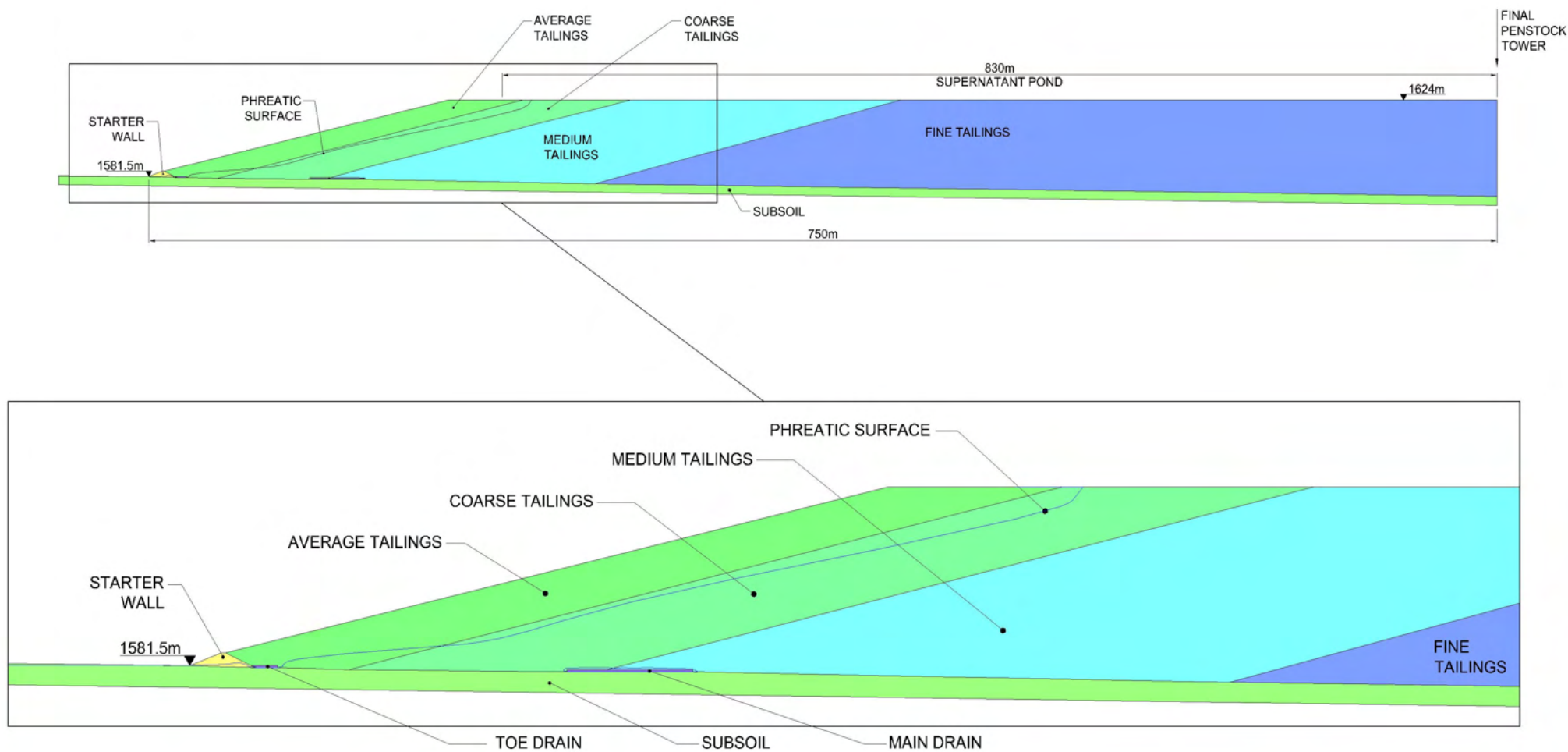
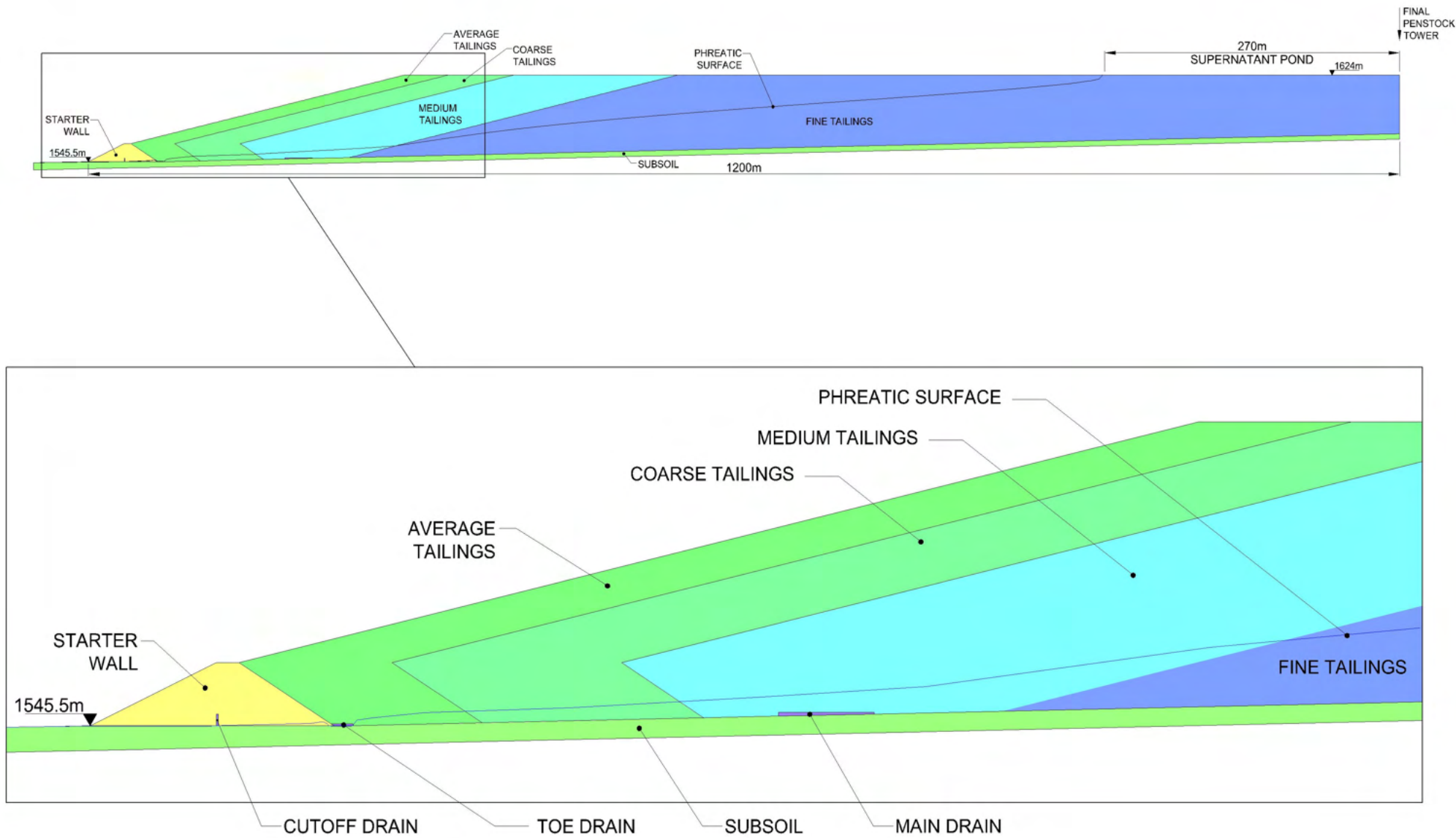
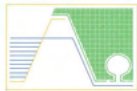


FIGURE 10: SECTION 3 - LARGE SUPERNATANT POND

APPENDIX 3: UPSET CONDITION - MAIN DRAIN FAILURE FOR ALL SECTIONS



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DOORNPOORT TAILINGS DAM
SEEPAGE ANALYSIS
SECTION 1 - MAIN DRAIN FAILURE

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FIGURE 11

FIGURE 11: SECTION 1 - MAIN DRAIN FAILURE

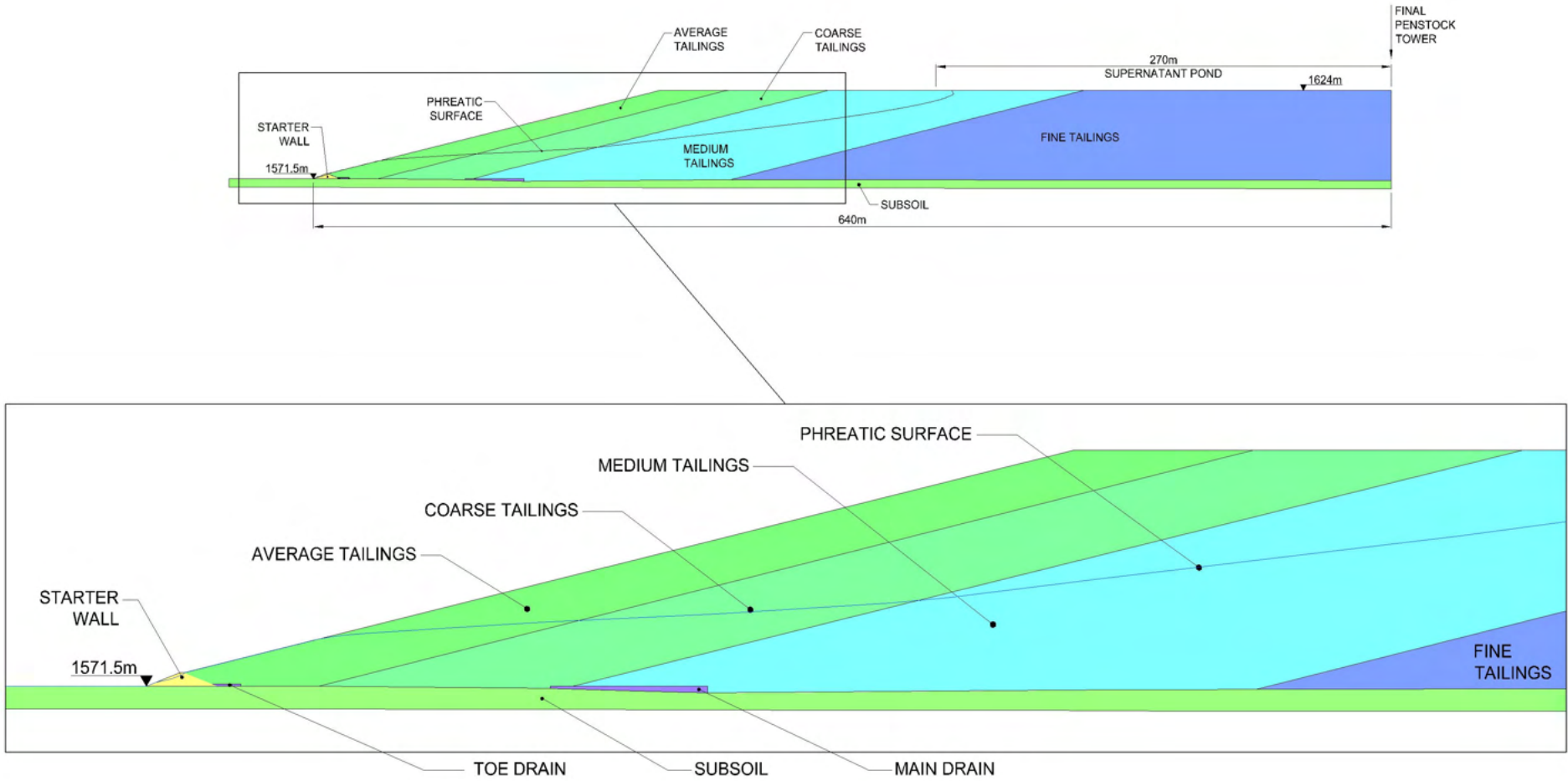


FIGURE 12: SECTION 2 - MAIN DRAIN FAILURE

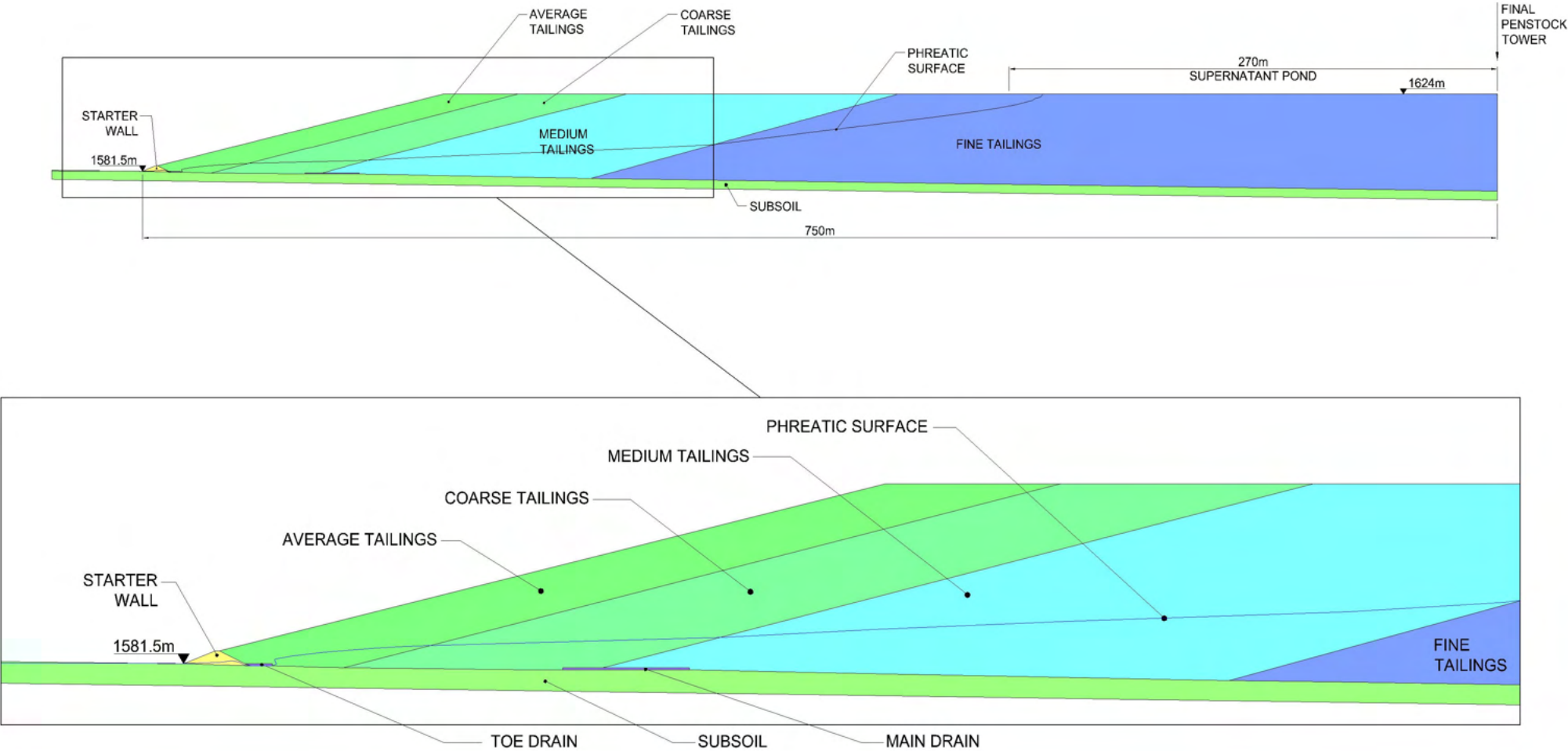


FIGURE 13: SECTION 3 - MAIN DRAIN FAILURE

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**APPENDIX 5: SLOPE STABILITY ANALYSIS FOR THE PROPOSED DOORNPPOORT TAILINGS
DAM AT SOUTH DEEP MINE**

Metago

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SLOPE STABILITY ANALYSIS FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

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SLOPE STABILITY ANALYSIS FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

1. INTRODUCTION

Metago Environmental Engineers (Pty) Ltd (Metago) in a joint venture with Golder and Associates Africa (GAA) were appointed by South Deep Mine to conduct the detailed design of a new tailings dam for the South Deep operation. The site selected for the new dam is referred to as Site 5 and is located on the farm Doornpoort. This report comprises an Appendix report to the detailed design report and documents the stability analyses conducted to confirm the design geometry of the proposed tailings dam.

2-dimensional limit state equilibrium modelling was undertaken for representative sections through the impoundment. The modelling assesses the intrinsic stability of the slope under selected operating conditions. The model was used to predict the stability of the proposed tailings storage facility based on the information concerning material strength parameters and soil profiles as documented in the geotechnical report (Golders Report No. 10307/10319/14/G of September 2007). The Chamber of Mines Guideline (1996) was used to benchmark the modelled safety factors against published guideline values.

The modelling uses the results of the seepage analyses to determine the likely location of the phreatic surface under various conditions considered. The seepage analyses are documented in Appendix Report A4 (Metago Report G001-02, August

2008). This report should be read together with the seepage report and the geotechnical report.

2. TERMS OF REFERENCE

The terms of reference of the analyses are as follows:

- Identify the slope sections that represent the highest risk both for the tailings storage facility (“TSF”);
- Analyse the effect of the founding materials on the stability of the tailings dam;
- Calculate the safety factor for the critical section under normal operating conditions and under realistic adverse operations (e.g. large supernatant pond); and
- Develop design recommendations that will ensure the stability of the slope for the life of the facility, particularly under adverse conditions.



FIGURE 1: SITE LAYOUT

3. SLOPE STABILITY MODEL DEFINITION AND METHODOLOGY

3.1. METHOD OF ANALYSIS

The slope stability was quantified using a safety factor calculated using SLOPE/W version 6.22, which is a Windows based software programme that uses a variety of 2-Dimensional user selected limit equilibrium methods. The software first calculates a deterministic solution, i.e. finding the minimum factor of safety without taking the variability of material properties into account. Secondly, the failure plane identified by the minimum factor of safety is then used to perform a probabilistic analysis, using the Monte Carlo process, to account for variability in material properties. This process takes random values from user specified intervals for the material properties (i.e. relative density, cohesion and friction angle) and calculates a factor of safety for the generated combination of properties. This step is repeated thousands of times, generating a spread of safety factors, from where a mean factor of safety and probability of failure (a factor of safety less than 1) can be computed. For the relevant failure plane, the deterministic minimum factor of safety and the probabilistic mean factor of safety are theoretically identical, and practically (due to computational restraints) very similar.

For this project, the Morgenstern-Price (with Half-Sine side function) method was used in the analysis. This method generates a factor of safety satisfying both horizontal and moment equilibria, and is hence a more accurate representation of the actual situation than the Ordinary, Bishop or Janbu methods.

For more information on the software algorithms, the reader is referred to the SLOPE/W online help and manual.

3.2. GEOMETRY

The final crest elevation of the tailings dam was set to be 1624mamsl, which is the maximum design elevation. Three sections were selected to allow a realistic analysis of the entire dam. The locations of the sections chosen for the analysis (shown in Figure 1) are as follows:

- Section 1 passes through the embankment at the point where the outer slope will ultimately be at its highest, to the location of the final penstock tower (Figure 2);
- Section 2 was taken from the final penstock tower to the closest point on the outer toeline (Figure 3); and
- Section 3 passes from the final penstock tower to the northern side of the dam (Figure 4).

The sections through the tailings were assigned different geotechnical properties based on experience, to more realistically model the variation of permeability resulting from the depositional profile.

The starter wall will be constructed with residual andesite present on the site. The starter wall is to be founded on the ferricrete horizon, where present. In the locations where the ferricrete layer is not present, the base material should be ripped and compacted. The majority of the footprint of the proposed TSF is underlain by andesite according to the geotechnical investigation.

In all cases the outer slope of the tailings dam was kept at an average of 1:4 and the outer embankment of the starter wall has a slope of 1:2. The outer slope of the dam is to be covered with a 1m layer of well vegetated topsoil from the basin of the site, but the topsoil layer was excluded from the stability analyses.

Both the traditional circular and block failure methods were analysed, and the slip surface optimisation process was utilised. This optimisation is applied once the critical slip surface has been found, by dividing the slip surface into a number of straight-line segments. SLOPE/W then looks for a lower factor of safety by moving the end points of the segments backwards and forwards until the lowest factor of safety is found. The optimisation then splits the longest segment in half and repeats the process until the lowest factor of safety has been found, or the factor of safety is within a specified tolerance.

3.3. PHREATIC SURFACE AND DRAINS

The phreatic surface assumed in the analysis was based on the outcome of seepage modelling documented in Appendix Report A4. The following phreatic surface conditions were analysed:

- Normal Pond Operation - Phreatic surface corresponding to normal operating conditions with the supernatant pond centrally located on the dam and with the pond covering approximately 10% of the top surface area. This corresponds to a supernatant pond size stretching a distance of 270m from the penstock tower; and
- Upset Conditions - Phreatic surface corresponds to the supernatant pond encroaching to within 30m of the crest for all of the Sections. This enlarged pond was modelled on the basis that this condition would exist for an extended period, typically more than one month, thereby allowing a phreatic surface to develop steady state conditions as documented in the seepage report. Various combinations of drain failures, some including the enlarged pond, were also modelled.

In all of the seepage analyses, a 5m wide toe drain was assumed to exist immediately upstream of the starter wall. The modelling of the main drain was assumed to be as follows:

- Section 1: 25m wide, and located 180m from the outer toeline;
- Section 2: 35m wide, and located 90m from the outer toeline; and
- Section 3: 30m wide, and located 90m from the outer toeline.

A 0.4m wide, 3.0m high, cutoff drain was also modelled in the centre of the starter wall for Section 1.

The tailings dam was assumed to be underlain by a subsoil layer, which has the same geotechnical properties as the starter wall.

3.4. MATERIAL PARAMETERS

The soil parameters (Table 1) used in the model were sourced from the geotechnical report.

The sample of ferricrete was excluded from the parameter calculations (mean, standard deviation, etc.) for the following reasons:

- The ferricrete horizon varies greatly over the site, and where present is generally between 0.2m and 0.9m, which is not representative of the average sample. This would consequently skew the calculation; and
- The ferricrete will be used when a higher grade of material is required elsewhere on site (e.g. construction of the access roads).

The number of Monte Carlo trials (described earlier) is a function of the number of variables (i.e. number of soils and properties of each soil) and the reliability required of the statistical results. For this analysis 10 000 trials were run, which gives a reliable statistical result regarding mean safety factors and failure probabilities.

TABLE 1: MATERIAL PARAMETERS

	UNIT WEIGHT				FRICTION ANGLE				COHESION			
	γ (kN/m ³)				ϕ (DEGREES)				c (kPa)			
	MIN	MEAN	MAX	SD	MIN	MEAN	MAX	SD	MIN	MEAN	MAX	SD
Starter Wall	15.1	17.4	19.7	0.46	3.4	31.4	62.4	6.2	0	14	79.5	13.1
Subsoil Layer	15.1	17.4	19.7	0.46	3.4	31.4	62.4	6.2	0	14	79.5	13.1
Average Tailings	16.15	18.25	20.35	0.42	0	28	70	8.4	N/A	0	N/A	N/A
Coarse Tailings	16.15	18.25	20.35	0.42	0	28	70	8.4	N/A	0	N/A	N/A
Medium Tailings	16.15	18.25	20.35	0.42	0	28	70	8.4	N/A	0	N/A	N/A
Fine Tailings	16.15	18.25	20.35	0.42	0	28	70	8.4	N/A	0	N/A	N/A
Filter Sand	9.33	19.13	28.93	1.96	13	38	63	5	N/A	0	N/A	N/A

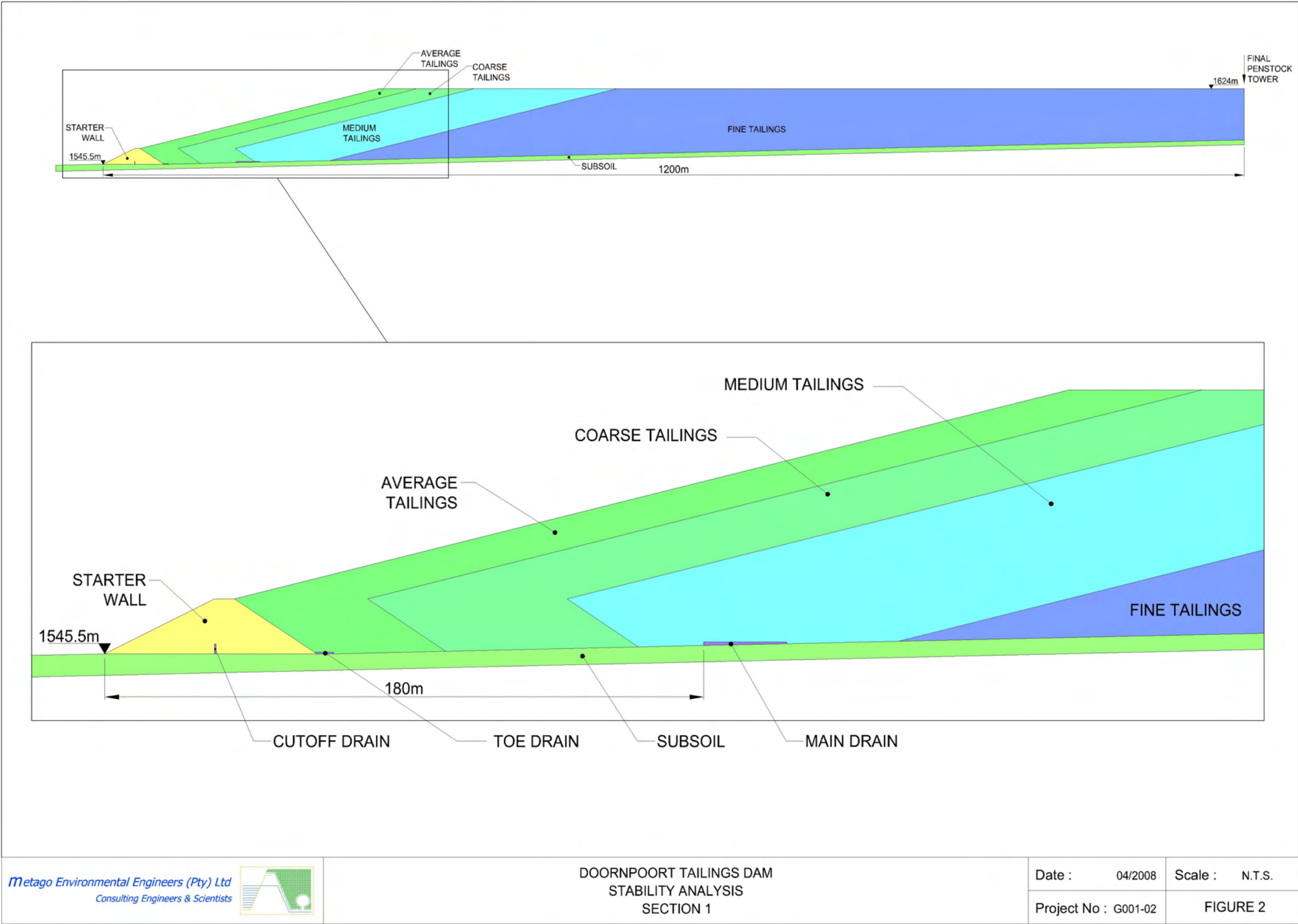


FIGURE 2: SECTION 1

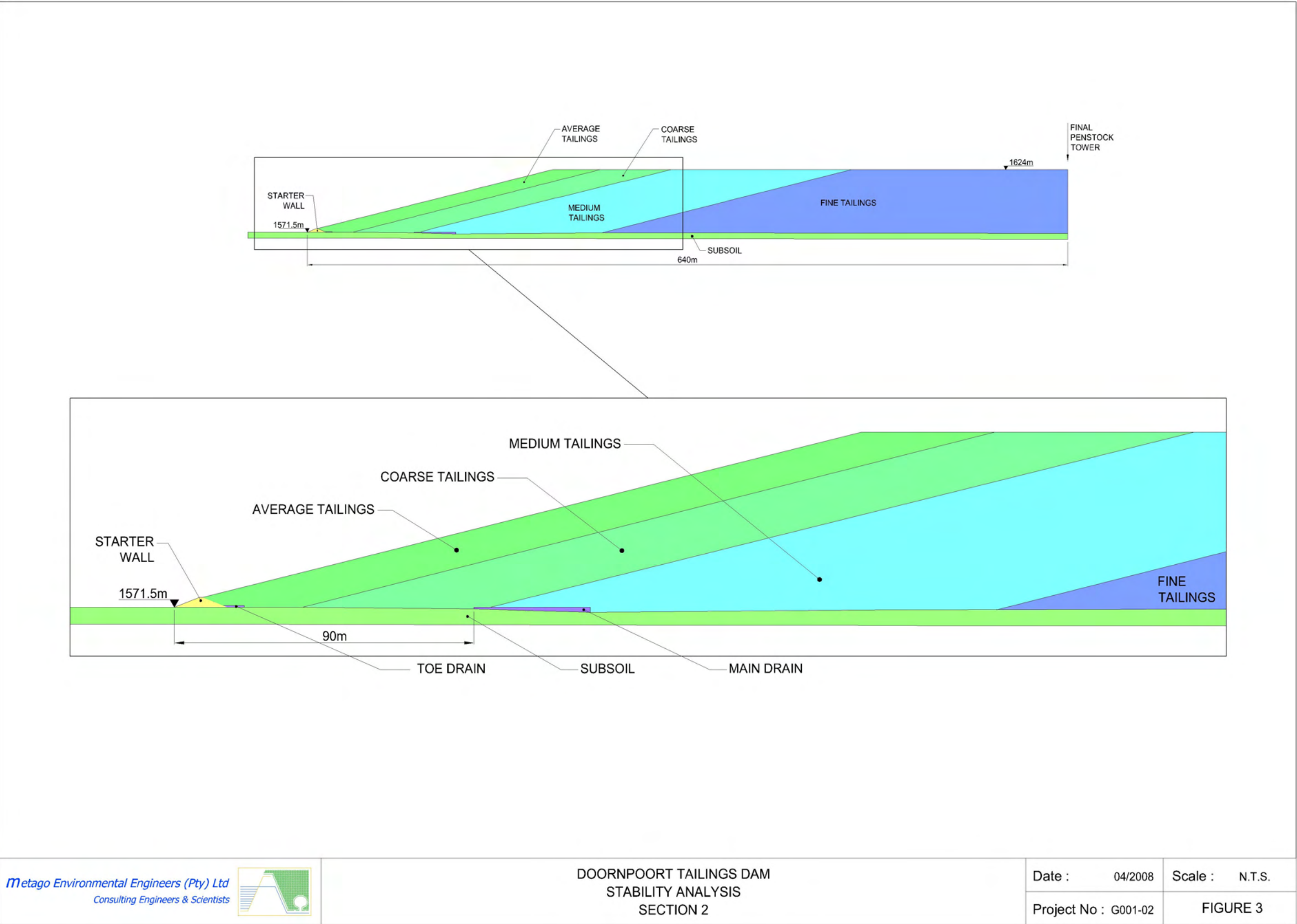


FIGURE 3: SECTION 2

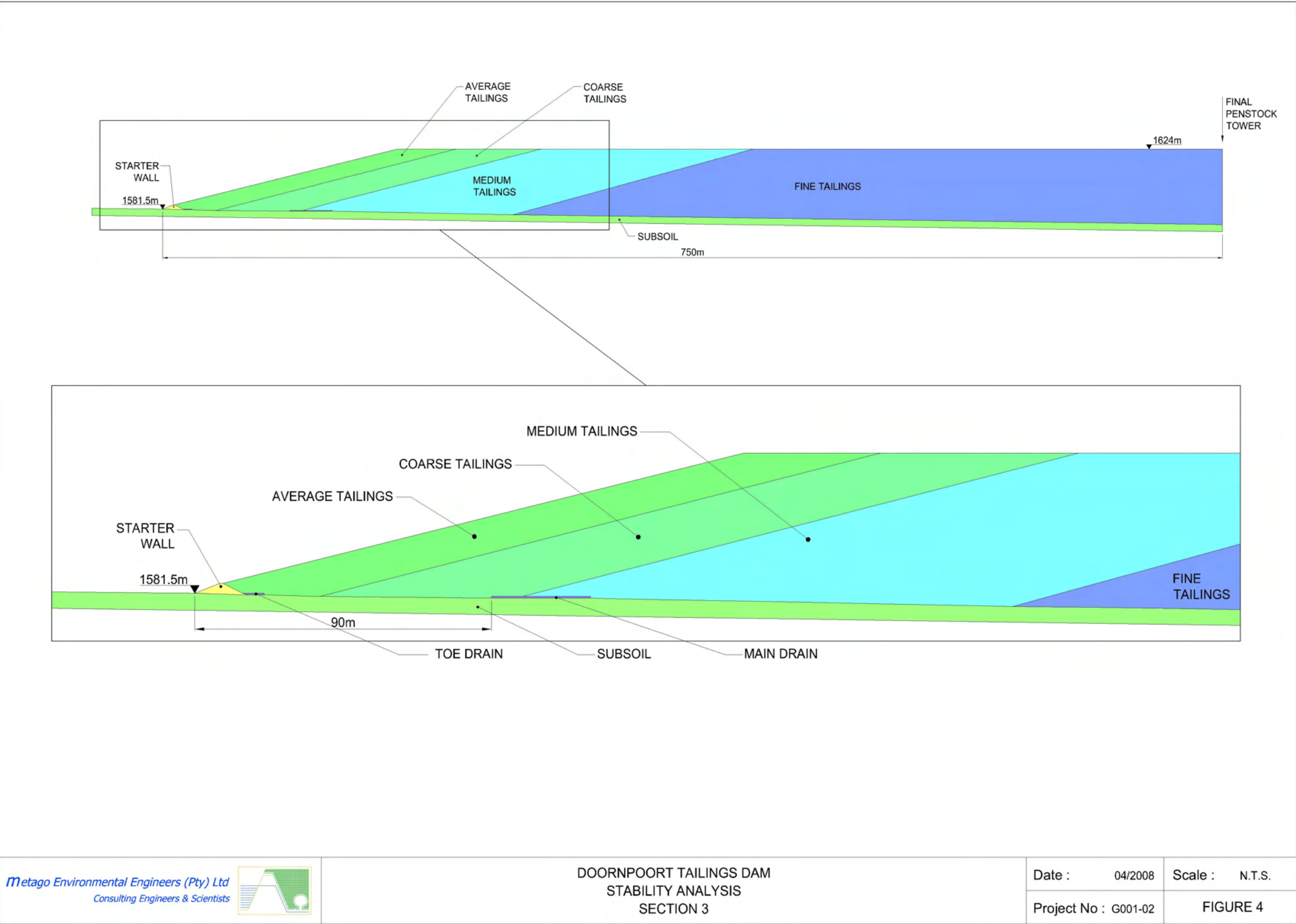


FIGURE 4: SECTION 3

4. ACCEPTABLE FACTOR OF SAFETY AND PROBABILITY OF FAILURE

The Chamber of Mines Guidelines (1996) recommends the following criteria for side slope stability:

- The factor of safety (FOS) should be greater than 1.3 for regularly monitored tailings dams; and
- The factor of safety should be greater than 1.5 for an abandoned side slope, e.g. tailings dams at closure.

However, the deterministic approach in finding the factor of safety fails to account for the variability in material properties, which may affect the stability of slopes to a large extent. Hence, a probabilistic analysis is also done, as described earlier.

The risk (i.e. probability of failure) that can be tolerated is the prerogative of the stakeholders concerned. This risk tolerance may differ between the operational and closure phases of a tailings facility.

Guidelines for acceptable failure probabilities for side slopes are documented in Cole (1993). These guidelines indicate that the failure probability should

- not exceed 0.07% (1 : 1 430) for short-term slopes;
- not exceed 0.007% (1 : 14 300) for medium-term (semi-permanent) slopes; and
- not exceed 0.0007% (1 : 143 000) for long-term slopes (i.e. tailings dams at closure).

Metago are of the opinion that the mine should adopt a maximum acceptable failure probability of 0.001% (i.e. failure probability < 1:100 000) for the operational phase of the Doornpoort Tailings Dam.

5. RESULTS

The results of the analyses are presented in Table 2. The results show that during normal operations, with the drains all operating normally and the pool covering 10% of the top surface area, the TSF side slope is adequately stable with safety factors above the recommended safety factor of 1.3, based on the average strength parameters assumed.

TABLE 2: SLOPE STABILITY ANALYSES RESULTS

SECTION	OPERATING CONDITIONS	FAILURE MODE	MAX FACTOR OF SAFETY	MEAN FACTOR OF SAFETY	MIN FACTOR OF SAFETY	PROBABILITY OF FAILURE	FIGURE
1	Normal	Block (Optimised)	2.44	2.04	1.68	<1:100 000	Figure 6
1	Normal	Circular (Optimised)	2.39	2.04	1.67	<1:100 000	Figure 7
2	Normal	Circular (Optimised)	2.93	2.19	1.62	<1:100 000	Figure 8
3	Normal	Circular (Optimised)	2.89	2.19	1.65	<1:100 000	Figure 9
1	Upset – Large Supernatant Pond	Circular (Optimised)	2.24	1.80	1.46	<1:100 000	Figure 10
1	Upset – Main Drain Failure	Circular (Optimised)	2.37	2.02	1.69	<1:100 000	Figure 11

Under normal operating conditions, where the phreatic surface is towards the centre of the tailings mass, the resulting safety factors, which range from 1.643 to 2.426, indicate that the slope is stable irrespective of the failure mode that is chosen.

The scenarios which resulted in the shallow slip surface occurring on the 1:4 tailings slope give safety factors ranging from 1.75 to 2.93. However, these scenarios do not give a significant failure surface, and so can be ignored in terms of their factor of safety, as their resulting failure profile will be more influenced by erosion than a shallow slip failure.

6. DISCUSSION

Generally, failures do not arise because of a single fault but usually because of a series of faults acting together. Figure 5 illustrates how a series of initiating events could give rise to failure of the proposed tailings dam. Usually, dams fail because of either:

- Overtopping of the embankment;
- Classical slip circle or wedge type failures; or
- Piping failure in which a “pipe” forms beneath the surface of the dam because of internal erosion of tailings material, this enlarges rapidly ultimately forming a conduit between the supernatant pond and the edge of the dam.

Any of the above faults can give rise to a flow slide caused by liquefaction of a significant portion of the dam material. The consequence of a flow slide is often catastrophic as it affects a significant area downstream of the dam.

The key variables that affect the stability of this dam are as follows:

- The location of the phreatic surface: Increasing the pore pressure along the failure surface reduces the effective shear strength along the failure surface;
- The strength of the materials through which a failure surface passes; or
- The bulk density of materials above the failure surface: As materials become wet their density increases.

From Figure 5 it is clear that the distance from the pond edge to the embankment is a critical factor in determining the risk of failure. Except when the pond is within 30m of the crest (Section 1), the seepage analyses showed that the drains effectively draw down the phreatic surface to the extent that there is no daylighting on the side slope of the starter wall or tailings material.

The overtopping failure risk can be mitigated through the timeous construction of dam lifts. This in turn requires that the shear strength and trafficability of the material over which construction activities are to take place is sufficient to allow this activity. The design is based on a maximum rate of rise of 1.6 m/yr, which based on experience, is considered adequate to achieve acceptable shear strength for construction purposes.

As a result of the inclusion of a geotextile separation layer, in the form of a Sealmac layer between the tailings and the 1m layer of topsoil, the risk of piping should be mitigated. However, the same layer may prevent daylighting of the phreatic surface beneath the cover from being observed. This means that monitoring of piezometers and drain flows will be critical in terms of assessing the condition of the phreatic surface within the dam.

The construction phase will need to include monitoring of the material strength parameters to ensure that material variability was sufficiently accounted for in the design.

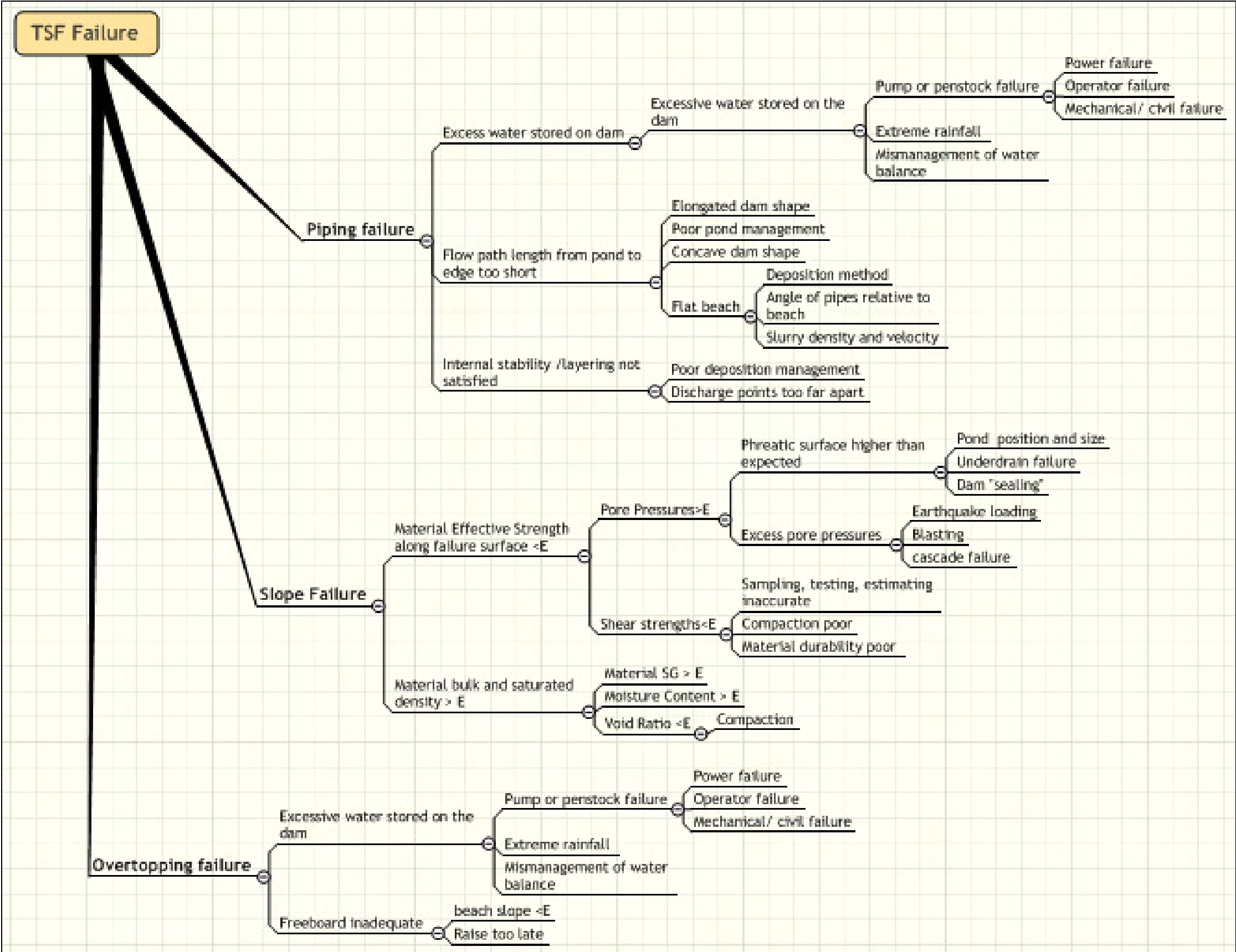


FIGURE 5: TAILINGS DAM FAILURE FAULT TREE

7. CONCLUSIONS

From the analyses, it can be concluded that:

- The results indicate that the slope is stable with respect to the guidelines, i.e. a safety factor greater than 1.3, (Chamber of Mines 1996) under normal operating conditions. Under normal operating conditions, the factor of safety is at least 1.64;
- Under the conditions where the phreatic surface daylights (as shown in Figure 10), the factor of safety is still above the minimum value recommended by the Chamber of Mines Guidelines of 1.3; and
- The Sealmac layer is expected to mitigate the risk of piping failure of the dam, but could also mask any daylighting of the phreatic surface, caused by preferential flow paths;

8. RECOMMENDATIONS

The following recommendations are made with respect to the slope stability:

- The pond size should be minimised at all times through correct operation of the penstock rings and return water system;
- The risk of formation of preferential flow paths leading to daylighting beneath the composite cover will need to be monitored during the operational phase of the TSF. Use should be made of piezometers in combination with the usual monitoring of drain flow rates. The different drains have separate drain outfall pipes to determine which drain (toe, cutoff or maindrain) is collecting water)
- The bill of quantities has included provision for a boxcut beneath the starter wall. During construction it will be necessary to confirm the founding conditions and provided that the properties of the founding materials exceed the average shear strength parameters assumed, the boxcut depth may in consultation with Metago be adjusted.

9. REFERENCES

Chamber of Mines 1996, Guidelines for Environmental Protection, The Engineering design, operation and closure of Metalliferous, Diamond and Coal Residue Deposits, volume 1/1976 (Revised 1983 and 1995)

Cole, K., 1993, Building over Abandoned Shallow Mines. Paper 1: Considerations of Risk and Reliability, Ground Engineering, pp 35 – 37

Golders Report No. 10307/10319/14/G, South Deep Gold Mine Geotechnical Investigation for the Proposed Tailings Storage Facility, September 2007

Metago Report G001-02 Appendix Report A4, Seepage Analysis for the Proposed Tailings Storage Facility, South Deep Gold Mine, March 2008

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Reviewer

Metago Environmental Engineers (Pty) Ltd

APPENDIX A: NORMAL OPERATING CONDITIONS FOR ALL SECTIONS

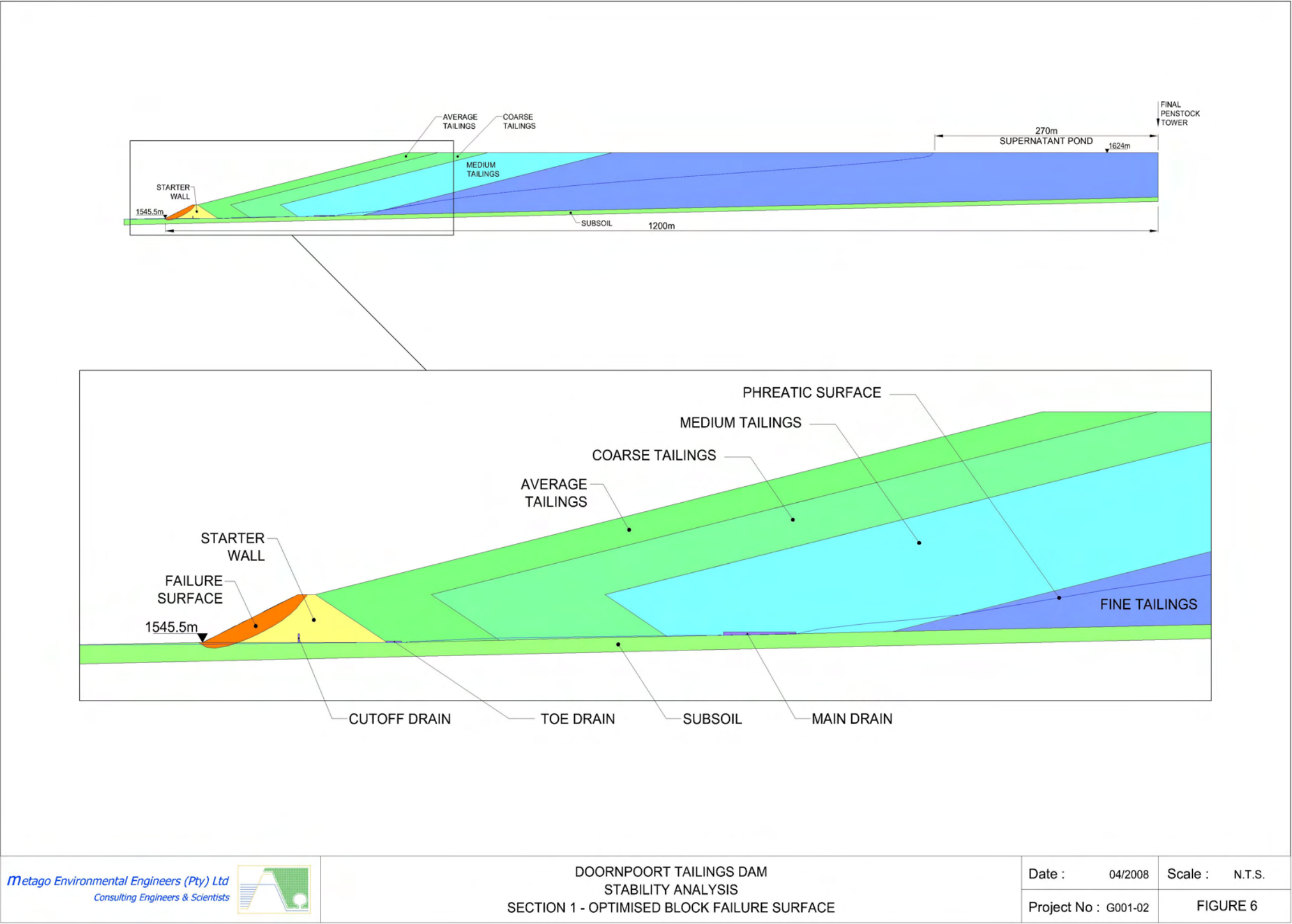


FIGURE 6: SECTION 1 - OPTIMISED BLOCK FAILURE SURFACE

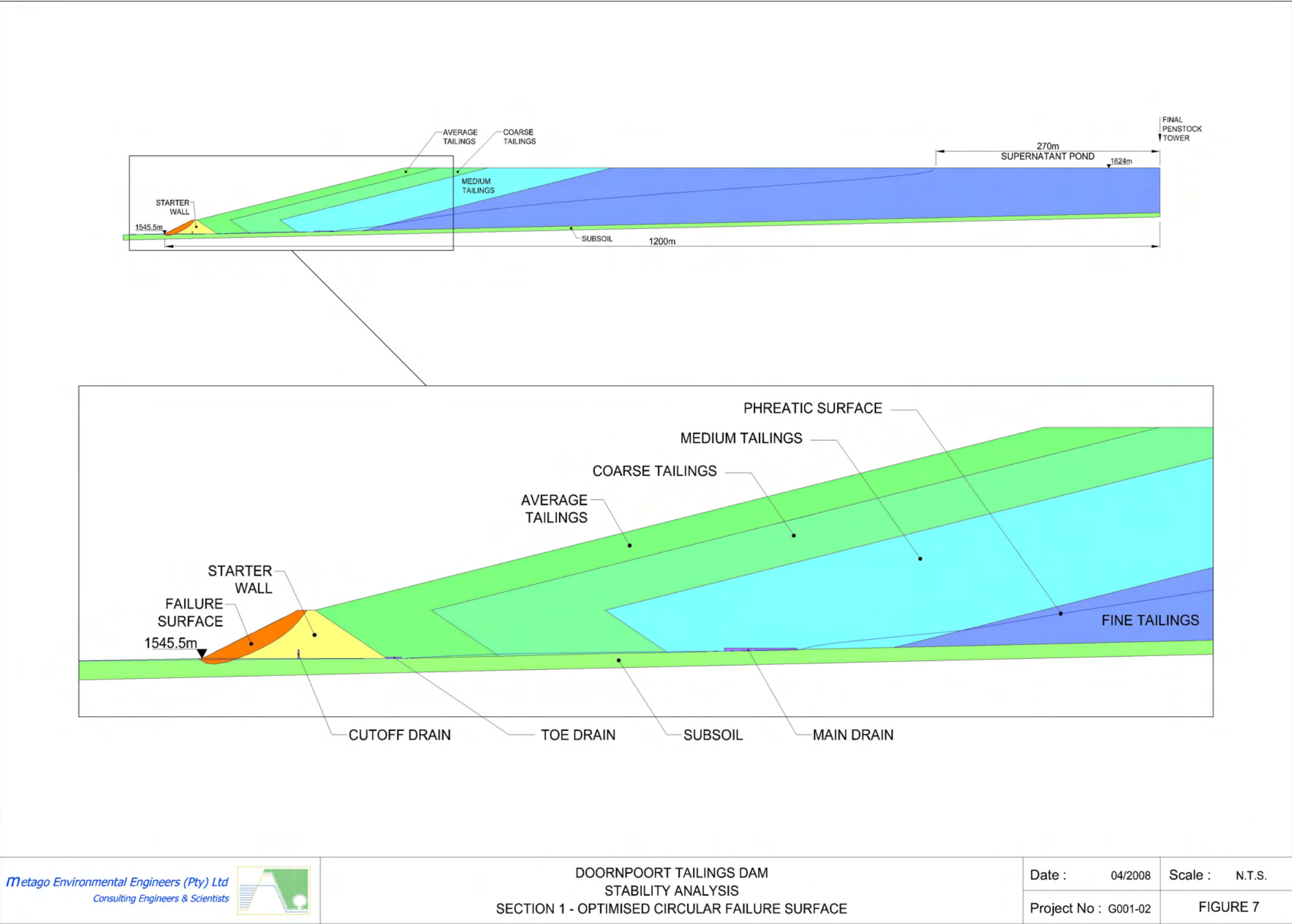
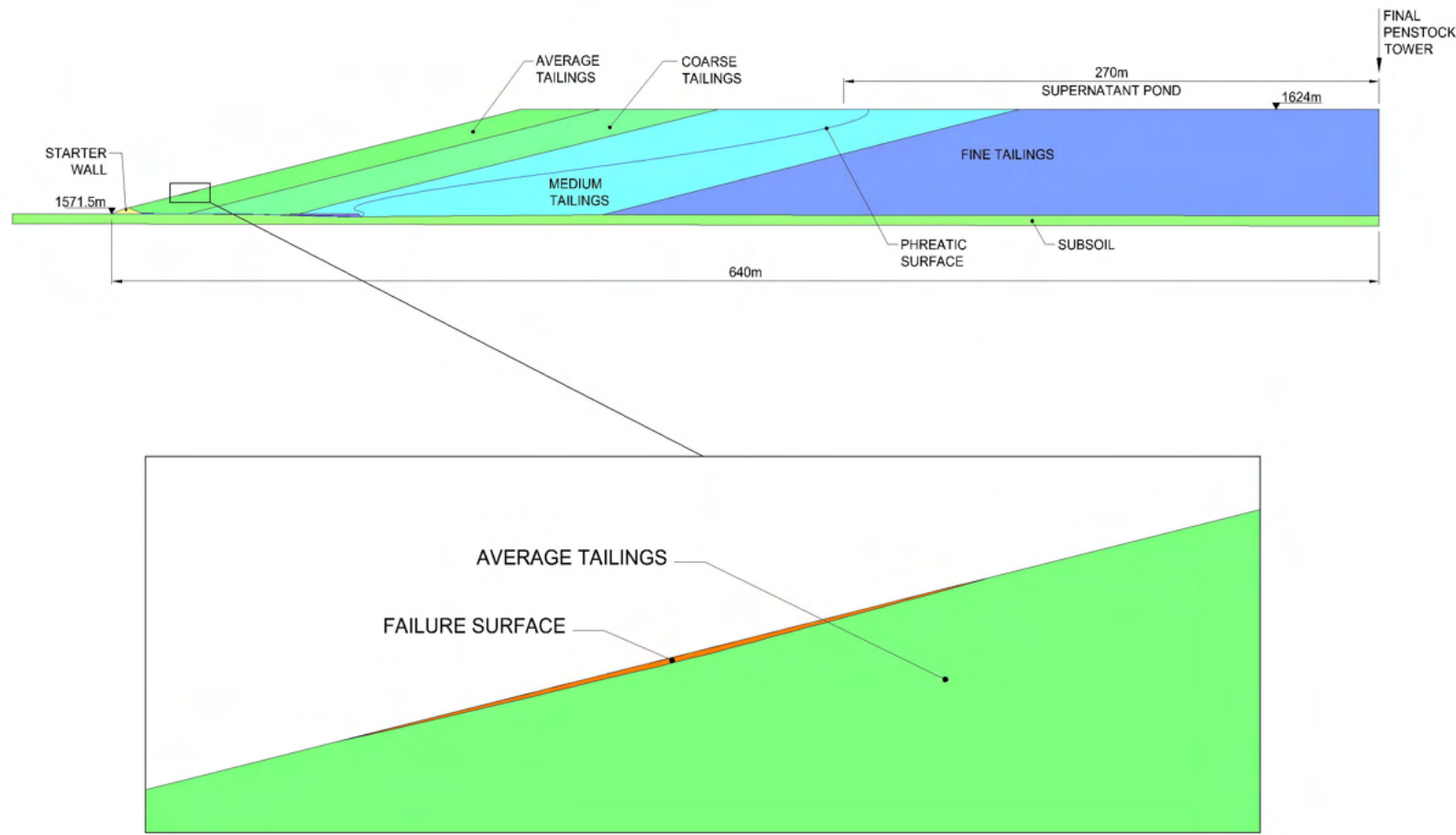
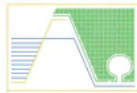


FIGURE 7: SECTION 1 - OPTIMISED CIRCULAR FAILURE SURFACE



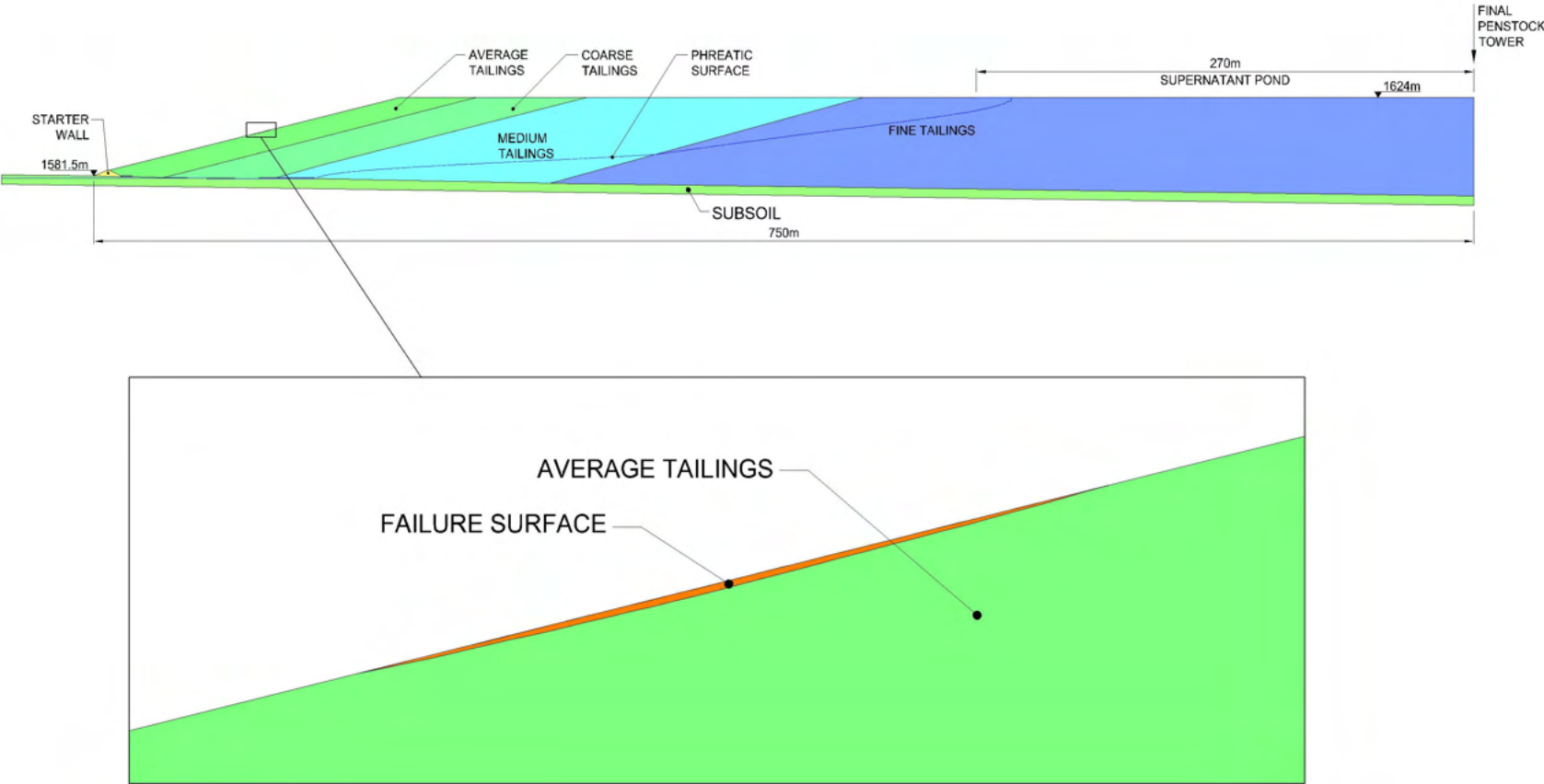
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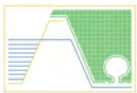
DOORNPOORT TAILINGS DAM
STABILITY ANALYSIS
SECTION 2 - OPTIMISED CIRCULAR FAILURE SURFACE

Date :	04/2008	Scale :	N.T.S.
Project No :	G001-02		FIGURE 8

FIGURE 8: SECTION 2 - OPTIMISED CIRCULAR FAILURE SURFACE



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DOORNPOORT TAILINGS DAM
STABILITY ANALYSIS
SECTION 3 - OPTIMISED CIRCULAR FAILURE SURFACE

Date :	04/2008	Scale :	N.T.S.
Project No :	G001-02		FIGURE 9

FIGURE 9: SECTION 3 - OPTIMISED CIRCULAR FAILURE SURFACE

APPENDIX B: UPSET CONDITIONS FOR SECTION 1

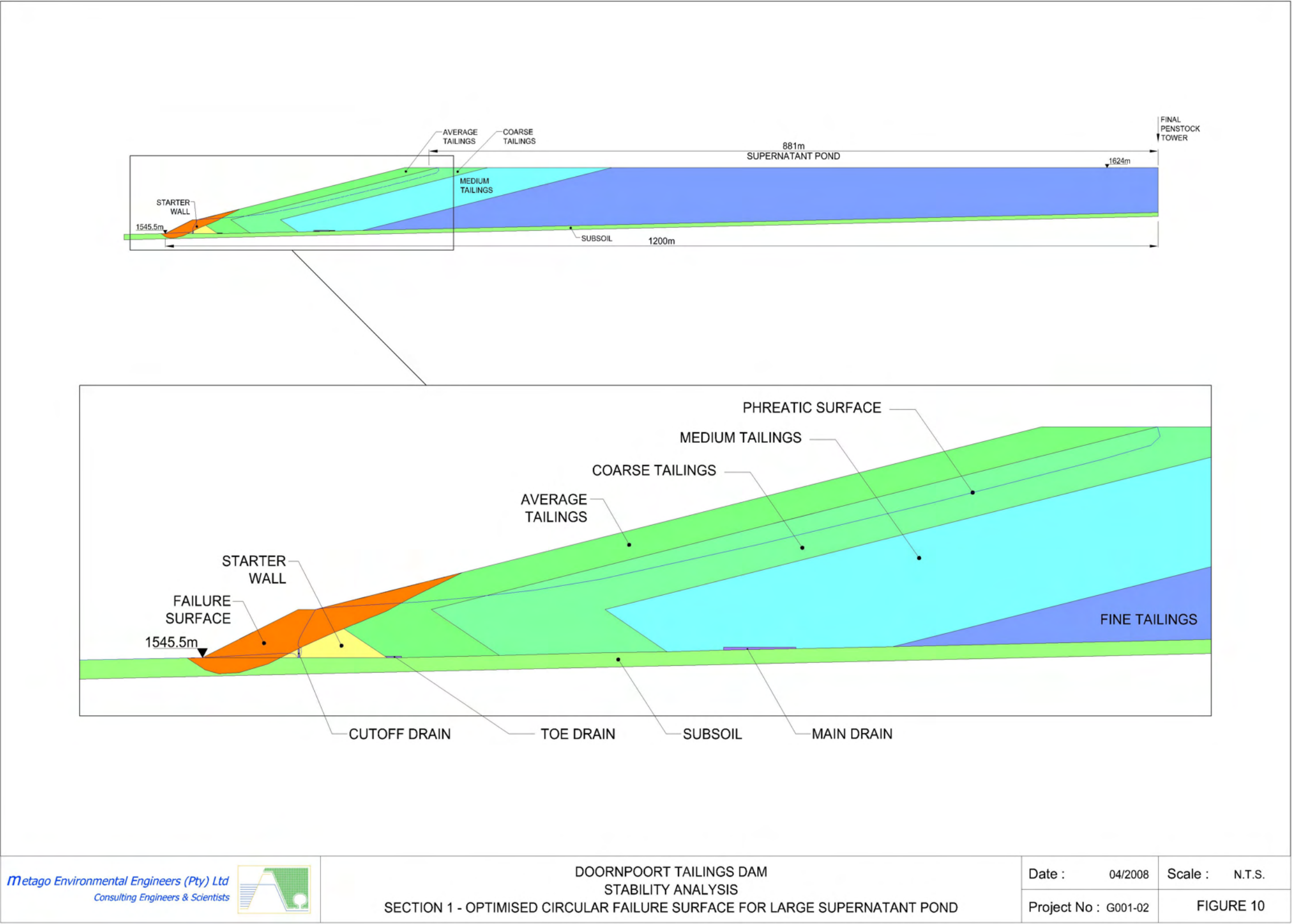


FIGURE 10: SECTION 1 - OPTIMISED CIRCULAR FAILURE SURFACE FOR LARGE SUPERNATANT POND

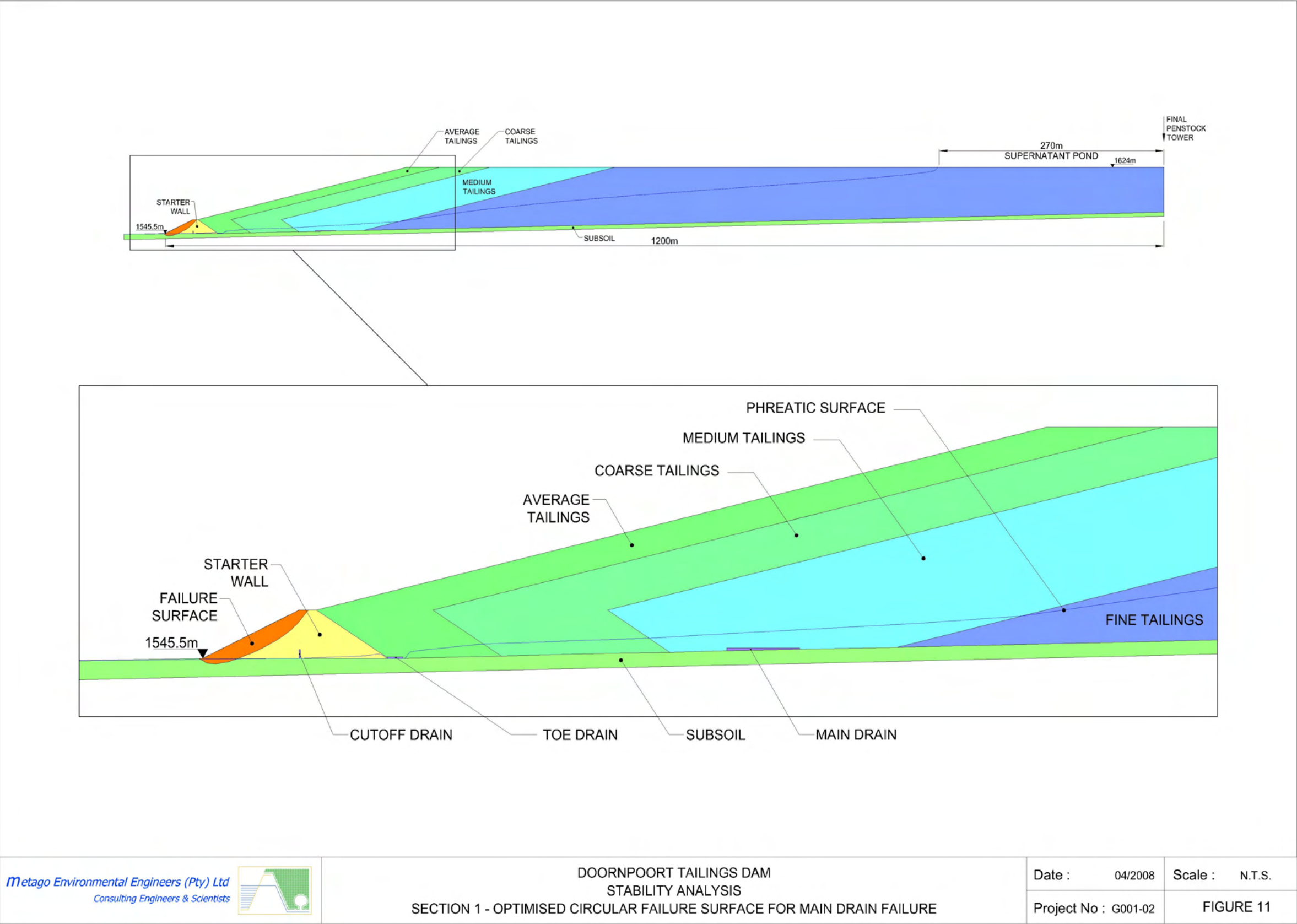


FIGURE 11: SECTION 1 - OPTIMISED CIRCULAR FAILURE SURFACE FOR MAIN DRAIN FAILURE

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APPENDIX 6: EROSION MODELLING FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

Metago

Environmental Engineers (Pty) Ltd



EROSION MODELLING FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

Prepared For

South Deep Gold Mine

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Project No. G001-02

August 2008

Report No. A6

EROSION MODELLING FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

1. INTRODUCTION

The Erosion Modelling Report forms part of the detailed design of the proposed Doornpoort Tailings Storage Facility (TSF) for South Deep Mine.

This report describes the landscape evolution modelling undertaken to select the geometry of the final side slope of the Doornpoort tailings storage facility ("TSF").

2. BACKGROUND INFORMATION

A major design consideration of the new Doornpoort Tailings Dam was the sustainability of the vegetation cover in the post closure period and the aftercare costs associated with the management of impacts such as surface water erosion, dust and land capability.

The most common approach used to date in the Witwatersrand gold and uranium tailings dams has been to construct a ring dyke using the tailings material by building a perimeter wall (daywall) to create freeboard. These dams are generally either vegetated directly or protected in some other way to reduce wind and water erosion rates, such as through the application of a waste rock cover. The side slopes were generally constructed with step-ins of approximately 4 m width at 4 m vertical intervals resulting in an average 1 : 3 side slopes and 1 : 2.125 intermediate slopes.

The acid generating tailings was then leached for a limited period using an irrigation system with vegetation then being established directly on the tailings surface.

In Metago's opinion, based on observation of a number of these dams on the Witwatersrand over many years, this approach is not sustainable and typically fails within 10 to 15 years of ceasing to actively manage the slopes and vegetation for the following reasons:

- The step-in's require ongoing frequent maintenance to avoid the development of major erosion gullies which channel water to localised points which then initiates the development of massive erosion gullies.
- The tailings becomes toxic to the vegetation over time due to the capillary rise of products of acid generation.
- The rate of erosion increases to the extent that nutrients are lost from the soil faster than they are made available to the vegetation cover.

The downward spiral of degradation of the vegetation cover and acceleration of erosion is illustrated in Figure 2-1.

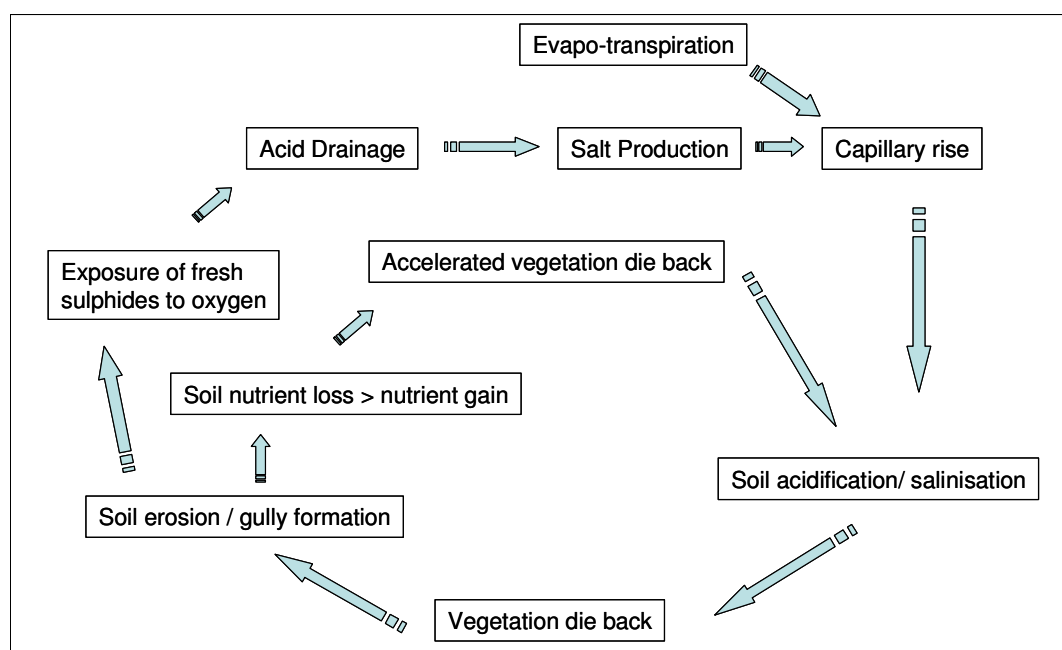


FIGURE 2-1: FAILURE SPIRAL FOR DIRECTLY VEGETATED ACID GOLD TAILINGS DAMS

This problem has been recognised for many years and various attempts to change the way in which tailings dams are rehabilitated have been made. The most successful of these to date has been the application of various forms of rock cladding to reduce the tailings erosion rate and dust emissions. While the rock generally forms a sterile and inhospitable environment for plants and animals it does assist in reducing dust emissions and sediment emissions significantly. Erosion of the tailings still occurs and the solution still requires maintenance. The step-ins on the tailings dam side slopes still present a problem with respect to long term erosion and the risk of gully formation.

Metago has found through the application of landscape evolution models (which simulate the development of the eroded landscape over time), that step-ins generally do not work unless the edge berm of the step-in is made significantly more robust, than has been the case on South Africa's gold tailings dams. Small step-ins inevitably fill up with sediment causing the stormwater runoff on the step in to eventually overtop the crest which leads to the development of a major erosion gully.

The lack of vegetation on the rock clad side slope presents a problem from a closure perspective as this implies that the land capability is reduced to virtually zero, at least with respect to the side slopes. The rock clad solution also results in continued degradation of surface water quality as there is no significant reduction in the acid generation and salt production rate. The closure target for the South Deep Doornpoort dam was to achieve a runoff quality that is not significantly different from the runoff quality from undisturbed land. A second objective was to achieve a level of biodiversity over the tailings dam that was equivalent to that of a similar tract of undisturbed land. Hence it was necessary to design a slope that was capable of supporting vegetation indefinitely with minimal ongoing maintenance, which would give rise to essentially clean runoff suitable for discharge to the environment.

This investigation compares the erosion rate from three alternative hypothetical slope geometries. All slopes are assumed to be soil clad and vegetated. The capacity of the tailings dam remains the same for each option considered by maintaining the same average slope of 1V:4H.

For each case, it is assumed that a 1m thick soil layer is to be placed on top of a low permeability geomembrane which is placed over the tailings. The soil cover is assumed to be vegetated with a level of biodiversity commensurate with that which would be observed on similar natural slopes in the area.

The effect of the composite cover is as follows:

- It reduces the oxygen flux into the underlying tailings, thereby reducing the rate of production of acid generation products;
- It reduces the rate of infiltration into the tailings thereby reducing the mobility of acid generation products both downwards, (under gravity as a wetting front) and upwards (through evapotranspiration). This in turn improves the runoff quality from the side slope; and
- It reduces the overall erosion rate due to the increased cohesiveness of the natural soil cover compared to the tailings.

The investigation seeks to obtain an indication of the relative performance of the alternative slope profiles in terms of water erosion over the long term. To this end a long term erosion simulation programme, SIBERIA, has been applied to the alternative slope profiles which have been generated in 3D digital terrain models and exported into SIBERIA. Erosion parameters derived from erosion testing of soil covers at other mines have been applied in the simulations. From the results, an indication of the potential performance of the decommissioning proposals has been obtained. The results and preferred slope profile are documented in this report.

It is important to note that erosion parameters have been adapted from other mining operations and are not site specific. Since there can be significant variation in these parameters depending on the particle size distribution of the soil and climatic conditions, the results of the landscape evolution modelling can be considered indicative only. Their primary use of the results of this investigation will be to decide on the relative benefits of the different slope profiles modelled. The traditional tailings dam construction method has not been modelled using the landscape evolution model SIBERIA, but erosion rates have been calculated using the Universal Soil Loss Equation.

3. TERMS OF REFERENCE

The terms of reference for this report were as follows:

- Draw on available data from other mining operations to assess potential erosion parameters;
- Carry out long-term erosion modelling using existing digital terrain data and the program SIBERIA, on three different candidate slope profiles;
- Based on the results of the erosion modelling, recommend a preferred slope profile; and
- Document the above in a report.

4. AVAILABLE INFORMATION

The following information has been provided for application in the modelling:

- Layouts of the proposed tailings dam including digital terrain data;
- Plans and sections through the proposed tailings dam indicating the proposed slope profiles after decommissioning; and
- Rainfall and evaporation data as supplied by the Weather Bureau in South Africa.

5. CANDIDATE SLOPES

Figure 5-1 to Figure 5-4 illustrate the candidate slopes considered in this investigation, and compares them with the typical conventional slope geometry used on gold tailings dams in South Africa. Table 5-1 summarises the geometries of the candidate slopes.

FIGURE 5-1: CONSTANT SLOPE

FIGURE 5-2: TWO STEP-INS

FIGURE 5-3: ONE STEP-IN

FIGURE 5-4: CONVENTIONAL SLOPE

TABLE 5-1: SUMMARY OF CANDIDATE SLOPES

CANDIDATE SLOPE	HEIGHT (Y)	NUMBER OF STEP-INS	OVERALL SLOPE	INTERMEDIATE SLOPE	WIDTH OF STEP-INS (X)	FIGURE NUMBER
1	80m	0	1 : 4	N/A	N/A	Figure 5-1
2	80m	2	1 : 4	1 : 3.5	25m	Figure 5-2
3	80m	1	1 : 4	1 : 3.8	25m	Figure 5-3
Conventional	80m	20	1 : 3	1 : 2.125	4m	Figure 5-4

6. WATER EROSION RATE PREDICTION

The rate of erosion, measured as a mass of eroded material, removed from a surface over a time period, is dependent on the interaction of many factors as illustrated in the systems diagram shown as Figure 6-1. In the Figure, a solid arrow from one parameter to another indicates that increasing the value of the parameter at the start of the arrow will tend to increase the value of the parameter at the end of the arrow. A dotted arrow indicates that increasing the value of the parameter at the start of the arrow will result in a decrease in the value of the arrow at the end of the arrow. The effect may be non linear. For example, slope length has less effect on the erosion rate than slope angle.

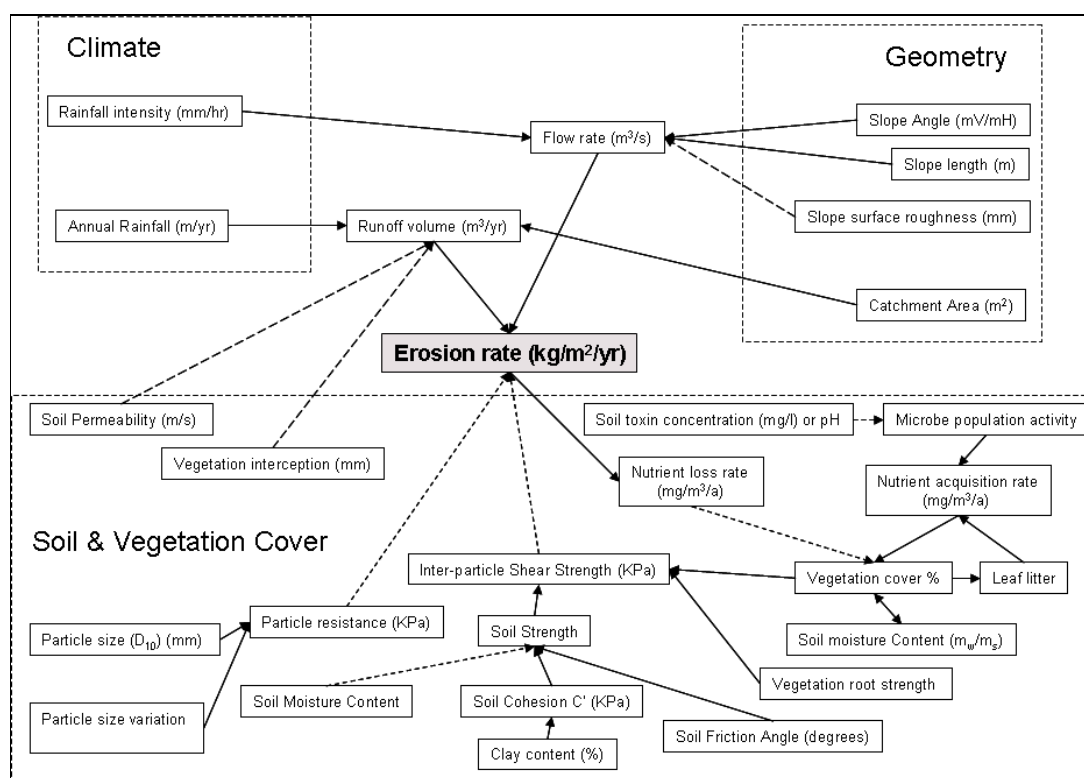


FIGURE 6-1: FACTORS AFFECTING EROSION RATES

Unfortunately, no model exists that can relate all the above parameters into a single equation so most erosion models are either empirical, relying on calibration factors, or consider only a few of the parameters listed above. Empirical models have the inherent risk that they fail to take cognisance of possible variations in certain underlying parameters.

6.1. UNIVERSAL SOIL LOSS EQUATION

The most commonly used model is the Universal Soil Loss Equation (“USLE”) (Refer to Table 13-1) which predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. The USLE model was created for use in selected cropping and management systems, but is also applicable to non-agricultural situations such as the tailings dam side slope. The USLE can be used to

compare soil losses from a particular field with a specific crop and management system/ design approach to "tolerable soil loss" rates.

Five major factors are used to estimate the soil loss for a given slope. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE given below (Equation 1), more accurately represent long-term averages.

EQUATION 1

$$A = R \times K \times LS \times C \times P$$

Where:

A represents the potential long term average annual soil loss (mass per unit area per unit time).

R is the rainfall and runoff factor.

K is the soil erodability factor.

LS is the slope length-gradient factor.

C is the crop/vegetation and management factor.

P is the support practice factor.

Refer to Table 6-1 for the potential long term average annual soil loss calculated from the USLE.

TABLE 6-1: RESULTS FOR CANDIDATE SLOPES FROM USLE

CANDIDATE SLOPE	A (MASS PER UNIT AREA PER UNIT TIME)
1	0.007047
2	0.006735
3	0.006879
Conventional	0.275406

It can be seen from Table 6-1 that the candidate slopes with the overall flatter gradient are more erosion resistant than the steeper conventional slope.

6.2. REVISED UNIVERSAL SOIL LOSS EQUATION

The USLE soil has been improved over the years with additional experimentation and data and has been modified to the Revised Universal Soil Loss Equation ("RUSLE") (Refer to Table 13-1).

EQUATION 2

$$A = R \times K \times L \times S \times C \times P$$

K factor is soil erodability factor which represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. Soils high in clay have low K values, about 0.05 to 0.15, because they resistant to detachment. Coarse textured soils, such as sandy soils, have low K values, about 0.05 to 0.2, because of low runoff even though these soils are easily detached. Medium textured soils, such as the silt loam soils, have a moderate K values, about 0.25 to 0.4, because they are moderately susceptible to detachment and they produce moderate runoff. Soils having a high silt content (such as gold tailings) are most erodible of all soils. They are easily detached; tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.4.

Organic matter reduces erodability because it reduces the susceptibility of the soil to detachment, and it increases infiltration, which reduce runoff and thus erosion.

TABLE 6-2: RESULTS FOR CANDIDATE SLOPES FROM RUSLE

CANDIDATE SLOPE	A (TONS PER ACRE PER YEAR)		
	BARREN TAILINGS	VEGETATED TAILINGS	VEGETATED SOIL
1	43.5	27.2	21.7
2	50.5	31.6	25.3
3	45.8	28.6	22.9
Conventional	129.7	81.1	64.9

Note: Units different to Table 6-1.

It may be concluded from the results in Table 6-1 and Table 6-2 that all the vegetated soil clad slopes significantly outperform the barren and vegetated tailings slopes. It can also be seen that the candidate slopes easily outperform the conventional slope with respect to soil erosion significantly.

The USLE provides a good indication of the average rate of erosion from a particular slope but has the limitation that it cannot predict where the erosion will take place or how the landscape will evolve over time as a result of water erosion processes. Metago has used a landscape evolution software package to compare the candidate slope profiles and evaluate the relative performance of these slopes over the long term. The landscape evolution modelling approach is better suited for the evaluation of the design of step-ins, edge berms, crest berms, etc. The approach is briefly described in the following section.

7. OVERVIEW OF EROSION MODELLING SOFTWARE

SIBERIA is a long term erosion model developed by Willgoose et al in 1989 (Refer to Table 13-1) to explore the linkages between the time evolving geomorphic form of natural landscapes and the hydrology and erosion processes occurring on them, and how these processes, in turn, determine the future evolution of the natural landform. SIBERIA works with a gridded digital terrain model, which evolves in time in response to runoff and erosion derived from physically based erosion models. These models are based on commonly accepted erosion physics, specifically relationships between catchment area and runoff rate such as that typically used in regional flood frequency analysis:

EQUATION 3

$$Q = \beta_3 A^{m_3}$$

Where:

Q is the characteristic discharge out of the catchment;

β_3 is the runoff rate; and

A is the catchment area.

The characteristic discharge is the mean peak discharge.

The erosion model is similar to that used in traditional agricultural sediment transport models where the rate of sediment transport is related to discharge, slope and a transport threshold:

EQUATION 4

$$Q_s = \beta_1 Q^{m_1} S^{n_1} - \text{threshold}$$

Where:

Q_s is the mean annual sedimentation rate;

β_1 is the erodability (including the material erodability, vegetation cover factor and any cropping practice factors (USLE terminology));

S the slope; and

m_1 and n_1 are parameters to be calibrated for the erosion process.

The erosion is relatively insensitive to the exponent n_1 which is commonly taken as 2. The exponent m_1 is modified during calibration to ensure that the concavity of the modelled slope is similar to the prototype. Commonly m_1 is in the range 1 to 1.5. The threshold is a simple allowance for shear stress mobilisation of the material.

The threshold applies to armoured slopes of clean (no fines) or bound materials, which is applicable to South Deep.

Equation 3 and Equation 4 may be combined to yield Equation 5 below:

EQUATION 5

$$Q_s = \beta_1 \beta_3^{m_1} A^{m_1 m_3} S^{n_1} - \text{threshold}$$

Solution of Equation 5 by finite elements at each grid point is affected by SIBERIA to derive the eroded position of the grid point at the end of each time step. This eroded topography is therefore being continuously updated thus enabling the simulation of gully formation.

8. OVERVIEW OF EROSION MODELLING PROCESS

Long term landform modelling incorporating gully formation has been carried out using the program SIBERIA for which Metago has developed additional software to allow the geometric modelling of the tailings dam using digital terrain modelling (DTM) packages. The software enables the preparation of input files for SIBERIA. Outputs from SIBERIA are then re-imported into the DTM package and a digital terrain model of the eroded slope is generated. From this model, it is possible to assess eroded volumes, gully depths and drainage patterns.

In the course of this assessment the following process has been adopted:

- A slice of the slope 400m wide and 500m long was taken up from the lowest point (Figure 8-1);
- A DTM has been generated for each Scenario slice; and
- A SIBERIA simulation has been run to 250 years for the Scenarios using the generated DTM.

A few alterations to the slice were required to create a more realistic erosion model:

- The contours on the sloped were “roughened” slightly to give a more realistic slope texture; and
- A large berm was placed on the crest which sloped towards the inside of the TSF to contain all water on the top, and consequently only the erosion resulting from rainfall on the outer slope was considered.

FIGURE 8-1: LAYOUT FOR EROSION AREA MODELLED

9. EROSION MODELLING PARAMETERS

The exponent m_3 in Equation 3 is typically in the range 0.6 to 0.8. In the absence of detailed storm runoff data for vegetated slopes at South Deep, and since the catchment area is relatively small, it is considered acceptable to put the exponent equal to unity. Therefore, for a square metre of catchment, β_3 will be equal to the average annual rainfall less infiltration. To account for infiltration β_3 has been modified to represent a runoff factor of the order of 0.7.

Erodability parameters derived for other mining operations in Southern Africa and Australia where the topsoil is clayey have been adopted for this level of assessment. It is important to note, however, that significant differences in parameters can occur between mining operations as well as over a slope on any given operation depending on the particle size distribution of the soil, segregation behaviour during placement, etc.

The range of erodability parameters that have been modelled is set out in Table 9-1:

TABLE 9-1 : ASSUMED EROSION PARAMETERS

β_1	M_1	N_1
0.5×10^{-2}	1.5	2

It should be noted that SIBERIA does not model the erosion at the interface between the soil layer and the tailings. Only the performance of the vegetated soil layer itself is modelled. The analyses presented here are regarded as reasonably representative of the actual situation notwithstanding SIBERIA's limitations.

10. EROSION MODELLING RESULTS

The results of the erosion modelling are set out in the Appendices as follows:

APPENDIX	CONTENT
1	Three dimensional oblique views of each of the Scenarios for 250 years
2	Long Sections for each of the Scenarios for 100 and 250 years
3	Reshaping of the starter wall

Specific comments on the results are offered below:

10.1. CONSTANT SLOPE WITH NO STEP-INS

The erosion modelling indicated that noticeable gully formation occurred on the crest of the starter wall, as a result of the sudden change in slope. SIBERIA predicted negligible erosion (less than 25mm) after 250 years on the constant slope.

10.2. TWO STEP-INS

The erosion modelling indicated that noticeable gully formation occurred on the crest of the starter wall, and on the crests of the berms to a lesser degree. The erosion depth is predicted to be very close to 25mm again.

10.3. SINGLE STEP-IN

The erosion modelling indicated that noticeable gully formation occurred on the crest of the starter wall, and on the crest of the berm to a lesser degree. The erosion depth is predicted to be very close to 25mm on the longer slope sections again.

11. COMMENTS ON RESULTS

The predicted depth of erosion on the long sections should not be taken as exact, as the modelling was undertaken in order to qualitatively compare the Scenarios. The depth of erosion should consequently only be used for an indicative comparison of the possible erosion.

The berms on the step-ins were sized to hold back the surface runoff down the slice. This is not a realistic situation as the berms were required to be modelled as being 2m high to be able to contain the runoff. It should be noted that should one of the berms fail, which is a high risk when the time frame of post closure is considered, the result would be the rapid formation of a large, potentially catastrophic, gully. One method to prevent the failure of the berms is continued surface runoff management. This is however not a practical solution as maintenance would be required, which is counter productive in obtaining closure.

The results are considered to be a realistic comparative indication between the Scenarios.

12. SUMMARY AND CONCLUSIONS

The erosion modelling may be summarised and conclusions drawn as follows:

- Erosion parameters have been drawn from other similar mining operations; no site specific erosion testing has been conducted at South Deep. The results of the erosion modelling are therefore seen as a qualitative guide as to the potential long term performance of the side slope after decommissioning rather than precise predictions of erosion depths;
- A constant 1:4 slope above the starter wall has the practical advantages of allowing easier access to the top of the TSF and the vegetation to grow more easily. While it would be advantageous to construct the starter wall at the constant 1:4 slope, this is prohibitively costly. As an alternative, the starter wall can be constructed at a steeper angle and then a step in created at the level of

the top of the starter wall which then allows the slope to be flattened to 1:4 over the entire length of the slope;

- The erosion modelling indicated that noticeable gully formation occurred on the crest of the starter wall, as a result of the sudden change in slope, however, this was not to a concerning degree. The crest and outer slope of the starter wall are to be re-shaped in the current closure design as illustrated in Figure 13-7; and
- Based on the modelling undertaken, the difference in erosion rates between the different candidate slope geometries is negligible, provided that the step-ins never fail. In the event that there is a chance that the step-ins fail or overtop at some stage after closure, the smooth slope would outperform the configurations with the step-ins. In Metago's opinion, the risk of a step in failings at some stage in future, for example as a result a burrowing animal is high. Hence, in Metago's opinion, the smooth slope configuration (Option 1) without any step ins is the preferred geometry.
- In order to calibrate the erosion model and test the proposed concurrent cover, it is recommended that a trial slope is constructed at the earliest available opportunity. This would allow the erosion parameters to be more accurately determined. Once correctly calibrated, the erosion model can be used to accurately predict the actual long term physical sustainability of the slopes.

13. REFERENCES

TABLE 13-1: REFERENCES

REFERENCES	SOURCE
Equation 1	http://www.omafra.gov.on.ca/english/engineer/facts/00-001.htm
Equation 2	http://www.iwr.msu.edu/rusle/
Willgoose et al	Willgoose G R, Bras R L and Rodriguez-Iturbe I. 1989. <i>A physically based channel network and catchment evolution model</i> , TR 322, Ralph M. Parsons Laboratory, Dept. of Civil Engineering, MIT, Boston, MA.

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Alistair James Pr Eng

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Reviewer

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APPENDIX 1: THREE DIMENSIONAL OBLIQUE VIEWS (ALL SCENARIOS)

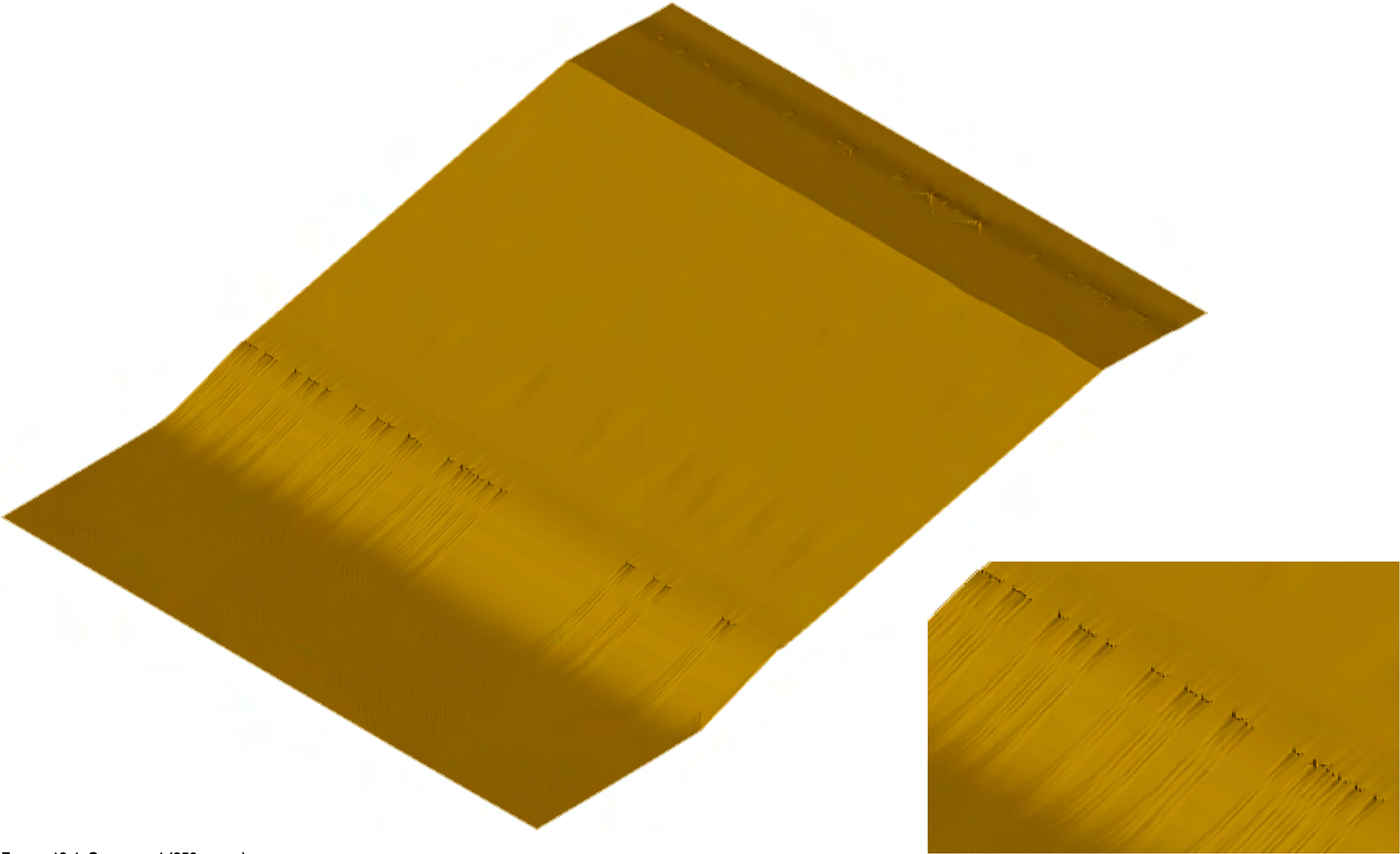


FIGURE 13-1: SCENARIO 1 (250 YEARS)

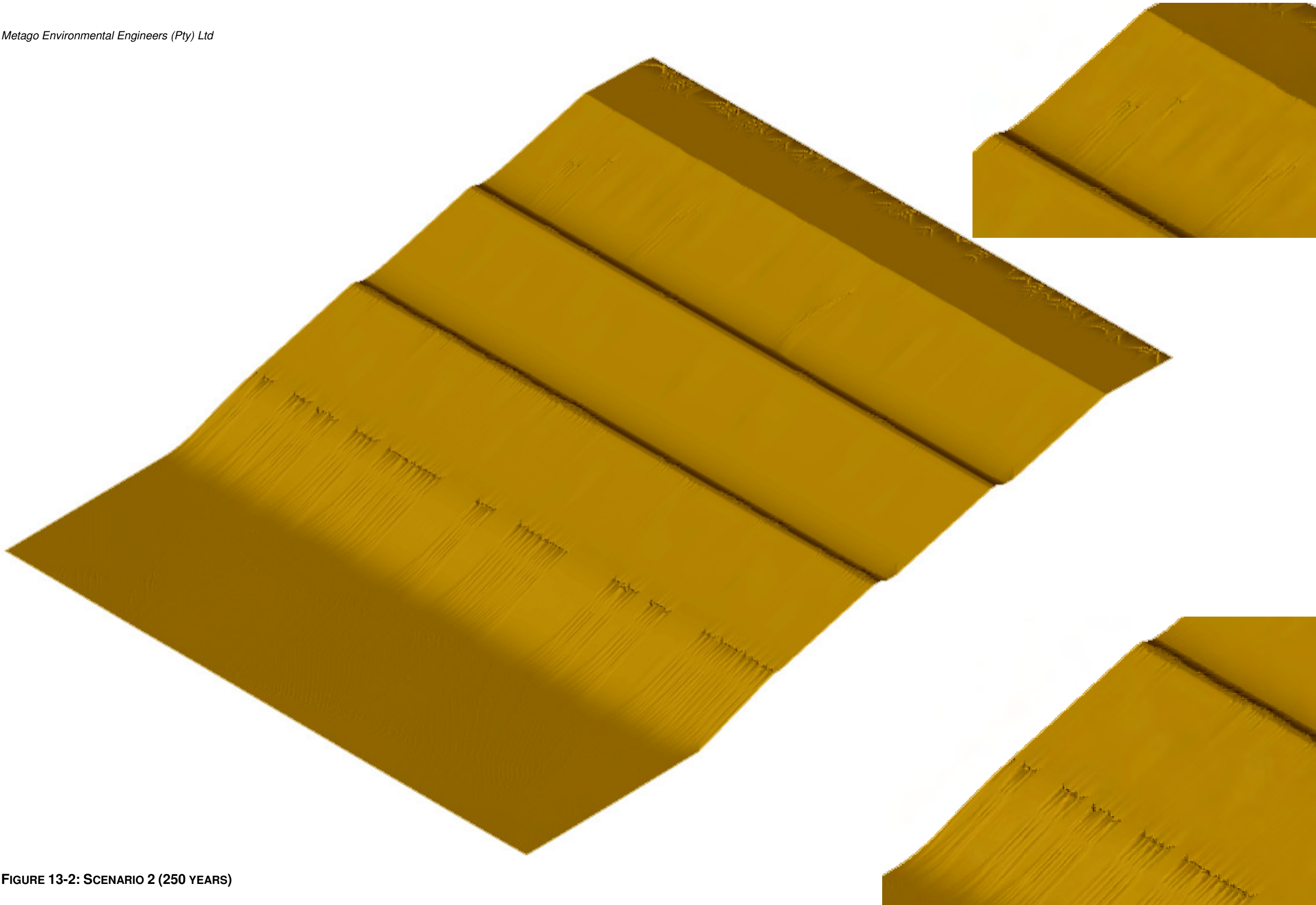


FIGURE 13-2: SCENARIO 2 (250 YEARS)

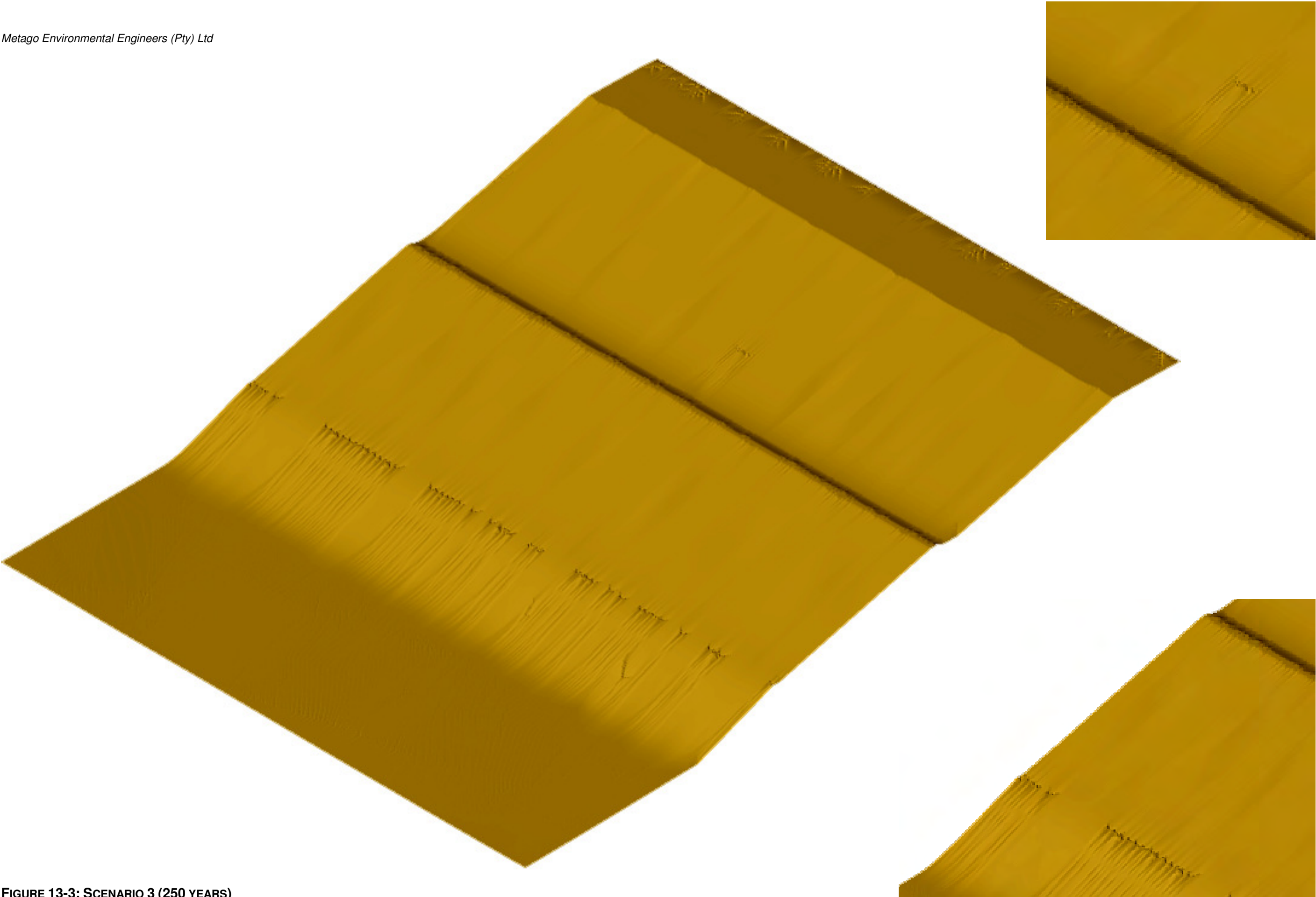


FIGURE 13-3: SCENARIO 3 (250 YEARS)

APPENDIX 2: LONG SECTIONS (ALL SCENARIOS)

FIGURE 13-4: LONG SECTION FOR SCENARIO 1

FIGURE 13-5: LONG SECTION FOR SCENARIO 2

FIGURE 13-6: LONG SECTION FOR SCENARIO 3

APPENDIX 3: RESHAPING OF THE STARTER WALL

FIGURE 13-7: RESHAPING OF THE STARTER WALL

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APPENDIX 7: WATER BALANCE FOR THE PROPOSED DOORNPPOORT TAILINGS DAM AT SOUTH DEEP MINE

Metago

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WATER BALANCE ANALYSIS FOR THE PROPOSED DOORNPOORT TAILINGS DAM AT SOUTH DEEP MINE

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0475528 8

APPENDIX 5: EVAPORATION DATA: ZUURBEKOM WEATHER STATION DWAF
STATION NO. C2E007



Project No. G001-02

August 2008

Report No. A7

WATER BALANCE ANALYSIS FOR THE PROPOSED DOORNPPOORT TAILINGS DAM AT SOUTH DEEP MINE

1. INTRODUCTION

This report documents the water balance for the proposed Doornpoort Tailings Dam and forms part of the detailed design of the tailings dam for South Deep Mine. The water balance model, which uses a probabilistic approach to determine monthly rainfall and evaporation, has been used to define the required return water dam storage capacity and to determine the volume of water that will be available to the plant for reuse on a monthly basis.

The return water dam is sized to satisfy the requirements of Regulation 704 of the National Water Act of 1998 No. 56, which states that the facilities should be designed to “not spill more than once in every 50 years”.

The model does not take cognisance of upset conditions caused by inappropriate operations.

2. TERMS OF REFERENCE

The terms of reference for the water balance were to develop a model that determined the following:

- The required storage capacity of the return water dam to satisfy the requirements of Regulation 704; and

- The volume of water on a monthly basis that will be available to be pumped back to the process plant.

3. INPUT DATA

The input data comprised three data sets, the rainfall data that was supplied by the South African Weather Service, the evaporation data from the Department of Water Affairs and Forestry and the data that was derived from the design criteria (Table 3-3).

The rainfall data was supplied as the full rainfall record for the nearest station (see Table 3-1), which was then analysed statistically in Excel, together with the @Risk add in. The analysis provided the “best fit” statistical distributions for each month (Jan – Dec) that included a distribution and the relevant parameters. The evaporation data was analysed similarly using a normal distribution (Table 3-2).

TABLE 3-1: RAIN GAUGE DETAILS

Station Number	0475528 8
Station Name	ZUURBEKOM
Geographical Position	Lat:-26.3000 Lon:27.8000 Height:1578 m
Temporal Range	1903 – 2005 (103 Years)

The report encloses a summary of the full rainfall record and the monthly evaporation data as Appendix 4 and Appendix 5 respectively.

TABLE 3-2: STATISTICAL PARAMETERS DERIVED FOR MONTHLY RAINFALL AND EVAPORATION

MONTH	RAINFALL			EVAPORATION	
	DISTRIBUTION	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
January	Lognormal	108.5	73.0	169	21.5
February	Lognormal	93.4	66.3	139	28.2
March	Lognormal	77.6	53.6	131	21.9
April	Lognormal	42.3	35.1	103	13.7
May	Lognormal	20.9	30.7	87.1	14.3
June	Lognormal	6.4	13.3	70.4	10.7
July	Lognormal	7.0	18.8	79.3	11.1
August	Lognormal	7.6	14.7	112	13.9
September	Lognormal	20.2	25.8	149	18.4
October	Lognormal	66.1	52.2	168	31.6
November	Lognormal	101.8	65.0	166	24
December	Lognormal	110.6	53.8	172	32.8

TABLE 3-3: INPUT DATA

	FULL TSF FOOTPRINT	PHASE 1 OF TSF ONLY	
AREAS			
Tailings Area (Crest area)	1,867,386	1,664,569	m ²
Side Slopes	1,415,686	100,059	m ²
Catchment Paddocks	216,662	118,491	m ²
Stormwater Canal	23,967	13,857	m ²
Access Road	98,196	67,779	m ²
Berm and Pipeline Servitude	40,564	24,444	m ²
Tailings Area (Wet beach - Dry beach ratio)	30%		Wet Beach
	70%		Dry Beach
RUNOFF COEFFICIENTS			
Wet Beach	0.8		
Dry Beach	0.3		
Pool	1		
Side slopes	0.3		
Catchment Paddocks	0.3		
Stormwater Canal	0.9		
Access Road	0.3		
Berm and Pipeline Servitude	0.3		
POND DATA			
Average Pond Area	280,108	249,685	m ²
RETURN WATER DAM DATA			
Capacity (Final)	1,000,000	500,000	m ³
Catchment Area	245,776	122,888	m ²
Water surface area (minimum)	234,078	117,039	m ²
SLURRY CHARACTERISTICS			
Maximum Monthly Tailings Production (Dry, excluding Backfill)	233,000	233,000	t/month
Slurry density	1.4	1.4	t/m ³
Mean SG	2.7	2.7	

Slurry void ratio	3.25	3.25	
Moisture content	1.20	1.20	
Water Received at TSF (as part of slurry to tailings dam)	280,463	280,463	m ³ /month
DEPOSITED TAILINGS			
Dry tailings density	1.35	1.35	t/m ³
Void ratio on settling	1	1	
Moisture content	0.37	0.37	
Water content after settling	86,296	86,296	m ³ /month
Water released to pond through settling	194,167	194,167	m ³ /month
SEEPAGE VOLUMES			
Seepage loss from tailings dam	93.0 x 10 ⁻³	93.0 x 10 ⁻³	m ³ /month
Seepage collection by the toe drain	155.4	155.4	m ³ /month
Seepage collection by the main drain	1,914.2	1,914.2	m ³ /month
PLANT WATER REQUIREMENT			
Monthly Plant Water Requirement	397,222	397,222	m ³ /month

4. METHODOLOGY

The methodology used to develop the model is as follows:

- The dam geometry was assumed to be that of the facility near closure, which is the worst case scenario from a return water dam sizing perspective;
- The rainfall data was used to calculate the runoff volumes for each distinct area, which in turn reported either to the supernatant pond then the return water dam or directly to the return water dam;
- The production data was used to calculate the portion of slurry water that would report to the supernatant pond and the return water, taking into account interstitial losses;
- Any spillage from the return water dam was calculated;
- The evaporation data was then applied to the pools and the return water dam to calculate the final volume of water;

- The model was then run, through @Risk (which uses Monte Carlo simulation) with the rainfall and evaporation distributions, sufficient times to generate a distribution relating to the spillage from the return water dam, which is limited by Regulation 704 to “not spill more than once in 50 years”; and
- Through a series of iterations using different capacities as the input parameter, the minimum capacity for the return water dam was found.

As part of one of the trade-off studies, the option of phasing the return water dam was investigated. This involved reducing the return water dam to a single compartment, and running the model again using smaller capacities and the relevant catchment data to the proposed Phase 1 of the TSF construction.

5. WATER BALANCE MODEL

The water balance model is presented by detailing each stage in the model's calculation

5.1. CALCULATION OF AREAS AND RAINFALL RUNOFF

Rainfall is a significant contributor to the volumes entering into the tailings facility system. The volumes are calculated from a monthly rainfall depth for a given month that is assumed to fall on one of the following regions, each with an assumed runoff coefficient and a measured area:

- The supernatant pond;
- The wet beach;
- The dry beach;
- The side slopes;
- The catchment paddocks;
- The stormwater canal;
- The access road; and
- The berm and pipeline servitudes.

5.2. RELEASE OF WATER FROM TAILINGS SLURRY AND DEPOSITED TAILINGS

The volume of water that is derived from the slurry reporting to the tailings is calculated from the water released as the solids are deposited, assuming a certain void ratio. Although water is released at a later stage as the tailings material consolidates, it is assumed that this water is lost through evapo-transpiration.

5.3. POOL WATER BALANCE

The pool water balance is calculated using the inflows from the tailings beach supernatant runoff water and the rainfall run off from the pertinent areas and the losses, which are calculated from seepage and evaporation. The result is a monthly volume that would be decanted to the return water dam. No long term storage on the TSF is assumed.

5.4. RETURN WATER SYSTEM BALANCE

The return water dam volumes are calculated on a monthly basis from the following:

- Inflows:
 - The decanted water from the TSF pools; and
 - The rainfall runoff from the areas that were not included in the pool water calculation.
- Losses and outflows:
 - Any spillage, if the inflows are greater than the capacity of the return water dam;
 - Evaporation; and
 - The plant water requirement.

A final volume is then calculated that is used as an initial volume for the subsequent month.

5.5. MODEL LIMITATIONS

The main limitation of the water balance modelling is that the return water dam has only be modelled under normal operating conditions. If the return water dam is not operated correctly, it will spill more frequently than the modelling results indicate. Upset conditions include not discharging the clean water from the stormwater channel when necessary, and adding extra water to the system through excessive use of plant water make up from sources other than the return water dam.

6. RESULTS

The results from the simulation show that with a return water dam of 1 000 000 m³, the following is true of the model (Table 6-1) under normal operating conditions:

- Spillages to the environment will occur on average once every 62.9 years (The mean expected value for 50 years is 0.77);
- The expected mean spillage volume is calculated to be 2 662 m³ per spill event;
- The volume of water stored in the return water dam is between 26% and 28% for 90% of the operational life of the dam, with a mean value of 27%;
- There will be sufficient water, on average, only 10% of the time for the plant's full water requirements; and
- When there is a short fall, the mean amount of make up water for the plant from another source is expected to be 168 366 m³ per month.

The results of reducing the return water dam to a single compartment for Phase 1 of the TSF predict spillages to the environment occurring once every 13.3 years (The mean expected value for 50 years is 3.8). The results of the phasing of the compartments can be seen in Table 6-2.

TABLE 6-1: @ RISK SIMULATION RESULTS (1 000 000m³ CAPACITY – TOTAL TSF FOOTPRINT 233 000TPM)

NAME	MINIMUM	MEAN	MAXIMUM	X1	P1	X2	P2	X2-X1	P2-P1	ERROR
Mean Volume (before Spillage)	252,943	271,530	292,476	261,585	5%	282,640	95%	21,055	90%	0
Mean Percentage of Capacity stored after rain	25.3	27.1	29.2	26.2	5%	28.2	95%	2.1	90%	0
Max Percentage of Capacity stored after rain	63.2	94.3	100.0	77.4	5%	100.0	95%	22.6	90%	0
Number of Spills over a 50year period	0	0.77	6	0	5%	3	95%	3	90%	0
Spillage Volume (m ³)	0	2,688	55,889	0	5%	12,113	95%	12,113	90%	0
Average Pumped from RWD (m ³ /month)	218,393	228,857	241,132	223,261	5%	234,409	95%	11,147	90%	0
Number of times make up water is required over a 50year period	508	543	570	526	5%	558	95%	32	90%	0
Mean make up volume (m ³ /month)	156,091	168,366	178,829	162,800	5%	173,944	95%	11,144	90%	0
January Monthly Distribution (Percentage)	32	36	43	34	5%	39	95%	6	90%	0
February Monthly Distribution (Percentage)	30	36	43	32	5%	39	95%	6	90%	0
March Monthly Distribution (Percentage)	28	33	39	30	5%	36	95%	6	90%	0
April Monthly Distribution (Percentage)	23	27	32	25	5%	29	95%	4	90%	0

NAME	MINIMUM	MEAN	MAXIMUM	X1	P1	X2	P2	X2-X1	P2-P1	ERROR
May Monthly Distribution (Percentage)	20	22	26	20	5%	23	95%	3	90%	0
June Monthly Distribution (Percentage)	18	19	22	18	5%	20	95%	1	90%	0
July Monthly Distribution (Percentage)	18	19	21	18	5%	20	95%	1	90%	0
August Monthly Distribution (Percentage)	17	18	21	17	5%	19	95%	1	90%	0
September Monthly Distribution (Percentage)	18	19	22	18	5%	20	95%	2	90%	0
October Monthly Distribution (Percentage)	23	27	31	25	5%	29	95%	4	90%	0
November Monthly Distribution (Percentage)	29	34	40	31	5%	36	95%	5	90%	0
December Monthly Distribution (Percentage)	32	37	42	34	5%	39	95%	5	90%	0

TABLE 6-2: @ RISK SIMULATION RESULTS (CONSTRUCTION PHASING TRADE-OFF STUDY)

NAME	MINIMUM	MEAN	MAXIMUM	x1	p1	x2	p2	x2-x1	p2-p1	ERROR
Mean Volume (before Spillage)	219,552	226,737	234,445	223,051	5%	230,665	95%	7,614	90%	0
Mean Percentage of Capacity stored after rain	43.9	45.2	46.7	44.6	5%	45.9	95%	1.4	90%	0
Max Percentage of Capacity stored after rain	90.3	100.0	100.0	100.0	5%	100.0	95%	0.0	90%	0
Number of Spills over a 50year period	0	3.793	14	1	5%	7	95%	6	90%	0
Spillage Volume (m ³)	0	7,009	45,871	864.2747	5%	16,520	95%	15,656	90%	0
Average Pumped from RWD (m ³ /month)	203,827	210,031	217,344	206,695	5%	213,309	95%	6,614	90%	0
Number of times make up water is required over a 50year period	577	588	598	582	5%	594	95%	12	90%	0
Mean make up volume (m ³ /month)	179,878	187,192	193,396	183,913	5%	190,514	95%	6,601	90%	0
January Monthly Distribution (Percentage)	50	55	62	52	5%	58	95%	6	90%	0
February Monthly Distribution (Percentage)	48	53	61	51	5%	56	95%	6	90%	0
March Monthly Distribution (Percentage)	45	50	56	48	5%	53	95%	5	90%	0
April Monthly Distribution (Percentage)	41	44	48	42	5%	46	95%	3	90%	0

NAME	MINIMUM	MEAN	MAXIMUM	X1	P1	X2	P2	X2-X1	P2-P1	ERROR
May Monthly Distribution (Percentage)	38	40	43	38	5%	41	95%	3	90%	0
June Monthly Distribution (Percentage)	36	37	39	37	5%	38	95%	1	90%	0
July Monthly Distribution (Percentage)	36	37	39	36	5%	38	95%	2	90%	0
August Monthly Distribution (Percentage)	35	35	38	35	5%	36	95%	1	90%	0
September Monthly Distribution (Percentage)	35	36	40	35	5%	38	95%	2	90%	0
October Monthly Distribution (Percentage)	42	46	51	43	5%	48	95%	5	90%	0
November Monthly Distribution (Percentage)	49	54	60	51	5%	57	95%	6	90%	0
December Monthly Distribution (Percentage)	51	56	61	53	5%	58	95%	5	90%	0

7. CONCLUSIONS

Based on the results, the following can be concluded:

- The return water dam must have a design capacity of 1 000 000 m³;
- There is a requirement for water to be added to the system from external sources, but this additional water should only be allowed to enter the system when there is a deficit.
- Phasing construction of the return water dam would not satisfy Regulation 704 of the National Water Act of 1998 No. 56.

8. RECOMMENDATIONS

- The return water dam needs to be operated very carefully. If additional water is added to the system when it is not needed, then the dam will spill more frequently. Consequently it is critical that an operational procedure is put in place to ensure water is always used from the return water dam before any additional water is added to the system.
- A measuring rope marking 10% intervals has been incorporated in each compartment to allow the level of water in the dam to be easily determined on site. Water level sensors have also been incorporated in each compartment near the outlet sumps to allow the dam to be monitored remotely.
- The clean water in the stormwater channel will need to be monitored to ensure that the quality is high enough for it to be spilled to the environment when necessary.

Justin Walls

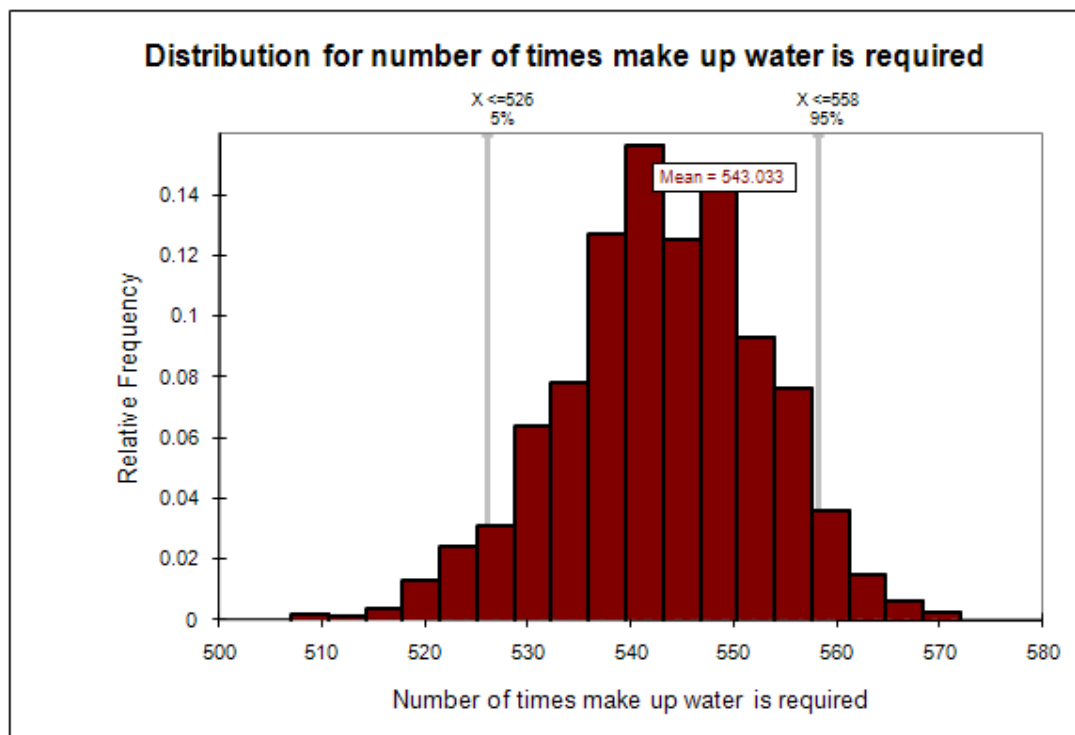
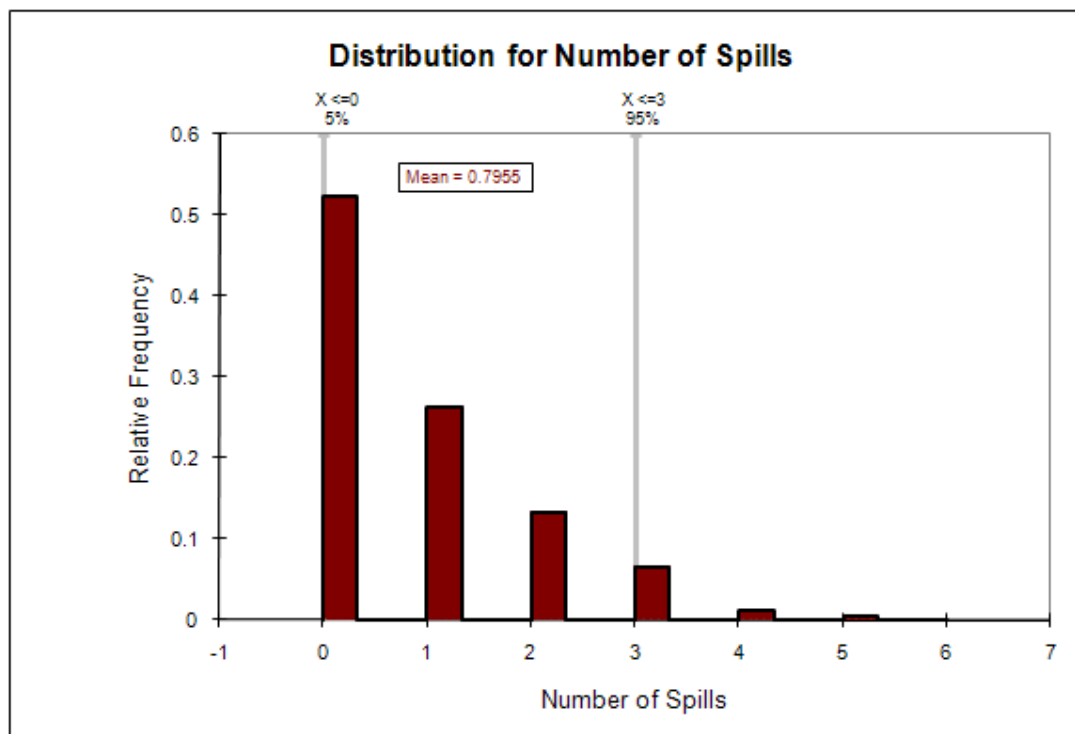
Author

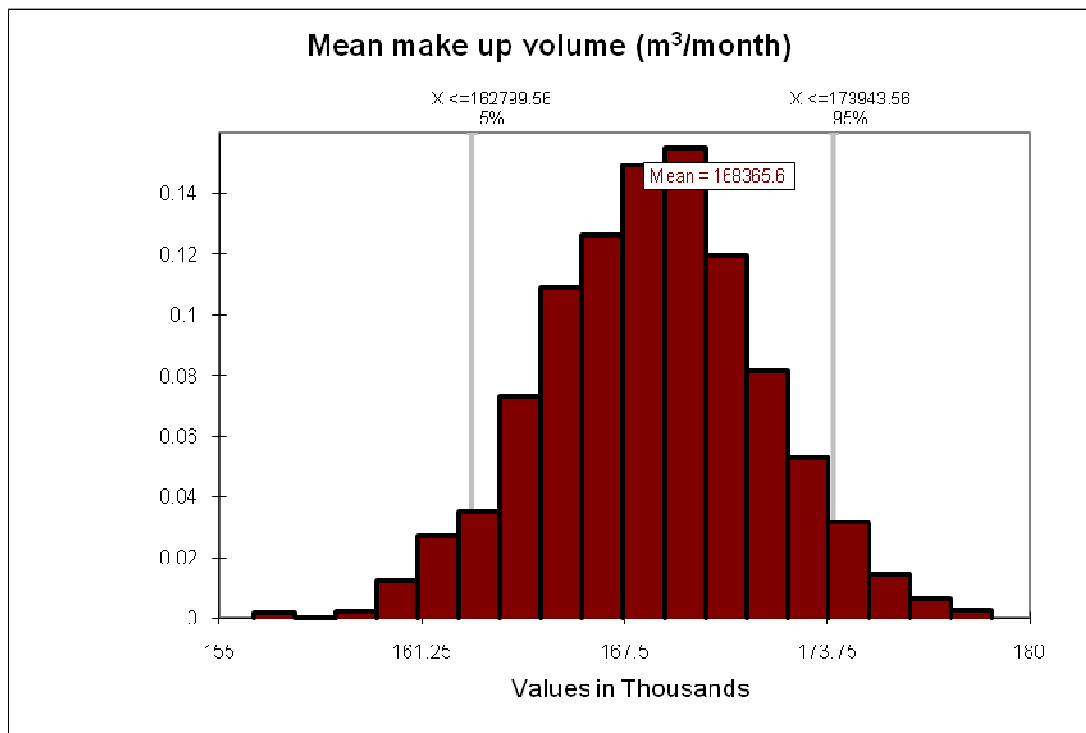
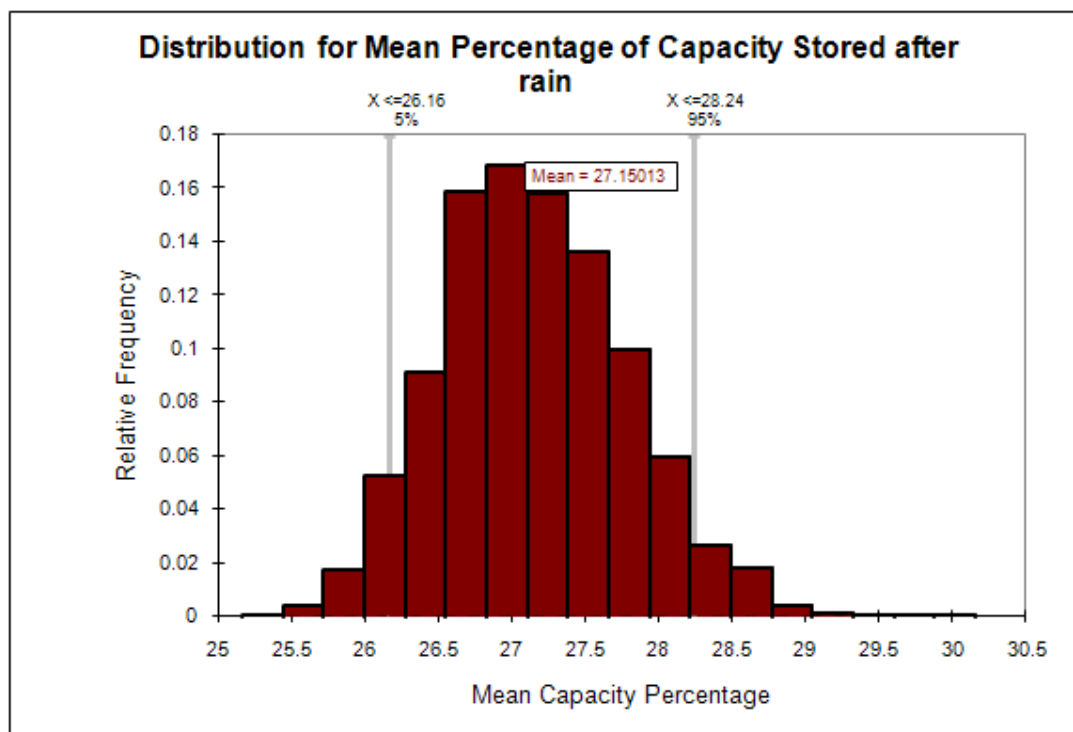
Alistair James Pr Eng

Reviewer

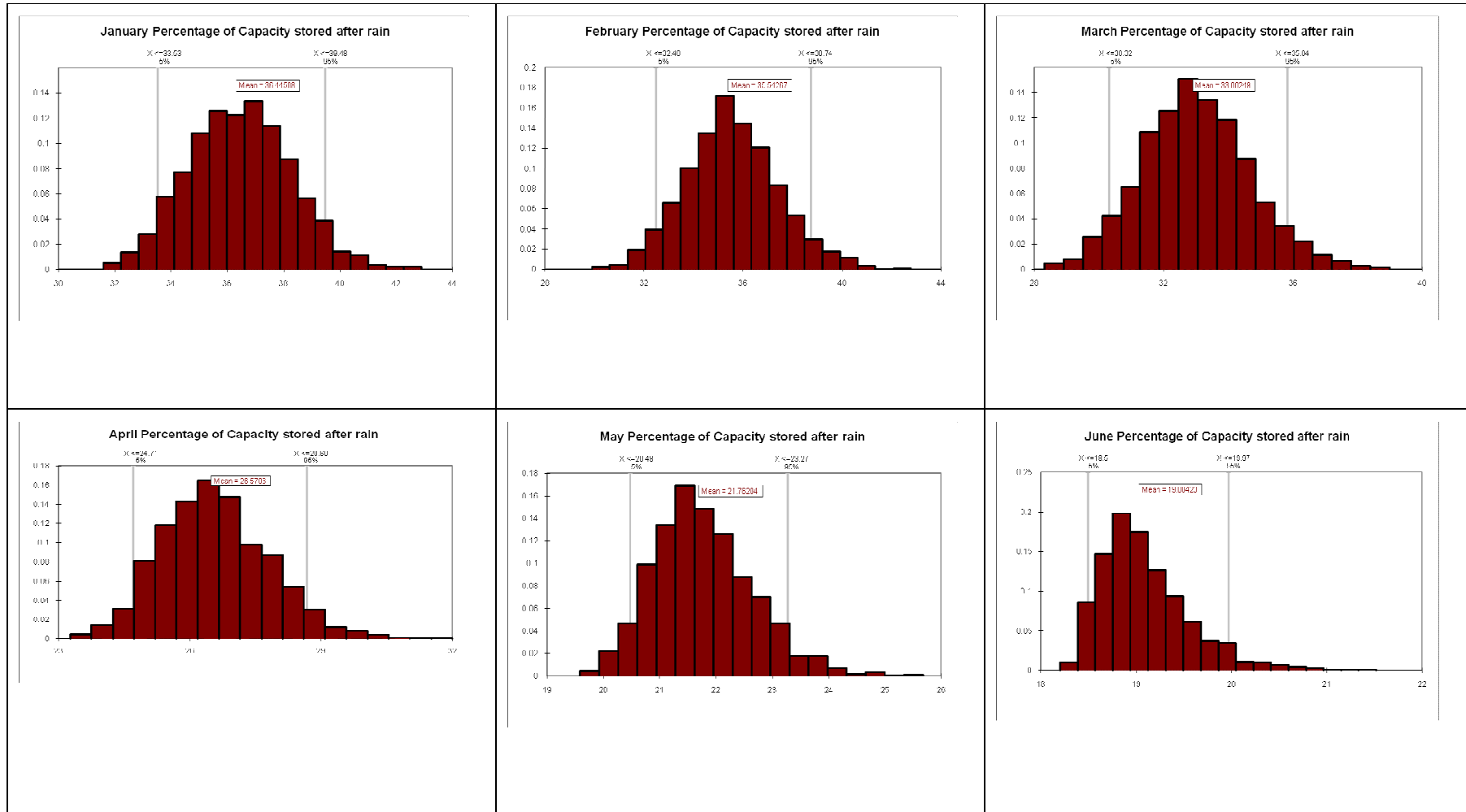
Metago Environmental Engineers (Pty) Ltd

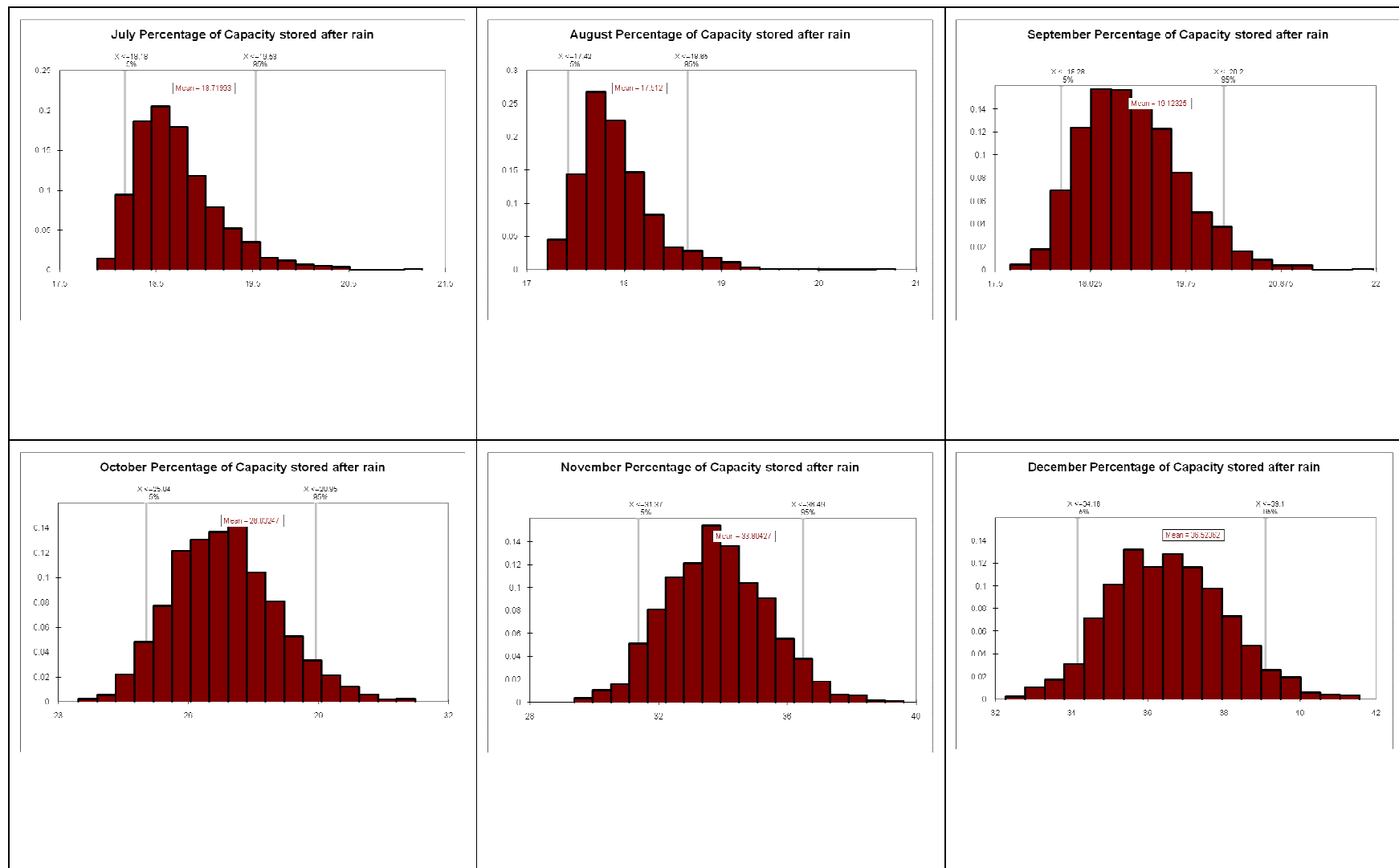
APPENDIX 1: GRAPHICAL RESULTS



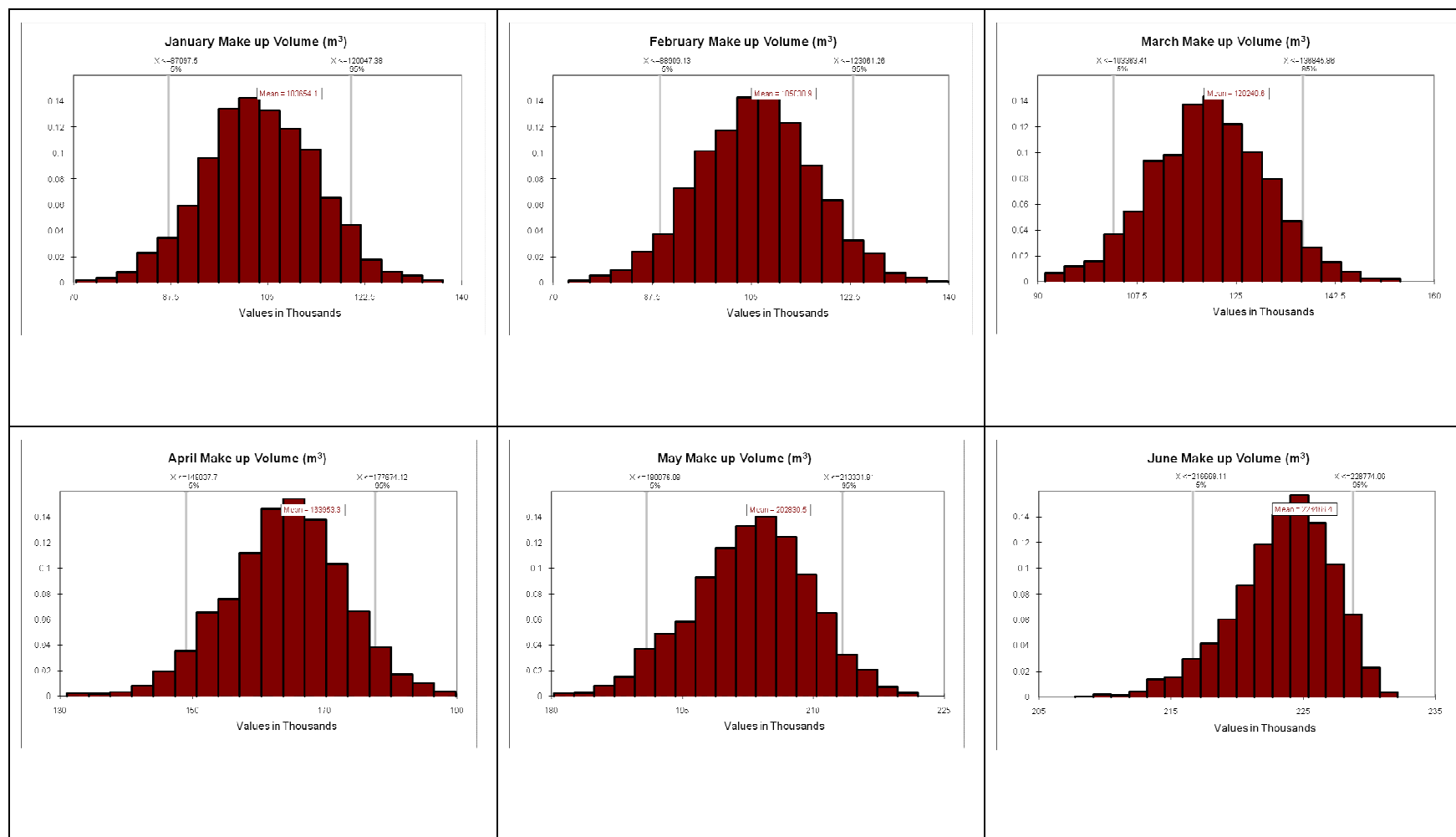


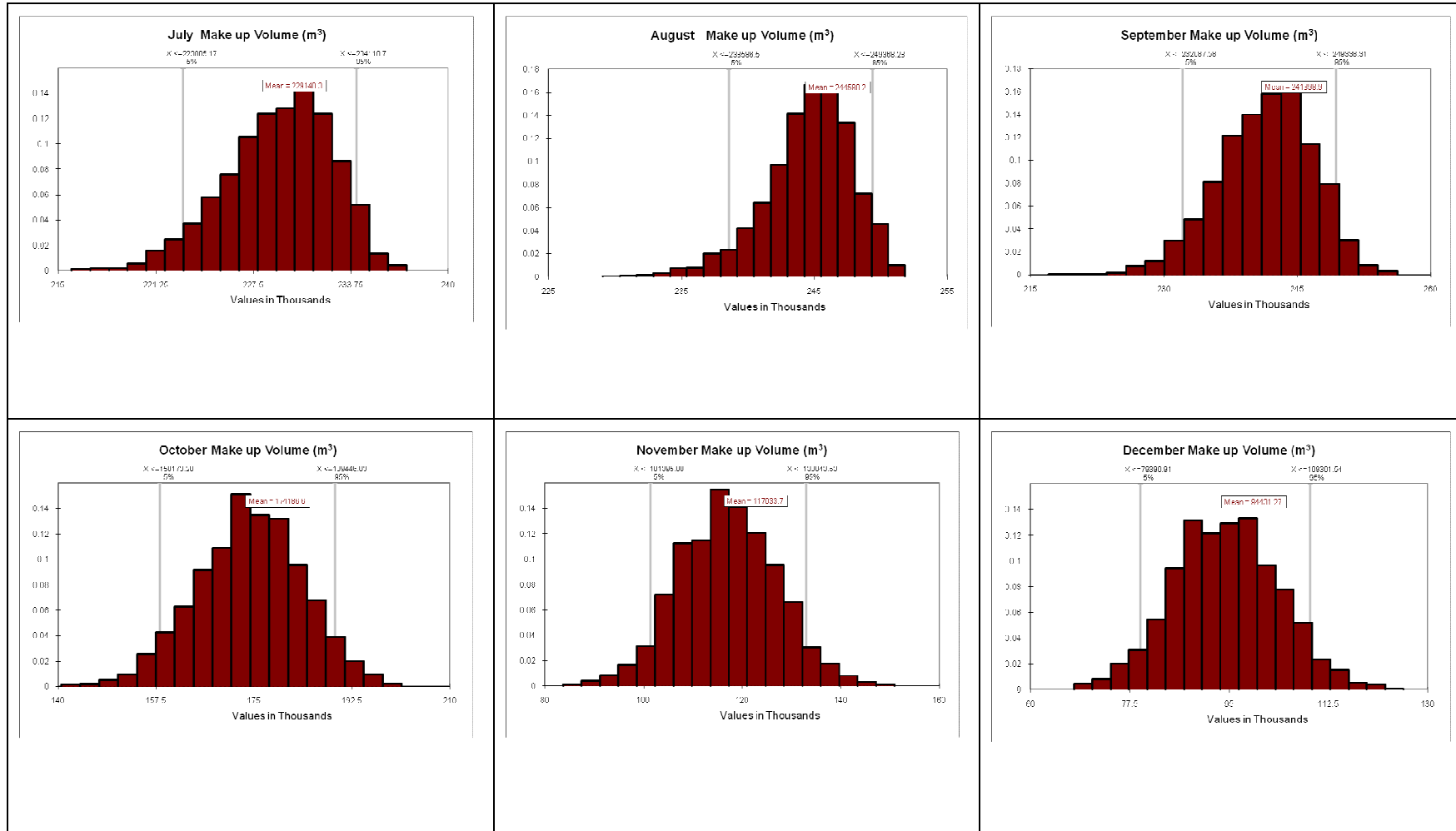
APPENDIX 2: MONTHLY DISTRIBUTIONS FOR THE PERCENTAGE CAPACITY STORED IN THE RETURN WATER DAM AFTER RAIN





APPENDIX 3: MONTHLY DISTRIBUTIONS FOR THE MAKE UP WATER REQUIREMENTS





APPENDIX 4: RAINFALL SUMMARY FOR ZUURBEKOM GAUGE, STATION 0475528 8

YEAR	MONTH												GRAND TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	
Mean	108.5	93.4	77.6	42.3	20.9	6.4	7.0	7.6	20.2	66.1	101.8	110.6	659.5
Std Dev	73.0	66.3	53.6	35.1	30.7	13.3	18.8	14.7	25.8	52.2	65.0	53.8	256.3
1903	0	0	0	0	0	0	0	0	10.9	31.6	109.8	149.8	302.1
1904	139.4	117.4	141.9	4.3	13	7.6	0	0	2	32.6	161.3	76	695.5
1905	114.4	92.9	42.7	44.3	11.7	0	0	2.1	10.9	14.6	157.4	94.5	585.5
1906	67.4	79.5	111.9	26.8	20.3	0	0	0	3.8	68.8	88.8	109	576.3
1907	129.5	0	81.7	98.7	6.9	0	0	0	55.4	90.8	94.2	86.4	643.6
1908	84.3	79.9	80.7	9.1	1	0	12.9	7.1	14.7	45.2	80.6	56.2	471.7
1909	413.7	142	83.8	17.3	19.4	0	7.4	33	23.9	49.6	164.1	99.7	1053.9
1910	0	0	0	0	0	0	0	0	0	0	0	0	0
1911	0	0	0	0	0	0	0	0	0	0	0	0	0
1912	0	0	0	0	0	0	0	0	0	0	0	0	0
1913	0	0	0	0	0	0	0	0	0	0	0	0	0
1914	0	0	0	0	0	0	0	0	7.1	35.9	158.6	227.8	429.4
1915	239.7	103.3	28.7	2.3	37.1	0	48.4	12	28.9	77.2	145.6	62.1	785.3
1916	72.7	57.2	72.4	16.6	8.5	0	0	0	0	44.9	82.7	137.5	492.5
1917	164.2	113.1	45.9	63.5	15.8	11.3	22.4	43.9	6.7	18.3	283.3	204.1	992.5
1918	126.8	261.3	101.1	0	5.1	0	9.4	95.8	28.9	126.4	166.4	191	1112.2
1919	72.8	31	54.2	32.2	3.8	2.6	2.5	0	7.9	46.3	185.9	79.2	518.4

YEAR	MONTH												GRAND TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	
1920	94.6	93.6	72.5	14.2	30.8	0	0	0	36.8	108.5	99.6	76	626.6
1921	65.2	118.5	176.1	22.4	12.7	0.8	0	0	29.5	94.2	65	144.6	729
1922	73.1	89.9	82.3	25.4	25.9	11.2	0	15.2	14	68.2	135.6	76.5	617.3
1923	193.7	155.9	37.8	35.6	20.8	7.1	0	0.5	12.5	18.5	99.4	105	686.8
1924	126.3	48.2	194.8	25.9	29.7	0	0	5.1	53.5	39.8	118.3	271.7	913.3
1925	77.3	188.6	165.2	69.7	58.3	9.4	0	2.8	40.6	34.5	73.4	61.4	781.2
1926	77.6	82	81.3	18.1	45.7	7.4	19.8	0	26.4	27.3	77.8	89.1	552.5
1927	89.9	48.7	111.7	29.8	0.5	0	37.1	1.3	0	72.3	50.7	62.9	504.9
1928	208.4	113.8	38.4	58.1	2.1	3.9	0	8.4	19.1	61.4	117.4	86.6	717.6
1929	150.1	112.8	155	58.3	12.7	59.1	0.8	0	76.6	118.7	117.7	147.1	1008.9
1930	126.7	81.1	98.8	7.8	7.9	0.3	28.7	14.5	0	13.5	76.9	167.5	623.7
1931	134.7	70.7	29.2	63.1	0	0.3	44.4	0	0.3	28.9	82.2	77.6	531.4
1932	58.5	117.1	144.4	37.3	11.4	0	0	0	12.4	42.5	74.5	89.4	587.5
1933	49.4	23.6	69.7	108	1.8	4.3	0.5	0	13.2	8.3	230.7	122	631.5
1934	126.9	65.3	63.4	15.8	63.7	4.3	8.7	25.9	0	49	163.3	144.3	730.6
1935	60.2	83.5	74.6	19.4	6.9	0	0	17.3	1.9	36.2	12.5	98.5	411
1936	122.2	119.1	101.7	21.9	142.7	2	0.5	0	4.1	37.1	186.6	53.1	791
1937	2.5	202.9	80.8	118.4	170.8	0	2.3	0	8.9	18.6	106.1	161.3	872.6
1938	136.5	82.1	21.4	129.9	15.5	15.6	2.8	13.9	27.7	48.7	28.7	197.6	720.4
1939	82.9	172.5	116	18.8	54.1	0	52.9	24.1	27.4	24.1	186.3	115	874.1
1940	105.7	61.7	71	50.5	36	30	0	3.3	79.6	21.1	60.7	157.1	676.7

YEAR	MONTH												GRAND TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	
1941	101.3	84.4	73.5	71.6	0	0	0	0.5	6.6	105.5	21.3	113.9	578.6
1942	283.5	147.6	100.6	25.9	6.2	3.6	0	33.5	40.3	62	99.2	198.2	1000.6
1943	89.1	37.8	89.6	103.2	49.2	1.5	64	22.9	32.2	145.9	51.6	116.1	803.1
1944	112.3	333.2	52.6	1.8	9.2	90.5	0	0	67.3	116.9	153	37.9	974.7
1945	119.8	83.8	173.6	4.6	21.1	0	0	0	0	21.1	74.9	98.2	597.1
1946	214.9	145.2	104.6	27.2	40.6	0	0.3	0	0.5	38.2	86.6	110.1	768.2
1947	98.7	101.1	112.2	51	1.3	1.5	3.9	0	12.7	47	57.5	135.2	622.1
1948	117.7	99.2	104.4	72.4	20.1	0	1.8	0	5.4	65.4	144.4	54.7	685.5
1949	206.7	50.8	43	25.9	1.5	10.6	2.8	0	10.1	67.2	175.3	251.6	845.5
1950	88.5	55.9	204.2	68.3	78.1	10.9	4.3	0.3	3.9	64.3	80.5	183.9	843.1
1951	160.5	149.3	122.1	112.8	146.7	0	10.4	52.6	17.8	307.2	52.1	140.2	1271.7
1952	287	319.9	186.3	126.4	31.8	28.4	148.8	1.3	0	148.8	434.8	150.9	1864.4
1953	43.1	198.5	137.3	30	13	0	0	0	0	27.9	89.8	80	619.6
1954	234.8	81.8	35.3	40	21.8	2	0	0	5.4	34.8	137.7	58.7	652.3
1955	185.5	157.9	43.6	58.6	35.1	0.4	0	1.3	0.1	58.1	121.8	142.1	804.5
1956	51.4	136.2	65.6	0.2	49.7	0	13.7	0	24.9	130.4	112.3	87.1	671.5
1957	51.4	185	91.5	25	19.3	32.7	49.4	23.4	115.8	81.3	103.9	77	855.7
1958	132.7	113	91.8	101.7	4.9	1	0	0.1	73.2	27.6	124.2	123.3	793.5
1959	0	0	0	0	0	0	10.2	0	1.8	82.6	128.8	92.4	315.8
1960	79.4	59.7	44.9	70.7	2.5	3	0.1	18.5	2	67.9	149.3	159.1	657.1
1961	45.9	58.4	53.4	132.9	41.8	6.8	0.3	0.1	16.5	59.7	119.5	183.5	718.8

YEAR	MONTH												GRAND TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	
1962	54.5	79.6	60.6	63.8	0.2	0.1	0	1.5	15.4	35.9	163.8	43.6	519
1963	117.2	25.6	55	40.7	10.5	28	8.1	0	5	42.3	184.9	72.1	589.4
1964	97.3	47.5	65.1	48.8	7.5	13.1	0	0.8	2.3	155.3	56.8	84.2	578.7
1965	104.3	80.8	23.3	75.9	1.9	0.7	13.8	0.3	0.7	15.5	48.6	57.1	422.9
1966	96.9	139.4	9.5	63.4	11	5.7	0	1.6	11.6	103	50	139.2	631.3
1967	180.1	91.1	213.6	64.2	15.1	0.1	0.2	11.2	3.4	84.9	98.2	103.9	866
1968	49.5	109.5	86.9	71.7	11.3	0.3	0	7.2	2	28.1	98.4	57.1	522
1969	29.4	85.6	97.3	33	60.4	0	0.2	3.5	11.6	125.2	96.4	100.2	642.8
1970	67.2	77.4	30.7	44.8	20.7	6.9	14.7	0	12.8	41.9	78.3	80	475.4
1971	194.5	55.7	70.5	164.1	49.9	13	0.3	0	25.9	51.1	0	93.5	718.5
1972	93.8	37.5	107	73	10.1	3	0	1.2	5.4	60.5	60.8	94	546.3
1973	78.1	36.6	37.8	73.3	1.5	0	0	4.2	40.4	72.3	81.9	91	517.1
1974	71.3	146.9	57.6	70.4	11	1.5	4.4	1.1	10.7	76.6	161.9	120.3	733.7
1975	121.9	179.2	82	82.1	11.9	1.2	0	1.8	0	19.5	145.5	129.2	774.3
1976	92.8	109.1	129	67.8	62.7	0	0	0	29.6	121.9	71.4	91.8	776.1
1977	202.9	8.6	124.3	51	1.7	0	0	0.8	58.2	84.6	117.2	222.7	872
1978	282.6	161.9	71.4	38.2	1.5	1	0	8.9	33.4	45.5	103.3	56.4	804.1
1979	78.7	74.6	18.3	30.5	23.9	1.7	16.1	51.4	27.3	94.7	150.4	90.3	657.9
1980	185	118.3	47.2	29.1	2.5	0	0	0	41.7	53	131.6	128.6	737
1981	207.9	190.8	84.8	28.1	0.1	5	0	16.6	11.7	85.3	65	120.5	815.8
1982	88.3	39.7	139.7	22.3	0	4.7	18.9	0	16.9	56.2	20.9	119	526.6

YEAR	MONTH												GRAND TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	
1983	45.3	44.4	19.3	27.3	5.9	33.2	6	0	12	122.6	91.2	133.7	540.9
1984	37.9	26.7	25.5	12.9	0.1	9.5	12.5	2.5	26	43.2	99.4	44.3	340.5
1985	145.7	65.5	45.7	0	11	0	3.5	8	15.6	116.8	25.6	121.4	558.8
1986	91.6	16.5	45.1	52.9	0	19	0	36.5	3.6	91.5	63	137.1	556.8
1987	134.3	56	149.8	10.5	0	0	0	24	164	38.1	122.8	89.4	788.9
1988	81.4	63.3	114.8	27.6	4.3	8.5	2.6	0	58.2	93.6	61	77.8	593.1
1989	134	216.5	16.2	76.3	8	55	0	3	0	23.8	194.5	154.8	882.1
1990	43.1	97.1	51.5	83.2	0.4	0.5	0	1.5	3.3	50.7	39.5	93.6	464.4
1991	85.4	97	113.8	0	0	7	0	0	21	41.1	40.1	109	514.4
1992	18.9	54.8	45	43.5	10	13.5	0	24.5	14.4	22.2	109.1	221.6	577.5
1993	47.3	90.7	88.5	27	6.1	0	0	3.3	46	298.8	93.5	120	821.2
1994	143.9	105.3	67	13.5	0	0	0	0	0	93	43.6	179.8	646.1
1995	141	20.5	91.7	40.5	0	0	0	2.3	12	131.9	131.9	151.9	723.7
1996	83.1	206.9	45.8	53.5	21.7	0	0	18.2	8.3	124.5	57.2	109.8	729
1997	178.7	102	287.1	47.7	108.5	4.5	2	8.5	31.8	49	107.4	105.5	1032.7
1998	262.5	87	40.5	0.7	0	0	0	0	33.8	82.2	256.7	29.5	792.9
1999	46.6	48.5	65	32	25	0	0.5	3	38	8.5	33.5	0	300.6
2000	11.6	253.5	143.5	20	26	5.5	0	0	32	105	53.5	140.2	790.8
2001	79.8	72.5	50.5	18	29	15.5	0	2	50.5	177	51	130	675.8
2002	90.8	75	60	18	50	15.5	0	17.5	6.8	123.7	21	107	585.3
2003	81	10	0	9	0	9.5	0	0	0	0	98.7	80	288.2

YEAR	MONTH												GRAND TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	
2004	155	63.5	50	41.5	41.5	6.5	10.5	38	0	36.5	46	177	666
2005	52	40	0	50	3.1	0	0	0					145.1
Grand Total	11176.6	9616.5	7989.1	4355.5	2152.5	659.3	725.8	785.6	2065.4	6740.4	10386.1	11279.8	67932.6

Raw Data Source: South African Weather Service

APPENDIX 5: EVAPORATION DATA: ZUURBEKOM WEATHER STATION DWAF STATION NO. C2E007

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Mean	168.91	138.79	130.67	102.72	87.07	70.40	79.34	111.86	148.46	167.49	166.05	171.95	1536.46
Std Dev	21.51	28.21	21.95	13.69	14.33	10.65	11.13	13.90	18.44	31.58	23.98	32.83	110.35
1959		131.2	133.1	116.1	87.1	67.6	66.3	113.8	149.9	189.5	151.9	166.9	1373.4
1960	183.6	140.2	126.7	109	82	64	81	94.7	150.1	181.1	150.6	190.7	1553.7
1961	162.8	143.8	114.8	116.4	80.5	52.3	65	101.6	146.6	213.4	149.9	175.3	1522.4
1962	165.1	141.2	131.6	96.2	78.5	81	76	108.5	164.3	198.4	143.5	186.2	1570.5
1963	149.1	148.3	140.7	92.5	80.5	51.8	68.1	110	149.1	169.9	149.6	180.1	1489.7
1964	172.5	164.8	146.3	104.4	75.2	58.7	68.8	103.9	156.2	130.6	175	150.6	1507
1965	175	161	156.2	96	83.6	67.1	75.7	107.5	145.6	196.6	174.3	230.4	1669
1966	200.9	133.3	160.5	102.6	92.5	68.1	87.1	120.4	154.2	173	193.8	173.2	1659.6
1967	159.5	110.8	126	75.2	67.3	60.9	67.1	85.1	138.7	163.1	157.3	174.7	1385.7
1968	176.3	175	96.1	97.8	65.3	61.9	80.8	103.7	154.7	193.6	155.7	180.4	1541.3
1969	208.3	146	108.2	99.3	69.1	61.7	67.8	93.7	143.3	122.2	170.9	163.1	1453.6
1970	177.8	139.2	142.8	108.5	79	60.7	66.8	104.4	146.3	156	167.6	180.6	1529.7
1971	152.6	112.8	125.5	97.4	67.8	56.1	66.5	107.7	136.4	148.6	160.6	168.7	1400.7
1972	133.4	157.5	95.3	89.7	73.9	64	76.7	115.1	158.5	165.6	166.7	209.5	1505.9
1973	212.1	141.2	139.4	81.5	95.3	68.1	74.2	113.3	172.7	146.1	176.3	160.3	1580.5
1974	153.9	121.2	119.9	71.4	83.8	70.6	70.8	113.8	146.1	190.8	133.4	167.4	1443.1
1975	159.5	104.9	97.3	76.7	75.2	60.7	74.2	100.8	132.9	172	155.2	144	1353.4
1976	116.1	115.8	102.9	81.3	59.7	64.5	72.9	108.7	130.8	126.5	156	175.5	1310.7

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1977	156.7	166.9	112	104.9	102.6	83.1	82.3	119.4	136.1	180.3	196.6	179.3	1620.2
1978	135.9	117.1	113.8	99.3	92.2	68.1	75.2	126.2	128.8	166.1	163.3	181.9	1467.9
1979	169.4	146.1	170.1	110.7	89.9	68	74.5	88.3	136.7	173	148.6	172.1	1547.4
1980	165.2	121.7	118.2	109.7	94.6	71.5	67.5	104	127.9	189.8	164	170.3	1504.4
1981	150.2	124.7	116.4	103.3	75.6	68.5	78.5	85.9	144	143.1	193.6	175.8	1459.6
1982	174.2	131.6	133.4	87.5	95.5	70.2	70.7	104	137	156.4	191.8	198.2	1550.5
1983	181.5	181	159.7	108.3	103.1	75.5	75	107.2	175.6	170.2	179.5	142.5	1659.1
1984	195	187.7	160.7	108.4	90.1	73.5	67.2	117.5	149	168.7	174.5	212.3	1704.6
1985	167.3	135	137.4	127	104	96.5	109.5	125	155.4	145.3	157.4	168.4	1628.2
1986	176.8	154.9	161.4	103.9	99	74	96	128	141.1	153.5	131.7	221.9	1642.2
1987	182.3	166	131.9	115.7	102	81.5	96	125.1	120.2	151.6	175.7	173.4	1621.4
1988	193.3	167.3	120.3	98.2	88.3	72.5	77.6	112.5	142.7	158	179.7	144.8	1555.2
1989	144.8	110.5	133.2	102.3	76	57.3	79	128.5	138	179.8	172.8	191.3	1513.5
1990	168.7	146.1	129.1	91.7	76	84	98	134	159.8	193.9	197.5	176.1	1654.9
1991	164.3	143	105.7	122	120.6	87	98	145	134.2	163.1	171.1	161.9	1615.9
1992	218.2	230.1	168	127	112	70.5	83	104.5	175	178.2	167.1	181.6	1815.2
1993	193.9	143.7	132.9	110.8	109.5	89	97	116.3	176.5	28.5	148	167.5	1513.6
1994	142.4	60.8	126	111.5	106	85.5	89	129	172	182	171.1	195.3	1570.6
1995	175.5	160.5	130.7	114.5	77	68	91.6	123.8	158	179.9	166.9	156.9	1603.3
1996	155.2	125.3	141.4	91.8	77.6	67	87	106.2	146.3	169.5	138.2	172.8	1478.3
1997	161.6	154.3	89.4	92.4	72.1	68.5	67	105	96.3	139	166.4	180.2	1392.2
1998	157.5	128.8	130	115.7	105	80	85	116	145	153.2	93.7	153.6	1463.5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1999	154.6	139.5	134.2	110	79.5	68	78.5	102.5	150	161.5	184	4.2	1366.5
2000	141	121.7	102.6	84	73.5	54.5	64	93	127	134.3	159.1	174.9	1329.6
2001	188.5	124.5	173.8	101	81	65.5	77	113	136.5	194.1	112.8	165	1532.7
2002	185.8	130	135.6	127	107	73.3	88.5	96	142.8	178.5	188.5	184.5	1637.5
2003	193.3	74.5	174.5	121.5	111	74.3	88	123	165	196.5	180.5	210	1712.1
2004	171	104.5	101	102.5	84	74	83.5	125	173	204.5	204	115.5	1542.5
2005	147.1	137	135	113.4	91.1	99.5	99	147	211.5	242.5	238		1661.1

Source: <http://www.dwaf.gov.za/hydrology/cgi-bin/his/cgihis.exe/Data?Station=C2E007&DataSet=S01&DataType=Monthly&StartDT=19590102&EndDT=20051201>

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APPENDIX 8: DWAF CLASSIFICATION FOR THE PROPOSED DOORNPOORT TAILINGS DAM



PRIVATE BAG X313 PRETORIA 0001

Only applicable if the maximum wall height of the dam exceeds 5 metres and the gross storage capacity is more than 50 000 cubic metres

[illegible]

2. PROPERTY ON WHICH THE DAM IS OR WILL BE SITUATED AND LOCALITY

2.1. Property description as per title deed																													
P	o	r	t	i	o	n		5	0		o	f		D	o	o	r	n	p	o	o	r	t						
3	4	7		l	Q																								

2.2. Magisterial district										W	e	s	t	e	r	n		A	r	e	a						
---------------------------	--	--	--	--	--	--	--	--	--	---	---	---	---	---	---	---	--	---	---	---	---	--	--	--	--	--	--

2.3. Nearest city/town										W	e	s	t	o	n	a	r	i	a								
------------------------	--	--	--	--	--	--	--	--	--	---	---	---	---	---	---	---	---	---	---	--	--	--	--	--	--	--	--

2.4. Distance to nearest city or town																	1	0	km
---------------------------------------	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	---	---	----

2.5. Direction from nearest city or town										S	o	u	t	h										
--	--	--	--	--	--	--	--	--	--	---	---	---	---	---	--	--	--	--	--	--	--	--	--	--

2.6. Number of 1:50 000 scale topographical map															*	2	6	2	7	B	C
---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	---	---	---	---	---	---	---

* *A copy of the relevant portion of this map which clearly indicates the position of the dam and downstream area must be attached*

Latitude:

2	6
---	---

^o

2	8
---	---

'

0	6
---	---

" Longitude:

2	7
---	---

^o

3	8
---	---

'

1	9
---	---

"

2.8. Title deed number	T	5	6	5	5 /	1	9	8	6								
------------------------	---	---	---	---	-----	---	---	---	---	--	--	--	--	--	--	--	--

3.1. Name of dam	Doornpoort			Return			Water			Dam				
------------------	------------	--	--	--------	--	--	-------	--	--	-----	--	--	--	--

[illegible]

domestic supply		irrigation		industrial use	
stock watering		fisheries		other (specify below)	
Describe "other"					

pollution control	☒	wastewater disposal	☐	industrial residue	☐
oxidation / evaporation	☐	mine residue	☐	other (specify below)	☐
Describe "other"	☐	☐	☐	☐	☐

[illegible]

3.6. Proposed starting date of construction

M	e	t	a	g	o		E	n	v	i	r	o	n	m	e	n	t	a	l				
P	O		B	O	X		1	5	9	6													
C	r	a	m	e	r	v	i	e	w								Postal code			2	0	6	0

3.8. Tel. no. of designer or consultant	0	1	1		4	6	7		0	9	4	5			
---	---	---	---	--	---	---	---	--	---	---	---	---	--	--	--

(For enlargement or alteration of an existing dam, particulars must be for the completed structure)

earthfill	☒	rockfill	☐	gravity	☐
buttress	☐	arch	☐	multi-arch	☐
earth "service" reservoir	☐	reinforced concrete "service" reservoir	☐		
mine residue deposit *	☐	industrial residue deposit *	☐		

[illegible]

4.2. Maximum wall height

**

	6	,0	m
--	---	----	---

**** Note! Wall height is the vertical difference between the lowest downstream ground elevation on the outside of the dam wall and the non-overspill crest level or the general top level of the dam wall**

4.3. Crest length of wall

2	1	5	0	m
---	---	---	---	---

4.4. Gross storage capacity

			1	0	0	0	0	0	0	m ³
--	--	--	---	---	---	---	---	---	---	----------------

4.5. Area of water surface at full supply level

		2	2	,5	ha
--	--	---	---	----	----

4.6. Maximum full supply water depth (*must be provided*)

	8	,5	m
--	---	----	---

5. PARTICULARS OF DEVELOPMENT DOWNSTREAM OF THE DAM

Describe with the aid of a 1:50 000 scale map the nature and situation of development downstream of a dam that would be threatened by a failure of the dam. Development means any houses, dwellings, other buildings, roads, bridges, cultivated lands, orchards, powerline foundations etc.

The area downstream of the dam wherein all development must be described is defined as follows;

- For every one metre of maximum wall height, at least one kilometre of the valley downstream of the dam wall should be analysed
- For the calculation of the width of the strip the following heights above river bed may be assumed;

2/3 of maximum wall height for the first kilometre downstream and 1/2 of the maximum wall height for the rest of the downstream distance

5.1. Development downstream of the dam (houses, dwellings and other similar structures)

Distance downstream (km)	Purpose or use of structure	Height above river bed (m)	Distance from river (m)	Number of inhabitants or users
2.25	Farm land	0.5	0	0
4.5	Wall	1.5	0	N/A
4.75	Farm land	0.5	0	0
6.75	Farm land	0.5	0	0
7.75	Wall	1.5	0	N/A

5.2. Road and railway crossings downstream of the dam

Distance downstream (km)	(1) Type of road or railway	If a road, is it tarred? (Y/N)	Height of road / railway above river bed (m)	Bridge, culvert or pipe openings				(2) Type of crossing	(3) Visibility distance (m)	Number of vehicles per day
				Width (mm)	Height (mm)	Diameter (mm)	How many?			
1.75	SRD	N	2.5	,				B	i 999 ii 600	
3.25	FRD	N	1.5	,				C	i 80 ii 250	
4.5	FRD	N	0	,				D	i 200 ii 80	
5.5	FRD	N	0	,				D	i 400 ii N/A	
6.5	FRD	N	0	,				D	i 250 ii N/A	
									i 80	



DEPARTMENT OF WATER AFFAIRS AND FORESTRY



DAM SAFETY OFFICE

PRIVATE BAG X313 PRETORIA 0001

**APPLICATION FOR CLASSIFICATION OF A PROPOSED NEW DAM
OR ENLARGEMENT OR ALTERATION OF AN EXISTING DAM**

Only applicable if the maximum wall height of the dam exceeds 5 metres and the gross storage capacity is more than 50 000 cubic metres

1. PARTICULARS OF THE DAM OWNER

1.1. Name of dam owner	S	o	u	t	h		D	e	e	p		G	o	l	d							
	M	i	n	e																		
1.2. Owner's postal address	P	O		B	O	X		7	7	6												
	W	e	s	t	e	r	n		A	r	e	a										
																Postal code	1	7	8	0		
1.3. Tel. no. of dam owner	0	1	1		4	1	1		1	0	0	0										
1.4. Name and postal address of person in control of the dam (if applicable)																						
	G	o	r	d	o	n		V		T	h	o	m	p	s	o	n					
	P	O		B	O	X		7	7	6												
	W	e	s	t	e	r	n		A	r	e	a						Postal code	1	7	8	0
1.5. Tel. no. of person in control of the dam		0	1	1				4	1	1			1	0	0	0						

2. PROPERTY ON WHICH THE DAM IS OR WILL BE SITUATED AND LOCALITY

2.1. Property description as per title deed	P	o	r	t	i	o	n		1	o	f		D	o	o	r	n	p	o	o	r	t
	3	4	7		I	Q																

2.2. Magisterial district	W	e	s	t	e	r	n		A	r	e	a						
---------------------------	---	---	---	---	---	---	---	--	---	---	---	---	--	--	--	--	--	--

2.3. Nearest city/town	W	e	s	t	o	n	a	r	i	a								
------------------------	---	---	---	---	---	---	---	---	---	---	--	--	--	--	--	--	--	--

2.4. Distance to nearest city or town			1	0	km
---------------------------------------	--	--	---	---	----

2.5. Direction from nearest city or town	S	o	u	t	h									
--	---	---	---	---	---	--	--	--	--	--	--	--	--	--

2.6. Number of 1:50 000 scale topographical map	*	2	6	2	7	B	C
---	---	---	---	---	---	---	---

* *A copy of the relevant portion of this map which clearly indicates the position of the dam and downstream area must be attached*

Latitude:

2	6
---	---

^o

2	8
---	---

'

0	8
---	---

" Longitude:

2	7
---	---

^o

3	8
---	---

'

5	2
---	---

"

2.8. Title deed number	T	2	6	9	7 /	1	9	9	4								
------------------------	---	---	---	---	-----	---	---	---	---	--	--	--	--	--	--	--	--

3.1. Name of dam	Doornpoort			Tailings				Dam							
------------------	------------	--	--	----------	--	--	--	-----	--	--	--	--	--	--	--

[illegible]

domestic supply		irrigation		industrial use	
stock watering		fisheries		other (specify below)	
Describe "other"					

pollution control	☐	wastewater disposal	☐	industrial residue	☐
oxidation / evaporation	☐	mine residue	☒	other (specify below)	☐
Describe "other"	☐	☐	☐	☐	☐

[illegible]

3.6. Proposed starting date of construction

M	e	t	a	g	o		E	n	v	i	r	o	n	m	e	n	t	a	l						
P	O		B	O	X		1	5	9	6															
C	r	a	m	e	r	v	i	e	w												Postal code	2	0	6	0

3.8. Tel. no. of designer or consultant	0	1	1		4	6	7		0	9	4	5			
---	---	---	---	--	---	---	---	--	---	---	---	---	--	--	--

(For enlargement or alteration of an existing dam, particulars must be for the completed structure)

earthfill	☐	rockfill	☐	gravity	☐
buttress	☐	arch	☐	multi-arch	☐
earth "service" reservoir	☐	reinforced concrete "service" reservoir	☐		
mine residue deposit *	☒	industrial residue deposit *	☐		

[illegible]

4.2. Maximum wall height

**

8	0	,0	m
---	---	----	---

**** Note! Wall height is the vertical difference between the lowest downstream ground elevation on the outside of the dam wall and the non-overspill crest level or the general top level of the dam wall**

4.3. Crest length of wall

5	2	5	0	m
---	---	---	---	---

4.4. Gross storage capacity

	1	5	2	1	3	5	1	3	0	m ³
--	---	---	---	---	---	---	---	---	---	----------------

4.5. Area of water surface at full supply level

	1	8	6	,5	ha
--	---	---	---	----	----

4.6. Maximum full supply water depth (*must be provided*)

8	0	,0	m
---	---	----	---

5. PARTICULARS OF DEVELOPMENT DOWNSTREAM OF THE DAM

Describe with the aid of a 1:50 000 scale map the nature and situation of development downstream of a dam that would be threatened by a failure of the dam. Development means any houses, dwellings, other buildings, roads, bridges, cultivated lands, orchards, powerline foundations etc.

The area downstream of the dam wherein all development must be described is defined as follows;

- For every one metre of maximum wall height, at least one kilometre of the valley downstream of the dam wall should be analysed
- For the calculation of the width of the strip the following heights above river bed may be assumed;

2/3 of maximum wall height for the first kilometre downstream and 1/2 of the maximum wall height for the rest of the downstream distance

5.1. Development downstream of the dam (houses, dwellings and other similar structures)

Distance downstream (km)	Purpose or use of structure	Height above river bed (m)	Distance from river (m)	Number of inhabitants or users
2.5	Farm land	0.5	0	0
4.75	Wall	1.5	0	N/A
5	Farm land	0.5	0	0
7	Farm land	0.5	0	0
8	Wall	1.5	0	N/A

5.2. Road and railway crossings downstream of the dam

Distance downstream (km)	(1) Type of road or railway	If a road, is it tarred? (Y/N)	Height of road / railway above river bed (m)	Bridge, culvert or pipe openings				(2) Type of crossing	(3) Visibility distance (m)	Number of vehicles per day
				Width (mm)	Height (mm)	Diameter (mm)	How many?			
2	SRD	N	2.5	,				B	i 999 ii 600	
3.5	FRD	N	1.5	,				C	i 80 ii 250	
4.75	FRD	N	0	,				D	i 200 ii 80	
5.75	FRD	N	0	,				D	i 400 ii N/A	
6.75	FRD	N	0	,				D	i 250 ii N/A	
									i 80	

7	FRD	N	0	,				D	ii 300
8	FRD	N	0	,				D	i 175
									ii 350
10	FRD	N	0	,				D	i 300
									ii 40

(1) *Type of road or railway* - Use one of the following abbreviations

NRD = national road

MRD = main road

SRD = secondary road

DRD = district road

FRD = farm road

STR = single track railway

MTR = multi-track railway

Explain other abbreviations

[illegible]

(2) *Type of crossing* - Use one of the following abbreviations

C = culverts or pipes encased in concrete

E = culverts or pipes buried in earthfill or rockfill

B = concrete bridge with piers

D = drift with same height as river bed

Explain other abbreviations

	=	
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(3) *Visibility distance* - This is the distance to a bridge or crossing from where a motorist can see if there is any danger in using the bridge or crossing. Both approach distances are required. **The order in which i and ii are written does not matter.**

If the distance equals or exceeds 1 kilometre, enter 999

5.3. Other development downstream of the dam, not covered by 5.1 or 5.2

Note: Since the Tailings Dam is to be 80m high, it is theoretically necessary to check 80km			
downstream of the dam wall as a result of it being tailings, it will not physically be able to slide 80km			
downstream.			
We are aware that this will be a high hazard dam, and so we have just looked at the first 10km			
downstream to give a view of what is there.			

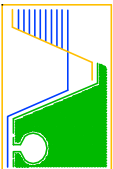
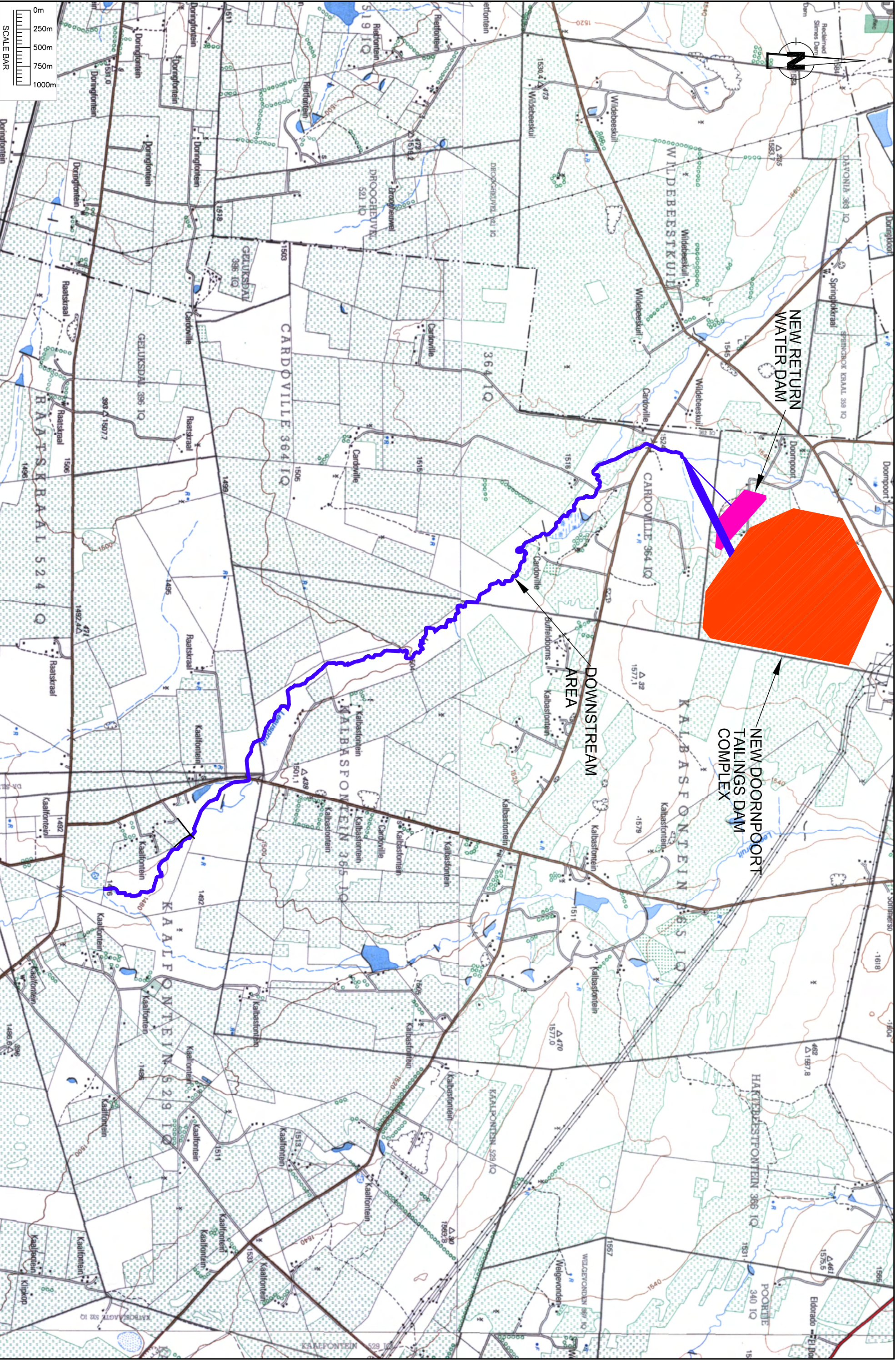
6. DECLARATION BY APPLICANT

I declare that the information given by me for the classification of the above dam is true and correct.

Signature: _____

Date:

NB! Remember to attach a clear copy of the relevant topographical map (see 2.6)





water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

011.411 1716

Att. Tarina

(3)
DW 6/1

bb12@dwaf.gov.za

✉ Mrs H. Marais
☎ (012) 336-8213
📁 12/2/C222/36
12/2/C222/37

Vice President and Head of Operation
South Deep Gold Mine
P.O. Box 776
WESTERN AREA
780

2008-02-29

ATTENTION: MR G.V. THOMPSON

Sir

CLASSIFICATION OF DAMS WITH A SAFETY RISK IN TERMS OF CHAPTER 12 OF THE NATIONAL WATER ACT, 1998 (ACT 36 OF 1998), READ WITH REGULATIONS 2 AND 3 OF THE REGULATIONS PUBLISHED IN GOVERNMENT NOTICE R. 1560 OF 25 JULY 1986:

- I PROPOSED DOORNPOORT RETURN WATER DAM ON PORTION 50 OF THE FARM DOORNPOORT 347 IQ, DISTRICT WESTERN AREA; AND
- II PROPOSED DOORNPOORT TAILINGS DAM ON PORTION 1 OF THE FARM DOORNPOORT 347 IQ
- A. IMPORTANT NOTICE: THE NATIONAL WATER ACT, 1998

Please note that in terms of section 163(4) of the National Water Act, 1998, the Regulations published in Government Notice R. 1560 of 25 July 1986 are in force until officially withdrawn by notice given in the Government Gazette by this Department. The expression "approved professional person" (APP) has the same meaning as "approved professional engineer" (APE) and the term "licence" has the same meaning as "permit", where mentioned in the aforementioned Regulations.

B. APPLICATIONS

Your applications dated 4 December 2007, refer.

✓
Pasloa/09

C. CLASSIFICATION OF THE PROPOSED DOORNPPOORT RETURN WATER DAM

Vertical wall height	6 metres
Storage capacity	1 000 000 cubic metres
Size classification	Small
Hazard potential rating	Significant
Category	II

The classification is based on available information. If you have any information on the basis of which you feel the classification is incorrect, you should submit a substantiated application in writing for its revision

D. REQUIREMENTS

1. **No construction work as stipulated in regulation 4.1 of the said regulations may commence before the appropriate steps have been followed:**
 - 1.1 Obtain the services of an approved professional person. Enclosed is a list of consulting engineering firms to assist you in obtaining the services of an approved professional person. You are advised to obtain at least three (3) quotations before appointing a person. The person you appoint, must submit an application to the Dam Safety Office of this Department on the enclosed form (DW691E) to be approved.
 - 1.2 Submit an application for a licence to construct on the enclosed form (DW695E). The approved professional person must submit this application, together with design drawings of the proposed works, to the Dam Safety Office at the above address, where the required licence will be considered and issued.
 - 1.3 Submit an application for a licence to impound after completion of the dam on the enclosed form (DW696E). Impoundment of water in the dam may not commence until you are in possession of a licence to impound issued by this Department.
2. In terms of section 120 of the National Water Act, 1998, the dam must be registered at the Dam Safety Office of this Department within 120 days of the date on which the dam becomes capable of containing, storing or impounding water. The enclosed form (DW693E) must be completed and submitted to the Dam Safety Office for this purpose.

E. CLASSIFICATION OF THE PROPOSED DOORNPPOORT TAILINGS DAM

1. In terms of section 117(c)(i) of the National Water Act, 1998, a dam with a storage capacity of more than 50 000 cubic metres and a vertical wall height exceeding 5,0 metres is considered to be a dam with a safety risk.
2. According to the information, the proposed Doornpoort Tailings Dam is not regarded a dam with a safety risk on condition that the Dam will not store more than 50 000 cubic metres under normal operating conditions. Since the dam in question does not meet the above minimum requirements, classification and registration of the dam are not required.

F. YOUR ATTENTION IS DRAWN TO THE FACT THAT A LICENCE TO CONSTRUCT IN TERMS OF CHAPTER 12 SHALL NOT BE ISSUED UNLESS THE FOLLOWING PROVISIONS AND REGULATIONS ARE COMPLIED WITH:

- 1 The required licence or entitlement to water use in terms of chapter 4 of the National Water Act, 1998 or recognition of an existing lawful use in terms of sections 32 and 33 of the said Act. Address enquiries and applications in this regard to:

Acting Regional Head: Gauteng
Department of Water Affairs and Forestry
Private Bag X995
PRETORIA
0001

☎: (012) 392 1300
Fax: (012) 392 1304

2. The provisions and regulations of Government Notices R.1182 and R.1183 of 5 September 1997, promulgated in terms of section 21 of the Environment Conservation Act, 1989 (Act 73 of 1989) regarding control over activities which may have a detrimental effect on the environment must be complied with. Enquiries in this regard should be addressed to:

Director-General
Department of Agriculture, Conservation
Environment and Land Affairs
P.O. Box 8769
JOHANNESBURG
2000

☎: (011) 335 1980
Fax: (011) 333 0620

Yours faithfully


ACTING DIRECTOR-GENERAL

Copy to:

- (i) Acting Regional Head: Gauteng (Attention: Mr H.A. Smit)
- (ii) Regional Director: Gauteng (Attention: Mr M.L.J. Botha)
- (iii) Director-General: Department of Agriculture, Conservation, Environment and Land Affairs, P.O. Box 8769, Johannesburg, 2000 (i.e. paragraph E.2 in this letter)

Enclosure: DW691E, DW693E, DW695E and DW696E

APPENDIX 9: RISK ASSESSMENT

Reference	Risk Area	Risk/ concern Description	Lifecycle period	P[Occurrence] 1=Almost never 2=Occasional 3=Sometimes 4=Often 5=Definite	Cause	Consequence	Consequence Ranking 1=insignificant 5=very serious	Detection	Protection	Investigation Brief		
			C= construction O=Operation D=Decom. A=aftercare							Objective	Responsibility	By When
1	Tailings Delivery System											
	Comprises ring main (at ground level), buried risers, spigot delivery pipes, spigots and night wall pipe plus associated valves	1 Failure of riser pipes leading to environmental damage, erosion of cover etc.	O,A	2	Seismic events, settlement, corrosion (unlined pipe), poor quality pipes	Washout, erosion	1	Physical inspection. Yearly thickness detection program.	Rubber lined pipes. Rock clad and bush cutting program			
		2 Difficulty in accessing riser mains on 1:4 slope for repair and maintenance	C,O	2	High seasonal fluctuation	Delays to repairs	1	None	Crushed hard rock zones to be constructed in the immediate vicinity of riser pipes on 1:4 slopes			
		3 Channelling of runoff around riser mains leading to erosion gullies	O	2	Concentration of runoff	Erosion gully formation	1	Visual	Rock clad slope at risers, repair of gully's			
		4 Collapse of spigot valves	O	3	Negative pressure		1	Visual	none			
		5 Failure of riser pipes where they pass beneath access ramps	O	2	Vehicles	Washout, additional maintenance, vegetation damage	1	Visual	Encase pipe in concrete			
		6 Valve failure	O	4	Wear and tear. Partially closed	Clean up, spillage	1	Inspection means enquiry	training			
		7 Valve theft and vandalism	O	2	Access control failure	Operational disruptions and cost	1	Inspection (possibly cameras)	T.B.D	Coordinate with South Deep fibre optic detection system	Shaun Martin	End August
		8 Vehicle collision	O	3	Bad driving, slippery roads, vehicle maintenance	Damage to pipes	1		Small bund wall between road and pipe			
2	Outer Embankment											
2.1	Wall raising Operation											
	Comprises haulage of soil, placement, spreading and compaction of outer soil wall. Single way up ramps and down ramps provided to cater for bell articulated dump trucks. Wall is raised using an inner and outer paddock wall with cross walls at 200m centres. Inner paddock wall and cross wall constructed using tailings. Outer paddock wall constructed using a combination of tailings and soil. The soil forms a final cladding for the tailings dam which is ultimately top soiled and vegetated to provide erosion resistance similar to that of a natural slope.	1 Spigot Ted beach too wet to access with machinery	O	2	Tailings finer than expected, production higher than expected	Provided freeboard is managed, no serious consequence	1	Visual/ trial	Rate of rise limited to 1.8m/yr. Use of high floatation excavation equipment			
		2 Over spray of tailings onto outer slope causing die back of vegetation and possibly erosion	O	3	Pipe Leakage	Damage to vegetation and clean up cost	1	Visual	Planned Maintenance			
		3 Insufficient subsoil available for cladding (Note: Topsoil will be stripped from the tailings dam basin to a depth of 300mm)	O	1	Insufficient excavatable soil available Gold Fields owned surrounding properties or failure to get EIA approval to take soil.	High cost of bringing in soil	4	Geotech investigation	None	Characterize and investigate borrow areas	Tharina/ Golder/ Metago	Defer to optimization stage
2.2	Tailings Starter Walls											
	Homogenous earth starter walls maximum height 22m. Minimum height 3m. Compacted in layers. Curtain drain provided to sections that are in excess of 11 m.	1 Toe seepage through starter embankment	O	2	Phreatic surface not drawn into upstream toe drain or main drain	Vegetation die back at the toe of the slope which triggers erosion gully formation up the slope	3	Visual inspection and Piezometers	1) Low rate of rise, 2) Provision of curtain drain, toe drain and main drain			
		2 Slope failure	O	2	Phreatic surface significantly higher than anticipated plus shear strengths much lower than anticipated.	Slope failure could result catastrophic dam failure/ loss of life etc.	5	Piezometers, seepage and stability analyses	Flat slope and comprehensive under drains result in a low risk.			

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		3	Excessive Erosion	O, A	3	Stream Power exceeds erosion resistance	High Maintenance costs	3	Visual inspection / DTM survey	Temporary vegetation cover to be applied to TSF during the operational phase. Flattening of the starter walls to remove sharp change in slope and armouring of the slope with rock/soil mixture.			
		4	Overtopping	O	1	Possible causes include: 1) Excessive water stored on top. 2) Low spots along outer embankment.	Catastrophic failure of dam causing prolonged plant shut down, possible loss of life etc.	5	Daily monitoring of pool. Survey of freeboard	Freeboard caused by wall construction			
		5	Vehicle accident	C	3	Various	Loss of life, injury and damage to property	5	N/A	Armco barrier system provided to access ramps. One way vehicle system on ramps. Speed limit enforcement			
2.3	Pool Wall												
	Pool wall raised using a standard RSA procedure for packing of gold tailings day walls	1	Water trapped on upstream side of pool	O	1	Poor Orientation of pool wall	Difficulty raising pool wall	3	Visual	Orientate pool to minimize trapping.			
		2	Decant of stormwater leads to washaways	O	5	Rain	Wash aways	2	Visual	Management procedures			
		3	Pool wall cannot be raised as it cannot be widened	O	5	Trying to build a wall over water	unable to raise wall	4	visual	Run pipe down pool wall, Ops manual			
3	Decant system												
	Comprises temporary penstock intakes, single final penstock intake intake tower with three stages, plus outfall pipe (either concrete encased steel or concrete)												
3.1	Temporary Penstock Intakes	1	Delay in returning water to plant during commissioning .	O	5	Temporary penstocks do not receive water early enough	Leads to build up of water on the dam, which leads to failure to satisfy R704 later on	3		Start first intake early. Look at commissioning dates	Look at water availability during commissioning	Golder/ Metago	September
		2	Inadequate capacity	O	5	Long decant times after major storms	Larger pool than desired with associated possible consequences including 1) problematic commissioning of drains, 2) lower shear strengths of tailings	1		Four penstocks can be operated at once. Behind starter wall. Ops manual			
		3	Damage of rings, or injury to people during handling of penstock rings	O	4	Weight and size of rings	Possible breakage of the rings and injury. Leakage of tailings in to penstock	4	Visual inspection	Ops manual. Design of mechanized handling system			
		4	Drowning due to high suction forces	O	1	High suction forces across intakes and operators in contact with intakes	Loss of life			Cage and operating procedures (harnesses, pairs). Mentis grid			
		5	Differential settlement due to drag down on towers causes penstock outfall pipe failure	O	2	Differential loads	Penstock failure (dam shut down)	3	Camera inspection	Move off main pipe			

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		6	Sealing of temporary intakes (loss of plug in to pipe)	O	2	Failure of mechanism holding pipe up	Stops dam operation	5	none	Create temporary intakes on side channels	Look at temporary intake design	Metago	
3.2	Final Penstock tower	1	Large differential settlement across base of tower causes leaning	O	1	Differences in compressibility of materials and loads	Ring raising	5	Survey	QA, QC during construction. Monitoring during operations	Confirm with Rocla if offset ring for large diameter available	Metago/ Golder	End August
		2	Large differential settlement between base of tower and penstock outfall pipe	O	2	Differences in compressibility of materials and loads	Penstock outfall failure	5	Camera survey	Foundation preparation. Slip joint			
		3	Abrasion at base of tower due to falling water	O	3	Energy of water	Wear of penstock pipe			MS lost shutter, baffles, plunge pool, copon covering layer	Use specialist advisor	Metago/ Golder	
		4	Corrosion of Concrete / acid attack	O	1	ARD	Corrosion and failure	3	Visual and camera inspection	copon covering			
		5	Bearing failure of tower foundation	A	1	Bearing strength lower than expected, draw down of phreatic surface	Final penstock would need to be replaced with a floating penstock	3	None	Appropriate sealing of penstock outfall pipe. Decommissioning procedure			
		6	Collision - low flying aircraft	O	1	Aircraft failure	Loss of life. Reclaiming wreck. Reconstruction of penstock	5	Visual	Solar powered red flashing light to be mounted on top of tower			
		7	Lightning Strike	O	5	Lightning	Loss of life and injury	4		Earthing system and shelters	Goldfields to look at change rooms	Metago	
		8	Severe vibration of tower structure / pressure surges & falling water	O	2	Unstable flow conditions (hunting) - poor air entry, lack of energy dissipation	Damage to structure	4	Inspection during operation	Design includes provision of energy dissipaters & air entry conduits			
		9	Seismic activity	See above					South Deep Investigation				
		10	Access failure	O	1	Poor design or construction of access catwalk and pool wall	Redesign or reconstruction of access	2	Visual	Quarterly monitoring			
3.3	Penstock Outfall pipe												
		1	Pipe Abrades and does not last 50 year design life	O	1	Erosion over extended time period	Eventual pipe failure- replacement with floating penstock	4	Camera inspection	Sewer pipe with sacrificial layer used.			
		2	Pipe corrodes due to acid attack	O, A	1	Acid attack due to infiltration of acid from tailings above.	As above	4	Camera inspection	Pipe is buried well beneath tailings and outside of the zone of acidification of tailings (neutral zone)			
		3	Pipe collapses due to vertical stresses	O,A	1	Inadequate design or poor quality of construction	Pipe failure - need to replace penstock with a floating penstock or barge system.	4	Camera inspection	Concrete encased. Grouted on closure			
		4	Large differential settlements over short distances of pipeline	O	1	Changes in underlying compressibility of soils over short distances (e.g. dyke crossings)	Possible penstock failure	4	Survey	Design incorporates flexible joints to accommodate limited settlement			
		5	Blockage due to settlement of solids	O	1	Settling of solids under low flow conditions	Need to flush	1	Water backs up in tower	Operating Procedures			
		6	Sediment forms hard cement like deposit in pipe	O	1	Cement from backfill plant	Pipe does not flush easily	3	Water backs up in tower	Regular discharge of reasonably high flows			

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		7	Pipe floats out of trench during or shortly after commissioning	O	1	Inadequate design	Failure of penstock outfall pipe requiring substitution with a floating penstock system	4	Camera system	Concrete encased, tie downs etc.			
		8	Piping failure from pond to penstock pipeline	O	1	Higher permeability along pipeline interface	Operational disruption	4	None	Orientate pool wall such that pond is away from the penstock pipeline. Puddle flanges provided in starter wall			
		9	Vandalism	O	3	Failure of access controls	Damage to pipeline, blockage, damage to flow measuring equipment	4	Camera system and security fence	Pipeline is buried.			
3.4	Catwalk	1	Catwalk width insufficient to transport large rings	O	1	Design fault	High incidence of ring breakage, injury to operators	2	Observation	Catwalks designed wider than normal to accommodate larger rings and trolley.			
		2	Catwalk platform insufficient	O	1	Design fault	Difficult operations and safety and health risks	2	Observation	Design			
		3	Rings too heavy to handle on catwalks	O	2	Larger than normal rings used. Each ring weighs 90kg instead of the normal 60Kg.	High incidence of ring breakage, injury to operators	2	Observation	Ring trolley to be designed			
4	Security Systems and Access control	1	Access by the public to pump stations, RWD, silt traps and TSF	C, O, A	5	Insufficient Access Control	Theft, injury, loss of life, interference	5	Surveillance system	24/7 security guards during construction. 4 strand bard wire fence around TSF during construction. Concrete palisade fence.			
5	Under drain System												
5.1	Drains comprise an inner and outer blanket drain plus a small curtain drain in the main starter wall	1	Erosion of drainage material prior to commissioning resulting in damage to drains	O	1	Rainfall	Drains fail to operate correctly	3	Visual	Drains protected by surrounding berm wall and covered with loose coarse tailings. Tailings covered by bidim which is removed immediately prior to commissioning. Ops manual. Supervision.			
		2	Drains blind during commissioning	O	3	Deposition of fines over drains	Drains fail to operate correctly	3	No flow (entering manholes) under conditions when flow would be expected	Ops Manual			
		3	Drains clog due to precipitates, fungal materials etc. during operation	O	3	Oxygen entry, acid generation	Slope stability, toe seepage	3	As above	Drains outlets equipped with upturn to prevent oxygen ingress. Ops manual			
		4	Drains fail to draw down the phreatic surface resulting in toe seepage and potential slope instability	O	2	Multiple	As stated	3	Detection at adjacent drain	Design of drain, QA, QC during construction and commissioning			
		5	Non-perforated outfall pipes float out of trenches during commissioning	C,O	2	Buoyancy force> Weight	Re-work - final profiles incorrect leading to sedimentation etc.	2	Visual during construction and commissioning	Design			

Reference	Risk Area		Risk/ concern Description	Lifecycle period	P[Occurrence] 1=Almost never 2=Occasional 3=Sometimes 4=Often 5=Definite	Cause	Consequence	Consequence Ranking 1=insignificant 5=very serious	Detection	Protection	Investigation Brief		
											Objective	Responsibility	By When
5.2	Under drain collection system												
	Outfall pipes drain under gravity to a perimeter drainage collection pipe. The inner and outer drains discharge to the same perimeter drainage pipe (which has replaced the conventional solution trench) Each underdrain gravity pipe enters the collector pipe at a manhole	1	Sedimentation of the inner or outer drain collection pipes	O	4	Sediment migration through drains particularly shortly after commissioning each drain section	Increased Maintenance - flushing	1	Block outlet pipes - possible cause of no flow condition	Operational procedure - rodding and flushing of pipeline from manholes. Provision of adequate manholes			
		2	Sedimentation of the main drainage collection pipes on the perimeter of the dam	O	3	Sediment deposition	Increased maintenance requirement. Possible overflow of underdrainage water to stormwater collection canal. Discharge of acid water to RWD	1	Visual	Operational procedure - rodding and flushing of pipeline from manholes. Provision of adequate manholes	Flushing of collection line, from RW pipeline	Golder/ Metago	
		3	Methane gas collection in manholes	O,D, A	1	Possible emissions from anoxic zones	Possible explosions	4	Gas monitors	Cross Bars under manhole lid. Ops procedure.			
		4	HCN concentration in manholes	O,D, A	2	Reduced pH will tend to cause HCN(g) to be released from water	Death	5	Gas monitors	Cross Bars under manhole lid. Ops procedure.			
		5	Corrosion of concrete manholes due to acid attack.	O,D,A	2	Acid fumes/ discharge	Injury, increased maintenance	2	Visual inspection	Soil cladding will reduce acid generation rate once drains are covered. Maintenance			
		6	Theft and vandalism of manholes and lids	C,O	4	Illegal access to TSF complex	Cost	2	Visual inspection	Access control system			
		7	Corrosion of manhole lids	O	2	Acid fumes	Safety risk.	2	Visual inspection	Soil cladding will reduce acid generation rate once drains are covered. Maintenance			
		8	Flow rate exceeds pipe capacity leading to spillage from manholes	O	3	During commissioning, flow rates could be higher than pipe capacity	No significant consequence as spillage will be collected in the catchment paddock drain which enters the RWD	2	Visual inspection	Design + location			
6	Silt Trap												
	Receives water from Penstock outfalls and runoff from roads, side slopes and catchment paddocks. Comprises 2 reinforced concrete basins to allow continuous operation during cleaning. Pump provided to de-silt the silt trap to the tailings dam basin.	1	Silt overtops to RWD	O	3	Operation+ high very silt loads from penstock or catchment paddocks.	Sedimentation of RWD and loss of capacity. Damage to pumps	1	Visual inspection	Operational procedure			
		2	Silt trap structure rises or settles	C, O	1	Raised water table causes floating	Structural damage	3	Visual inspection- damage	Provided with subsoil drains around perimeter and beneath base			
		3	Silt trap passes higher than expected silt load to RWD	O	3	Finer PSD than expected+ higher flow rates	RWD sedimentation - more frequent maintenance	1	Visual inspection+ lab tests	Dual system allows for flexibility in desludging			
		4	Water passing to RWD is not clarified	O	2	High colloidal fraction from tailings or catchment paddocks	Return water contains settleable solids or colloids	1	Visual inspection+ Laboratory tests	Only protection in the case of colloidal size fraction would be to add flocculent. This is not a normal operation.			

[illegible]

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											Objective	Responsibility	By When
	Grouting of tailings penstock pipeline and construction of reverse filter												
	Construction of the perimeter berm												
	Removal of all access ramps except for those used by end user.												
9	Aftercare and Post closure Phase												
	Aftercare management involves ongoing	1	Erosion of soil cladding at a rate that exceeds soil formation rate	A	2	Climate change, Acid generation, inappropriate vegetation species	Ultimate die back of vegetation	4	Monitoring of various soil parameters and erosion rates during the life of the facility and after closure - monitoring programme	None			
		2	Bush/ grass fires	O,A	4	Arson, lightning	Loss of nutrients from soil leading to erosion	4	Visual	Fire breaks will need to be maintained in perpetuity - fence			
		3	Overgrazing	A	3	Selective grazing, uncontrolled grazing, head/Ha too high	Erosion of soil cladding and formation of gullies into acidic tailings	4	Visual & DTM- gully formation - monitoring programme	Fence/ access control/ land management			
		4	Damage to final Berms/ overtopping and erosion gully formation	O,A	1	Stormwater, filling of storage zone behind berms due to erosion and then final overtopping due to insufficient storage	Erosion gully formation downstream of berms, exposure of tailings	5	Visual & DTM- monitoring programme	Eliminate berms from the design to the extent practical. Where berms cannot be avoided, apply large robust berms.			
		5	Migration of salts and acid through soil cladding results in die back of vegetation and a reduction in landscape function, biodiversity, erosion	O,A	2	Capillary rise caused by evapotranspiration from the upper soil layer combined with oxygen entry to the tailings and associated oxidation of sulphide minerals etc.	Soils eventually become toxic to vegetation and vegetation die back followed by loss of erosion and loss of nutrients from the soil- desertification	5	Regular but infrequent (annual) analysis of soil samples taken from the cladding to determine trends in inorganic content.	Soil thickness of 1m is expected to reduce capillary rise to a minimal level. As an additional protection, a layer of bitumen impregnated Bidim could be applied between the tailings and soil.			
		6	Piping through tailings and then through the outer soil cladding leading to excessive erosion	A	3	Phenomenon commonly observed on old gold tailings dams with berms caused by a combination of layering and ponding.	Rat holes, ARD generation, loss of soil, erosion, polluted runoff release.	5	Physical observation	Primary protection offered by soil cladding and vegetation cover. Secondary protection could be provided by the addition of a layer of bidim between the tailings and the soil cladding to prevent piping.			
		7	Oxygen entry through the underdrain outlets leads to acid generation within the dam	O,A	1	Once drains stop flowing, pipes dry out and air can enter the dam through the underdrain outflow pipes.	ARD generation commencing from the drains. Should the dam wet up again, possible release of ARD to the groundwater or surface water via the drain outlet pipes.	2	None	Drain outlet pipes should be sealed after decommissioning by grouting the outlets			

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		8	Biodiversity level does not converge with time towards that of a similar slope in the vicinity of the TSF but reduces with time.	O,A	3	Rate of loss of nutrients, microbes etc. (pedological processes) exceeds rate of accumulation of the same.	Erosion of the soil cover and final exposure of the tailings with consequential impacts on surface runoff quality and dust emissions	5	Ongoing monitoring of a range of landscape function indicators such as microbial population, nutrients, plant species, vegetation cover etc. to establish temporal trends in these parameters	Potential occasional management interventions to establish a converging trend through for example the addition of fertiliser or compost.			

Willgoose G R, Bras R L and Rodriguez-Iturbe I. 1989. "A physically based channel network and catchment evolution model", TR 322, Ralph M. Parsons Laboratory, Dept. of Civil Engineering, MIT, Boston, MA.



Justin Walls

Author



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Reviewer

Steve Dorman Pr Eng

APP

Metago Environmental Engineers (Pty) Ltd