APPENDIX K
PRIMARY IMPOUNDMENT SETTLEMENT AND COVER CRACKING ANALYSES

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 EXISTING CONDITIONS 2

2.1 Liner and Drain System 2
2.2 Tailings Properties 2
2.3 Cover System 2

3.0 SEEPAGE ANALYSIS 3

3.1 General 3
3.2 Method of Analysis 3
3.3 Material Properties 3
3.4 Results 4

4.0 SETTLEMENT ANALYSES 5

4.1 General 5
4.2 Method of Analyses 5
4.3 Material Properties 6
4.4 Results 6
4.5 Sensitivity 6

5.0 COVER CRACKING ANALYSES 7

5.1 General 7
5.2 Section Analyzed 7
5.3 Tensile Strain to Cause Cracking 7
5.4 Horizontal Movement and Strain 7

6.0 REFERENCES 9

LIST OF TABLES

Table K.1 Material Properties for Seepage Analyses 3
Table K.2 Material Properties 6
Table K.3 Time to Reach 90 Percent Consolidation 6

LIST OF FIGURES

Figure K.1 Primary Impoundment, Transient Seepage Analysis, Time Period = 50 Years
Figure K.2 Primary Impoundment, Settlement Analysis
Figure K.3 Simplified Cross-Section Through Northwest Dike, Cover Cracking Analysis

LIST OF ATTACHMENTS

Attachment A Select Figures from URS (2008)

1.0 INTRODUCTION

This appendix presents the results of settlement and cover cracking analyses for the Primary Impoundment at the Cañon City Milling Facility in Cañon City, Colorado. This appendix has been prepared as an appendix to the 2012 Tailings Reclamation Plan, associated with Radioactive Materials License 369-01.

This appendix focuses on the evaluation of settlement for the Primary Impoundment. For the Secondary Impoundment, minimal settlement is anticipated upon reclamation. This is because the Old Ponds materials were excavated and placed in lifts, with water subsequently added to the surface for evaporation and air quality control. Minor settlement of the Old Ponds materials is anticipated due to the additional loading of random fill and cover.

For the Primary Impoundment, the areas of anticipated settlement upon reclamation are where there are significant thicknesses of slurried tailings. These areas are primarily in the lower portions of the impoundment. Consolidation of these areas will be due to both tailings dewatering and loading with random fill and cover soils.

The Nuclear Regulatory Commission guidelines (NUREG 1620; NRC, 2003) recommend that the cover subgrade surface achieve 90 percent of primary consolidation prior to placement of the cover system, in order to minimize differential settlement and cracking of the cover system. This report summarizes the evaluation of consolidation of the tailings in the Primary Impoundment due to cover loading and dewatering of tailings, including the time to reach 90 percent consolidation. Cracking potential of the cover was also evaluated. Existing conditions are discussed in Section 2.0. Seepage, consolidation, and cracking analyses are summarized in Sections 3.0, 4.0, and 5.0, respectively.

2.0 EXISTING CONDITIONS

Information on the existing conditions of the site was obtained from the Wahler (1980), SMI (2000), and MFG (2005) reports.

2.1 Liner and Drain System

The liner system in the Primary Impoundment consists of a synthetic (Hypalon) liner constructed over a compacted clay layer (Wahler, 1980). A drainage system was installed above the synthetic liner to protect the synthetic liner as well as provide lateral drainage to remove tailings pore water. The drainage system consists of a series of finger drains (comprised of geofabric-wrapped sand and gravel conduits) that drain by gravity to a low area of the impoundment. The remaining liner surface (between the finger drains) is covered with on-site soils (sandy to clayey silt). This drainage system was not constructed as a high-capacity water extraction system, but provides a means for reducing porewater pressures and removing tailings porewater along the base of the tailings. A plan view and details for the drain system were provided in Wahler (1980).

Tests conducted by Cotter Corporation (MFG, 2005) and by SRK (2007) indicate that the drain system is operable and can be pumped to remove water from the tailings. Pumping of the water from the drain system will reduce the pore pressures in the tailings and aid consolidation of the tailings. For the analyses presented in this report, the drain system was assumed to function properly for the duration of the time period analyzed.

2.2 Tailings Properties

Investigation of the physical characteristics of tailings above the drainage layer was conducted for Cotter Corporation by Shepherd Miller, Inc. (SMI) in 1999 (SMI, 2000). The investigation was conducted in two areas of the Primary Impoundment that were accessible with a drilling rig. The results of this investigation showed that the tailings in the areas investigated range from silty fine-grained sand to silt. The horizontal hydraulic conductivity of the tailings is relatively low (4×10^{-6} to 4×10^{-7} cm/sec), as are the values of coefficient of consolidation (0.003 to 0.3 cm^2/sec). This means that pore fluid flow from the tailings is somewhat limited by the tailings, and the rate of tailings porewater yield from the tailings is expected to be low.

2.3 Cover System

Two alternatives for the cover system were provided in MFG (2005) and included a multilayered cover system and a uniform cover system. The multilayered cover system includes from top to bottom: (1) 0.5-ft topsoil layer; (2) 1-ft sandy clay layer; (3) 2-ft sand layer; (4) 1-ft clay layer; and (5) minimum 1.5-ft random fill layer. The uniform cover system layers includes from top to bottom: (1) 0.5-ft topsoil layer; (2) 4-ft clayey sand layer; and (3) minimum 1.5-ft random fill layer. The materials to be used in the cover system were based on site investigation work conducted for Cotter Corporation by Water Waste and Land, Inc. (WWL) in 1989 (WWL, 1990) and summarized in MFG (2005). These cover systems were evaluated for this appendix.

The most recent cover design provided to the CDPHE is the ET cover system presented in MFG (2005). Cotter is also in the process of evaluating an alternative multi-layered cover design than the one presented in MFG (2005) at the request of CDPHE. The results of the analyses presented in Appendix K will be updated to reflect the final cover design.

3.0 SEEPAGE ANALYSIS

3.1 General

Two-dimensional seepage analysis was performed for reclamation conditions to determine the change in phreatic surface over time due to dewatering of the tailings. This information was used for consolidation analysis. The cross section used in the seepage analysis was a 25-ft thick homogeneous layer of slime tailings with a width corresponding to the average spacing of the finger drains (approximately 230 feet) within the estimated extent of the existing tailings. The thickness of tailings selected is the estimated maximum thickness of slime tailings based on the deposition history of the tailings and comparison of the topography for the site prior to placement of tailings as presented in Wahler (1980) versus the most current topography for the site dated 2007. The comparison of the topography was presented in Figure 1 in URS (2008). For ease of reference, this figure is provided in Attachment A.

3.2 Method of Analysis

The seepage analysis was conducted using the SEEP/W finite element software (GEO-SLOPE, 2007). SEEP/W is a widely used commercial software package that can be used to model movement and distribution of pore water within porous materials. SEEP/W can model both saturated and unsaturated flow for steady-state and transient conditions. The finite element model can accommodate both one-dimensional and two-dimensional flow. The two-dimensional form of the model was used to model the dewatering of the tailings.

Seepage analyses were performed for transient conditions for a time period of 50 years. The time period of 50 years was used for consolidation analysis. Initial conditions were estimated by assuming the tailings were saturated to the surface. The boundary condition for the collection system at the bottom of the tailings was represented as a pressure equals zero boundary. This allows any seepage into the collection system to be removed from the system.

3.3 Material Properties

The material properties used in the analyses are summarized in Table K.1 below.

Table K.1 Material Properties for Seepage Analyses

Material Type	Horizontal Hydraulic Conductivity, K_h (cm/s)	Anisotropic ratio, K_h/K_v	Porosity, n
Slime Tailings	1×10^{-6}	5	0.6

The horizontal hydraulic conductivity and anisotropy ratio used for the analysis were based on the values calculated from cone penetration test and consolidation test results presented in SMI (2000) for the 1999 tailings investigation. Calculated horizontal hydraulic conductivity values for slime tailings from the CPT testing ranged from 1.5×10^{-7} to 7×10^{-6} cm/s, with a typical value of 1×10^{-6} cm/s (SMI, 2000). The mean vertical hydraulic conductivity from a consolidation test for the slime tailings was calculated as 3.3×10^{-7} cm/s (SMI, 2000). Based on these values, a horizontal hydraulic conductivity value of 1×10^{-6} cm/s was used for the slime tailings in the seepage analysis. A value of 5 was used for the hydraulic conductivity anisotropy ratio which is slightly higher than the calculated value using the typical horizontal hydraulic conductivity value from the CPT results and the mean vertical hydraulic conductivity from the consolidation test results. The overall value of anisotropy for the slime and sand slime tailings was calculated as ranging from 5-10 in SMI (2000). The porosity value was calculated using the measured dry density and water content for the slime material with the average measured specific gravity as provided in SMI (2000).

The function for volumetric water content was estimated from the capillary moisture retention tests conducted on the tailings and presented in SMI (2000) and the calculated porosity. The function for hydraulic conductivity was estimated using the saturated hydraulic conductivity value listed above and the volumetric water content curve.

3.4 Results

The results of the transient analysis for a time period of 50 years are presented in Figure K.1. As shown in Figure K.1, the phreatic surface is lowered by approximately 5 feet over the first 10 years and a total of 9 feet over 50 years at the mid-point between the finger drains. The results of this analysis were used in the settlement analysis.

4.0 SETTLEMENT ANALYSES

4.1 General

This section presents the results of the settlement analysis for the Primary Impoundment. The settlement of the tailings impoundment includes settlement due to tailings dewatering, settlement due to loading from cover construction, and long-term (creep) settlement. The profile used in the consolidate analysis was a 25-ft thick homogeneous layer of slime tailings. The methods and results of the analyses are presented in the following sections.

4.2 Method of Analyses

The settlement of the tailings will be calculated by the following equation:

$$S_t = S_d + S_c + S_s$$

where: S_t = total settlement
S_d = settlement due to dewatering
S_c = settlement due to cover construction
S_s = long-term or secondary settlement (creep).

The settlement due to dewatering was calculated using traditional consolidation theory and changes in phreatic surface over time from the transient seepage analyses. Initial pore pressure conditions were estimated assuming the tailings were saturated to the top surface. Incremental pore pressures were taken as the pore pressures at select time steps from the transient seepage analyses in Section 3.0.

The settlement due to cover construction was calculated using traditional consolidation theory for the loading on the tailings from the 6-ft multi-layered cover system.

Long-term settlement (creep) takes place at a constant effective stress after essentially all excess pore pressures have dissipated. The long-term settlement was calculated using the results of laboratory tests for the tailings and traditional secondary settlement theory. The secondary settlements are based on a time equal to the design life of 1,000 years.

4.3 Material Properties

The material properties used in the analyses are summarized in Table K.2 below. The sources for the parameters are listed in the notes in Table K.2. For the slime tailings, the majority of the parameters are based on laboratory testing results presented in SMI (2000). For the cover soil, a uniform total density of 130 pcf was assumed.

Table K.2 Material Properties

Material Type	Dry Density (pcf)	Specific Gravity	Initial Gravimetric Water Content (%)	Total Density (pcf)	Porosity, n	Initial void Ratio, e	Coeff.of Consol., c_v (cm^2/sec)	Com-pression Index, C_c	Recom-pression Index, C_r
Slime	70[1]	2.9[1]	60[1]	112[2]	0.6[2]	1.6[2]	0.005[1]	0.33[1]	0.0165[3]
Cover	---	---	---	130[4]	---	---	---	---	---

[1]From laboratory values given in SMI (2000)
[2]Calculated value
[3]Estimated as 5 percent of C_c
[4]Assumed

4.4 Results

The results of the analysis are presented in Figure K.2. The settlement due to primary consolidation (settlement due to dewatering and cover construction, S_d and S_c) was calculated as 1.5 feet. Long-term settlement (S_s) was calculated as 0.3 feet. The total settlement was calculated as 1.8 feet. The time to reach 90 percent of primary consolidation was calculated as approximately 15 years. As noted previously, the final cover system design is in progress and these analyses will be updated to reflect the final design.

4.5 Sensitivity

The simplified sensitivity analysis was conducted to give an indication of the range of values for the time to reach 90 percent consolidation, using the laboratory data for tailings provided in SMI (2000). The parameters evaluated included porosity, coefficient of consolidation and horizontal hydraulic conductivity. The results are provided in Table K.3.

Table K.3 Time to Reach 90 Percent Consolidation

Case	Horizontal Hydraulic Conductivity[1], k_h (cm/s)	Initial void Ratio, e	Coeff.of Consol., c_v (cm^2/sec)	Time to Reach 90% Consolidation (yrs)
Base Case	1×10^{-6}	1.6	0.005	15
Higher Void Ratio	1×10^{-6}	1.8	0.005	14
Lower c_v	1×10^{-6}	1.6	0.003	16
Lower K_h	5×10^{-7}	1.6	0.005	32

The results indicate that varying c_v and void ratio do not significantly affect time to reach 90 percent consolidation, but a lower hydraulic conductivity does.

5.0 COVER CRACKING ANALYSES

5.1 General

Two alternatives for the cover system were provided in MFG (2005) as discussed in Section 2. The multi-layered cover system has a 1-ft thick radon barrier layer. If a cover system with a low-permeability layer is constructed, differential settlement could cause cracking of the radon barrier and reduce its effectiveness to attenuate radon flux and limit infiltration. Cover cracking analysis were conducted to determine the cracking potential for the radon barrier. The procedure for determining cracking potential is presented in the following sections. Cover cracking is not applicable to an ET cover system without a low permeability layer.

5.2 Section Analyzed

The section analyzed to determine the maximum horizontal strain is based on a simplified cross section through the northwest dike shown in Figure K.3. The section selected was from the northwest edge of the tailings to the base of the internal dike slope. The section width is approximately 90 feet. The maximum thickness of tailings is approximately 30 feet. The maximum settlement assuming the tailings in the vicinity of the internal dike slope are sand slimes is approximately 0.9 feet. The settlement at the northwest edge of the tailings is estimated to be 0 feet. The corresponding maximum differential settlement is then 0.9 feet.

5.3 Tensile Strain to Cause Cracking

Morrison-Knudsen Environmental Corporation (1993) presents a method for determining the tensile strain required to cause cracking of the radon barrier as a function of the plasticity index (PI) of the soil. The tensile strain at cracking is calculated by the equation below:

$$\varepsilon_f\,(\%) = 0.05 + 0.003 \times (PI)$$

where: $\varepsilon_f(\%)$ = tensile strain to cause cracking of the radon barrier, and
PI = plasticity index of radon barrier.

Assuming a conservatively low PI value for the radon barrier of 10, the tensile strain to cause cracking is 0.08 percent. The maximum horizontal tensile strain on the radon barrier must be less than 0.08 percent so that cover cracking will not occur.

5.4 Horizontal Movement and Strain

The horizontal movement at the top of the radon barrier can be calculated based on the following equation (Lee and Shen, 1969), which is referenced in NUREG 1620 (NRC, 2003) for cover cracking analysis:

$$m = \frac{2}{3} H\alpha$$

where: m = horizontal movement in feet,
H = thickness of relatively incompressible material (radon barrier overlying the compacted random fill), and
α = local slope of the settlement profile (expressed as decimal fraction).

The horizontal movement at the maximum tailing thickness is calculated to be 0.05 feet using a thickness of relatively incompressible material of 6.5 feet, and a total differential settlement of 0.9 feet over 90 feet. The thickness of relatively incompressible material was estimated

assuming a 1-ft radon barrier overlying a random fill layer. The thickness of the random fill layer for the multi-layered cover design is a minimum of 1.5 feet. The thickness used for this calculation was conservatively estimated as 5.5 feet.

The horizontal strain at any given point is the slope of the horizontal movement at that point, and is estimated to be equivalent to the maximum differential horizontal movement divided by the horizontal distance (0.05 ft/90 ft). Using these values, the maximum horizontal strain is calculated as 0.05 percent. This value is lower than the maximum allowable strain of 0.08 percent. This indicates that cracking of the clay radon barrier is not likely for the multi-layered cover system presented in MFG (2005). As noted previously, the final cover system design is in progress and these analyses will be updated to reflect the final design.

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6.0 REFERENCES

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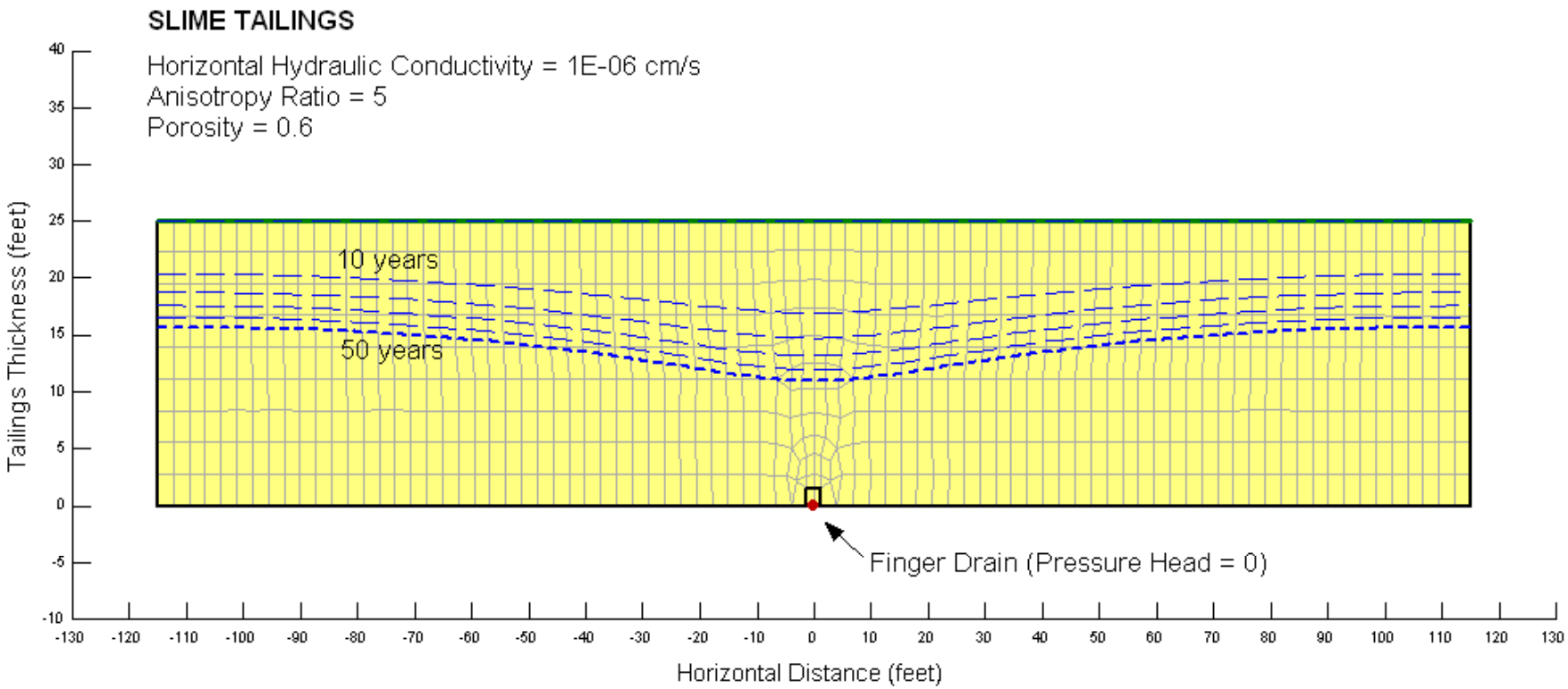
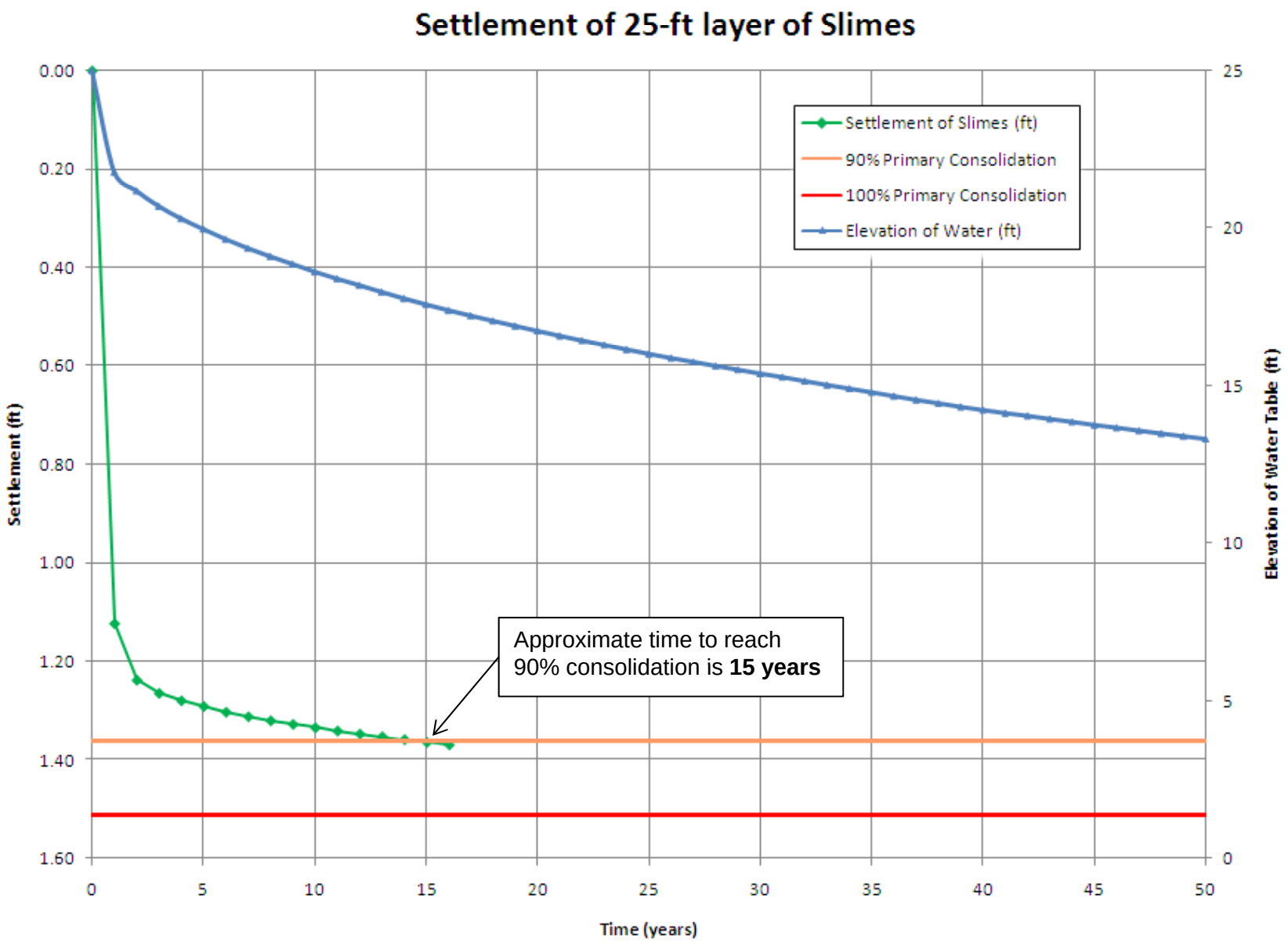


	cotter	PROJECT: CANON CITY MILLING FACILITY	MWH
		TITLE: PRIMARY IMPOUNDMENT TRANSIENT SEEPAGE ANALYSIS TIME PERIOD = 50 YEARS	DATE: DEC 2011 — FIGURE K.1
			FILENAME: Cotter figures_121709.pptx



cotter	PROJECT: CANON CITY MILLING FACILITY	MWH
	TITLE: PRIMARY IMPOUNDMENT SETTLEMENT ANALYSIS	DATE: DEC 2011 — FIGURE K.2
		FILENAME: Cotter figures_121709.pptx

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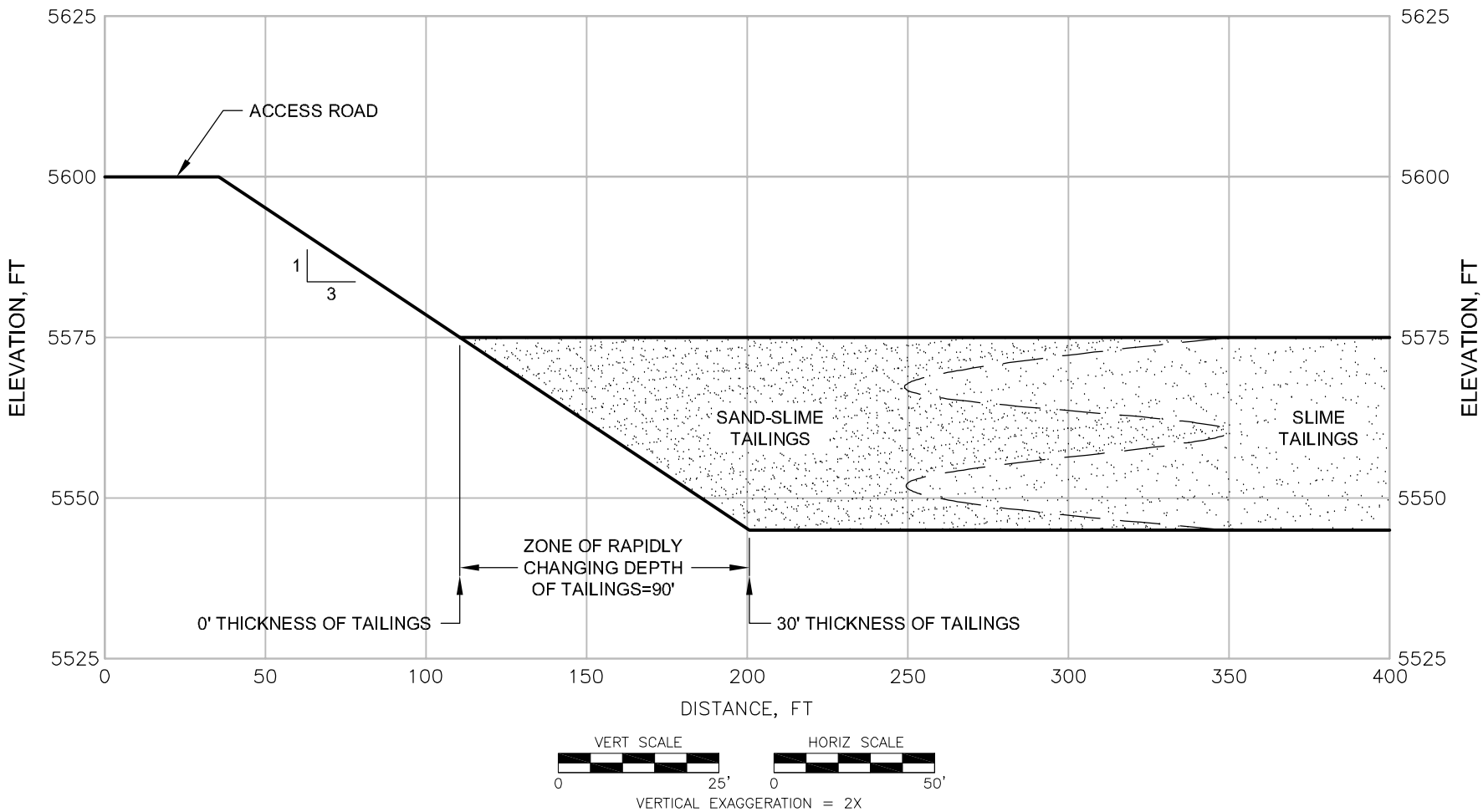


COTTER CORPORATION (N.S.L.)

PROJECT: CAÑON CITY MILLING FACILITY

TITLE: SIMPLIFIED CROSS SECTION THROUGH NORTHWEST DIKE COVER CRACKING ANALYSIS

MWH

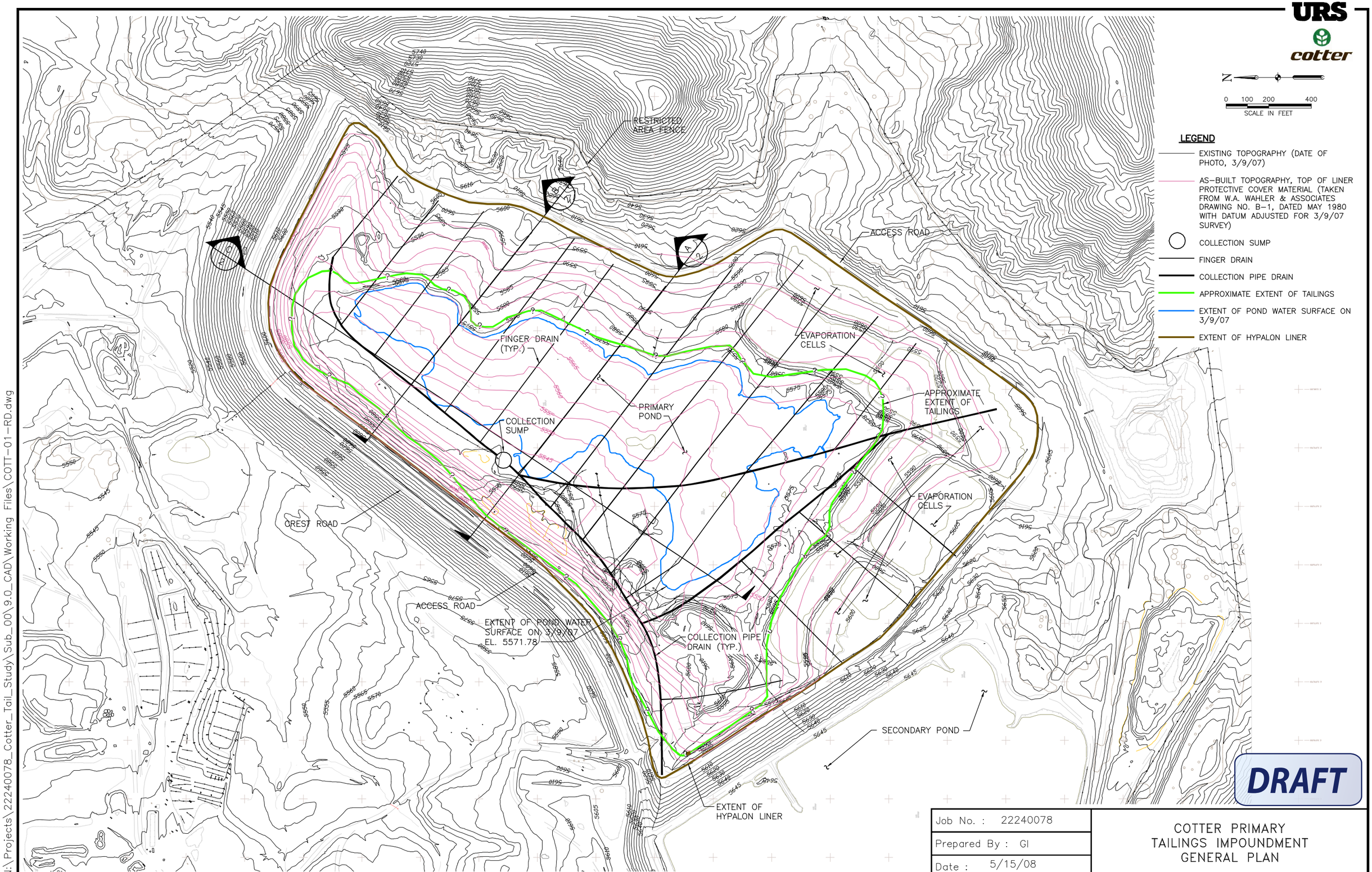
DATE: DEC 2011

FIGURE K.3

FILE NAME: 1007533 S XS

ATTACHMENT A

Select Figures from URS (2008)



Job No. : 22240078	COTTER PRIMARY TAILINGS IMPOUNDMENT GENERAL PLAN
Prepared By : GI	
Date : 5/15/08	

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FIG. 1

URS

cotter

CREST ROAD

ACCESS ROAD (EXTENT OF LINER)

6' THICK COVER

2.0' SETTLEMENT

EXISTING TOPOGRAPHY (3/19/07)

~10'

FILL

?

6' THICK COVER

2.4' SETTLEMENT

TAILINGS

WATER SURFACE EL. 5569.84 ON 8/29/07

6' THICK COVER

6' THICK COVER

6' THICK COVER

INITIAL PIEZOMETRIC ELEVATION AT TIME OF COVER PLACEMENT

2.4' SETTLEMENT

2.0' SETTLEMENT

1.2' SETTLEMENT

ESTIMATED TAILINGS SURFACE

40' COLUMN

30' COLUMN

25' COLUMN

20' COLUMN

10' COLUMN

TAILINGS

HYPALON LINER

AS-BUILT TOPOGRAPHY TOP OF LINER PROTECTIVE COVER MATERIAL (MAY 1980) WITH DATUM ADJUSTED FOR 3/9/07 SURVEY

FINAL PIEZOMETRIC ELEVATION

ELEVATION IN FEET

5620 5610 5600 5590 5580 5570 5560 5550 5540

0 100 200 300 400 500 600 700 800 900 1000 1100

DRAFT

LEGEND

TAILINGS COLUMN USED FOR SETTLEMENT ANALYSIS

NOTES:

1. SETTLEMENTS WERE CALCULATED BASED ON PLACING 6 FEET OF COVER OVER THE TAILINGS SURFACE FOLLOWED BY LOWERING THE PIEZOMETRIC LEVEL IN THE TAILINGS TO THE TOP OF THE LINER PROTECTIVE COVER MATERIAL.
2. SETTLEMENT REPRESENTS TOTAL SETTLEMENT AT 1000 YEARS.

SECTION A/1

0 50 100 200 HORIZONTAL SCALE IN FEET

0 5 10 20 VERTICAL SCALE IN FEET

Job No. : 22240078	TOTAL SETTLEMENT PROFILE WITH NO DEWATERING PRIOR TO PLACING COVER
Prepared By : GI	UPPER BOUND ESTIMATE
Date : 5/15/08	

FIG. 5

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