EVALUATION OF CONSOLIDATION AND WATER STORAGE CAPACITY RELATED TO PLACEMENT OF MINE MATERIAL ON THE EXISTING UNC MILL SITE TAILINGS IMPOUNDMENT

NORTHEAST CHURCHROCK MINE

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TABLE OF CONTENTS **Page**

FIGURES

TABLES

EXECUTIVE SUMMARY

This document evaluates whether water could be ‘squeezed’ from the existing tailing impoundments at the Church Rock Mill Site due to additional surcharge loading from placement of mine spoils from the Northeast Church Rock Mine Site on the tailings impoundments. This evaluation focuses primarily on the fine tailings which were placed wet and were covered with coarse grain tailings and a soil/rock cap about two decades ago. This report provides an evaluation of the long-term drainage from the fine tailings since placement, and the potential for water to be forced from the fine tailings in the existing impoundment.

A detailed evaluation was performed accompanied by an extensive sensitivity analysis. The evaluation is based on available data from existing documentation of the tailings closure and values from the literature. This report provides a more detailed and comprehensive analysis than the similar report submitted in February 2010.

Findings from this evaluation are:

a. There is no longer excess free water within the existing tailings, due to evapotranspiration, vertical drainage and lack of recharge;

b. Remaining water in the existing tailings is within the water storage capacity of the soils;

c. Reduction in the tailing’s soil porosity due to the ‘new’ surcharge loading or weight of the additional soil will not create excess or new free water.

In conclusion, this evaluation supports the proposition that the addition of NECR material directly on the existing tailings impoundment will not ‘squeeze’ water from the existing tailings into any existing groundwater.

1.0 INTRODUCTION

The Northeast Church Rock (NECR) Mine Site was an underground uranium mine active from 1968 to 1982, when it was placed in stand-by status. The site is located about 16 miles northeast of Gallup in McKinley County, New Mexico. The site is in a semi-arid climate averaging about 12-inches of precipitation per year at an elevation of about 7000-ft above sea level. The vegetation is generally categorized as a pinyon-juniper landscape with shrubs and native grasses.

In May 2009, USEPA issued an Engineering Analysis and Cost Evaluation (EE/CA) for the Mine Site evaluating potential removal actions, including consolidating mine spoils over the existing impoundments at the Church Rock Mill Site.

This report provides an evaluation of the potential for water to be forced from the fine tailings layer in the existing tailings impoundment due to the potential placement of spoils from the Mine Site Removal Action directly on the existing tailings impoundments and the subsequent consolidation of tailings.

2.0 PROFILES EVALUATED

The profiles presented in Figures 1 and 2 were chosen to evaluate typical and potential worst case scenarios in the North and Central Cell areas. The original design for closure of the tailings impoundment called for a minimum of 7-ft of coarse tailings including 2-ft of cover soil be placed above the fine tailings. Therefore this 2-ft cover over 5-ft of coarse tailings is consistent for all profiles.

Profiles 1 through 3 (Figure 1) represent profiles within the North Cell. The typical total tailings and cover thickness in the North Cell is 10-ft (US Filter, 2004). Parts of the North Cell impoundment sits directly on Zone 3 material while the remainder is above varied thicknesses of alluvium (US Filter 2004). Profile 1 represents the typical existing profile over alluvium - the alluvium average thickness beneath the North Cell is 40-ft (US Filter 2004). Profile 2 represents the typical existing profile that is directly above Zone 3 material. Profile 3 represents the worst case existing profile in the North Cell with the thickest fine tailings layer directly above alluvium.

Profile 4 (Figure 2) represents the worst case profile for Borrow Pit 2 (US Filter 2004). The 50-ft thickness of fine tailings is likely overly conservative given that Borrow Pit 2 had a depth of up to 50-ft, yet was filled with a significant volume of alluvium and material other than fine tailings. Nevertheless, Profile 4 was considered to allow a highly conservative calibration of the evaluation and modeling performed. Based on the results from monitoring of two piezometers located directly north of the borrow pit; no ground water migration is occurring from these areas. Therefore, the evaluation and modeling was intended to test the worst case in this area and verify that the calculated results would also predict no moisture migration from the borrow pits due to the placement of additional soils on the impoundment.

Profile 5 (Figure 2) represents the typical existing profile for the Central Cell. The Central Cell extends over both Zone 3 material as well as alluvium. Because the alluvium is less permeable than the Zone 3 material, alluvium was included in the profile to evaluate the worse case. The average thickness of fine tailings in the Central Cell over the alluvium is about 20-ft. The average thickness of alluvium beneath the Central Cell is about 40-ft.

Refer to Appendix A for details of the each soil layer properties for all profiles and references for these properties.

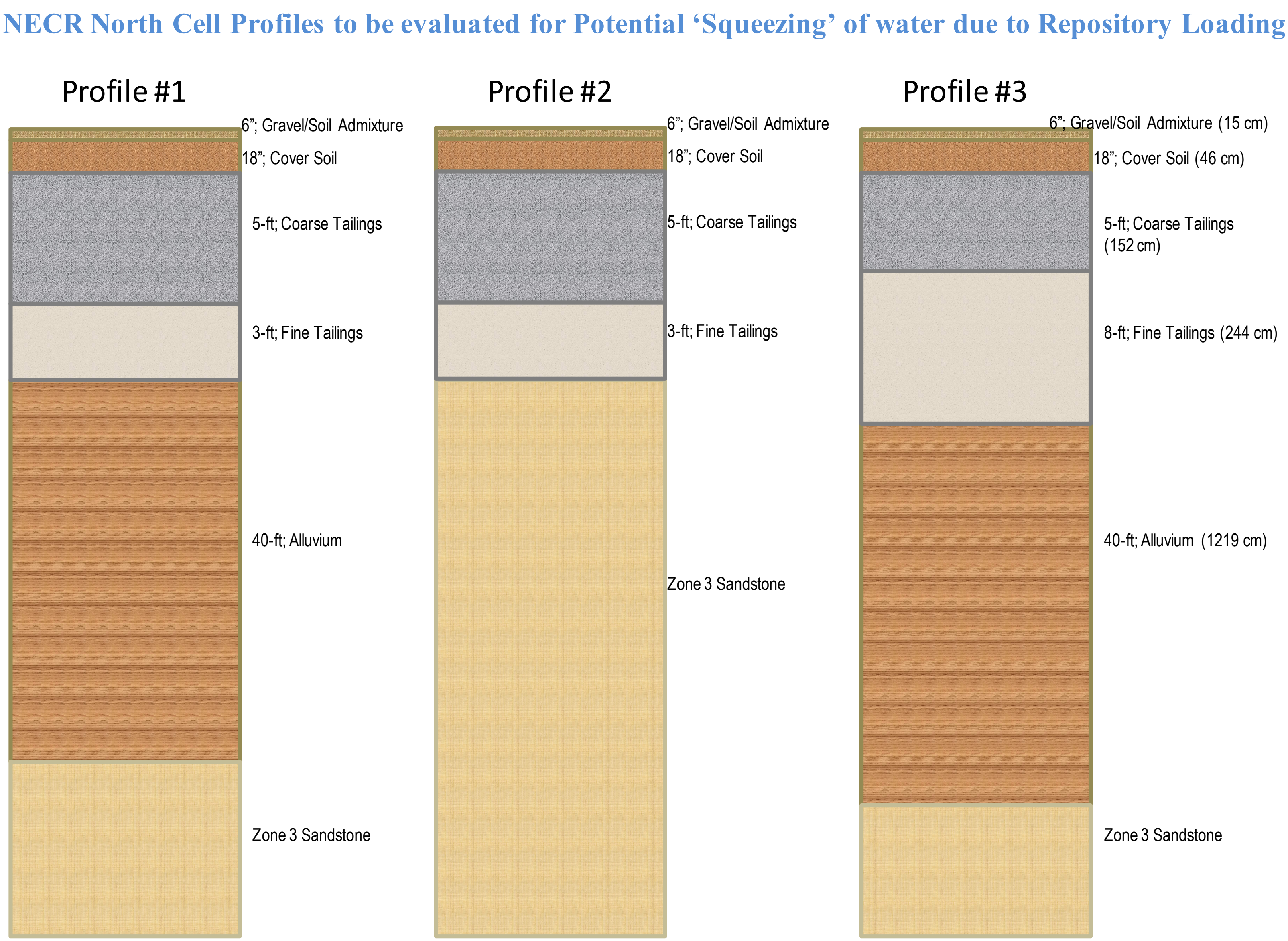


Figure 3. NECR North Cell Profiles to be Evaluated for Potential 'Squeezing' of Water due to Repository Loading

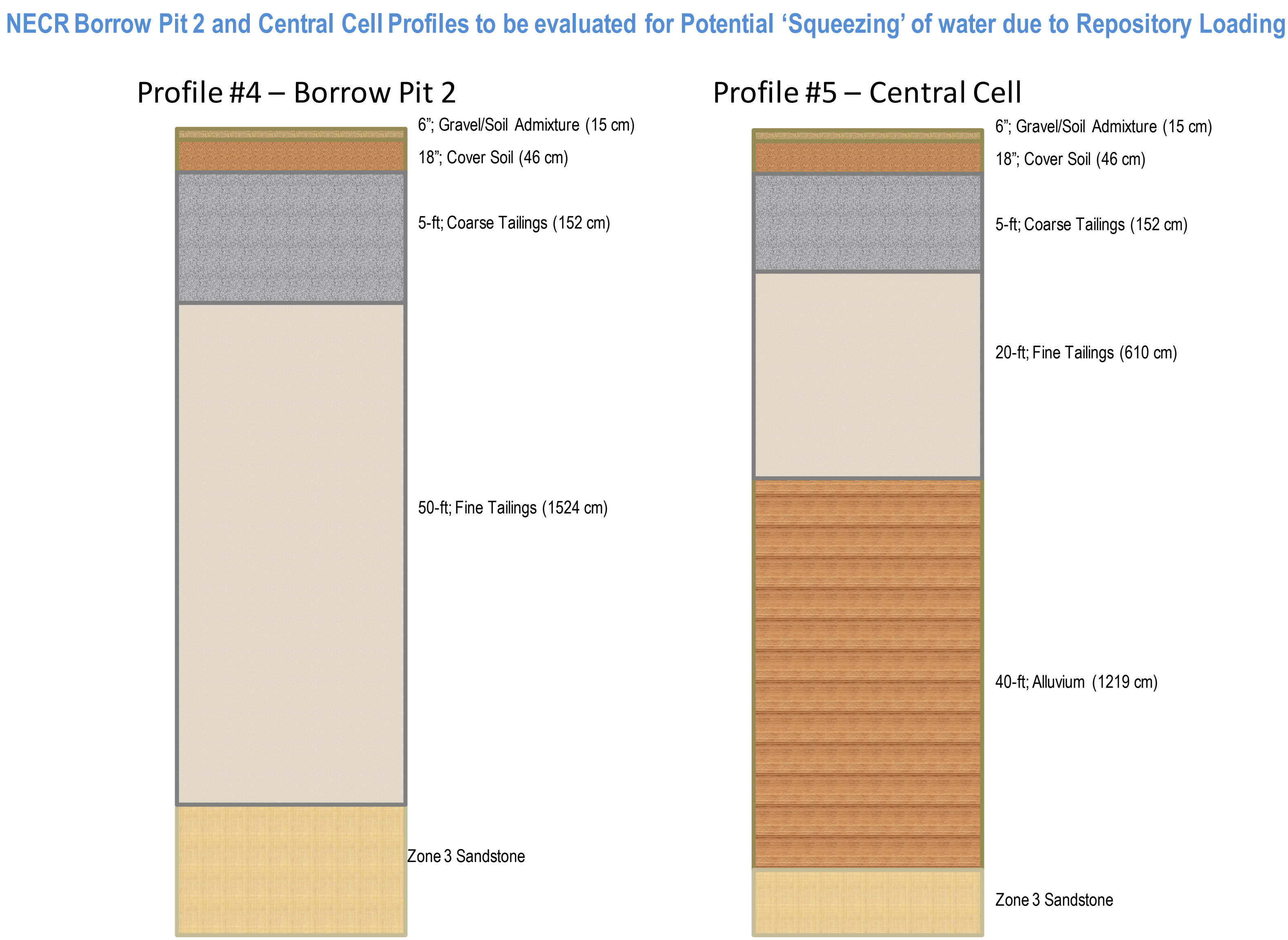


Figure 4. Borrow Pits 1/2 (Worst Case) and Central Cell (Typical) to be Evaluated for Potential 'Squeezing' Water

3.0 CONCEPTS UTILIZED IN ANALYSIS

This report provides a summary of the evaluation performed to calculate the estimated settlement of the existing fine tailings in the impoundment due to the weight of the potential placement of the new material on the surface of the impoundment. Furthermore, it provides an evaluation of the water storage capacity of the existing tailings material and the potential to have water 'squeezed' out from a reduction in the porosity of the tailings due to the subsequent potential consolidation.

Two predominant concepts were utilized in the analysis: (1) standard geotechnical engineering concepts associated with consolidation or settlement of soil and (2) the soil physics associated with water storage capacity of soil as well as the unsaturated flow of moisture within the soil profiles.

3.1 CONSOLIDATION

Consolidation occurs in three stages:

a. Immediate – this stage takes place as the soil is placed and therefore is considered immediate;

b. Primary – this stage occurs after placement of the soil and for relatively fine-grained soils such as the existing fine grained tailings involves the removal of excess pore water from the soil; and

c. Secondary – this stage is time dependent and occurs after completion of the primary consolidation.

Terzaghi's theory of consolidation was utilized to calculate the settlement in the existing fine grained tailings for the various profiles. Primary consolidation is represented by the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma+\Delta\sigma}{\sigma}\right) \qquad \text{Equation 3-1}$$

where: S_p = primary settlement;

C_c = primary consolidation coefficient;

H = fine tailings layer thickness before settlement;

e = void ratio;

σ = initial stress; and

Δσ = change in stress (additional weight due to spoils).

Secondary consolidation is represented by the following equation:

$$S_s = C_a \times H \times log\left(\frac{t_2}{t_1}\right) \qquad \text{Equation 3-2}$$

where: S_s = Secondary Settlement;

C_a = secondary consolidation coefficient;

H = fine tailings layer thickness;

t_2 = time from t_1; and

t_1 = time when primary consolidation is complete.

3.2 WATER STORAGE CAPACITY AND UNSATURATED FLOW

Unsaturated soil is comprised of liquid, solid, and gas. That is, in an unsaturated volume of soil, there will be some air-filled voids, some water-filled voids, and solid material. In a saturated volume of soil (θ_s), the air-filled voids are replaced with water-filled voids. The driest a soil volume can be is referred to as its residual moisture content (θ_r) where only adsorbed water remains. Refer to Figure 3 for a graphical explanation of the moisture states of a soil.

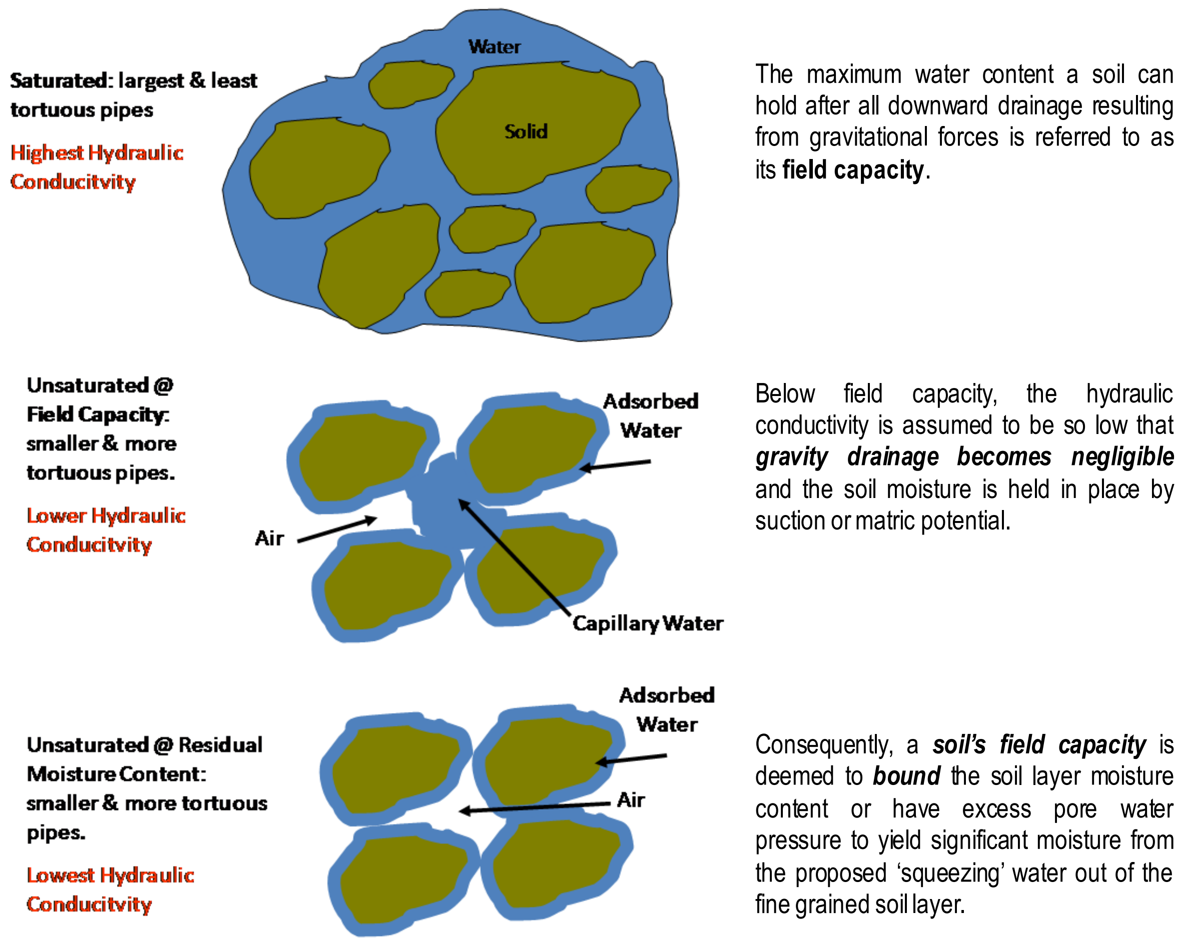


Figure 3. Moisture States of Soil

Soil has typical moisture characteristics based on properties such as texture (e.g. silt vs. sand) and density (e.g. loose vs. compacted). Thus the water storage capacity of soil is dependent on its texture and density. A soil texture consisting of a silt loam such as the fine-grained tailings typical of the NECR site has a relatively large water storage capacity compared to a sand or gravel. Also, the density of the soil affects its storage capacity because the higher density soils have less porosity and thus less voids to store water in. More specifically, the texture and density define the moisture characteristics of a given soil and influence the storage capacity of that soil and the ability of moisture to move within the soil. These characteristics can be represented by the relationship of soil suction or matric potential to the soil moisture content of a given soil (Figure 4).

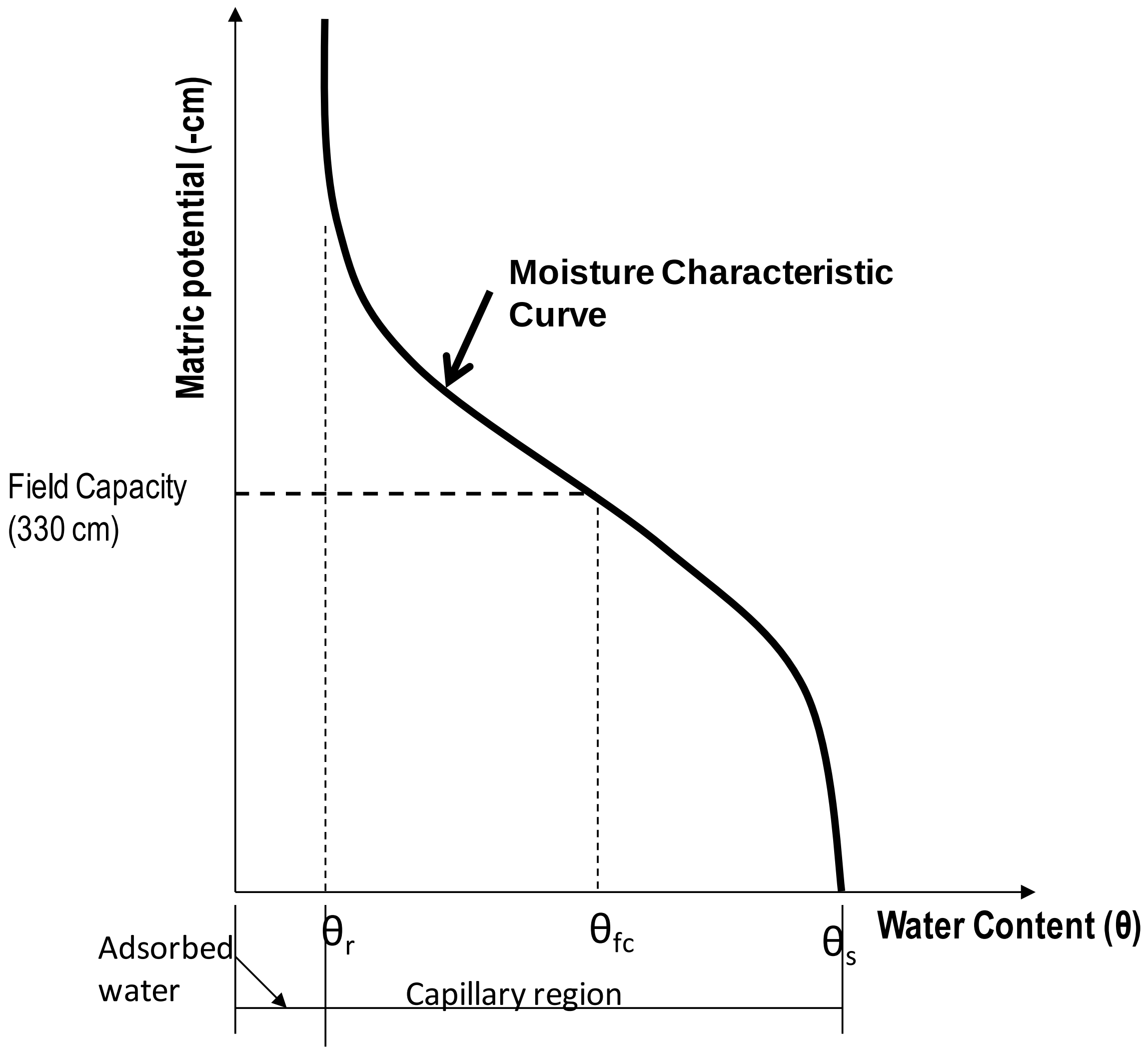


Figure 4. Typical Soil Moisture Characteristic Curve

A soil's water storage capacity is defined as the soil moisture content associated with field capacity multiplied by its thickness. The maximum water content (θ_{fc}) a soil can hold after all downward drainage resulting from gravitational forces is referred to as its field capacity (Figure 4). Field capacity is often arbitrarily reported as the water content at 330-cm of matric potential head (Jury *et al*. 1991). Soil that is drier than field capacity (less moisture content or higher soil suction) has a hydraulic conductivity so low that gravity drainage becomes negligible and the soil moisture is held in place by suction or matric potential. For this analysis, if the soil analyzed has moisture content that is drier or soil suction that is greater than its field capacity – it is assumed that water will be retained within its volume.

3.2.1 MODELING

The process to estimate the flow of water within an unsaturated soil medium is very complicated and generally requires computer modeling to perform. In this analysis, computer software [UNSAT H (Fayer 2000)] was utilized. The software is based on the Richard’s Equation (ITRC 2003) for unsaturated soil. The Richards Equation is as follows:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\varphi)\left(\frac{\partial\varphi}{\partial z} + 1\right)\right] - \forall(z,t)$$

where:

K = hydraulic conductivity,

φ = pressure head,

z = elevation above a vertical datum,

θ = water content,

t = time, and

$\forall(Z,T) = sink\ term\ for\ root\ water\ uptake$

UNSAT-H is a one-dimensional, finite-difference computer program developed at the Pacific Northwest National Laboratory by Fayer and Jones (1990). UNSAT-H simulates water flow through soils by solving Richards' Equation and simulates heat flow by solving Fourier's heat conduction equation.

UNSAT-H separates precipitation falling on an earthen cover into infiltration and overland flow. The quantity of water that infiltrates depends on the infiltration capacity of the soil profile immediately prior to rainfall (e.g., total available porosity). Thus, the fraction of precipitation shed as overland flow depends on the saturated and unsaturated hydraulic conductivities of the soil included in the final cover. If the rate of precipitation exceeds the soil’s infiltration capacity, the excess water is shed as surface runoff. UNSAT-H does not consider absorption and interception of water by the plant canopy or the effect of slope and slope-length when computing surface runoff since it is a 1-dimensional model.

Water that has infiltrated a soil profile during an UNSAT-H simulation moves upward or downward as a consequence of gravity and matric potential. Evaporation from the cover surface is computed using Fick's law. Water removal by transpiration of plants is treated as a sink term in Richards' Equation. Potential evapotranspiration (PET) is computed from the daily wind speed, relative humidity, net solar radiation, and daily minimum and maximum air temperatures using a modified form of Penman's equation given by Doorenbos and Pruitt (1977). Soil water storage is computed by integrating the water content profile. Flux from the lower boundary is via percolation.

4.0 METHODOLOGY & RATIONALE

Each of the profiles described in section 2 was analyzed to determine whether it is susceptible to having free water forced from the fine grained tailings due to surcharge pressure resulting from the placement of mine spoils and waste rock on the existing tailings impoundment. The detailed calculations performed for each respective profile are contained in Appendix C. The steps involved in the analysis of each profile are summarized as follows:

1. Establish the profile to be analyzed. This includes the soil layers and layers thicknesses. There were 5 profiles analyzed as described in section 2.0.
2. Establish the soil properties for each soil layer within each soil profile analyzed based on available site data and values from literature for similar materials. These properties include the soil classification, the saturated hydraulic conductivity, the soil-specific moisture characteristic curve and unsaturated soil properties (van Genuchten parameters), the depth below ground surface (BGS), the soil porosity, and the initial conditions including the moisture content and subsequent soil suction value. These values are tabularized in Appendix A.
3. Model each profile given its initial conditions for a period of 21 years using site specific average climate data using UNSAT H (described in section 3.2.1). The time period of 21 years was used because the tailings impoundment was covered about 21 years ago. The tailings were placed in a wet state. The moisture status of the each soil layer in each profile as it was installed is known from multiple as-built reports available from the United Nuclear Corporation (UNC) Mill site. Modeling the profiles for the 21-year period of time allowed for estimation of the moisture status of each profile today.
4. Prior to placement of the existing tailings impoundment cover (~1989 to 1991); settlement monuments were installed at 10 locations on the tailings impoundment prior to installation of the final cover. NRC guidance suggested that primary consolidation be complete prior to installation of the final soil cap to minimize damage of the final cover due to differential settlement. Data from this settlement monitoring is available in the UNC Mill site reports (Canonie Environmental 1990 and Canonie Environmental 1992). Primary consolidation was complete at about 100 days (+/-) for each of the settlement monuments. For each settlement monument, primary consolidation is graphically presented with respect to time. Utilizing equation 3-1 with the results from this settlement monitoring, all variables are known including the primary settlement except the primary consolidation index (C_c). Therefore, Equation 3-1 can be rearranged to calculate (C_c).
5. The secondary consolidation coefficient (C_a) was then calculated as a function of the primary consolidation coefficient (C_c). The relationship used was: $C_a = 0.03 \times C_c$ (Bowles 5th Ed. 1996).
6. Calculate the time dependent or secondary consolidation of the fine tailings in each profile for the 21-year period using the equation described in section 3.1. Key to calculating the secondary consolidation is establishing the primary consolidation and time period when the primary consolidation was complete.

Therefore t_1 is 100 days and t_2 is 21 years. *H* is the initial thickness of each of the fine tailings layer for each respective profile.

7. Calculate the revised porosity and void ratio for the fine tailings layer in each respective profile based on the secondary settlement calculated in step 6.
8. The modeling performed in step 3 will produce a final soil suction value (h_1) with respective to depth for each respective profile evaluated. These values are assumed to be the current condition of the impoundment. Using the initial moisture characteristic curve established in step 1 for the fine tailings layer, the current moisture content (Θ_1) of the fine tailings layer can be estimated using the following relationship: $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991).
9. Assume the mine spoils and waste rock is deposited directly on the final cover of the existing tailings impoundment. The depth and area of coverage of this material is varied in the sensitivity analysis performed. The weight of this material will cause additional primary consolidation to take place in the existing impoundment profile. Determine the primary consolidation in the fine tailings layer using equation 3-1.
10. Calculate the revised void ratio and porosity of the fine tailings layer taking into account the primary consolidation from the addition of the mine spoils and waste rock and the secondary consolidation that was calculated in step 6.
11. Develop a revised moisture characteristic curve for the fine tailings layer based on the revised porosity calculated in step 10. It was assumed that the revised porosity is equal to the new saturated moisture content of the fine tailings layer.
12. Utilizing the revised moisture characteristic curve developed in step 11, determine the soil suction value (h_2) for the fine tailings layer with respect to Θ_1 determined in step 8.
13. Compare h_2 with the fine soil layer's field capacity of 330 cm. If $h_2 > 330\ cm,$; then water in this layer will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the placement of the mine spoils and waste rock. If $h_2 < 330\ cm$, then there is excess pore water that can be 'squeezed' out. Note: soil suctions are generally negative but for this analysis, the soil suctions values are considered to be the absolute value to eliminate confusion from the signage.

5.0 RESULTS

The five profiles described in section 2.0 were analyzed (Appendix C) given their initial parameters (Appendix A) and modeling results (Appendix B). All results found that the fine tailings would be able to retain all free water within the fine tailings storage capacity. That is, the final soil suction values for the fine tailings layer for all five profiles were greater than its field capacity of 330 cm. Refer to Table 1 below.

Additionally two separate sensitivity analysis were performed on the five selected profiles to evaluate potential worse case conditions. During the first analysis, it was found that the most sensitive parameter was the saturated hydraulic conductivity of the underlying material below the fine grained tailings (alluvium or Zone 3 material). The US Filter (2004) report determined that the alluvium was less permeable than the Zone

3 material. However, there was some variability in the alluvium saturated hydraulic conductivity reported. Canonie (1991) reported based on pump tests performed that the saturated hydraulic conductivity of the alluvium could be as low as 8.1E-05 cm/sec. Consequently, the first sensitivity analysis changed the saturated hydraulic conductivity of the alluvium to 8.1E-05 cm/sec; while all other input parameters were kept the same as the original analysis. Profiles 1, 3, and 5 were analyzed as they had alluvium below the fine tailings whereas profiles 2 and 4 had Zone 3 material beneath them. Sensitivity analysis 1 found that given this worst case scenario for the alluvium, the results still showed that there would be no water forced from the fine grained tailings. Refer to Table 1, column 3.

A second set of sensitivity analysis were performed, lowering the saturated hydraulic conductivity of the coarse and fine grained tailings. The saturated hydraulic conductivity values for the coarse and fine grained tailings were changed to 7.194E-04 cm/sec and 3.667E-04 cm/sec, respectively. All other values were kept the same as the original analysis. The changed saturated hydraulic conductivity values for each were based on values from Rawls et al (1982) as reported in van Genucthen et al (1991). The reported grain size distributions reported for the coarse and fine grained tailings could be classified as a sandy loam and silt loam, respectively. This is using the US Department of Agriculture soil triangle soil classification system (Figure 5). Sensitivity analysis 2 found that given this worst case scenario for the tailings and alluvium, the results still showed that there would be no water forced from the fine grained tailings. Refer to Table 1, column 4.

In conclusion, the results of this conservative evaluation supports that the addition of soils directly on the existing tailings impoundment will not ‘squeeze’ water from the existing tailings.

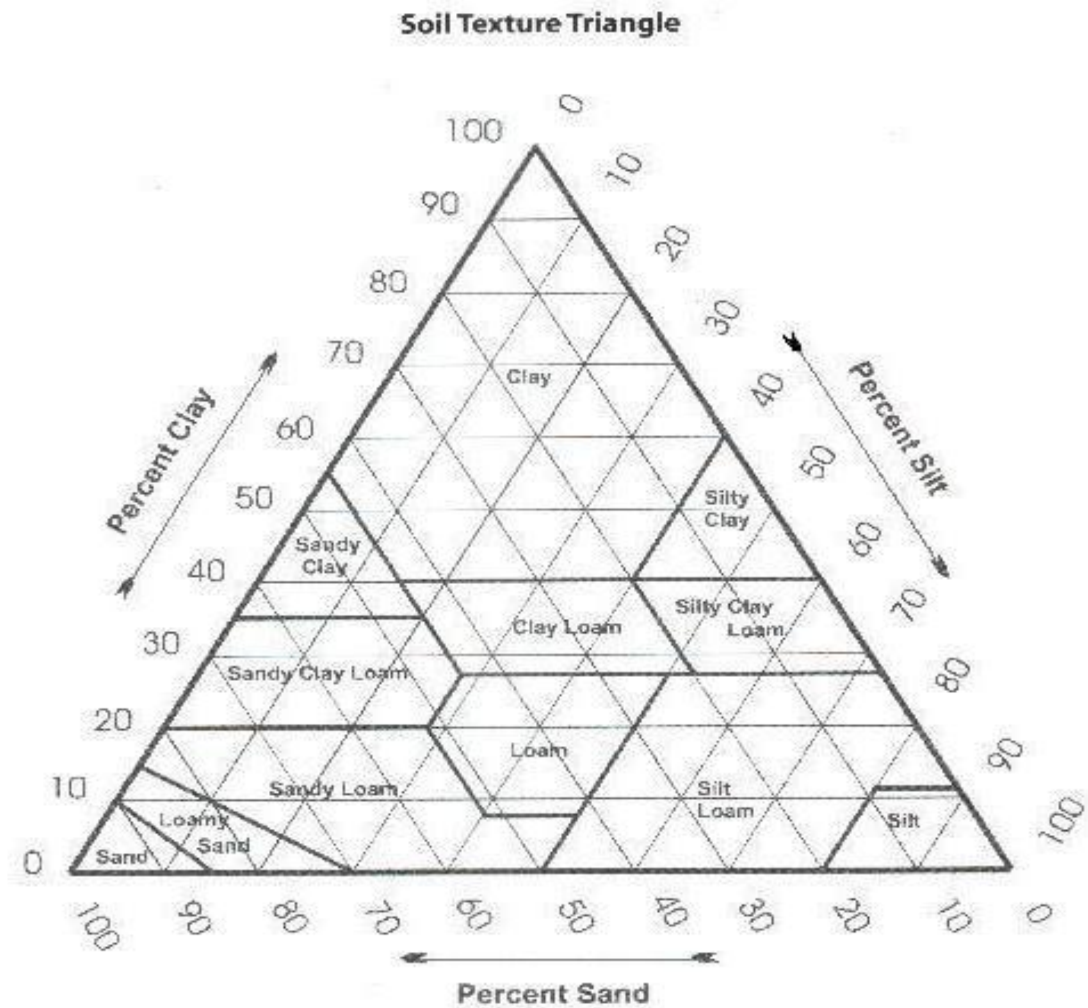


Figure 5. USDA Soil Classification

Sand: Soil particles between 0.05 and 2.0 mm in size
Silt: Soil particles between 0.002 mm and 0.05 mm
Clay: Soil particles smaller than 0.002 mm (2 microns) in size

The results from Sensitivity Analysis 2 determined that there would not be any water forced from the fine grained tailings as a result of the surcharge pressure induced by the placement of mine spoils and waste rock on the existing tailings impoundment. These results are found in Table 1, column 4.

Table 1. Final Soil Suction Values for the Fine-Grained Tailings Layer in Each Respective Profile

Profile	Original Run	Sensitivity 1	Sensitivity 2
		Alluvium K_{sat} (8.1E-05 cm/sec	Coarse Tailings K_{sat} (7.2E-04 cm/sec); Fine Tailings K_{sat} (3.7E-04 cm/sec)
1. North Cell (typical over Alluvium))	1457 cm	600 cm	1098 cm
2. North Cell (typical over Zone 3)	906 cm	-	430 cm
3. North Cell (worst case: 15-ft tailings + cover over Alluvium)	925 cm	394 cm	630 cm
4. Borrow Pit 2 (worst case: 50-ft thick fine tailings)	529 cm	-	373 cm
5. Central Cell (typical over Alluvium)	649 cm	436 cm	395 cm

Note: Field capacity is defined as 330 cm of soil suction; therefore any final soil suction value greater than field capacity is deemed to be within the water storage capacity of the soil layer and will not be forced out due to added surcharge loads (additional soil on existing tailings impoundment).

6.0 REFERENCES

1. Bowles, Joseph E. 1996. Foundation Analysis and Design. McGraw-Hill Publishers.
2. Canonie Environmental. 1987. Geohydrology Report, Church rock Site, UNC Mining and Milling, Gallup, NM. May 1987.
3. Canonie Environmental. 1987. North Cell Final Reclamation, As-Built Report. November 1987.
4. Canonie Environmental. 1987. Reclamation Plan for Alluvium, table 4.
5. Canonie Environmental. 1990. North Cell Interim Stabilization, As-Built Report. January 1990.
6. Canonie Environmental. 1991. Tailings Reclamation Plan, Vols 1, 2, and 3. August 1991.
7. Canonie Environmental. 1992. Central Cell Interim Stabilization, As-Built Report Addendum. April 1992.
8. Canonie Environmental. 1994. As-Built North Cell Final Reclamation, Nov 1994,
9. Canonie Environmental. 1995. Central Cell Final Reclamation, As-Built Report. June 1995.
10. Canonie Environmental. 1991. Tailings Reclamation Plan, Vol. I, Aug 1991, , p.34
11. Canonie Environmental. 1991. Tailings Reclamation Plan-Vol II, Canonie. Aug 1991.
12. Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for prediction crop water requirements. FAO Irrig. and Drain. Paper No. 24, 2nd ed., FAO Rome, Italy.
13. Dwyer, SF. 2003. Water Balance Measurements and Computer Simulations of Landfill Covers. PhD Dissertation, Department of Civil Engineering, University of New Mexico.
14. Fayer, M. J., and T. L. Jones. 1990. UNSAT-H version 2.0: Unsaturated soil water and heat flow model. PNL-6779, Pacific Northwest Laboratory, Richland, WA.
15. Fayer, M.J. 2000. UNSAT-H Version 3.0: Unsaturated Soil Water and Heat Flow Model, Theory, User Manual, and Examples. Pacific Northwest Laboratory, Richland, WA.
16. Hillel, D. 1998. Environmental Soil Physics. Academic Press, San Diego, CA.
17. ITRC. 2003. Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers. Interstate Technology and Regulatory Council, Alternative Landfill Technologies Team, Washington DC.
18. Jury, W.A., W.R. Gardner, and W.H. Gardner. 1991. Soil Physics, 5th Edition, John Wiley & Sons, Inc., New York, NY.

19. Rawls, W. J., D. L. Brakensiek, and K. E. Saxton. 1982. Estimating soil water properties. *Transactions, ASAE,* 25(5):1316-1320 and 1328.

20. Ritchie, J.T., and E. Burnett. 1971. Dryland evaporative flux in a semihumid climate, 2, plant influences. Agron. J. 63:56-62.

21. Samani, Z. A. and M.Pessarakli, 1986: Estimating Potential Crop Evapotranspiration with Minimum Data in Arizona, Transactions of the ASAE Vol. 29, No. 2, pp. 522-524.

22. Sergeant, Hauskins , and Beckwith. 1976. Geotechnical Investigation Report, Tailings Dam and Ponds. Church Rock Uranium Mill, United Nuclear Corporation, Church rock, NM. May 1976.

23. US Filter. 2004. Rationale and Field Investigation Work Plan to Evaluate Recharge and Potential Cell Sourcing to the Zone 3 Plume Church Rock Site, Gallup, NM. January 2004.

24. Van Genuchten, M.Th., F.J. Leij, and S.R. Yates. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils.

APPENDIX A

SOIL PROFILES & SOIL LAYER PROPERTIES

The following figures (Figures A1 and A2) include five profiles evaluated for consolidation due to repository loading and the subsequent potential of 'squeezing' water from existing fine tailings.

Profile 1 represents a typical section of the North Cell where there is alluvium beneath the tailings. Profile 2 represents a typical cross section in the North Cell where there is Zone 3 material beneath the tailings. Profile 3 represents the worst case section in the North Cell where the fine tailings are the deepest and there is alluvium beneath the tailings.

Profile 4 includes a worst case section through the Borrow Pit #2 whereby the fine tailings are likely the deepest anywhere on site. This section provides for the initial moisture condition of the fine tailings to be at field capacity as suggested by the EPA. This is an effort to calibrate the model based on evidence that monitoring equipment immediately north of this specific site show no fluid movement from the Borrow Pit 2 area. Profile 5 represents an average section across the Central Cell for evaluation.

NECR North Cell Profiles to be evaluated for Potential 'Squeezing' of water due to Repository Loading

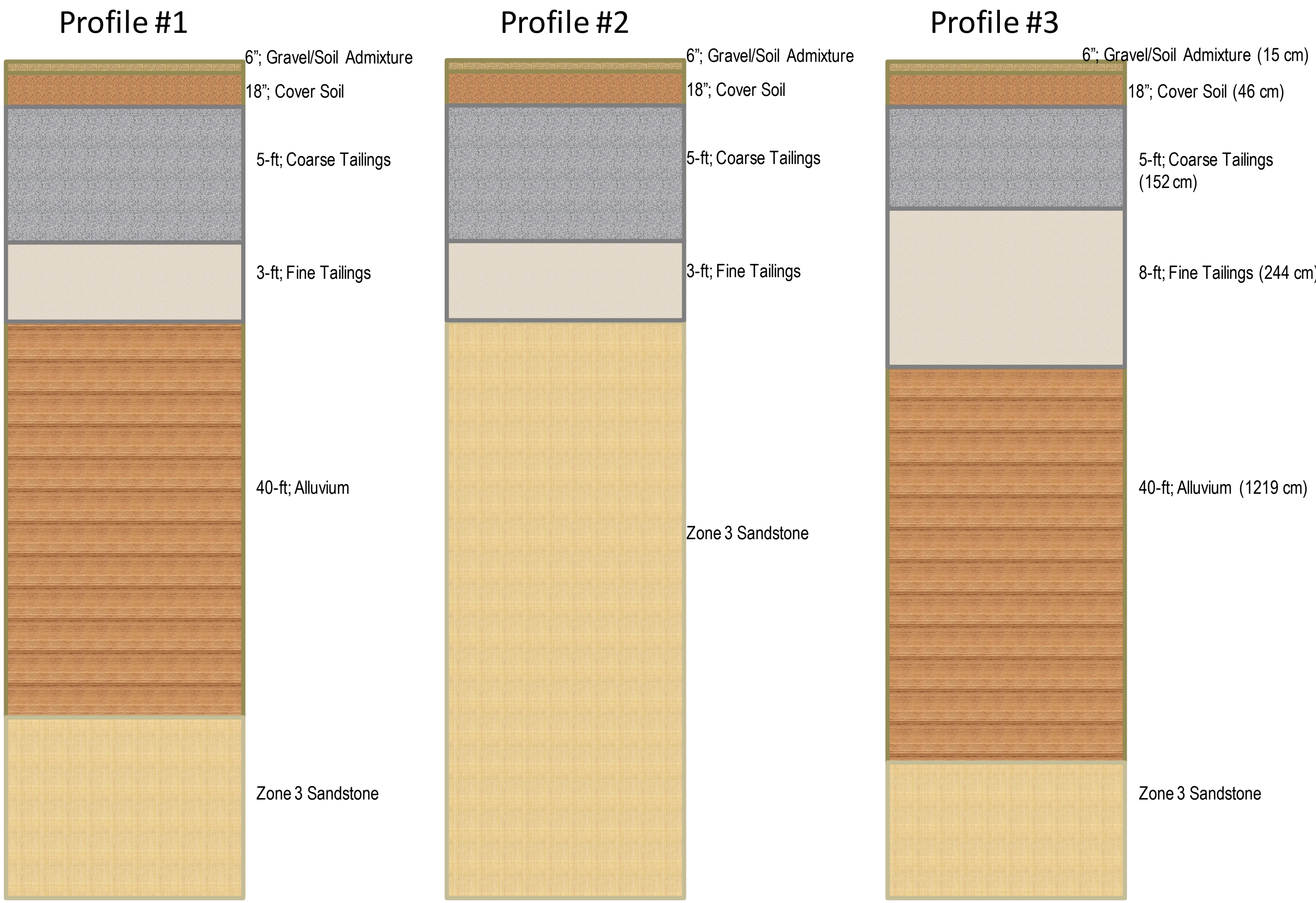


Figure A1. NECR North Cell Profiles to be evaluated for Potential 'Squeezing' of water due to Repository Loading

NECR Borrow Pit 2 and Central Cell Profiles to be evaluated for Potential 'Squeezing' of water due to Repository Loading

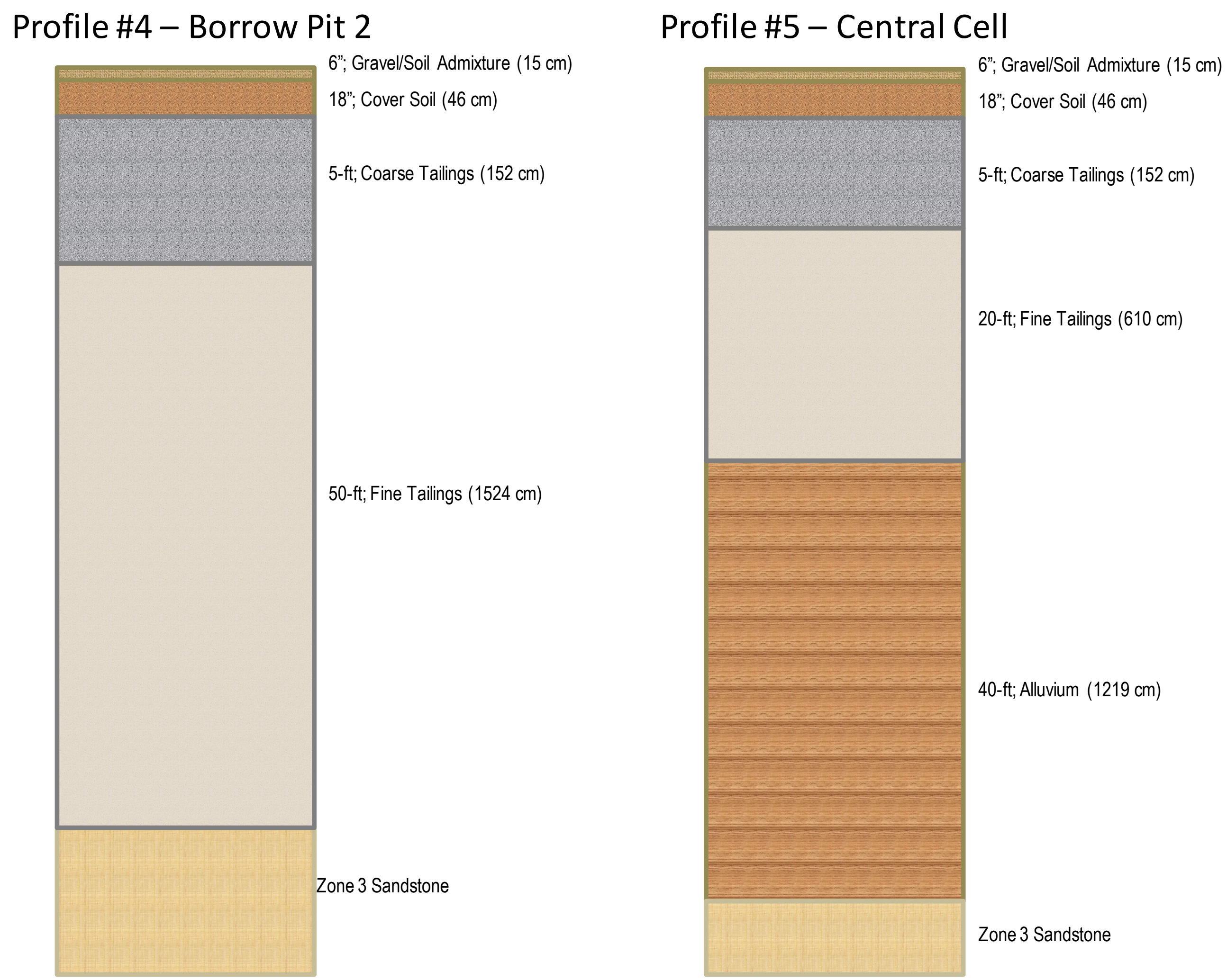


Figure A2. Borrow Pit 4 (Worst Case) and Central Cell (Average Section) to be evaluated for Potential 'Squeezing' Water from Profile

Profile#1:

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Cover: Rock/Soil Surface Layer	0 to 6-in	1E-03 cm/sec	0.43	0.06	0.1057	1.36	13.6% by weight	1. Values from Dwyer 2003. K_{sat} and VG -- These were measured values from a gravel/soil admixture @ Sandia Nat Lab 2. Depth from As-Built North Cell Final Reclamation, Nov 1994, Canonie Environmental 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This is estimated long-term natural moisture content.
Cover Soil	6-in to 2-ft	2.7E-05 cm/sec	0.39	0.075	0.039	1.194	13.6% by weight	1. K_{sat} avg value from S,H,B (May76) Geotech Investigation 2. GSD reported in North Cell Final Reclamation state the soil is a clay loam. Typical VG parameters for Clay Loam (USDA) per RETC 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								is estimated long-term natural moisture content.
Coarse Tailings	2-ft to 7-ft	2.3E-03 cm/sec	0.45	0079	0.068	1.322	20.47% by vol.	1. Depth based on reported tailings depth from US Filter report (2004) and Canonie Geohydrology report (1987). It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as having more sand than silt; USDA classification is sandy loam. VG parameters are those based on a sandy loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.45) for coarse tailings in Tailings Reclamation Plan-Vol II, Canonie (Aug 1991)

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								4. Ksat value US Filter (2004) p. 6
Fine Tailings	7-ft to 10-ft	2.3E-03 cm/sec	0.53	0.059	0.048	1.211	38.7% by vol.	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickest tailings plus cover depth in the north Cell is 10-ft. It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as more silt than sand – USDA classification is silt loam. VG parameters are those based on a silt loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.53) for coarse tailings in Tailings

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters θ_s	θ_r	α (1/cm)	n	Initial Moisture Content	Reference
								Reclamation Plan-Vol II, Canonie (Aug 1991) 4. Ksat value US Filter (2004) p. 6
Alluvium	10-ft to 50-ft	2.6E-03 cm/sec cm/sec	0.39	0.075	0.039	1.194	15.9%	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickness of alluvium reported beneath the North Cell is 40-ft. 2. Initial MC is that reported in Canonie (1987) Reclamation Plan for Alluvium, table 4. 3. The alluvium is typical 70% silt and 30% sand – classified per USDA as silt loam. VG parameters are those based on a silt loam - values from RETC model per USDA classification. 4. K_{sat} value Canonie Environmental, Reclamation Plan, Vol I, March 1991.
Zone 3 –	Below	6E-04						1. K_{sat} value from US Filter

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Gallup Sandstone	alluvium	cm/sec						(2004) report, p. 6 2. A unit gradient lower boundary condition will be placed at the base of the alluvium. This is justified because it is assumed near steady state conditions exist at this depth. The drainage from the unsaturated flow modeling will be verified to ensure it is less than the saturated hydraulic conductivity of the Zone 3.

[1] BGS = below ground surface

Profile#2:

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Cover: Rock/Soil Surface Layer	0 to 6-in	1E-03 cm/sec	0.43	0.06	0.1057	1.36	13.6% by weight	1. Values from Dwyer 2003. K_{sat} and VG -- These were measured values from a gravel/soil admixture @ Sandia Nat Lab 2. Depth from As-Built North Cell Final Reclamation, Nov 1994, Canonie Environmental 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This is estimated long-term natural moisture content.
Cover Soil	6-in to 2-ft	2.7E-05 cm/sec	0.39	0.075	0.039	1.194	13.6% by weight	1. K_{sat} avg value from S,H,B (May76) Geotech Investigation 2. GSD reported in North Cell Final Reclamation state the soil is a clay loam. Typical VG parameters for Clay Loam (USDA) per RETC 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								is estimated long-term natural moisture content.
Coarse Tailings	2-ft to 7-ft	2.3E-03 cm/sec	0.45	0079	0.068	1.322	20.47% by vol.	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as having more sand than silt; USDA classification is sandy loam. VG parameters are those based on a sandy loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.45) for coarse tailings in Tailings Reclamation Plan-Vol II, Canonie (Aug 1991)

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								4. Ksat value US Filter (2004) p. 6
Fine Tailings	7-ft to 10-ft	2.3E-03 cm/sec	0.53	0.059	0.048	1.211	38.7% by vol.	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickest tailings plus cover depth in the north Cell is 10-ft. It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as more silt than sand – USDA classification is silt loam. VG parameters are those based on a silt loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.53) for coarse tailings in Tailings

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								Reclamation Plan-Vol II, Canonie (Aug 1991) 4. Ksat value US Filter (2004) p. 6
Zone 3 – Gallup Sandstone	Below alluvium	6E-04 cm/sec						1. K_{sat} value from US Filter (2004) report, p. 6 2. A unit gradient lower boundary condition will be placed at the base of the alluvium. This is justified because it is assumed near steady state conditions exist at this depth. The drainage form the unsaturated flow modeling will be verified to ensure it is less than the saturated hydraulic conductivity of the Zone 3.

[1] BGS = below ground surface

Profile#3:

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Cover: Rock/Soil Surface Layer	0 to 6-in	1E-03 cm/sec	0.43	0.06	0.1057	1.36	13.6% by weight	1. Values from Dwyer 2003. K_{sat} and VG -- These were measured values from a gravel/soil admixture @ Sandia Nat Lab 2. Depth from As-Built North Cell Final Reclamation, Nov 1994, Canonie Environmental 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This is estimated long-term natural moisture content.
Cover Soil	6-in to 2-ft	2.7E-05 cm/sec	0.39	0.075	0.039	1.194	13.6% by weight	1. K_{sat} avg value from S,H,B (May76) Geotech Investigation 2. GSD reported in North Cell Final Reclamation state the soil is a clay loam. Typical VG parameters for Clay Loam (USDA) per RETC 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								is estimated long-term natural moisture content.
Coarse Tailings	2-ft to 7-ft	2.3E-03 cm/sec	0.45	0079	0.068	1.322	20.47% by vol.	1. Depth based on reported tailings depth from US Filter report (2004) and Canonie Geohydrology report (1987). It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as having more sand than silt; USDA classification is sandy loam. VG parameters are those based on a sandy loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.45) for coarse tailings in Tailings Reclamation Plan-Vol II, Canonie (Aug 1991)

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								4. Ksat value US Filter (2004) p. 6
Fine Tailings	7-ft to 15-ft	2.3E-03 cm/sec	0.53	0.059	0.048	1.211	38.7% by vol.	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickest tailings plus cover depth in the north Cell is 10-ft. It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as more silt than sand – USDA classification is silt loam. VG parameters are those based on a silt loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.53) for coarse tailings in Tailings

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								Reclamation Plan-Vol II, Canonie (Aug 1991) 4. Ksat value US Filter (2004) p. 6
Alluvium	15-ft to 55-ft	2.6E-03 cm/sec	0.39	0.075	0.039	1.194	15.9%	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickness of alluvium reported beneath the North Cell is 40-ft. 2. Initial MC is that reported in Canonie (1987) Reclamation Plan for Alluvium, table 4. 3. The alluvium is typical 70% silt and 30% sand – classified per USDA as silt loam. VG parameters are those based on a silt loam - values from RETC model per USDA classification. 4. K_{sat} value Canonie Environmental, Reclamation Plan, Vol I, March 1991.
Zone 3 –	Below	6E-04						1. K_{sat} value from US Filter

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Gallup Sandstone	alluvium	cm/sec						(2004) report, p. 6 2. A unit gradient lower boundary condition will be placed at the base of the alluvium. This is justified because it is assumed near steady state conditions exist at this depth. The drainage from the unsaturated flow modeling will be verified to ensure it is less than the saturated hydraulic conductivity of the Zone 3.

[1] BGS = below ground surface

Profile#4 (Borrow Pit#2):

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Cover: Rock/Soil Surface Layer	0 to 6-in	1E-03 cm/sec	0.43	0.06	0.1057	1.36	13.6% by weight	1. Values from Dwyer 2003. K_{sat} and VG -- These were measured values from a gravel/soil admixture @ Sandia Nat Lab 2. Depth from As-Built North Cell Final Reclamation, Nov 1994, Canonie Environmental 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This is estimated long-term natural moisture content.
Cover Soil	6-in to 2-ft	2.7E-05 cm/sec	0.39	0.075	0.039	1.194	13.6% by weight	1. K_{sat} avg value from S,H,B (May76) Geotech Investigation 2. GSD reported in North Cell Final Reclamation state the soil is a clay loam. Typical VG parameters for Clay Loam (USDA) per RETC 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								is estimated long-term natural moisture content.
Coarse Tailings	2-ft to 7-ft	2.3E-03 cm/sec	0.45	0079	0.068	1.322	20.47% by vol.	1. Depth based on reported tailings depth from US Filter report (2004) and Canonie Geohydrology report (1987). It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as having more sand than silt; USDA classification is sandy loam. VG parameters are those based on a sandy loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.45) for coarse tailings in Tailings Reclamation Plan-Vol II, Canonie (Aug 1991) 4. Ksat value US Filter (2004)

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								p. 6
Fine Tailings	7-ft to 57-ft	2.3E-03 cm/sec	0.53	0.059	0.048	1.211	Moisture content associated with field capacity	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickest tailings plus cover depth in the north Cell is 10-ft. It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as more silt than sand – USDA classification is silt loam. VG parameters are those based on a silt loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.53) for coarse tailings in Tailings Reclamation Plan-Vol II,

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								Canonie (Aug 1991) 4. Ksat value US Filter (2004) p. 6
Zone 3 – Gallup Sandstone	Below Tailings	6E-04 cm/sec						1. K_{sat} value from US Filter (2004) report, p. 6 2. A unit gradient lower boundary condition will be placed at the base of the alluvium. This is justified because it is assumed near steady state conditions exist at this depth. The drainage from the unsaturated flow modeling will be verified to ensure it is less than the saturated hydraulic conductivity of the Zone 3.

[1] BGS = below ground surface

Profile#5 (Central Cell):

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Cover: Rock/Soil Surface Layer	0 to 6-in	1E-03 cm/sec	0.43	0.06	0.1057	1.36	13.6% by weight	1. Values from Dwyer 2003. K_{sat} and VG -- These were measured values from a gravel/soil admixture @ Sandia Nat Lab 2. Depth from As-Built North Cell Final Reclamation, Nov 1994, Canonie Environmental 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This is estimated long-term natural moisture content.
Cover Soil	6-in to 2-ft	2.7E-05 cm/sec	0.39	0.075	0.039	1.194	13.6% by weight	1. K_{sat} avg value from S,H,B (May76) Geotech Investigation 2. GSD reported in North Cell Final Reclamation state the soil is a clay loam. Typical VG parameters for Clay Loam (USDA) per RETC 3. Initial MC from Tailings Reclamation Plan, Vol. I, Aug 1991, Canonie Environmental, p.34. This

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								is estimated long-term natural moisture content.
Coarse Tailings	2-ft to 7-ft	2.3E-03 cm/sec	0.45	0079	0.068	1.322	20.47% by vol.	1. Depth based on reported tailings depth from US Filter report (2004) and Canonie Geohydrology report (1987). It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as having more sand than silt; USDA classification is sandy loam. VG parameters are those based on a sandy loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.45) for coarse tailings in Tailings Reclamation Plan-Vol II, Canonie (Aug 1991)

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								4. Ksat value US Filter (2004) p. 6
Fine Tailings	7-ft to 27-ft	2.3E-03 cm/sec	0.53	0.059	0.048	1.211	38.7% by vol.	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickest tailings plus cover depth in the north Cell is 10-ft. It was stated that a minimum of 7-ft of coarse tailings and/or fill material plus the cover was placed over all fine tailings. 2. Initial MC is from the avg measured values Tailings Reclamation Plan-Vol II, Canonie (Aug 1991). 3. GSD reported as more silt than sand – USDA classification is silt loam. VG parameters are those based on a silt loam - values from RETC (Rawls et al 1982) per USDA classification with θ_s adjusted for the reported porosity (0.53) for coarse tailings in Tailings

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
								Reclamation Plan-Vol II, Canonie (Aug 1991) 4. Ksat value US Filter (2004) p. 6
Alluvium	27-ft to 67-ft	2.6E-03 cm/sec	0.39	0.075	0.039	1.194	15.9%	1. Depth based on reported tailings depths from US Filter report (2004) and Canonie Geohydrology report (1987). The typical thickness of alluvium reported beneath the North Cell is 40-ft. 2. Initial MC is that reported in Canonie (1987) Reclamation Plan for Alluvium, table 4. 3. The alluvium is typical 70% silt and 30% sand – classified per USDA as silt loam. VG parameters are those based on a silt loam - values from RETC model per USDA classification. 4. K_{sat} value Canonie Environmental, Reclamation Plan, Vol I, March 1991.
Zone 3 –	Below	6E-04						1. K_{sat} value from US Filter

Soil	Depth BGS[1]	K_{sat} (cm/hr)	Van Genuchten Parameters				Initial Moisture Content	Reference
			θ_s	θ_r	α (1/cm)	n		
Gallup Sandstone	alluvium	cm/sec						(2004) report, p. 6 2. A unit gradient lower boundary condition will be placed at the base of the alluvium. This is justified because it is assumed near steady state conditions exist at this depth. The drainage from the unsaturated flow modeling will be verified to ensure it is less than the saturated hydraulic conductivity of the Zone 3.

[1] BGS = below ground surface

APPENDIX B

MODELING PARAMETERS AND BOUNDARY CONDITIONS

MODEL INPUT PARAMETERS

A set of input parameters were developed for simulations using UNSAT-H for each soil profile. These parameters were developed based on field and laboratory measurements, values from the literature, and assumed values.

B.1 MODEL GEOMETRY

The model geometry is consistent with that described in section 2.0 and Appendix A for each respective profile.

B.2 BOUNDARY CONDITIONS

The profiles modeled utilized an upper boundary condition composed of site-specific average climate data for a period of 21 years. Weather data available through the United States Department of Commerce, National Climate Data Center was evaluated (http://cdo.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv=). An average climate year (1949) consisting of an annual precipitation of 11.7 inches (29.7 cm) of precipitation was utilized for 21 consecutive years. The PET during this period was calculated via New Mexico State University's Potential and Actual Crop Evapotranspiration Wizard. This software package available on the internet at http://weather.nmsu.edu/pet/JS_pet.htm was utilized to calculate daily PET values based on the daily weather data. The maximum and minimum daily temperatures, daily precipitation value, site latitude, and a site specific calibration coefficient of 0.16 were input parameters used to calculate PET (Samani and Pessarkli, 1986). The Samani method used to calculate PET correlates very well with the Penman method utilized within UNSAT H (Samani and Pessarkli, 1986).

The flow of water across the surface and lower boundary of the cover profile of interest is determined by boundary condition specifications. For infiltration events, the upper boundary was set to a maximum hourly flux (representative of local conditions). For these runs it was conservatively set to 0.4 inches (1 cm) per hour that produced minimal runoff while maximizing infiltration. The UNSAT-H program partitions PET into potential evaporation (E_p) and potential transpiration (T_p). Potential evaporation is estimated or derived from daily weather parameters (Fayer 2000). Potential transpiration is calculated using a function (Equation 1) that is based on the value of the assigned leaf area index (LAI) and an equation developed by Ritchie and Burnett (1971) as follows:

$$T_p = PET\,[a + b(LAI)^c] \quad \text{where } d \le LAI \le e \qquad \text{Equation B.1}$$

where:

a,b,c,d, and e are fitting parameters;

a = 0.0, b = 0.52, and c = 0.5, d = 0.1, and e = 2.7 (Fayer 2000)

The UNSAT-H program then partitioned the daily PET values into E_p and T_p. T_p was calculated using a function developed by Equation B.1 above.

The lower boundary condition used was set as a unit gradient.

B.3 VEGETATION DATA

The input parameters representing vegetation include the LAI, rooting depth and density, root growth rate, the suction head values that corresponds to the soil's field capacity, wilting point, and water content above which plants do not transpire because of anaerobic conditions. The onset and termination of the growing season for the site are defined in terms of Julian days. A percent bare area is also defined in the UNSAT H model and is often based on visual observation of undisturbed areas near the evaporation ponds. The maximum rooting depth should be based on expected vegetation characteristics. The root length density (RLD) in UNSAT H is assumed to follow an exponential function such as that defined in Equation 2:

$$RLD = a \exp(-bz) + c \qquad \text{Equation B.2}$$

where:

a,b, and c are fitting parameters

z = depth below surface

The parameters used for the RLD functions in Equation B.2 were: a = 0.315, b=0.0073, and c = 0.076 (Fayer 2000). The time required for maximum rooting depth establishment was set at full depth beginning on day 1. The rooting depth was conservatively set at 2-feet (60 cm) based on field observations. An average LAI of 1.8 was used (Dwyer 2003). The onset and termination of the growing season for the site were Julian days 75 and 299, respectively. The LAI was transitioned from 0 to 1.8 starting with Julian day 75 to 135. Day 135 through 250, the full LAI equal to 1.8 was utilized. The LAI was then transitioned down from 1.8 to 0 from Julian day 250 to 299. This was conservative since it is realistic that plants can transpire year round at this site. An average percent bare area of 75% was used in the UNSAT H model based on visual observation of native vegetation in the surrounding area. This is conservative given many areas have higher plant densities than the assumed 25% coverage and an effective ET Cover should produce vegetation as good as or better than the surrounding areas due to seeding operations and lack of a shallow caliche layer that limits the storage capacity in undisturbed areas. Furthermore, the assumed percent bare area of 75% essentially reduces the maximum LAI to 0.45 (25% of 1.8).

B.4 SOIL PROPERTIES RELATED TO VEGETATION

Suction head values corresponding to the wilting point, field capacity, and a head value corresponding to the water content above which plants do not transpire because of anaerobic conditions were defined. Matric potential or suction heads are generally written as positive numbers, but in reality are negative values. Consequently, the higher the value, the greater the soil suction. The maximum water content a soil can hold after all downward drainage resulting from gravitational forces is referred to as its field capacity. Field capacity is arbitrarily reported as the water content at about 10.8 ft (330-cm) of matric potential head (Jury et al. 1991). Below field capacity, the hydraulic conductivity is assumed to be so low that gravity drainage becomes negligible and the soil moisture is held in place by suction or matric potential.

Not all of the water stored in the soil can be removed via transpiration. Vegetation is generally assumed to reduce the soil moisture content to the permanent wilting point, which is typically defined as the water content at 656.2 ft (20,000 cm) of matric potential head for native grasses. This 656.2 ft (20,000 cm) value was conservatively used although some shrubs present in the area could remove water from the soil to a suction of 3280.8 ft (100,000 cm) (Hillel 1998). Evaporation from the soil surface can further reduce the soil moisture below the wilting point toward the residual saturation, which is the water content at an infinite matric potential. The head corresponding to the water content below which plant transpiration starts to decrease was defined as 32.2 ft (1000 cm) (Fayer 2000). The head value corresponding to the water content above which plants do not transpire because of anaerobic conditions was defined at 4-in (10 cm) based on the assumed moisture characteristic curves for the utilized soil hydraulic properties.

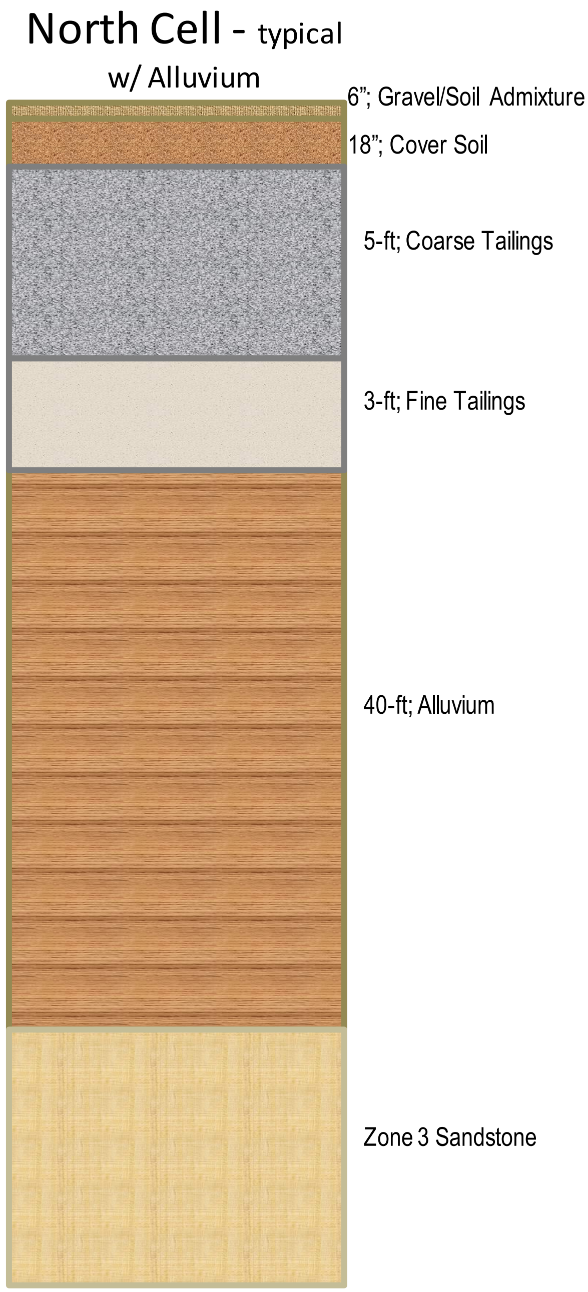
B.5 SOIL PROPERTIES

The soil properties are summarized in Appendix A and Section 5.0.

APPENDIX C

CALCULATIONS

Profile1: Typical North Cell Profile with underlying Alluvium



- Initial Stress Conditions for Fine Tailings Layer:

$$\sigma_0 = H_0 \times \gamma_w$$

where: $\sigma_0 = fine\ tailings\ layer\ stress$

$H_0 = initial\ fine\ tailings\ layer\ thickness = 3ft$

$\gamma_w = weight\ of\ tailings$
$= 110.1\ pcf\ [Ref: Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\sigma_0 = H_0 \times \gamma_w = 3ft \times 110.1\, pcf = 330.3psf$

$\Delta\sigma = (H_{ct} \times \gamma_{ct}) + (H_c \times \gamma_c) = 810.7\, psf$

where: $\Delta\sigma = stress\ due\ to\ material\ above\ fine\ tailings$

$H_{ct} = coarse\ tailings\ layer\ thickness = 5ft$

$H_c = cover\ layer\ thickness = 2ft$

$\gamma_{ct} = weight\ of\ coarse\ tailings$
$= 110.1\, pcf\ [Ref{:}\ Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\gamma_c = weight\ of\ coarse\ tailings$
$= 129.6\, pcf\ [Ref{:}\ North\ Cell\ Final\ Reclamation, Jan\ 1990]$

- Primary Consolidation: 3 settlement monuments were monitored in the North Cell (SM-8, SM-9, and SM-10). The average primary settlement of these monuments was 0.5ft (Ref: North Cell Final Reclamation, Jan 1990).
- Solve for the primary consolidation coefficient utilizing the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log \left(\frac{\sigma+\Delta\sigma}{\sigma}\right) \qquad \text{Equation 3-1}$$

where: S_p = primary settlement = 0.5 ft;

C_c = primary consolidation coefficient;

H = fine tailings layer thickness before settlement = 3ft;

e = void ratio = 1.12766;

σ_0 = initial stress; and

$\Delta\sigma$ = change in stress (additional weight due to spoils).

Therefore, $C_c = 0.2265$

- Solve for the secondary consolidation coefficient (C_a) utilizing the following equation (Bowles 1996):

$C_a = 0.03 \times C_c = 0.0068$

- Calculate the secondary consolidation from the time of final cover installation to present (21 years later):

$$S_s = C_a \times H \times log\left(\frac{t_2}{t_1}\right) \qquad \text{Equation 3-2}$$

where: S_s = Secondary Settlement;

C_a = secondary consolidation coefficient;

H = fine tailings layer thickness;

t_2 = time from t_1 = 21 years; and

t_1 = time when primary consolidation complete = 100 days.

$S_s = 0.0384\ ft$

- Determine the revised porosity (n_1) and void ratio (e_1):

$$S = H\left(\frac{e_0 - e_1}{1 + e_0}\right)$$

Solving for e_1 given S_s: $e_1 = e_0 - \frac{S(1+e_0)}{H} = 1.1$

Therefore, $n_1 = \frac{e_1}{1+e_1} = 0.52$

The profile was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B. The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 1982 cm and 23.9%, respectively. This is shown graphically below in Figure C1 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 1 modeled are also shown in Figure C2.

The following equation was utilized to calculate moisture content given the soil suction value:

$\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

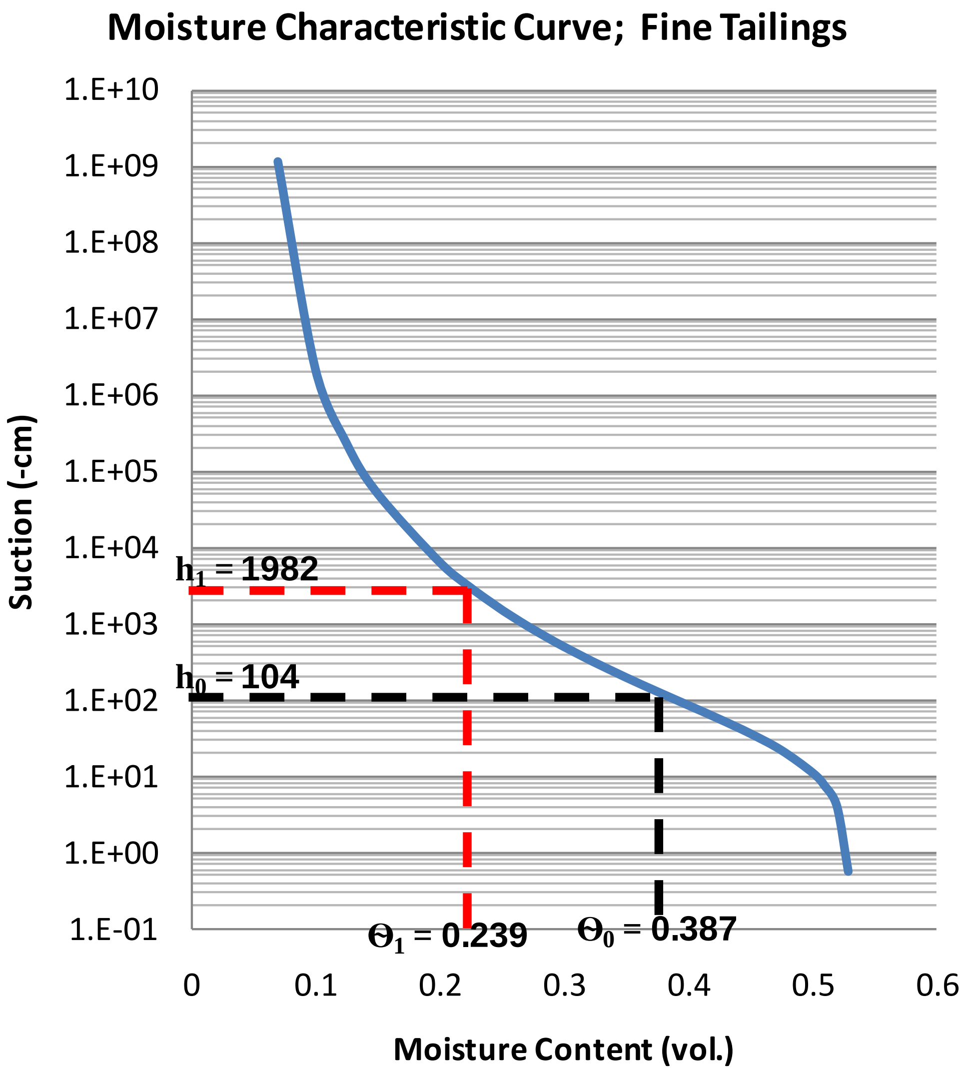


Figure C1. Moisture Characteristic Curve (Fine Tailings) with Initial (h_0) and Final (h_1) Moisture/Suction conditions

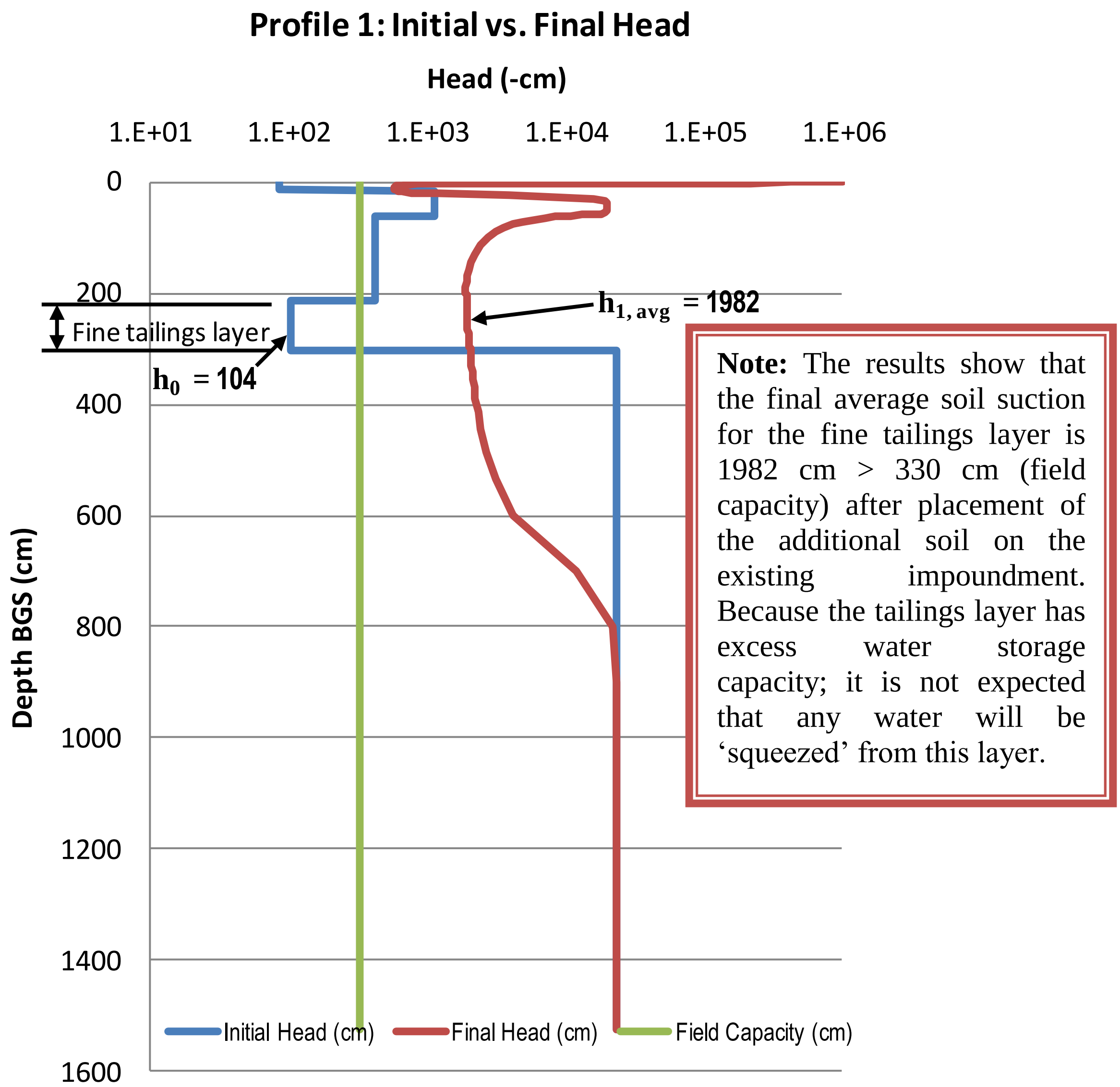


Figure C2. Profile C1 Initial and Final Soil Suction values compared to Field Capacity

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. These assumptions are conservative as the estimated volume includes a 20 percent contingency and the placement area may be greater than 36 acres. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.22 \times \left(\frac{2.96ft}{1+1.1}\right) log\left(\frac{1141+1958.7}{1141}\right) = 0.14ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.14(1+1.1)}{2.96} = 1.0$$

$$n_2 = \frac{e_2}{1+e_2} = 0.5$$

- Develop new Moisture Characteristic Curve (Figure C3) with $\theta_s = n_2$

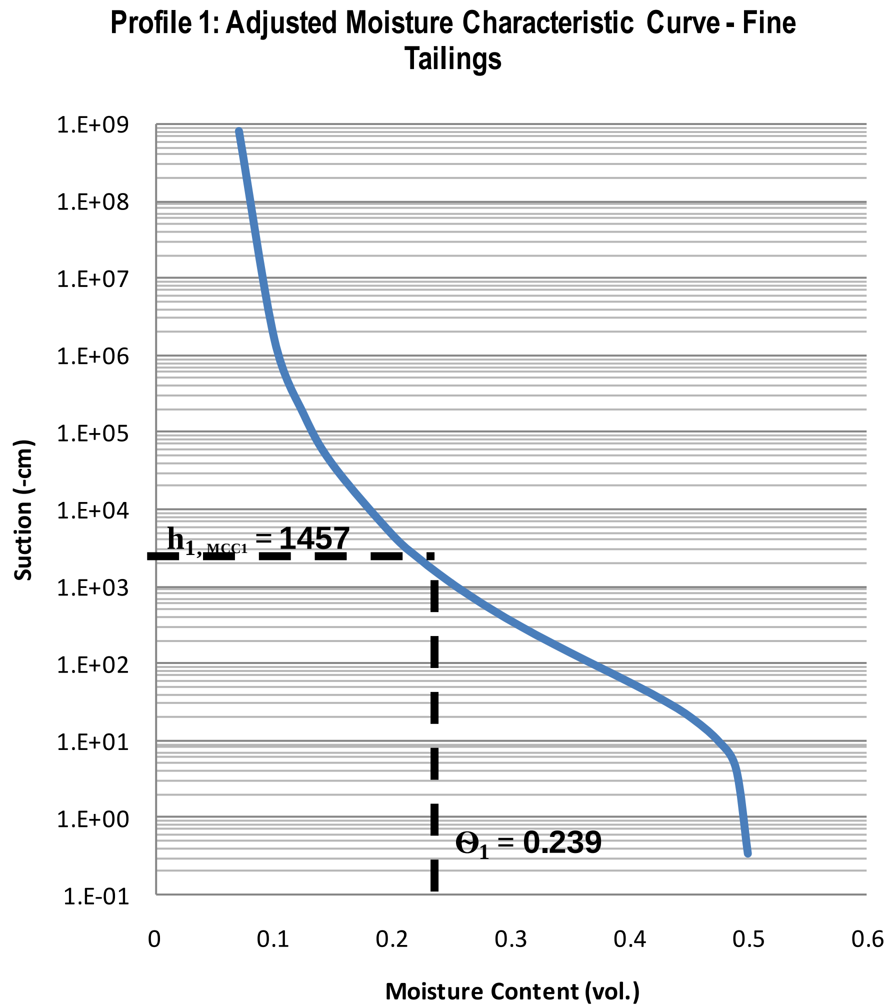


Figure C3. MCC adjusted for Reduced Porosity

- Conclusion. The final soil suction value ($h_{1, MCC1}$) is 1457 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

<u>Profile 1 - Sensitivity Analysis 1</u>: changed the saturated hydraulic conductivity of the underlying alluvium based on the worst case from pump tests reported in Canonie Environmental (March 1991). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 1 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the underlying alluvium was lowered to 8.1E-05 cm/sec (Canonie Environmental March 1991). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 819 cm and 27.6%, respectively. This is shown graphically below in Figure C4 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 1 modeled are also shown in Figure C5. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

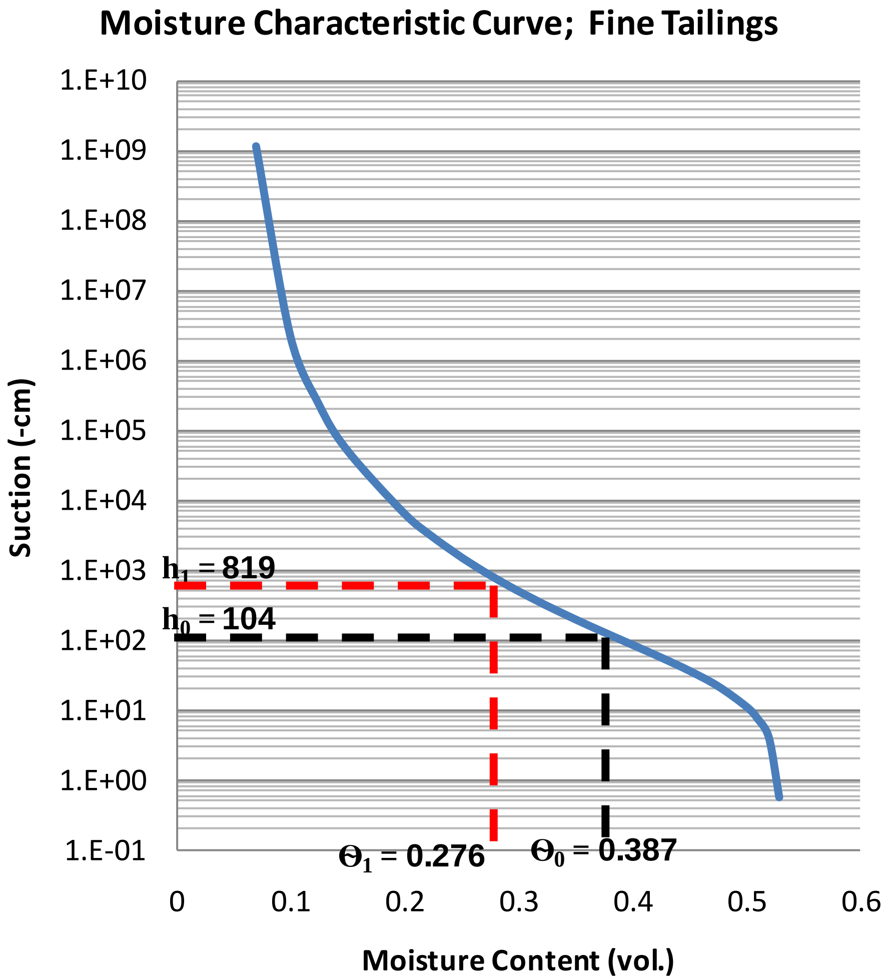


Figure C4. Profile 1, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 1

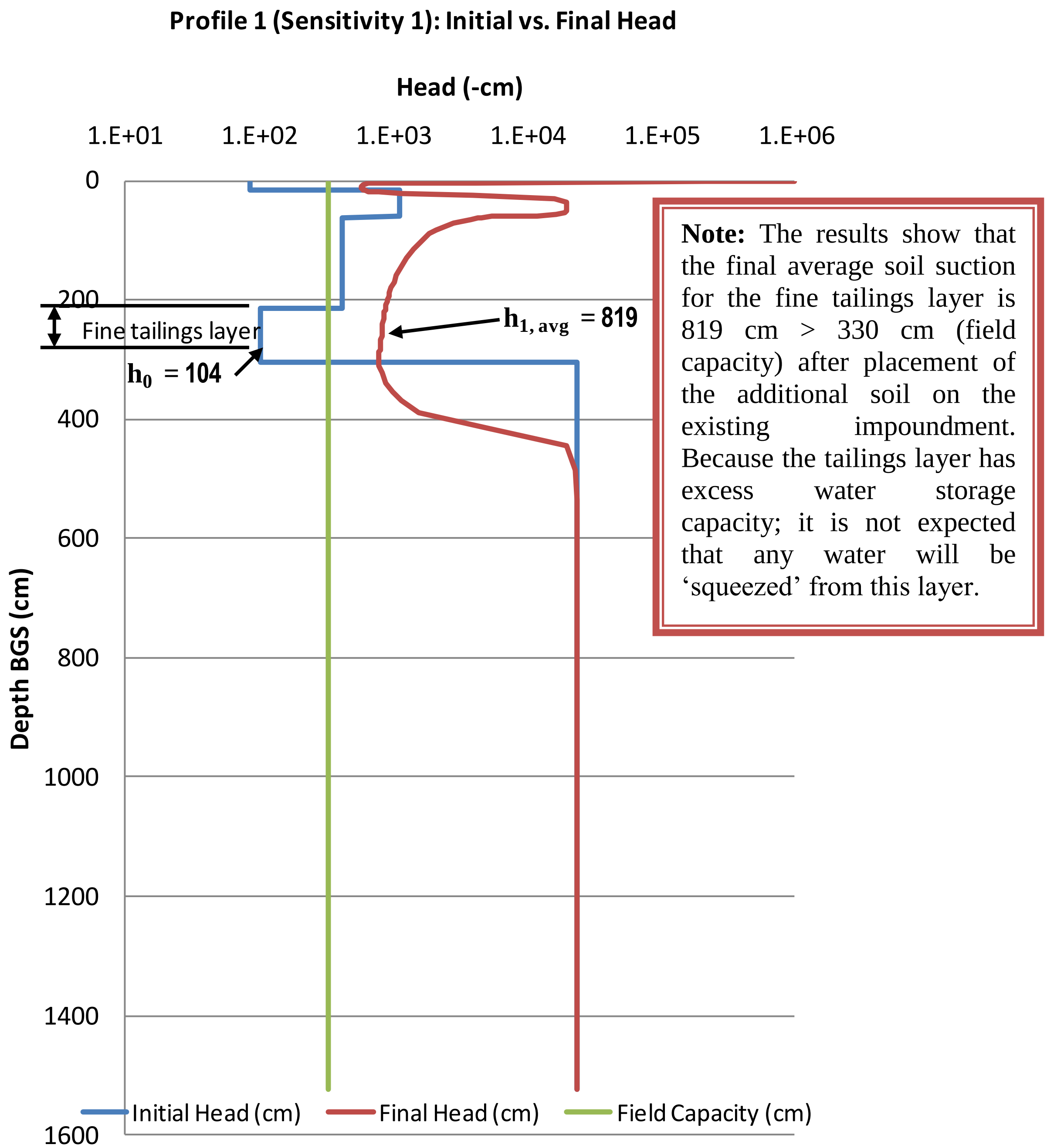


Figure C5. Profile 1 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 1

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.22 \times \left(\frac{2.96ft}{1+1.1}\right) log\left(\frac{1141 + 1958.7}{1141}\right) = 0.14ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.14(1+1.1)}{2.96} = 1.0$$

$$n_2 = \frac{e_2}{1+e_2} = 0.5$$

- Develop new Moisture Characteristic Curve (Figure C6) with $\theta_s = n_2$

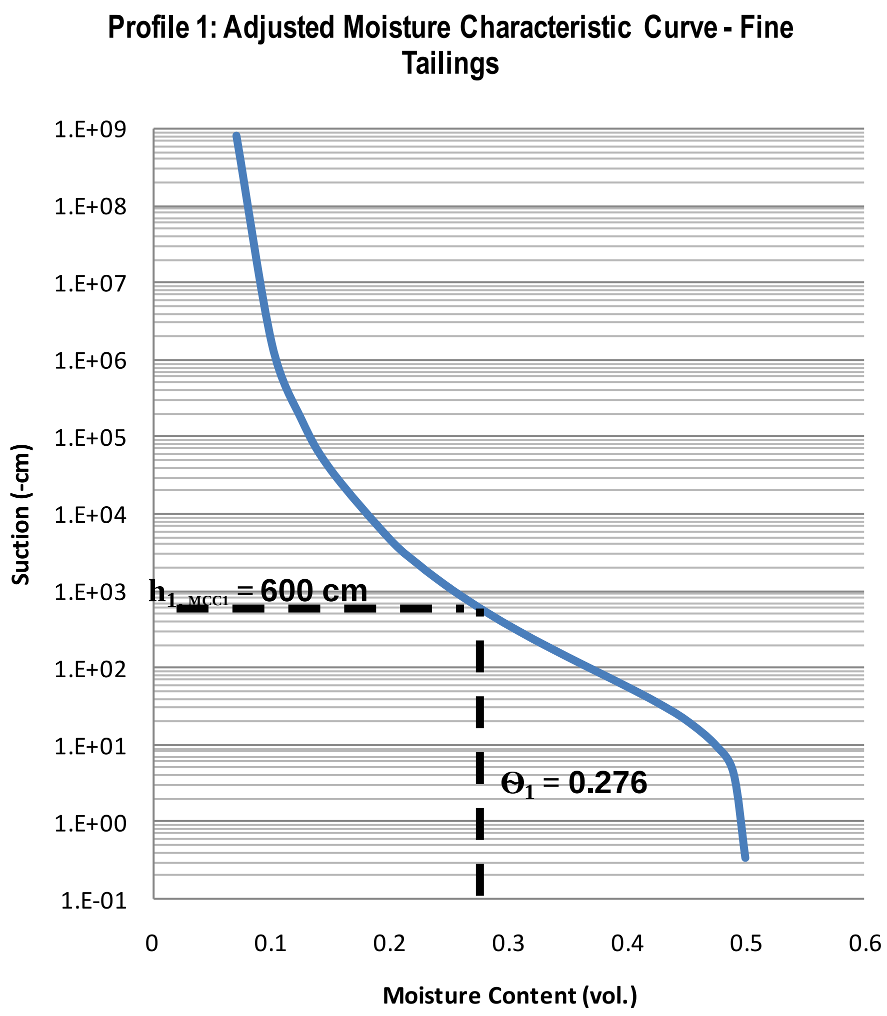


Figure C6. Profile 1, MCC adjusted for Reduced Porosity, Sensitivity Analysis 1

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 600 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile 1 - Sensitivity Analysis 2: changed the saturated hydraulic conductivity of the existing coarse and fine tailings based on the respective grain size distribution and reported values for each soil classification (Rawls et al 1982)). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 1 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the coarse tailings was lowered to 7.194E-04 cm/sec consistent with a sandy loam (Rawls et al 1982) and the fine tailings was lowered to 3.667E-04 cm/sec consistent with a silt loam (Rawls et al 1982). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 1495 cm and 25%, respectively. This is shown graphically below in Figure C7 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 1 modeled are also shown in Figure C8. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

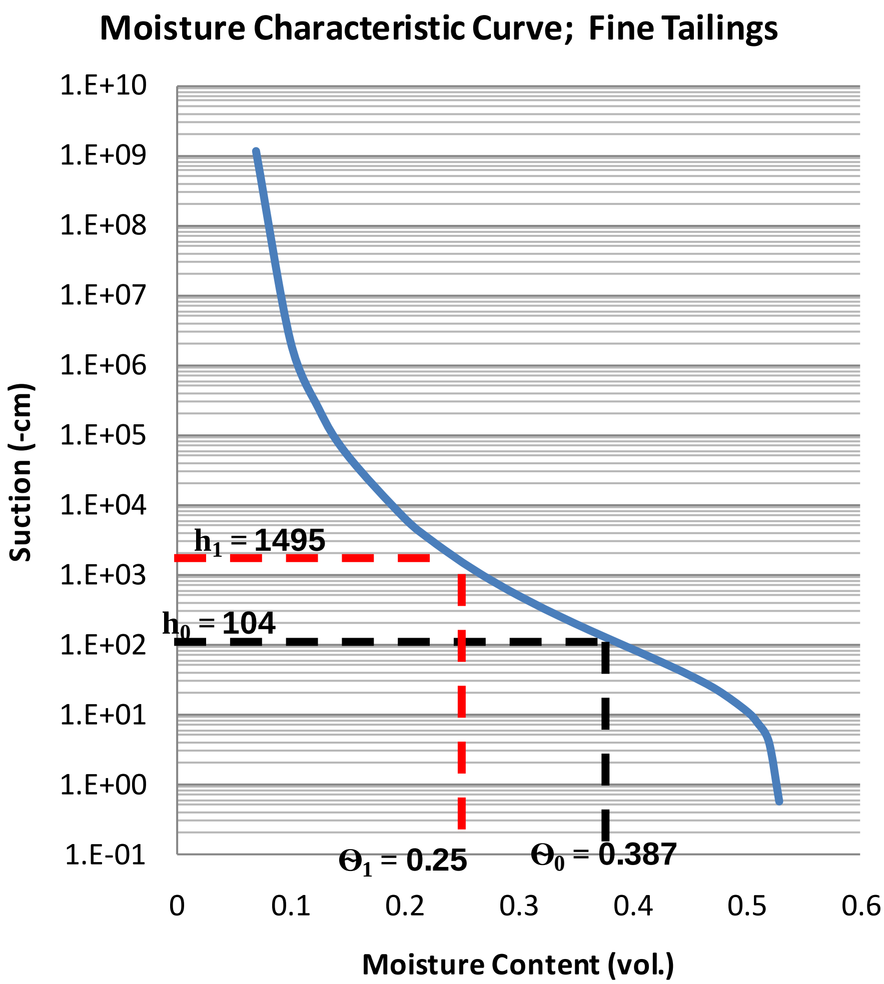


Figure C7. Profile 1, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 2

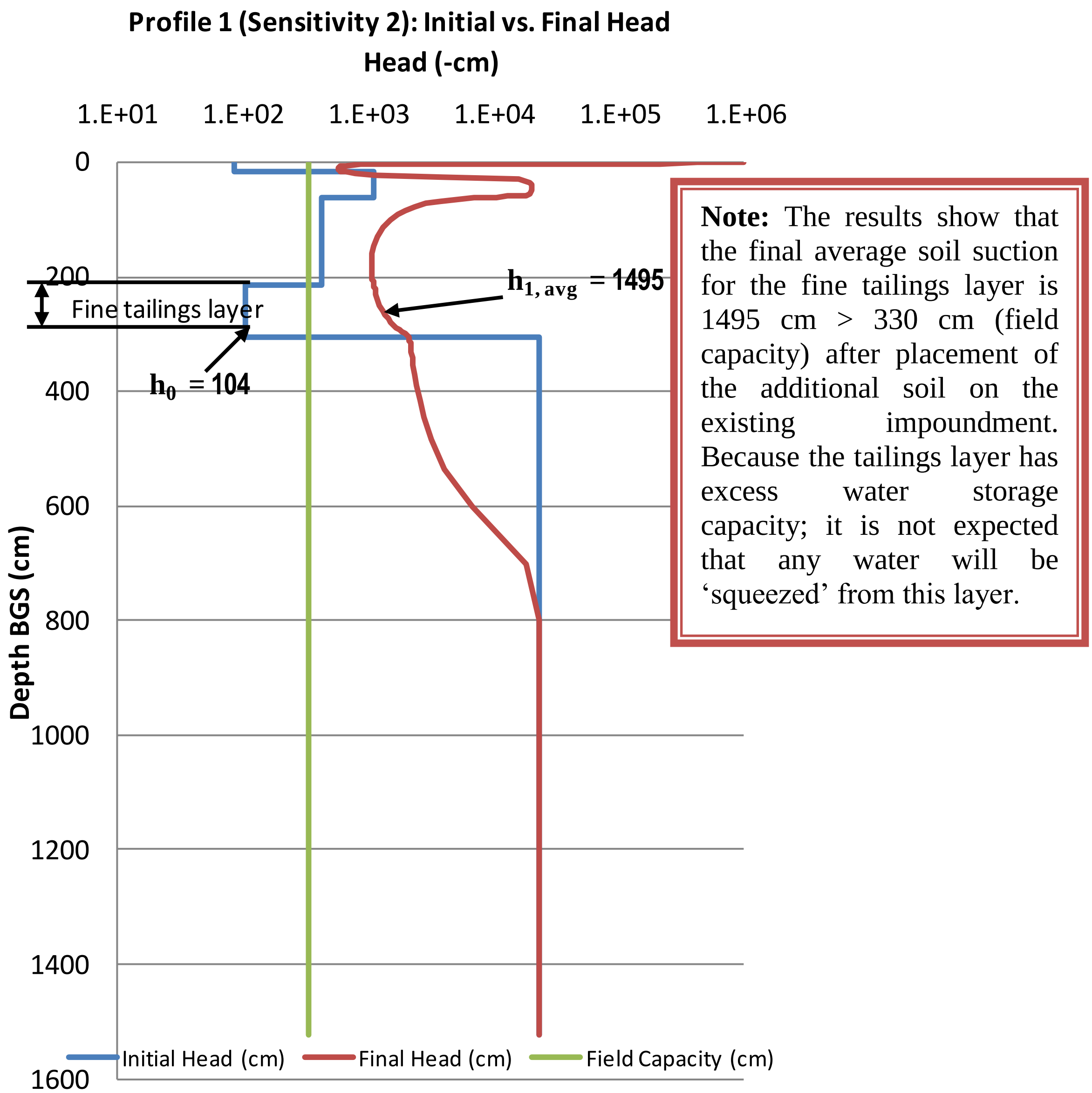


Figure C8. Profile 1 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 2

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.22 \times \left(\frac{2.96ft}{1+1.1}\right) log\left(\frac{1141 + 1958.7}{1141}\right) = 0.14ft$$

➢ Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.14(1+1.1)}{2.96} = 1.0$$

$$n_2 = \frac{e_2}{1+e_2} = 0.5$$

➢ Develop new Moisture Characteristic Curve (Figure C9) with $\theta_s = n_2$

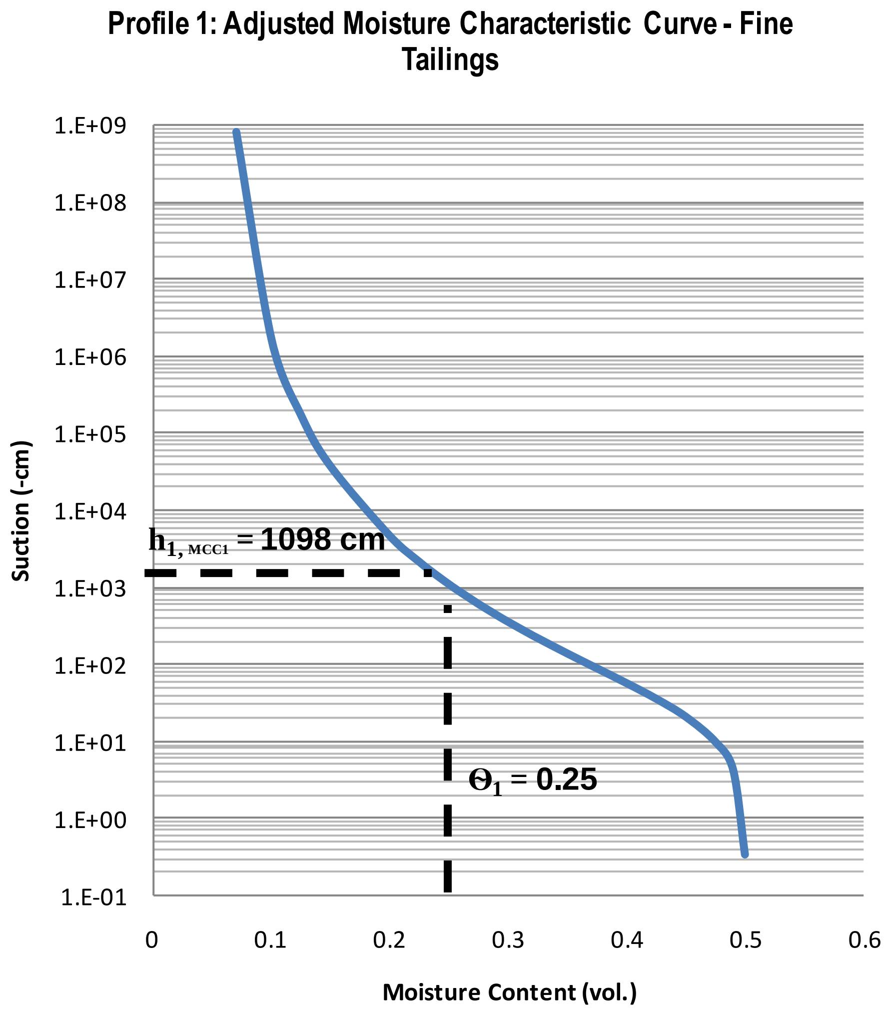
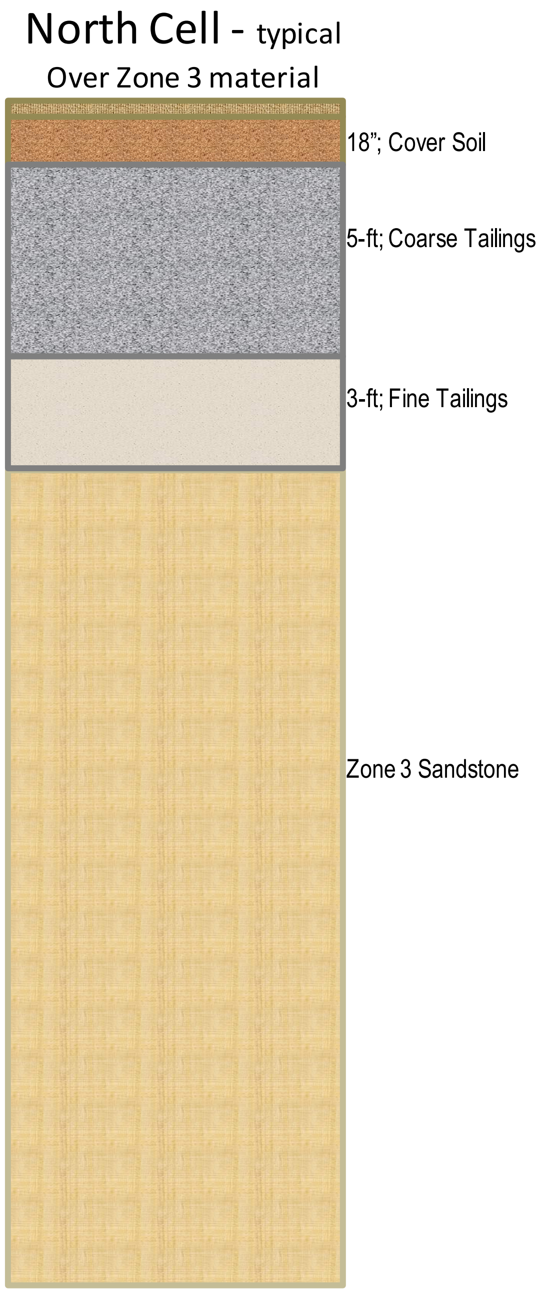


Figure C9. Profile 1, MCC adjusted for Reduced Porosity, Sensitivity Analysis 2

➢ Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 1098 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile2: Typical North Cell Profile with underlying Zone 3 material



- Initial Stress Conditions for Fine Tailings Layer:

$$\sigma_0 = H_0 \times \gamma_w$$

where: $\sigma_0 = fine\ tailings\ layer\ stress$

$H_0 = initial\ fine\ tailings\ layer\ thickness = 3ft$

$\gamma_w = weight\ of\ tailings$
$= 110.1\ pcf\ [Ref: Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\sigma_0 = H_0 \times \gamma_w = 3ft \times 110.1\, pcf = 330.3psf$

$\Delta\sigma = (H_{ct} \times \gamma_{ct}) + (H_c \times \gamma_c) = 810.7\, psf$

where: $\Delta\sigma = stress\ due\ to\ material\ above\ fine\ tailings$

$H_{ct} = coarse\ tailings\ layer\ thickness = 5ft$

$H_c = cover\ layer\ thickness = 2ft$

$\gamma_{ct} = weight\ of\ coarse\ tailings$
$= 110.1\, pcf\ [Ref: Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\gamma_c = weight\ of\ coarse\ tailings$
$= 129.6\, pcf\ [Ref: North\ cell\ Final\ reclamation, Jan\ 1990]$

- Primary Consolidation: 3 settlement monuments were monitored in the North cell (SM-8, SM-9, and SM-10). The average primary settlement of these monuments was 0.5ft (Ref: North Cell Final Reclamation, Jan 1990).
- Solve for the primary consolidation coefficient utilizing the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma+\Delta\sigma}{\sigma}\right) \qquad \text{Equation 3-1}$$

where: S_p = primary settlement = 0.5 ft;

C_c = primary consolidation coefficient;

H = fine tailings layer thickness before settlement = 3ft;

e = void ratio = 1.12766;

σ_0 = initial stress; and

$\Delta\sigma$ = change in stress (additional weight due to spoils).

Therefore, $C_c = 0.2265$

- Solve for the secondary consolidation coefficient (C_a) utilizing the following equation (Bowles 1996):

$C_a = 0.03 \times C_c = 0.0068$

- Calculate the secondary consolidation from the time of final cover installation to present (21 years later):

$$S_s = C_a \times H \times log\left(\frac{t_2}{t_1}\right) \qquad \text{Equation 3-2}$$

where: S_s = Secondary Settlement;

C_a = secondary consolidation coefficient;

H = fine tailings layer thickness;

t_2 = time from t_1 = 21 years; and

t_1 = time when primary consolidation complete = 100 days.

$S_s = 0.0384\ ft$

- Determine the revised porosity (n_1) and void ratio (e_1):

$$S = H\left(\frac{e_0 - e_1}{1 + e_0}\right)$$

Solving for e_1 given S_S: $e_1 = e_0 - \frac{S(1+e_0)}{H} = 1.1$

Therefore, $n_1 = \frac{e_1}{1+e_1} = 0.52$

The profile was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B. The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 1234 cm and 25.8%, respectively. This is shown graphically below in Figure C10 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 2 modeled are also shown in Figure C11.

The following equation was utilized to calculate moisture content given the soil suction value:

$\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

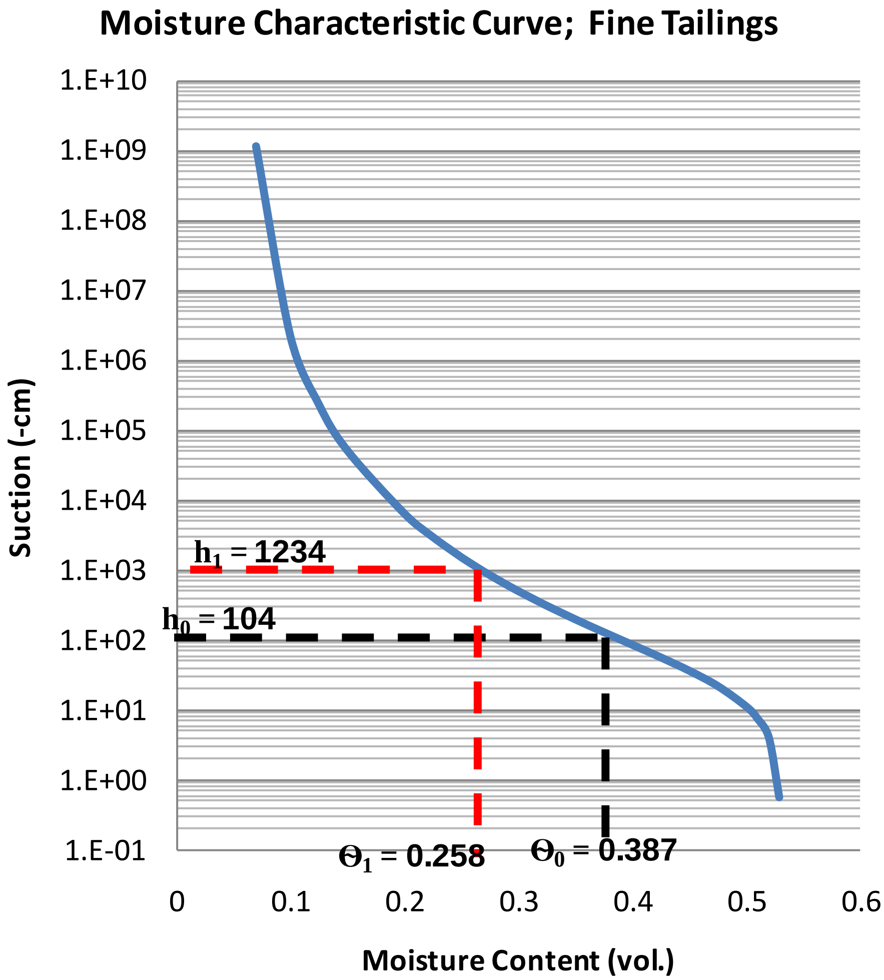


Figure C10. Profile 2, MCC (Fine Tailings) with Initial and Final Moisture/Suction conditions

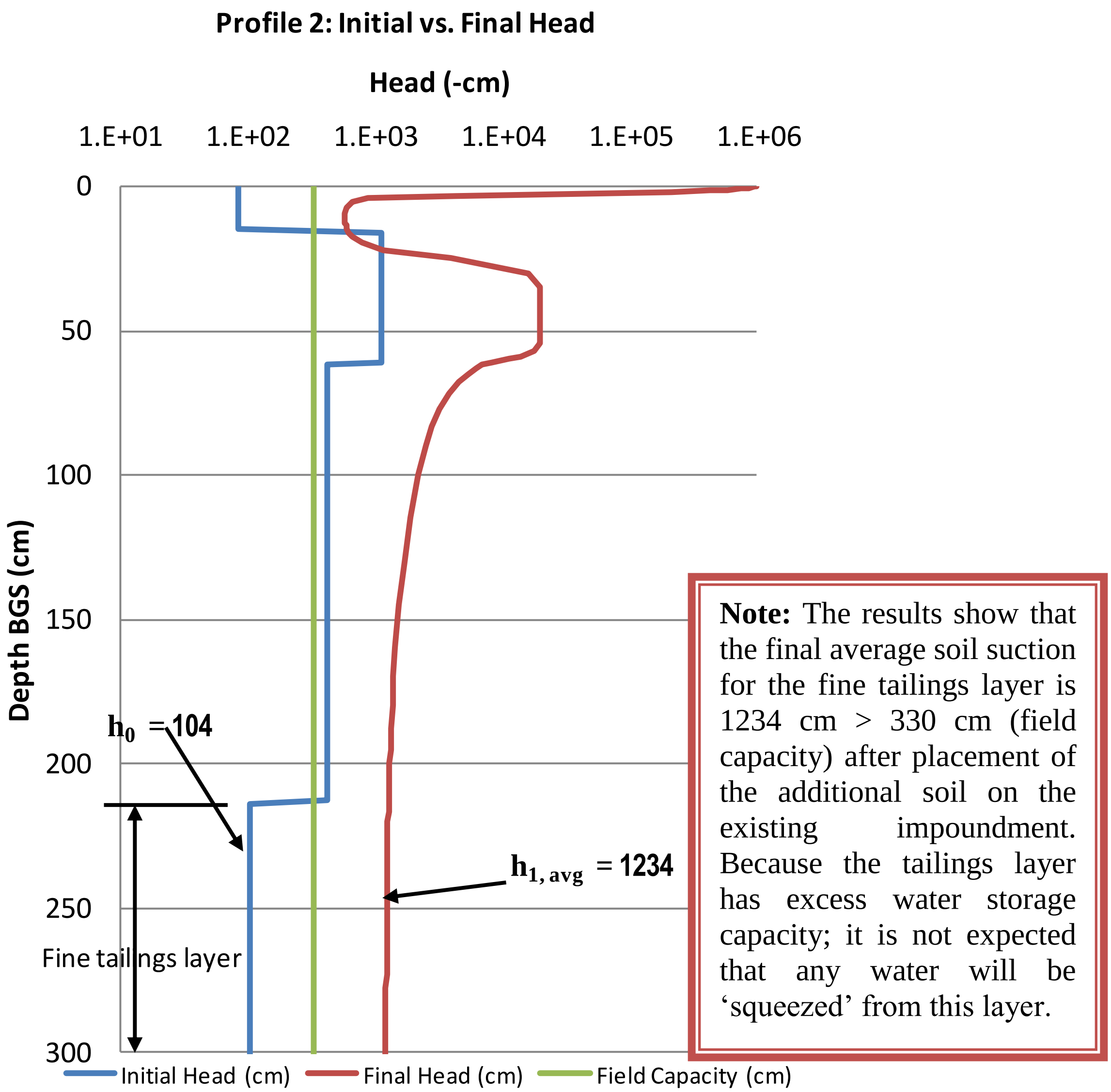


Figure C11. Profile 2 Initial and Final Soil Suction values compared to Field Capacity

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.22 \times \left(\frac{2.96ft}{1+1.1}\right) log\left(\frac{1141 + 1958.7}{1141}\right) = 0.14ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.14(1+1.1)}{2.96} = 1.0$$

$$n_2 = \frac{e_2}{1+e_2} = 0.5$$

- Develop new Moisture Characteristic Curve (Figure C12) with $\theta_s = n_2$

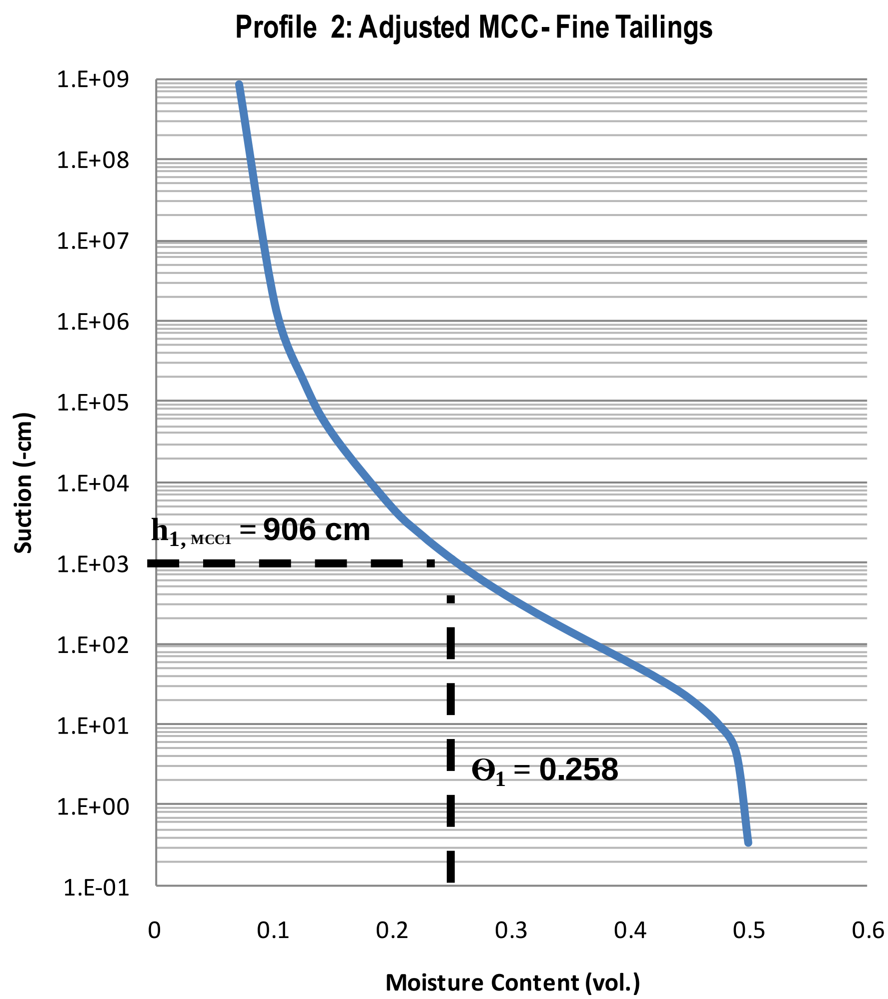


Figure C12. Profile 2, MCC adjusted for Reduced Porosity

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 906 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

<u>Profile 2 - Sensitivity Analysis 2</u>: changed the saturated hydraulic conductivity of the existing coarse and fine tailings based on the respective grain size distribution and reported values for each soil classification (Rawls et al 1982)). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 2 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the coarse tailings was lowered to 7.194E-04 cm/sec consistent with a sandy loam (Rawls et al 1982) and the fine tailings was lowered to 3.667E-04 cm/sec consistent with a silt loam (Rawls et al 1982). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 588 cm and 29.1%, respectively. This is shown graphically below in Figure C13 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 2 modeled are also shown in Figure C14. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

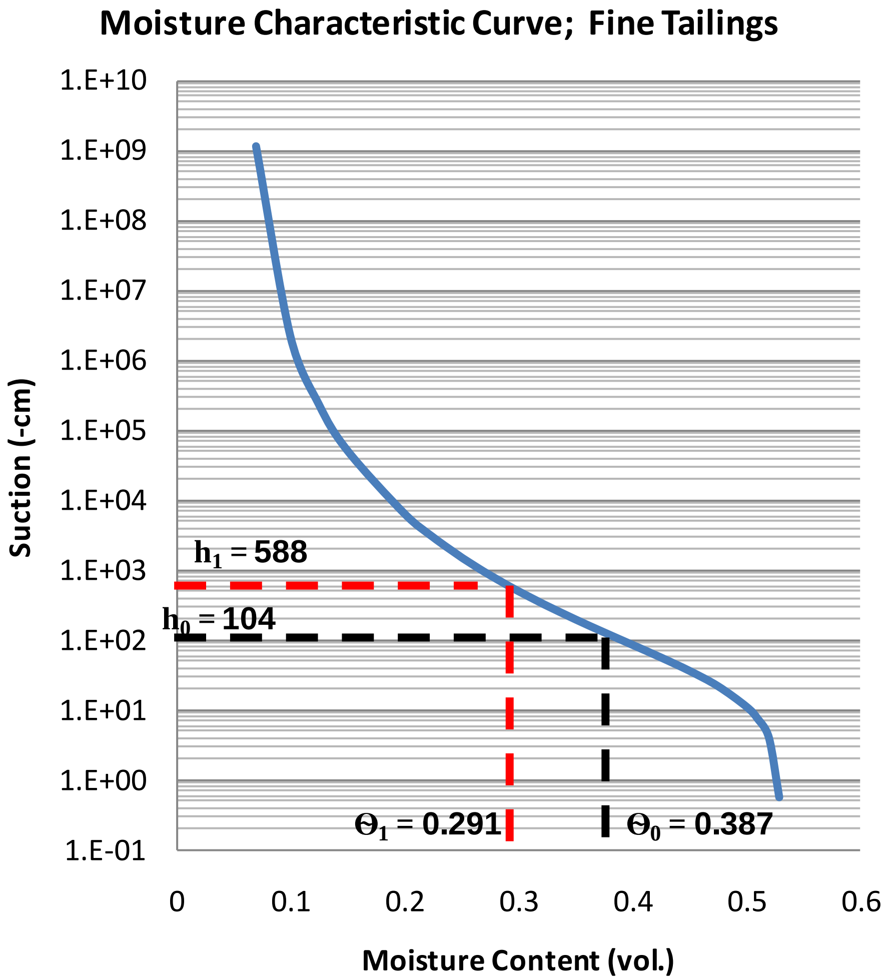


Figure C13. Profile 2, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 2

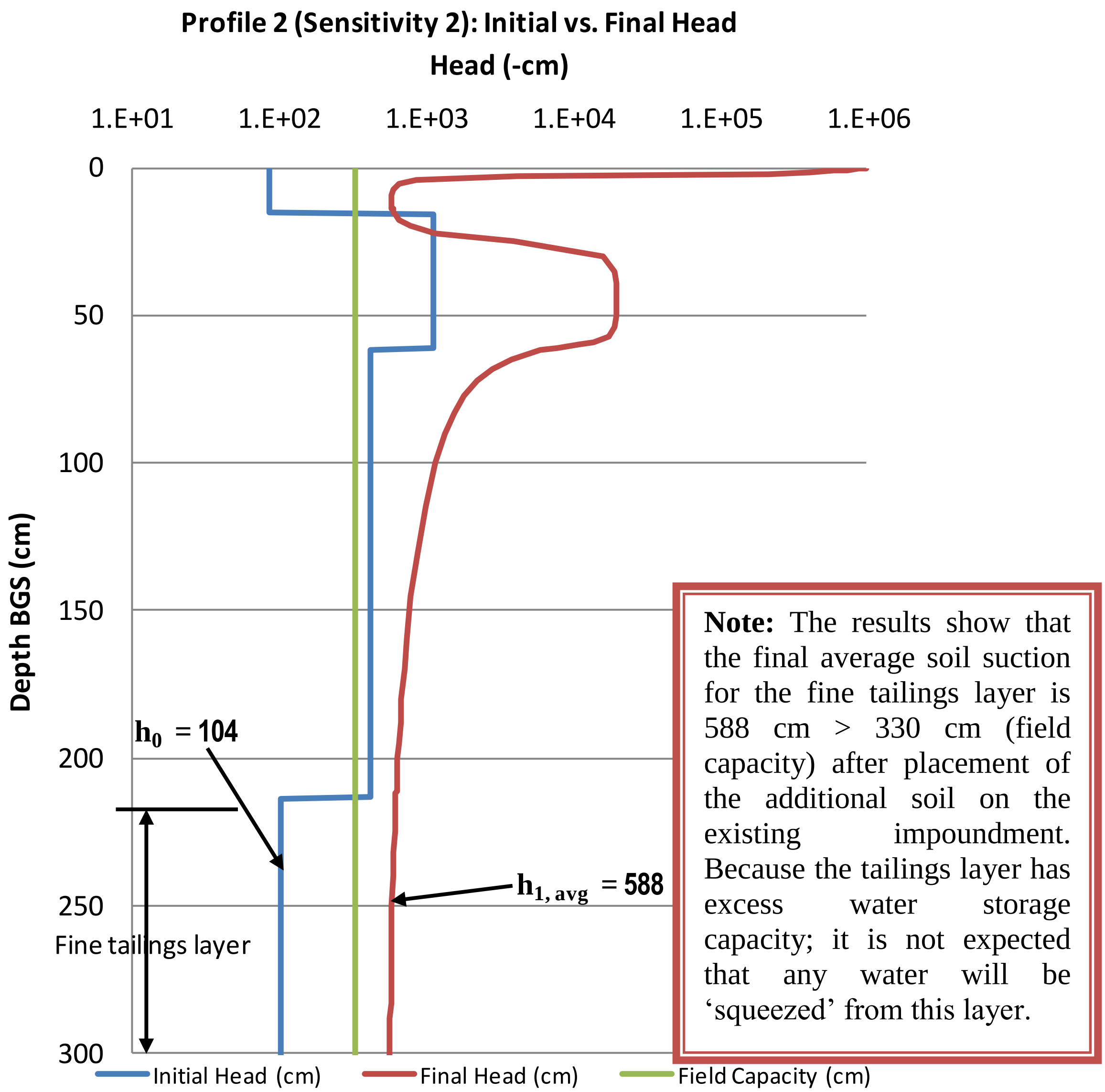


Figure C14. Profile 2 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 2

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.22 \times \left(\frac{2.96ft}{1+1.1}\right) log\left(\frac{1141 + 1958.7}{1141}\right) = 0.14ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.14(1+1.1)}{2.96} = 1.0$$

$$n_2 = \frac{e_2}{1+e_2} = 0.5$$

- Develop new Moisture Characteristic Curve (Figure C15) with $\theta_s = n_2$

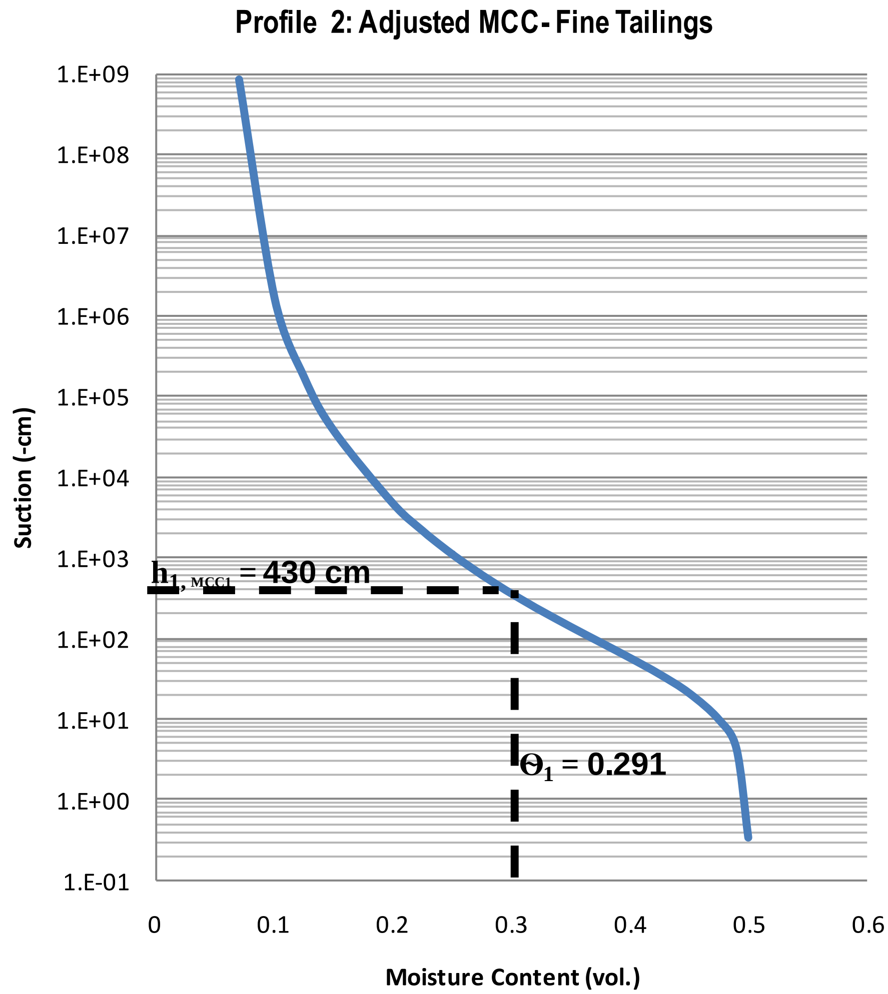


Figure C15. Profile 2, MCC adjusted for Reduced Porosity, Sensitivity Analysis 2

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 430 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be ‘squeezed’ out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile 3: Worst Case North Cell Profile w/ underlying Alluvium

- Initial Stress Conditions for Fine Tailings Layer:

$$\sigma_0 = H_0 \times \gamma_w$$

where: $\sigma_0 = fine\ tailings\ layer\ stress$

$H_0 = initial\ fine\ tailings\ layer\ thickness = 8ft$

$\gamma_w = weight\ of\ tailings$
$= 110.1\ pcf\ [Ref: Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$$\sigma_0 = H_0 \times \gamma_w = 8ft \times 110.1\, pcf = 880.8\, psf$$

$$\Delta\sigma = (H_{ct} \times \gamma_{ct}) + (H_c \times \gamma_c) = 810.7\, psf$$

where: $\Delta\sigma = stress\ due\ to\ material\ above\ fine\ tailings$

$H_{ct} = coarse\ tailings\ layer\ thickness = 5ft$

$H_c = cover\ layer\ thickness = 2ft$

$\gamma_{ct} = weight\ of\ coarse\ tailings$
$= 110.1\, pcf\ [Ref{:}\ Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\gamma_c = weight\ of\ coarse\ tailings$
$= 129.6\, pcf\ [Ref{:}\ North\ cell\ Final\ reclamation, Jan\ 1990]$

- Primary Consolidation: 3 settlement monuments were monitored in the North cell (SM-8, SM-9, and SM-10). The average primary settlement of these monuments was 0.5ft (Ref: North Cell Final Reclamation, Jan 1990).
- Solve for the primary consolidation coefficient utilizing the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma+\Delta\sigma}{\sigma}\right) \qquad \text{Equation 3-1}$$

where: S_p = primary settlement = 0.5 ft;

C_c = primary consolidation coefficient;

H = fine tailings layer thickness before settlement = 8ft;

e = void ratio = 1.12766;

σ_0 = initial stress; and

$\Delta\sigma$ = change in stress (additional weight due to spoils).

Therefore, $C_c = 0.195$

- Solve for the secondary consolidation coefficient (C_a) utilizing the following equation (Bowles 1996):

$$C_a = 0.03 \times C_c = 0.0058$$

- Calculate the secondary consolidation from the time of final cover installation to present (21 years later):

$$S_s = C_a \times H \times log\left(\frac{t_2}{t_1}\right) \qquad \text{Equation 3-2}$$

where: S_s = Secondary Settlement;

C_a = secondary consolidation coefficient;

H = fine tailings layer thickness;

t_2 = time from t_1 = 21 years; and

t_1 = time when primary consolidation complete = 100 days.

$$S_s = 0.088\, ft$$

- Determine the revised porosity (n_1) and void ratio (e_1):

$$S = H\left(\frac{e_0 - e_1}{1 + e_0}\right)$$

Solving for e_1 given S_S: $e_1 = e_0 - \frac{S(1+e_0)}{H} = 1.104$

Therefore, $n_1 = \frac{e_1}{1+e_1} = 0.525$

The profile was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B. The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 1142.3 cm and 26.1%, respectively. This is shown graphically below in Figure C16 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 3 modeled are also shown in Figure C17.

The following equation was utilized to calculate moisture content given the soil suction value:

$\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

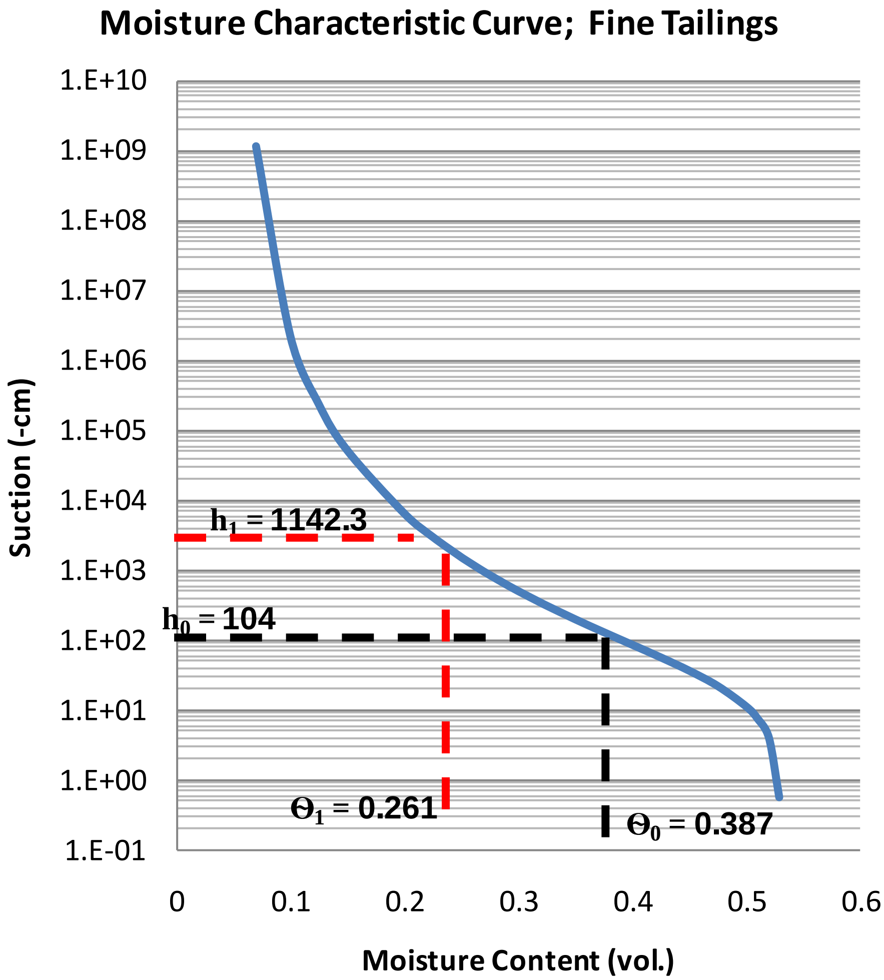


Figure C16. Profile 3, MCC (Fine Tailings) with Initial and Final Moisture/Suction conditions

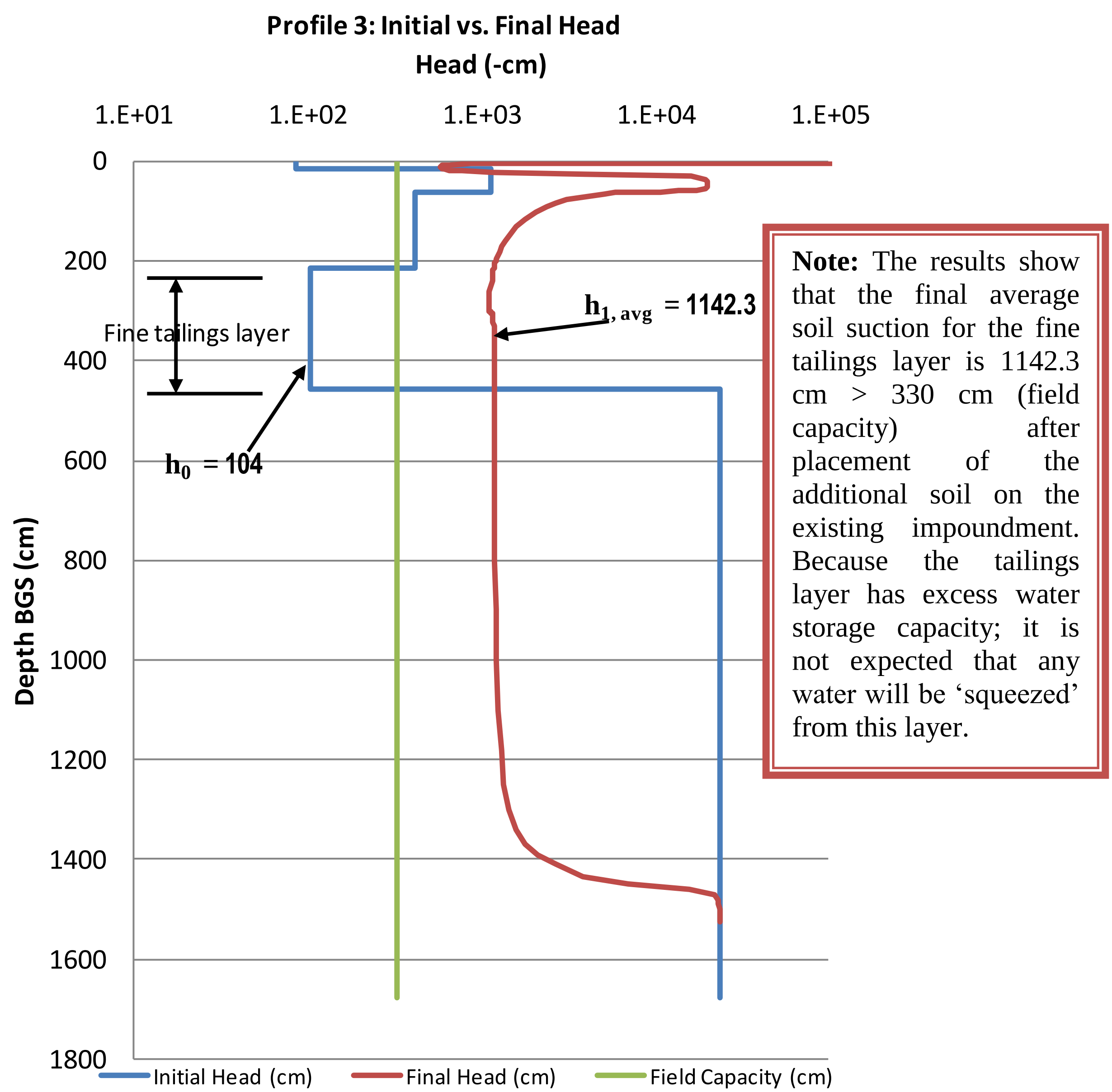


Figure C17. Profile 3 Initial and Final Soil Suction values compared to Field Capacity

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.195 \times \left(\frac{7.91ft}{1+1.104}\right) log\left(\frac{1691.5 + 1958.7}{1691.5}\right) = 0.244ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.244(1+1.1)}{7.91} = 1.04$$

$$n_2 = \frac{e_2}{1+e_2} = 0.51$$

- Develop new Moisture Characteristic Curve (Figure C18) with $\theta_s = n_2$

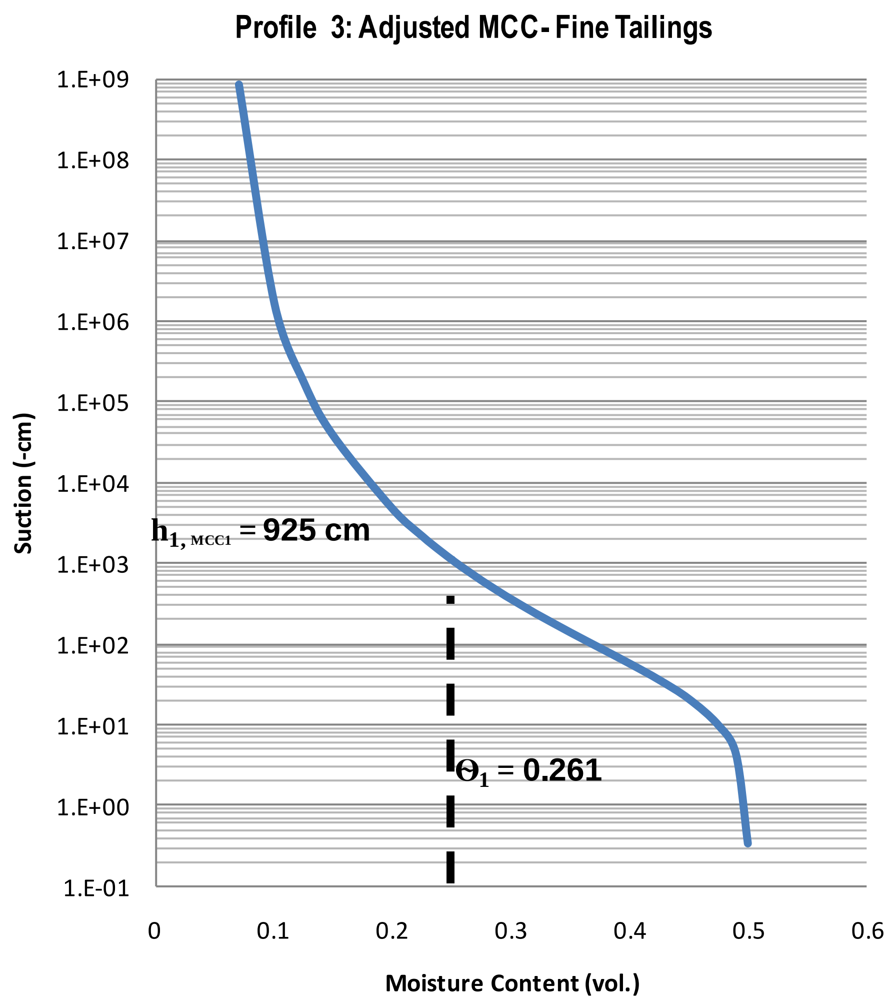


Figure C18. MCC adjusted for Reduced Porosity

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 925 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be ‘squeezed’ out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

<u>Profile 3 - Sensitivity Analysis 1</u>: changed the saturated hydraulic conductivity of the underlying alluvium based on the worst case from pump tests reported in Canonie Environmental (March 1991). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 3 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the underlying alluvium was lowered to 8.1E-05 cm/sec (Canonie Environmental March 1991). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 488 cm and 30%, respectively. This is shown graphically below in Figure C19 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 3 modeled are also shown in Figure C20. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

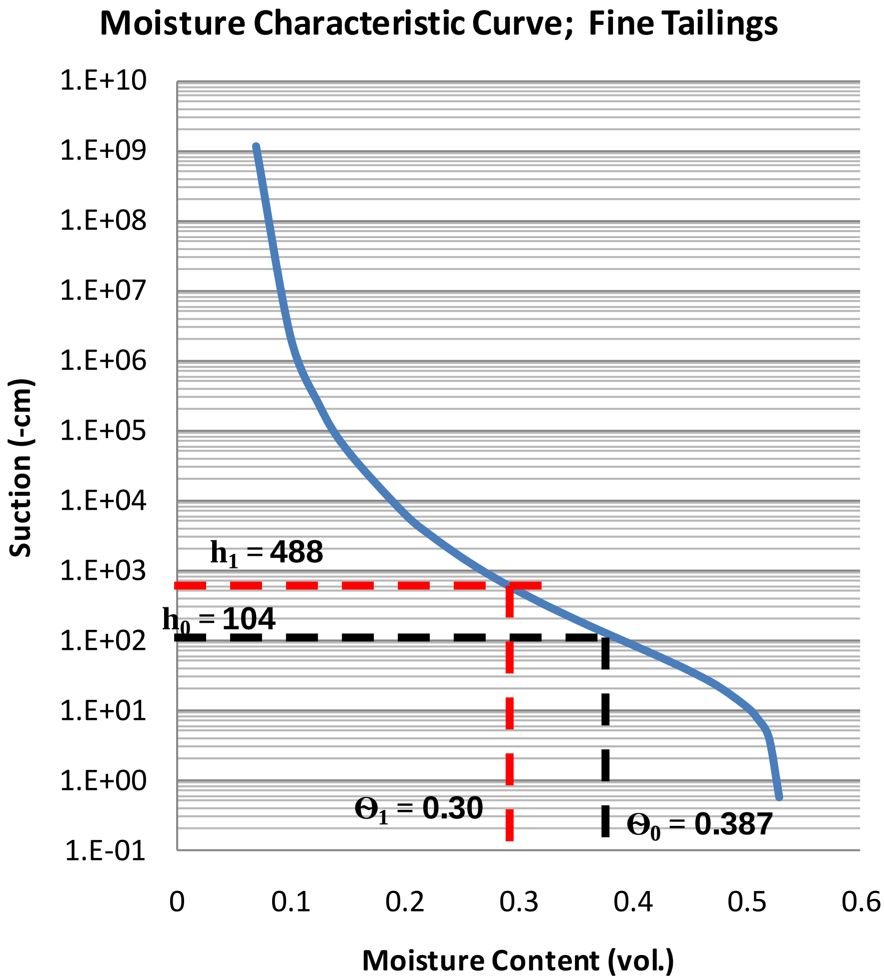


Figure C19. Profile 3, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 1

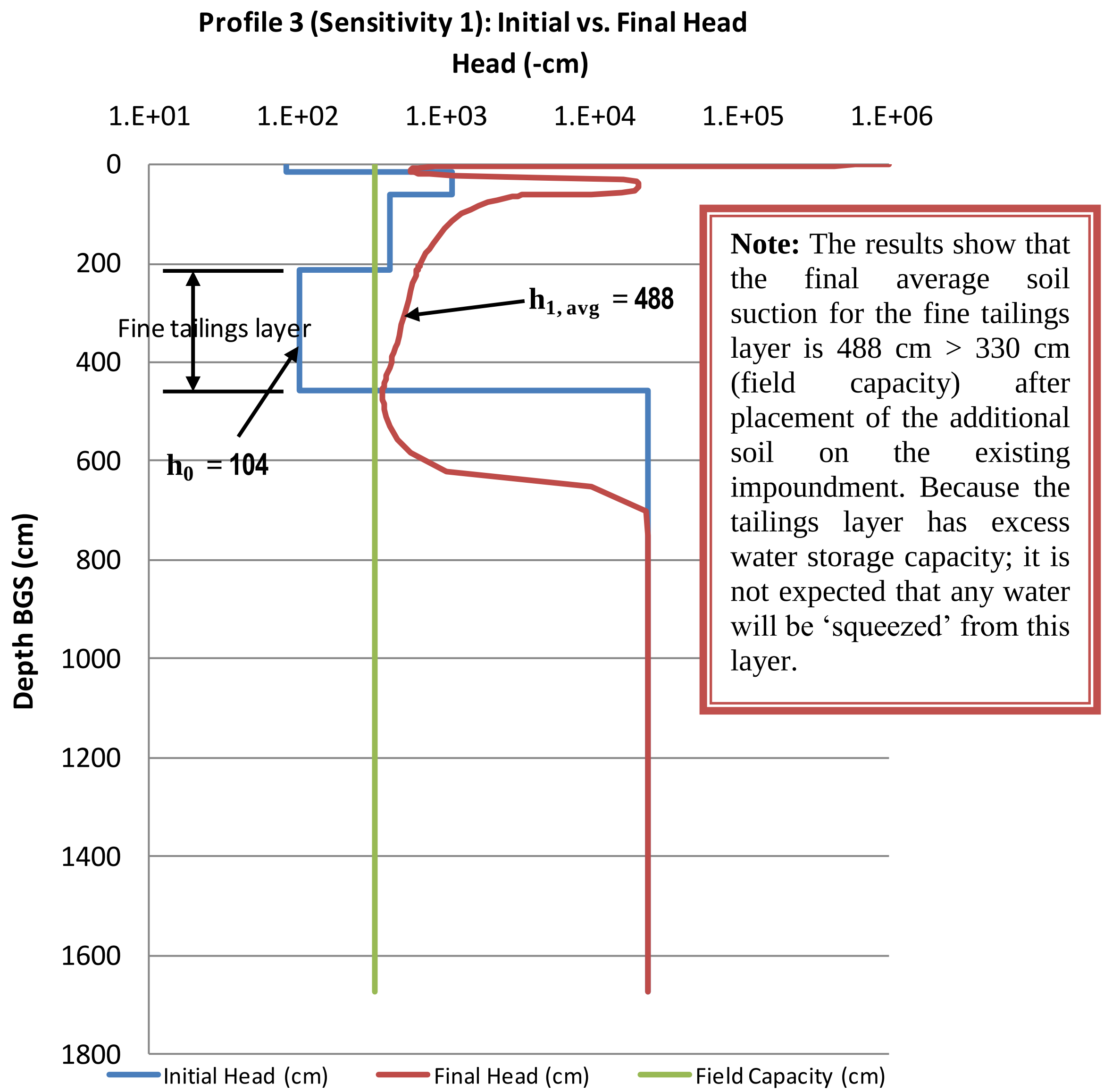


Figure C20. Profile 3 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 1

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.195 \times \left(\frac{7.91ft}{1+1.104}\right) log\left(\frac{1691.5 + 1958.7}{1691.5}\right) = 0.244ft$$

➢ Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.244(1+1.1)}{7.91} = 1.04$$

$$n_2 = \frac{e_2}{1+e_2} = 0.51$$

➢ Develop new Moisture Characteristic Curve (Figure C21) with $\theta_s = n_2$

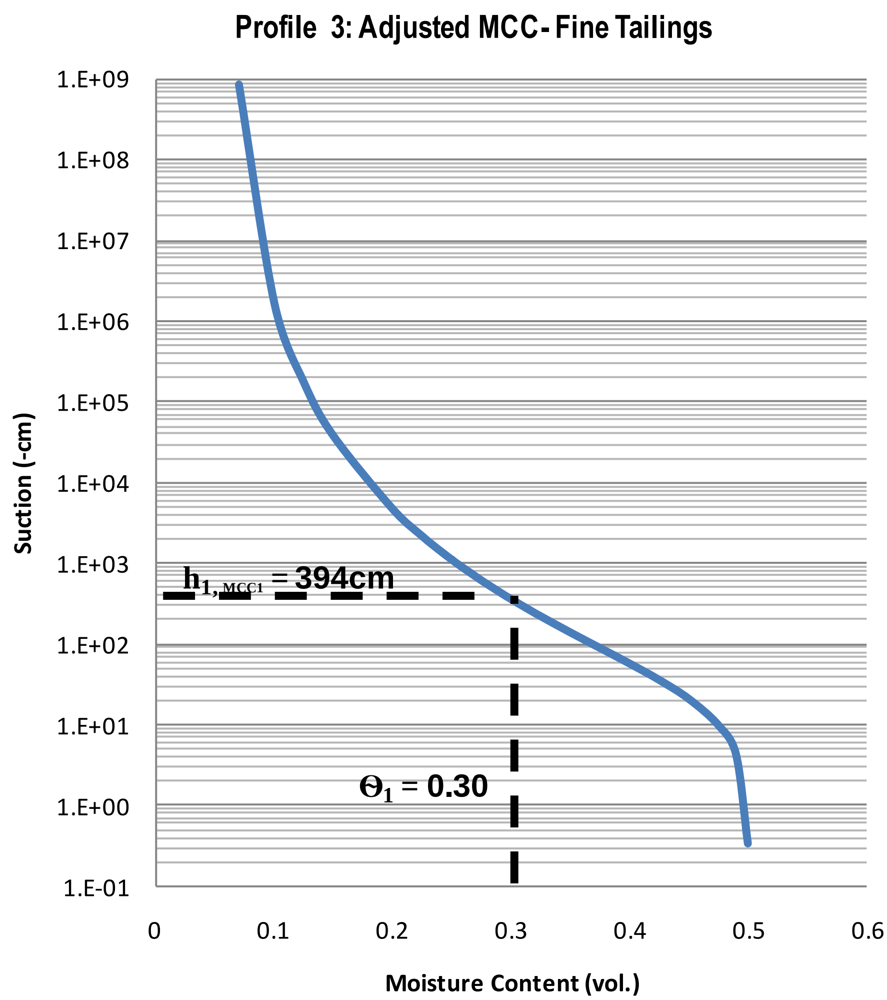


Figure C21. Profile 3, MCC adjusted for Reduced Porosity, Sensitivity Analysis 1

➢ Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 394 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be ‘squeezed’ out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

<u>Profile 3 - Sensitivity Analysis 2</u>: changed the saturated hydraulic conductivity of the existing coarse and fine tailings based on the respective grain size distribution and reported values for each soil classification (Rawls et al 1982)). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 3 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the coarse tailings was lowered to 7.194E-04 cm/sec consistent with a sandy loam (Rawls et al 1982) and the fine tailings was lowered to 3.667E-04 cm/sec consistent with a silt loam (Rawls et al 1982). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 780 cm and 27.8%, respectively. This is shown graphically below in Figure C22 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 3 modeled are also shown in Figure C23. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

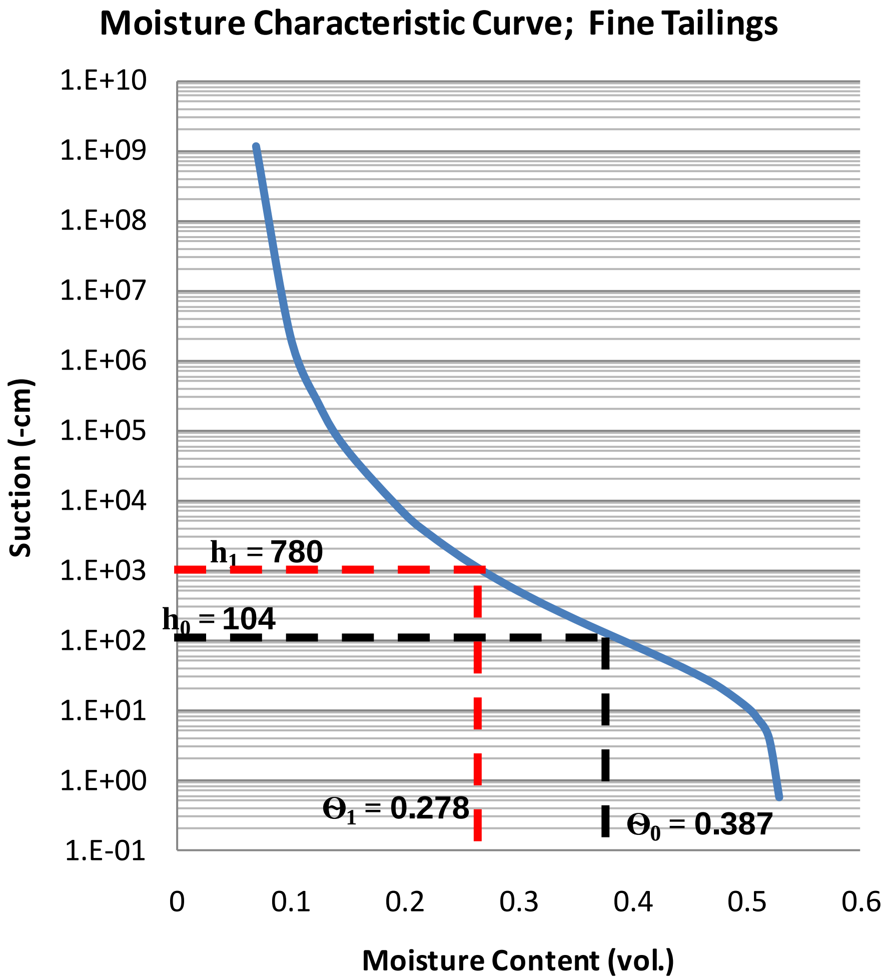


Figure C22. Profile 3, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 2

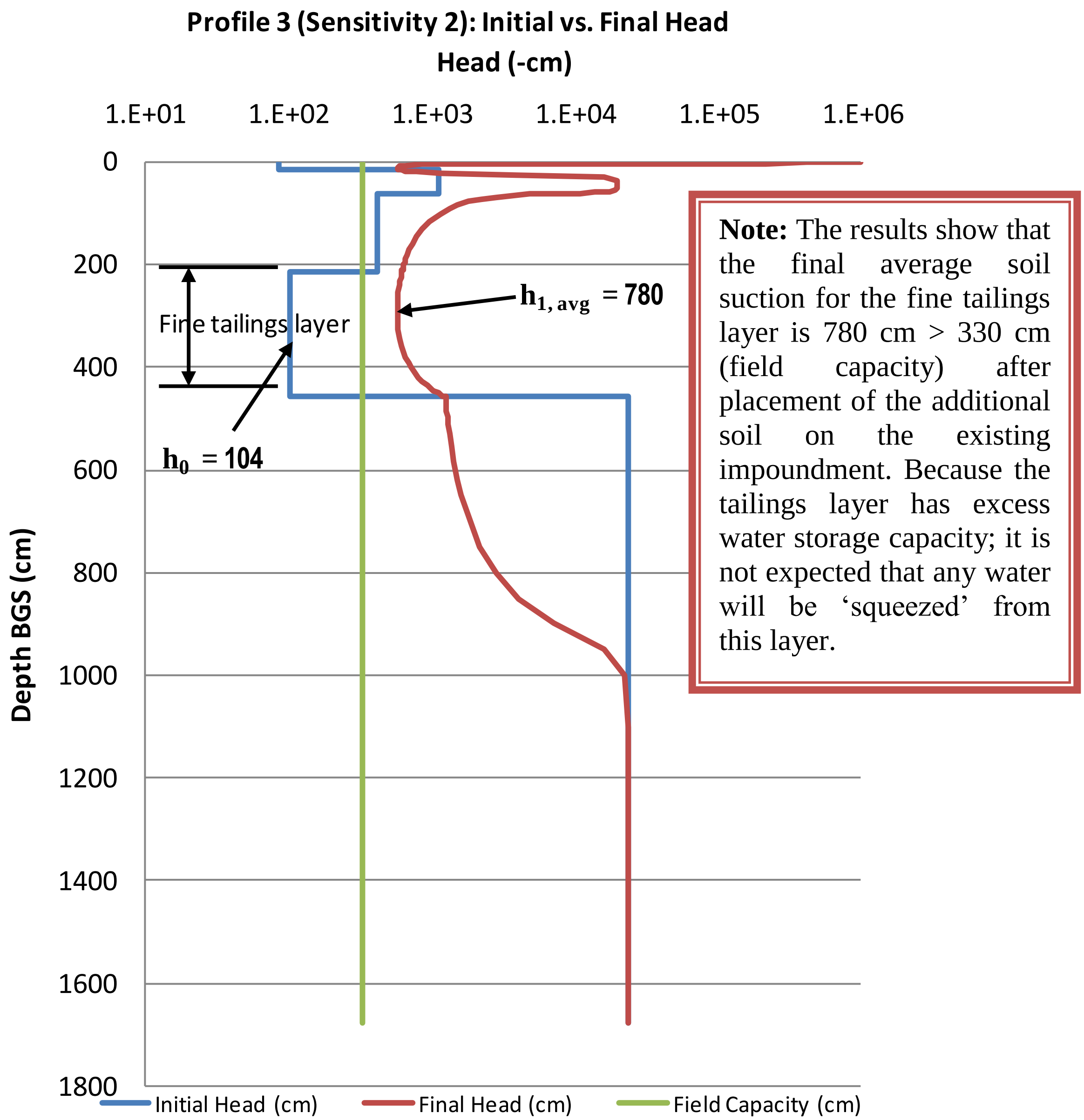


Figure C23. Profile 3 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 2

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 36 acres of the North Cell. The height of this material is therefore 15.5 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1958.7 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.195 \times \left(\frac{7.91ft}{1+1.104}\right) log\left(\frac{1691.5 + 1958.7}{1691.5}\right) = 0.244ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.244(1+1.1)}{7.91} = 1.04$$

$$n_2 = \frac{e_2}{1+e_2} = 0.51$$

- Develop new Moisture Characteristic Curve (Figure C24) with $\theta_s = n_2$

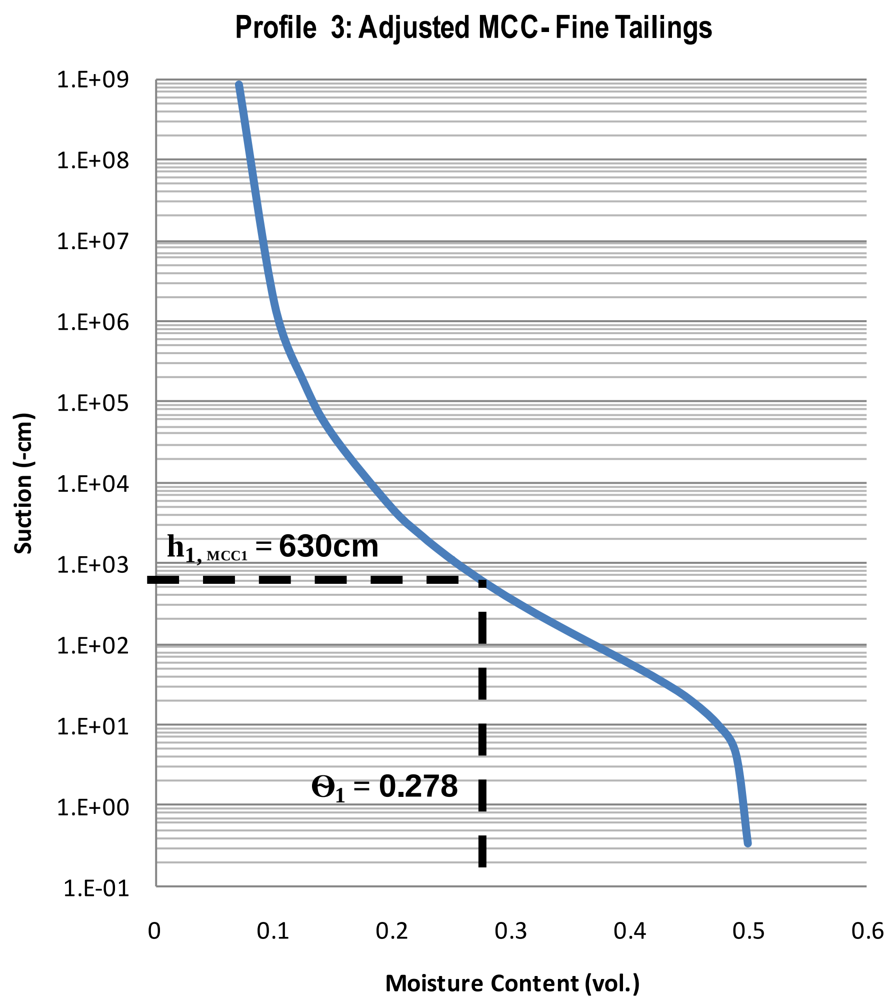
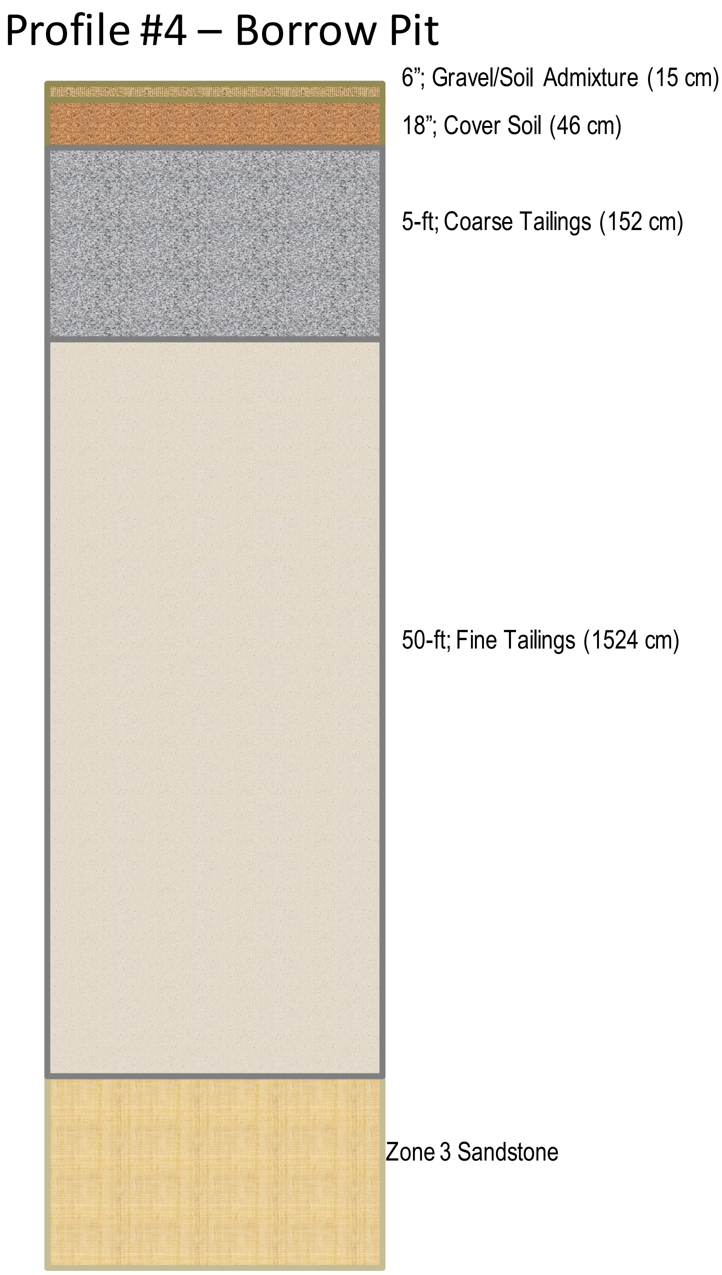


Figure C24. Profile 3, MCC adjusted for Reduced Porosity, Sensitivity Analysis 2

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 630 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile4: Worst Case Borrow Pits Profile with underlying Zone 3 material



- Initial Stress Conditions for Fine Tailings Layer:

$$\sigma_0 = H_0 \times \gamma_w$$

where: $\sigma_0 = fine\ tailings\ layer\ stress$

$H_0 = initial\ fine\ tailings\ layer\ thickness = 55ft$

$\gamma_w = weight\ of\ tailings$
$= 110.1\ pcf\ [Ref: Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$$\sigma_0 = H_0 \times \gamma_w = 55ft \times 110.1\,pcf = 6055.5\,psf$$

$$\Delta\sigma = (H_{ct} \times \gamma_{ct}) + (H_c \times \gamma_c) = 810.7\,psf$$

where: $\Delta\sigma = stress\ due\ to\ material\ above\ fine\ tailings$

$H_{ct} = coarse\ tailings\ layer\ thickness = 5ft$

$H_c = cover\ layer\ thickness = 2ft$

$\gamma_{ct} = weight\ of\ coarse\ tailings$
$= 110.1\,pcf\ [Ref{:}\ Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\gamma_c = weight\ of\ coarse\ tailings$
$= 129.6\,pcf\ [Ref{:}\ North\ Cell\ Final\ Reclamation, Jan\ 1990]$

- Primary Consolidation: The settlement monument nearest the Borrow Pits (SM-7) data was used with the primary settlement being 0.7ft (Ref: Central Cell Interim Stabilization, April 1992).
- Solve for the primary consolidation coefficient utilizing the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) \qquad \text{Equation 3-1}$$

where: S_p = primary settlement = 0.7 ft;

C_c = primary consolidation coefficient;

H = fine tailings layer thickness before settlement = 55ft;

e = void ratio = 1.12766;

σ_0 = initial stress; and

$\Delta\sigma$ = change in stress (additional weight due to spoils).

Therefore, $C_c = 0.229$

- Solve for the secondary consolidation coefficient (C_a) utilizing the following equation (Bowles 1996):

$$C_a = 0.03 \times C_c = 0.00686$$

- Calculate the secondary consolidation from the time of final cover installation to present (21 years later):

$$S_s = C_a \times H \times log\left(\frac{t_2}{t_1}\right) \qquad \text{Equation 3-2}$$

where: S_s = Secondary Settlement;

C_a = secondary consolidation coefficient;

H = fine tailings layer thickness;

t_2 = time from t_1 = 21 years; and

t_1 = time when primary consolidation complete = 100 days.

$$S_s = 0.71\,ft$$

- Determine the revised porosity (n_1) and void ratio (e_1):

$$S = H\left(\frac{e_0 - e_1}{1 + e_0}\right)$$

Solving for e_1 given S_S: $e_1 = e_0 - \frac{S(1+e_0)}{H} = 1.1$

Therefore, $n_1 = \frac{e_1}{1+e_1} = 0.524$

The profile was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B. The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile.

After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 585.7 cm and 29.1%, respectively. This is shown graphically below in Figure C25 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 4 modeled are also shown in Figure C26.

The following equation was utilized to calculate moisture content given the soil suction value:

$\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

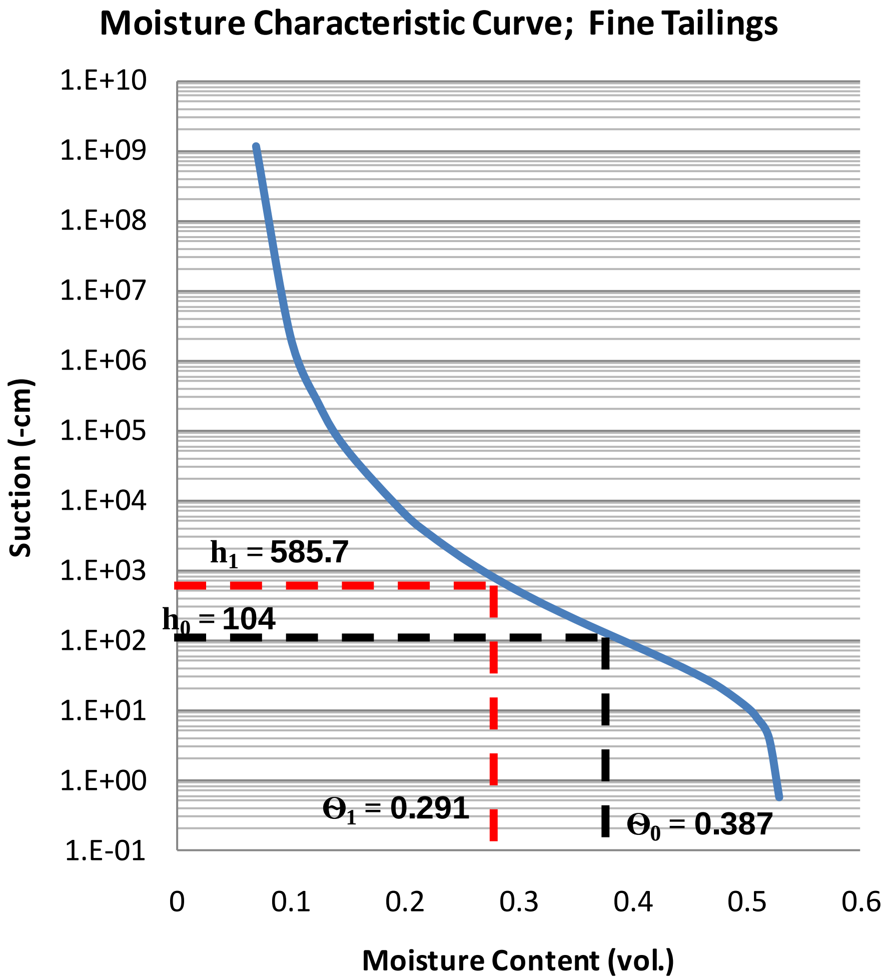


Figure C25. Profile 4, MCC (Fine Tailings) with Initial and Final Moisture/Suction conditions

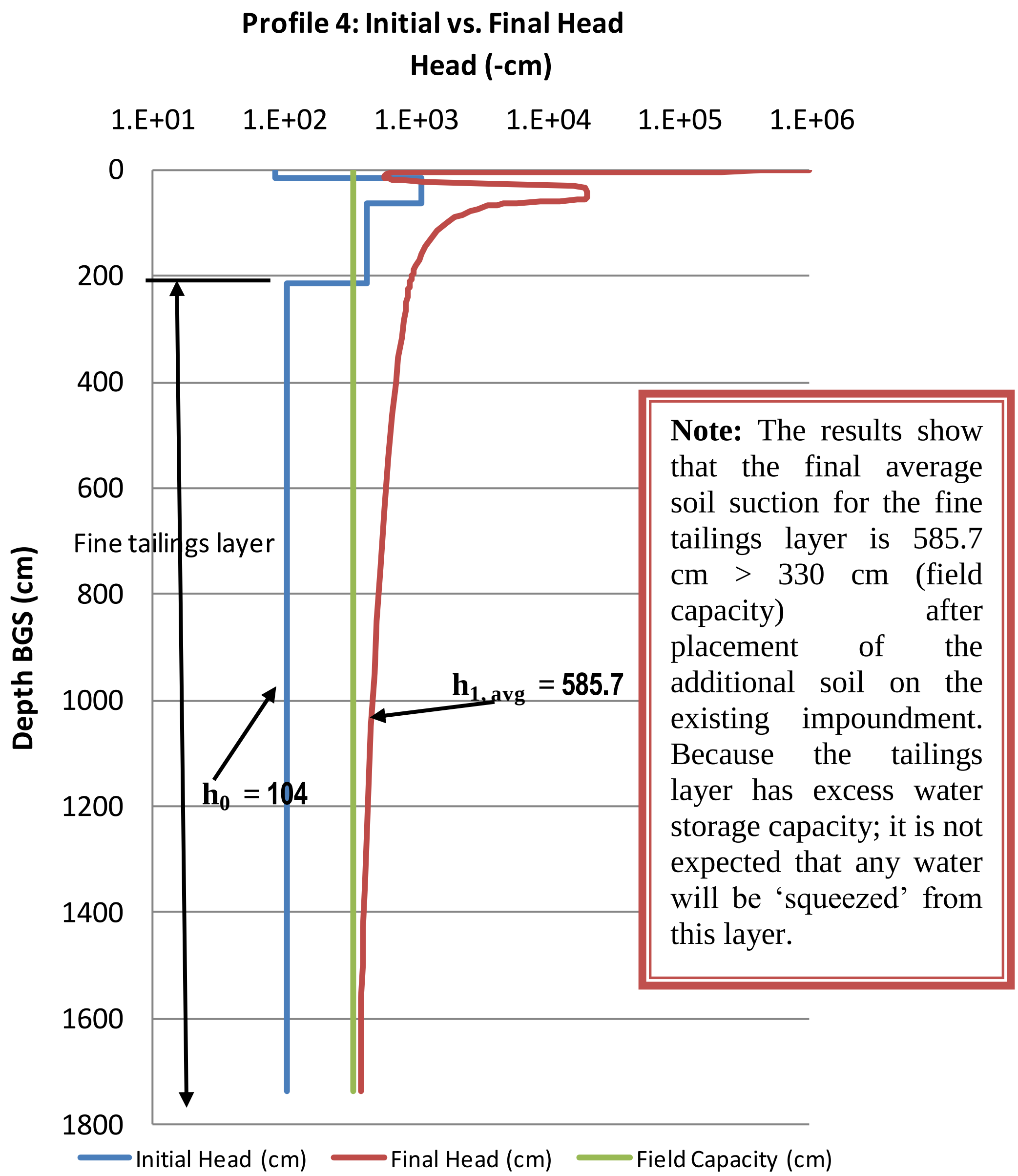


Figure C26. Profile 4 Initial and Final Soil Suction values compared to Field Capacity

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

Assumption: 900,000 CY of mine spoils and waste rock covers the entire 65 acres of the Central Cell. The height of this material is therefore 8.6 ft, assuming uniform coverage for simplicity. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1226.6 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.229 \times \left(\frac{54.3ft}{1+1.1}\right) log\left(\frac{6866 + 1226.6}{6866}\right) = 0.42ft$$

➢ Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.42(1+1.1)}{54.3} = 1.08$$

$$n_2 = \frac{e_2}{1+e_2} = 0.52$$

➢ Develop new Moisture Characteristic Curve (Figure C27) with $\theta_s = n_2$

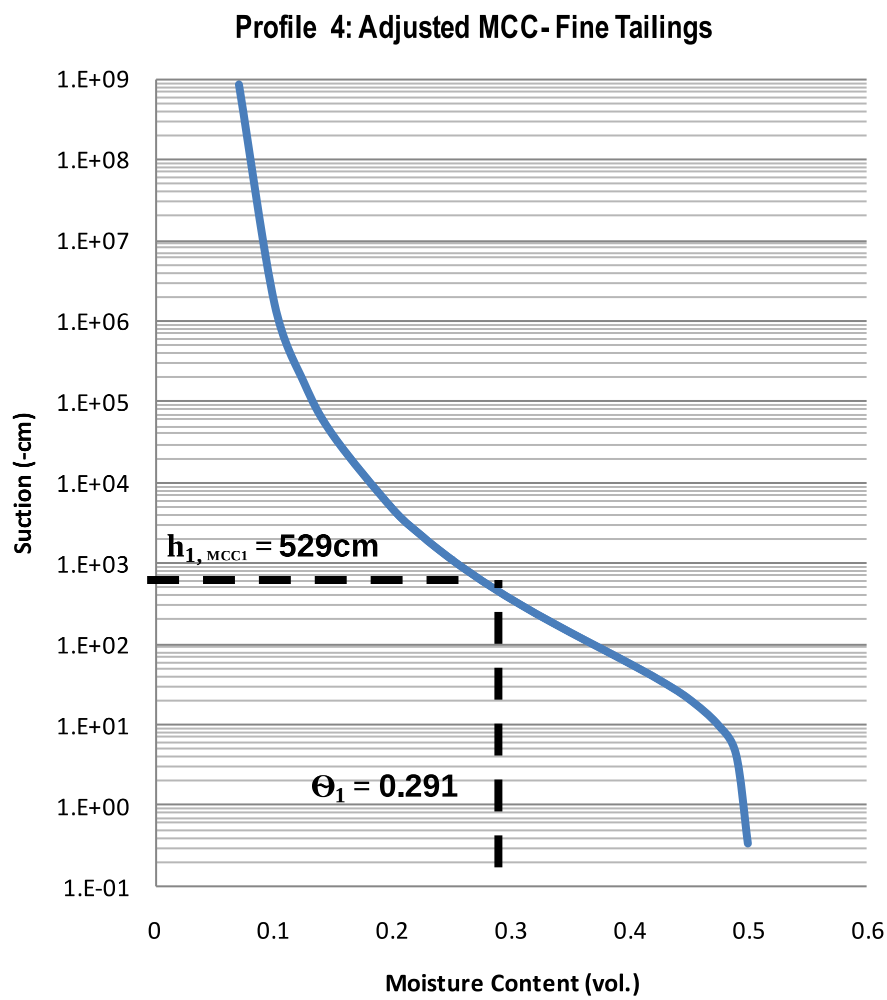


Figure C27. Profile 4, MCC adjusted for Reduced Porosity

➢ Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 529 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be ‘squeezed’ out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile 4 - Sensitivity Analysis 2: changed the saturated hydraulic conductivity of the existing coarse and fine tailings based on the respective grain size distribution and reported values for each soil classification (Rawls et al 1982)). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.

Profile 4 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the coarse tailings was lowered to 7.194E-04 cm/sec consistent with a sandy loam (Rawls et al 1982) and the fine tailings was lowered to 3.667E-04 cm/sec consistent with a silt loam (Rawls et al 1982). The initial suction value of the fine tailings layer was also set at 330 cm. The initial suction value was set equal to the field capacity. This was done to calibrate the model. That is, existing instrumentation located north of the borrow pits indicates there is no moisture migrating from the pits. Furthermore, it is likely the excess free water has drained since its installation because primary consolidation is complete, the wettest practical condition would be the moisture content associated with field capacity.

After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 413 cm and 30.9%, respectively. This is shown graphically below in Figure C28 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 4 modeled are also shown in Figure C29. The following equation was utilized to calculate moisture content given the soil suction value:

$\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

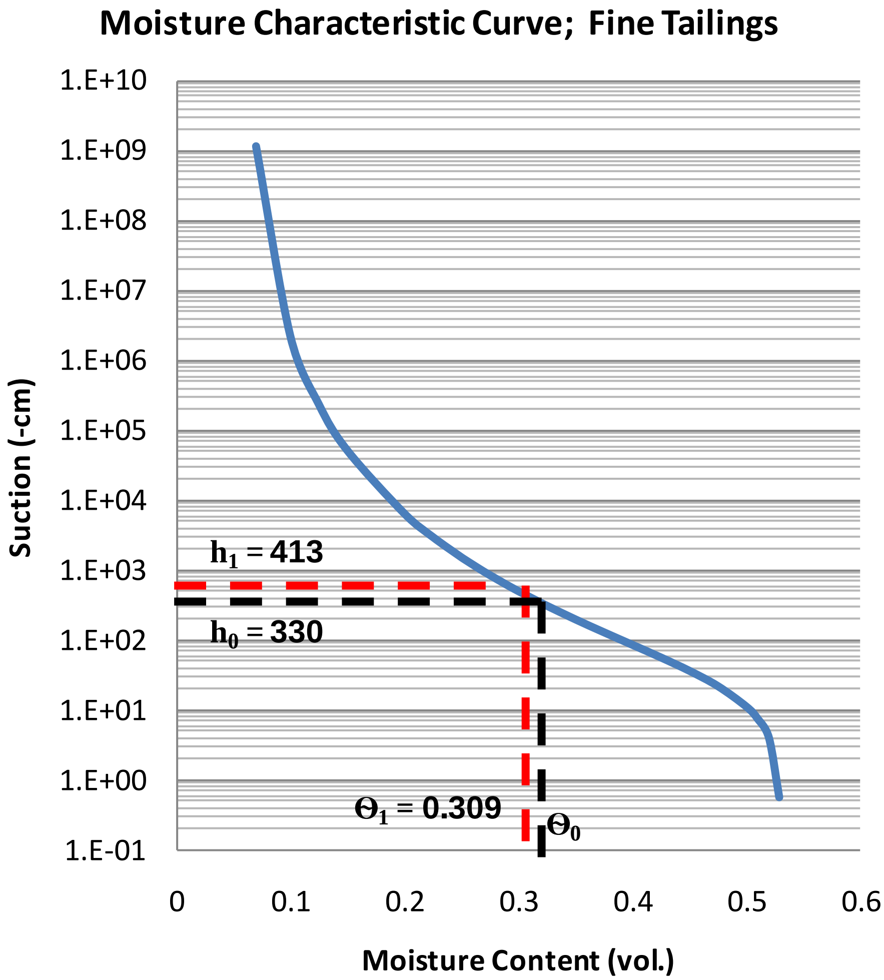


Figure C28. Profile 4, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 2

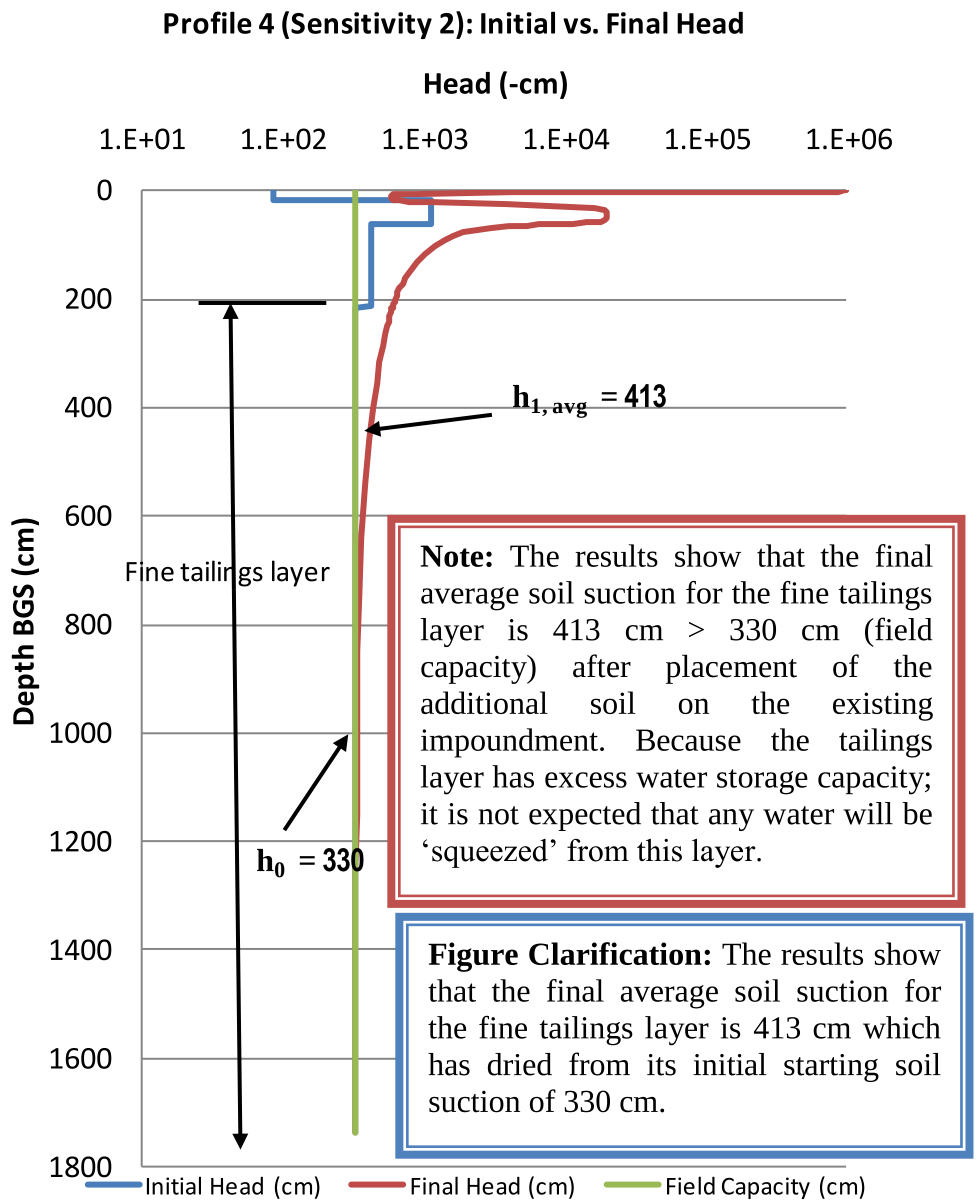


Figure C29. Profile 4, Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 2

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

Assumption: 900,000 CY of mine spoils and waste rock covers the entire 65 acres of the Central Cell. The height of this material is therefore 8.6 ft, assuming uniform coverage for simplicity. These assumptions are conservative as the estimated volume includes a 20 percent contingency and the placement area may be greater than 65 acres. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1226.6 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.229 \times \left(\frac{54.3ft}{1+1.1}\right) log\left(\frac{6866+1226.6}{6866}\right) = 0.42ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.1 - \frac{0.42(1+1.1)}{54.3} = 1.08$$

$$n_2 = \frac{e_2}{1+e_2} = 0.52$$

- Develop new Moisture Characteristic Curve (Figure C30) with $\theta_s = n_2$

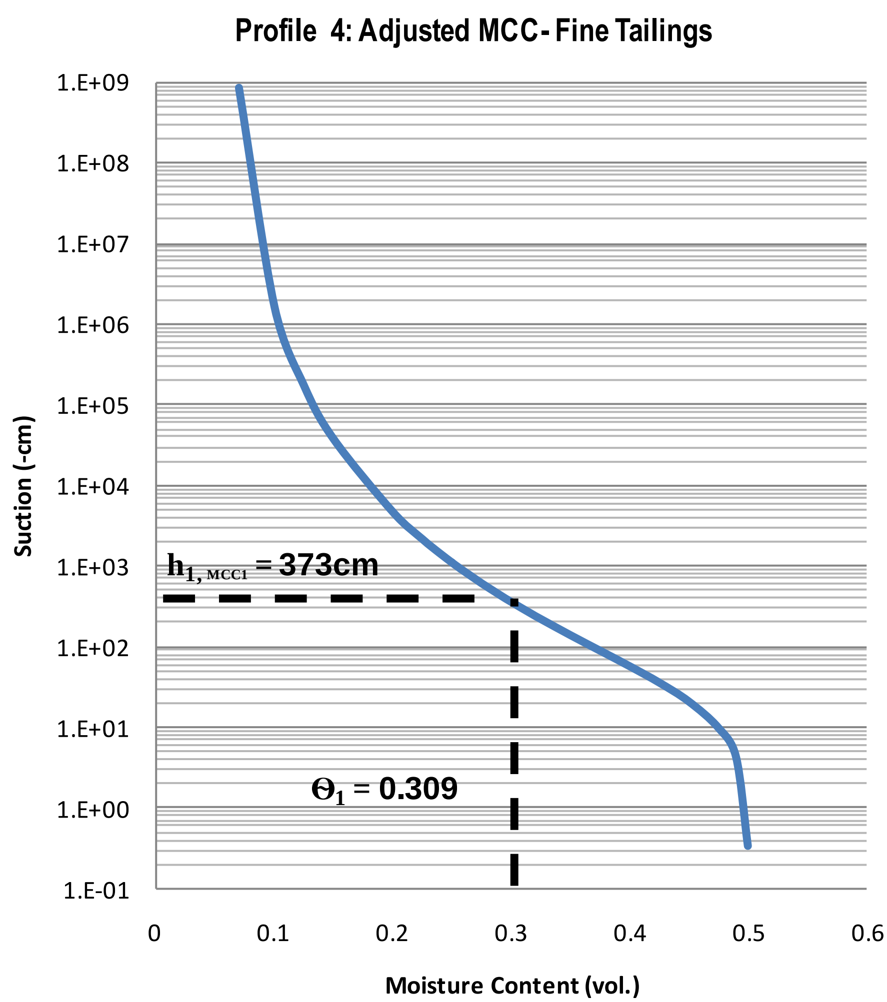
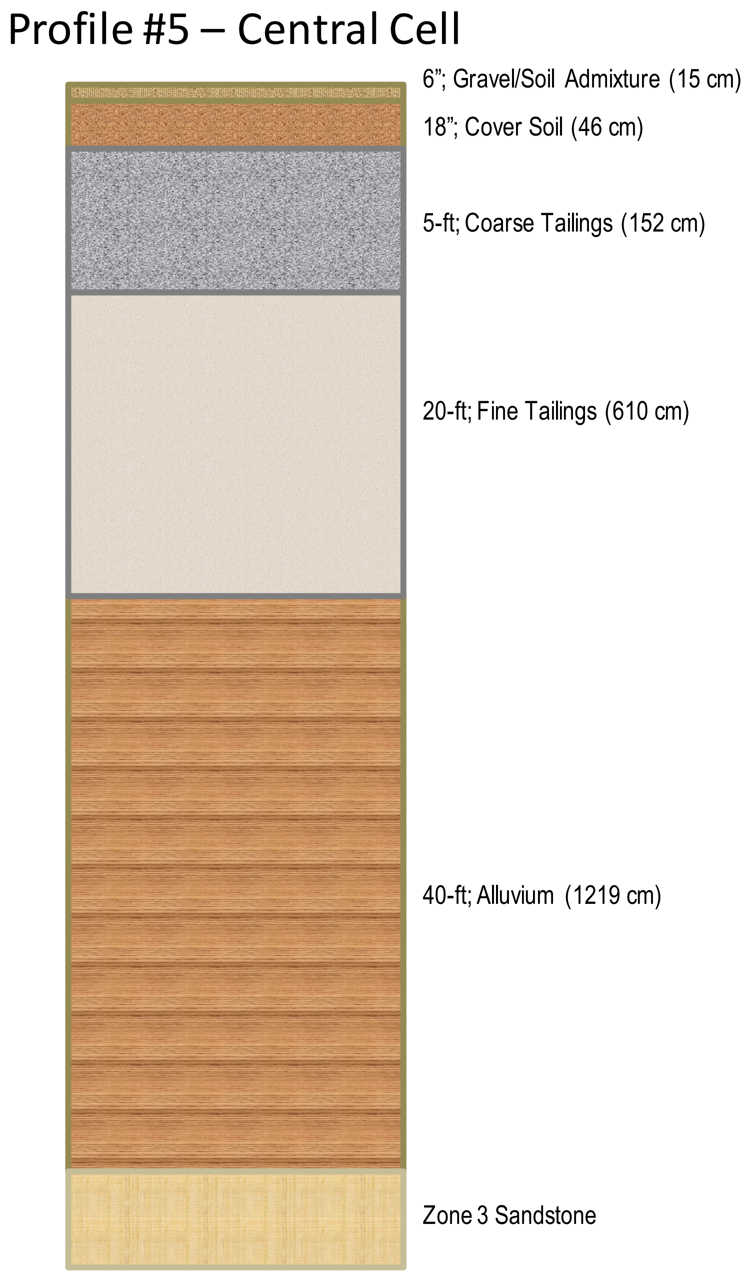


Figure C30. Profile 4, MCC adjusted for Reduced Porosity, Sensitivity Analysis 2

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 373 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be ‘squeezed’ out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile 5: Typical Case Central Cell Profile w/ underlying Alluvium



- Initial Stress Conditions for Fine Tailings Layer:

$$\sigma_0 = H_0 \times \gamma_w$$

where: $\sigma_0 = fine\ tailings\ layer\ stress$

$H_0 = initial\ fine\ tailings\ layer\ thickness = 20ft$

$\gamma_w = weight\ of\ tailings$
$= 110.1\ pcf\ [Ref: Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$$\sigma_0 = H_0 \times \gamma_w = 20ft \times 110.1\ pcf = 2202\ psf$$

$\Delta\sigma = (H_{ct} \times \gamma_{ct}) + (H_c \times \gamma_c) = 810.7\ psf$

where: $\Delta\sigma = stress\ due\ to\ material\ above\ fine\ tailings$

$H_{ct} = coarse\ tailings\ layer\ thickness = 5ft$

$H_c = cover\ layer\ thickness = 2ft$

$\gamma_{ct} = weight\ of\ coarse\ tailings$
$= 110.1\ pcf\ [Ref{:}\ Tailing\ Reclamaion\ Plan, Vol\ II, Aug\ 1991]$

$\gamma_c = weight\ of\ coarse\ tailings$
$= 129.6\ pcf\ [Ref{:}\ North\ Cell\ Final\ Reclamation, Jan\ 1990]$

- Primary Consolidation: The settlement monument nearest the Borrow Pits (SM-7) data was used with the primary settlement being 0.7ft (Ref: Central Cell Interim Stabilization, April 1992).
- Solve for the primary consolidation coefficient utilizing the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma+\Delta\sigma}{\sigma}\right) \qquad \text{Equation 3-1}$$

where: S_p = primary settlement = 0.7 ft;

C_c = primary consolidation coefficient;

H = fine tailings layer thickness before settlement = 20ft;

e = void ratio = 1.12766;

σ_0 = initial stress; and

$\Delta\sigma$ = change in stress (additional weight due to spoils).

Therefore, $C_c = 0.243$

- Solve for the secondary consolidation coefficient (C_a) utilizing the following equation (Bowles 1996):

$C_a = 0.03 \times C_c = 0.0073$

- Calculate the secondary consolidation from the time of final cover installation to present (21 years later):

$$S_s = C_a \times H \times log\left(\frac{t_2}{t_1}\right) \qquad \text{Equation 3-2}$$

where: S_s = Secondary Settlement;

C_a = secondary consolidation coefficient;

H = fine tailings layer thickness;

t_2 = time from t_1 = 21 years; and

t_1 = time when primary consolidation complete = 100 days.

$S_s = 0.275\ ft$

- Determine the revised porosity (n_1) and void ratio (e_1):

$$S = H\left(\frac{e_0 - e_1}{1 + e_0}\right)$$

Solving for e_1 given S_S: $e_1 = e_0 - \frac{S(1+e_0)}{H} = 1.098$

Therefore, $n_1 = \frac{e_1}{1+e_1} = 0.523$

The profile was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B. The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 757.8 cm and 27.9%, respectively. This is shown graphically below in Figure C31 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 5 modeled are also shown in Figure C32.

The following equation was utilized to calculate moisture content given the soil suction value:

$\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

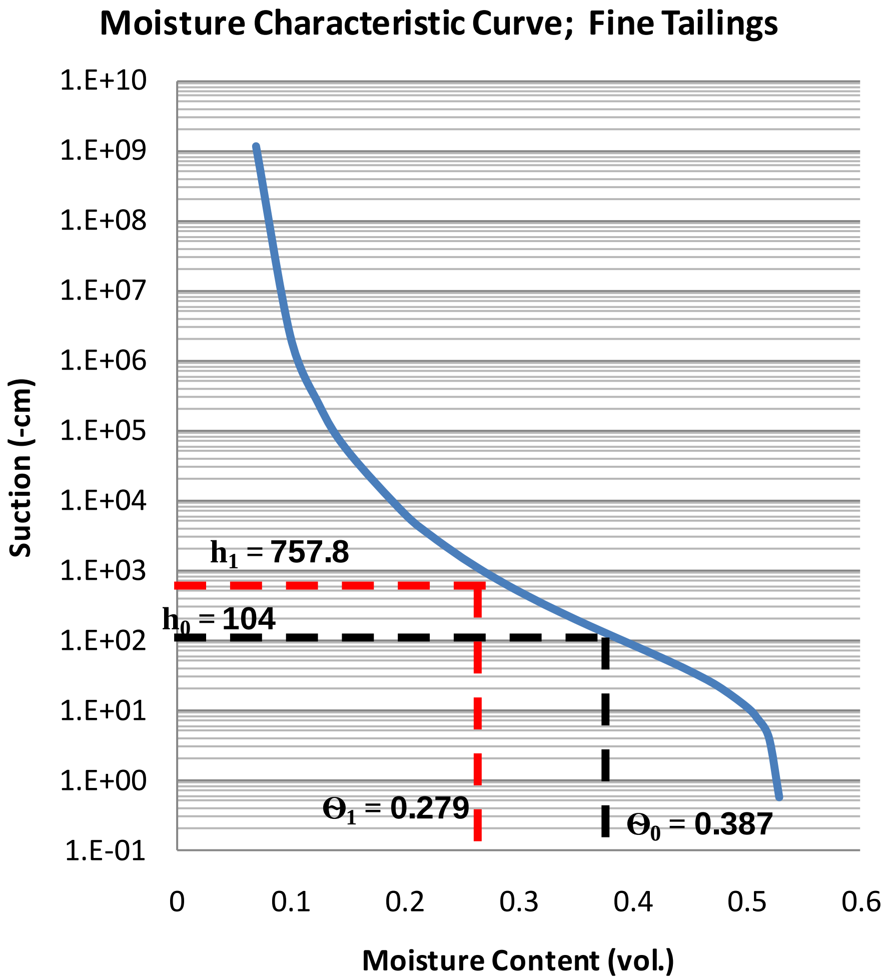


Figure C31. Profile 5, MCC (Fine Tailings) with Initial and Final Moisture/Suction conditions

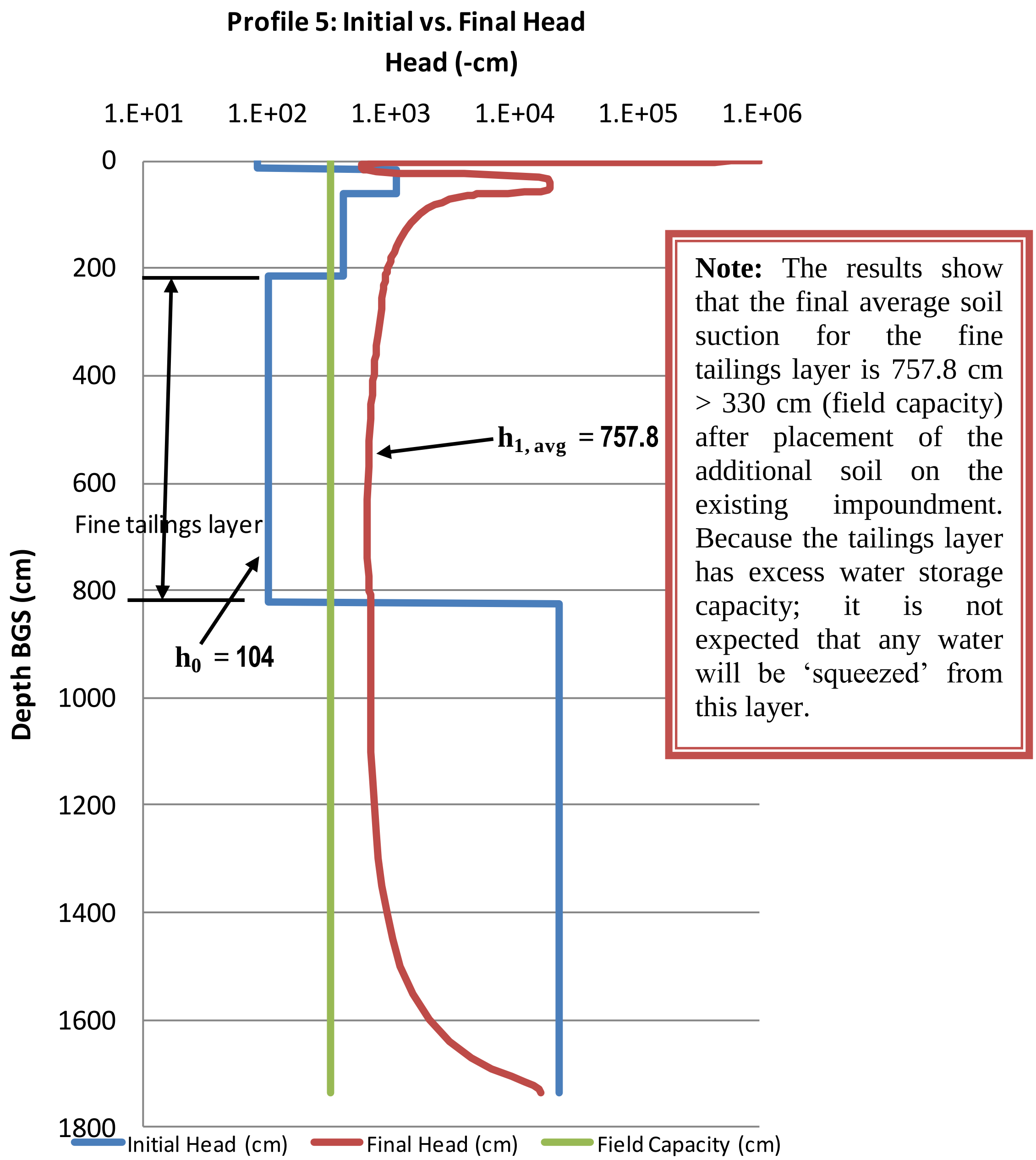


Figure C32. Profile 5 Initial and Final Soil Suction values compared to Field Capacity

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 65 acres of the Central Cell. The height of this material is therefore 8.6 ft, assuming uniform coverage for simplicity. These assumptions are conservative as the estimated volume includes a 20 percent contingency and the placement area may be greater than 65 acres. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste

rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1226.6 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.243 \times \left(\frac{19.725ft}{1+1.098}\right) log\left(\frac{3012.7+1226.6}{3012.7}\right) = 0.34ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.098 - \frac{0.244(1+1.098)}{19.725} = 1.06$$

$$n_2 = \frac{e_2}{1+e_2} = 0.515$$

- Develop new Moisture Characteristic Curve (Figure C18) with $\theta_s = n_2$

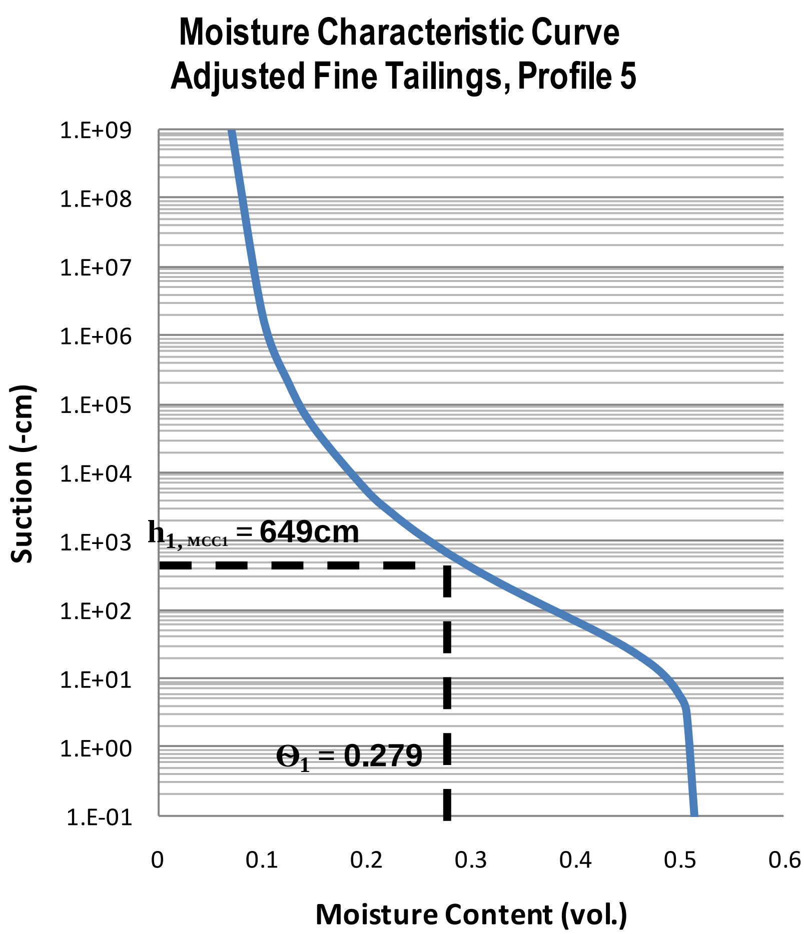


Figure C33. Profile 5, MCC adjusted for Reduced Porosity

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 649 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

Profile 5 - Sensitivity Analysis 1: changed the saturated hydraulic conductivity of the underlying alluvium based on the worst case from pump tests reported in Canonie Environmental (March 1991). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 5 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the underlying alluvium was lowered to 8.1E-05 cm/sec (Canonie Environmental March 1991). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 509.6 cm and 29.8%, respectively. This is shown graphically below in Figure C34 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 5 modeled are also shown in Figure C35. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

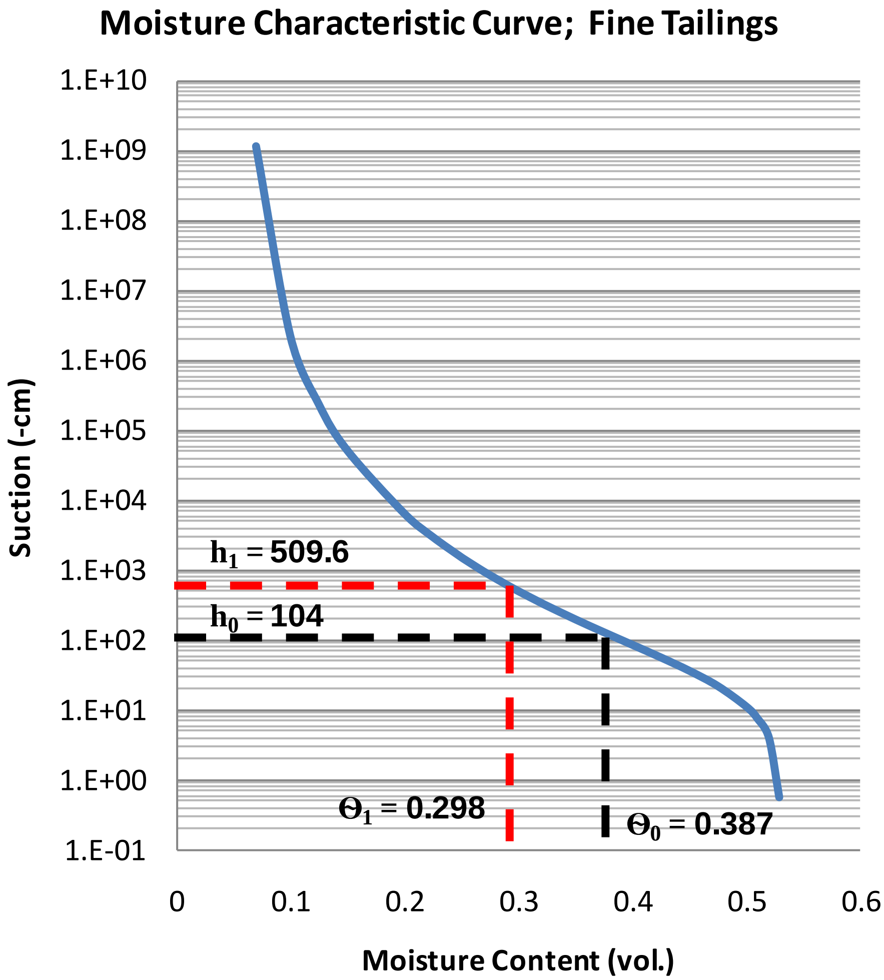


Figure C34. Profile 5, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 1

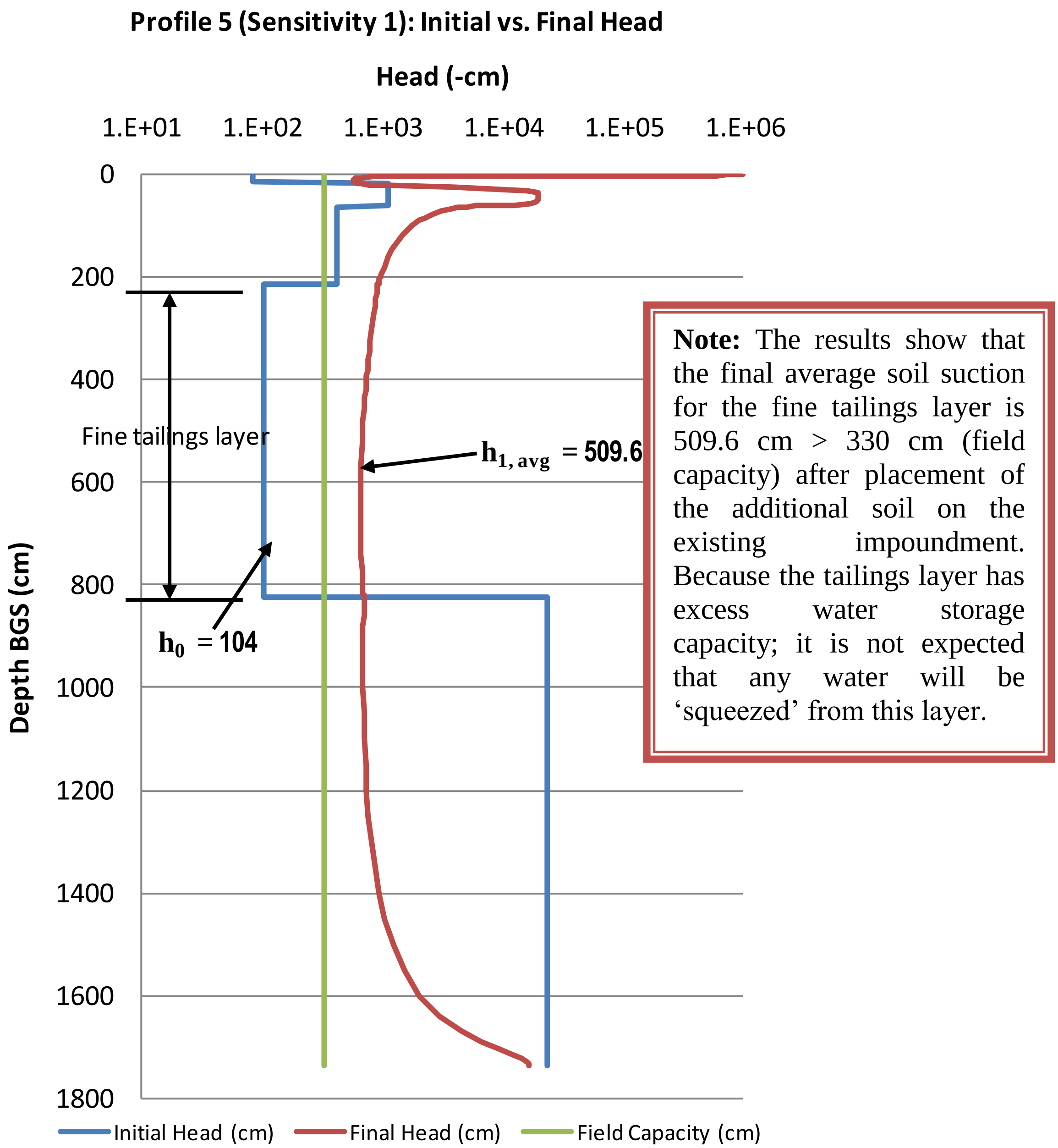


Figure C35. Profile 5 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 1

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 65 acres of the Central Cell. The height of this material is therefore 8.6 ft, assuming uniform coverage for simplicity. These assumptions are conservative as the estimated volume includes a 20 percent contingency and the placement area may be greater than 65 acres. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste

rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1226.6 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.243 \times \left(\frac{19.725ft}{1+1.098}\right) log\left(\frac{3012.7 + 1226.6}{3012.7}\right) = 0.34ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.098 - \frac{0.244(1+1.098)}{19.725} = 1.06$$

$$n_2 = \frac{e_2}{1+e_2} = 0.515$$

- Develop new Moisture Characteristic Curve (Figure C36) with $\theta_s = n_2$

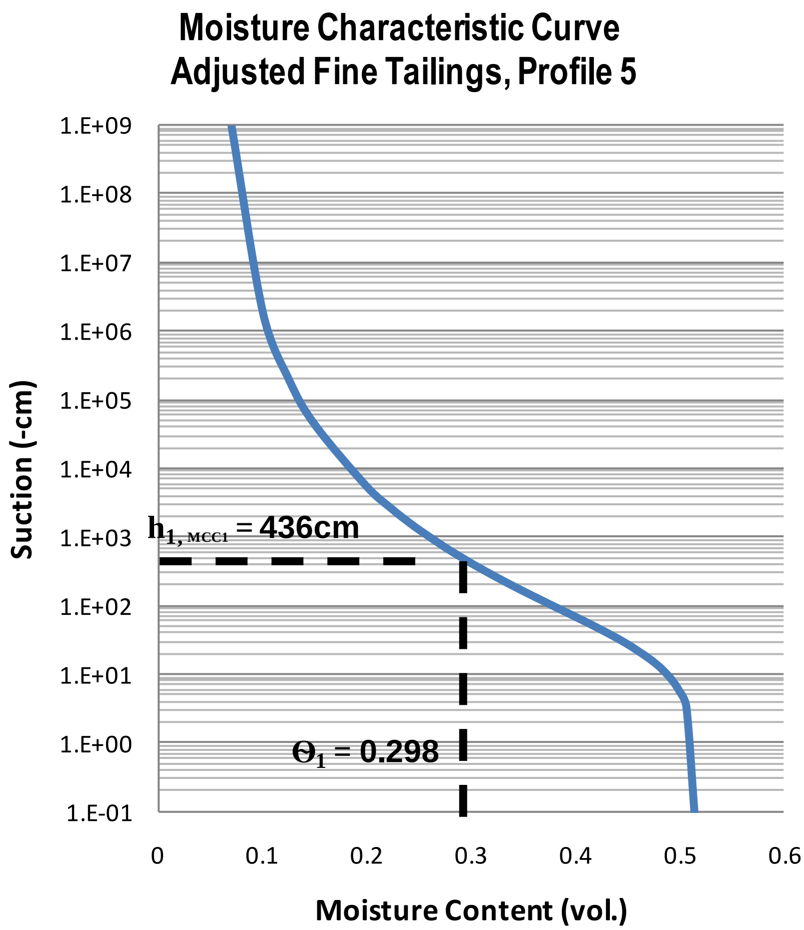


Figure C36. Profile 5, MCC adjusted for Reduced Porosity, Sensitivity Analysis 1

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 436 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.

<u>Profile 5 - Sensitivity Analysis 2</u>: changed the saturated hydraulic conductivity of the existing coarse and fine tailings based on the respective grain size distribution and reported values for each soil classification (Rawls et al 1982)). All other variables were kept consistent with the original analysis.

- All steps and subsequent results prior to the modeling performed in the original analysis are the same in the sensitivity analysis.
- Profile 5 was modeled using soil parameters summarized in Appendix A and other parameters and boundary conditions summarized in Appendix B, with the exception that the saturated hydraulic conductivity of the coarse tailings was lowered to 7.194E-04 cm/sec consistent with a sandy loam (Rawls et al 1982) and the fine tailings was lowered to 3.667E-04 cm/sec consistent with a silt loam (Rawls et al 1982). The initial suction value and moisture content of the fine tailings layer was 104 cm and 38.7%, respectively. The initial suction value is less than the field capacity of 330 cm and thus very wet. This is a conservative assumption given primary consolidation was complete and excess free water was likely removed from the profile. After the profile was modeled for a period of 21 years, the final soil suction value and moisture content of the fine tailings layer were 462 cm and 30.3%, respectively. This is shown graphically below in Figure C37 on the original moisture characteristic curve developed for the fine tailings layer. The initial soil suction values and final soil suction values for the entire Profile 5 modeled are also shown in Figure C38. The following equation was utilized to calculate moisture content given the soil suction value:

  $\theta_1 = [\theta_s - \theta_r][1 + (\alpha h_1)^n]^{-m} + \theta_r$ (van Genuchten et al 1991)

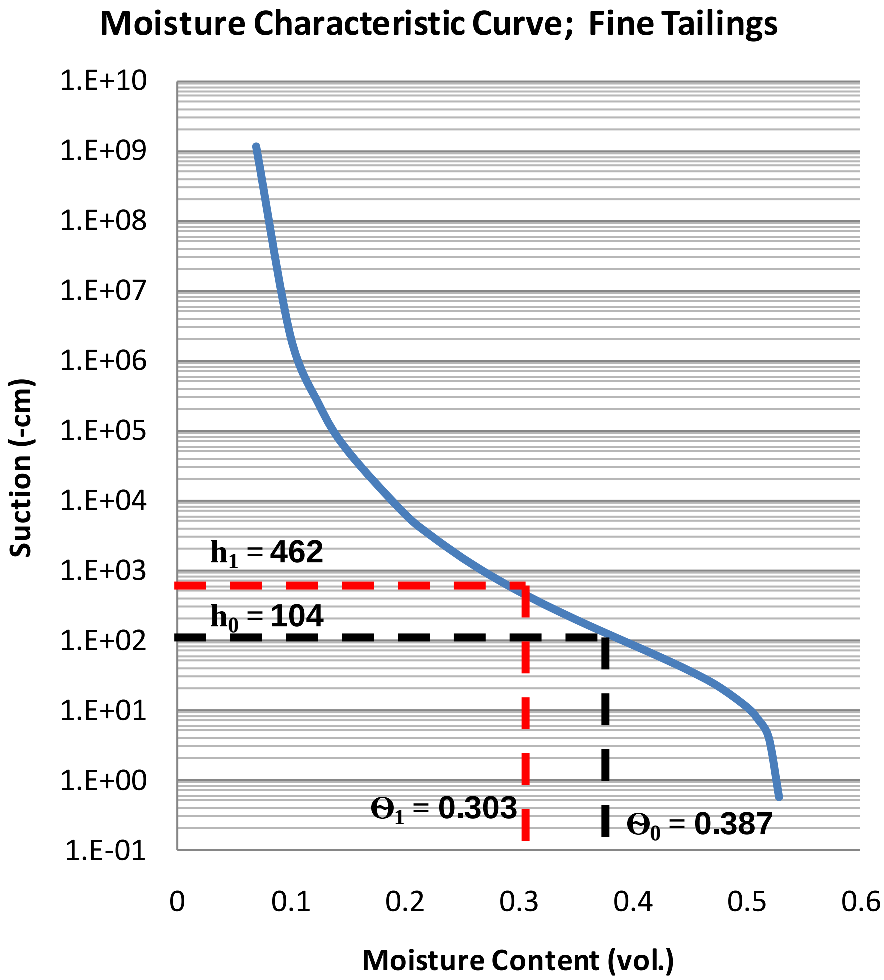


Figure C37. Profile 5, Initial and Final Moisture/Suction conditions; Sensitivity Analysis 2

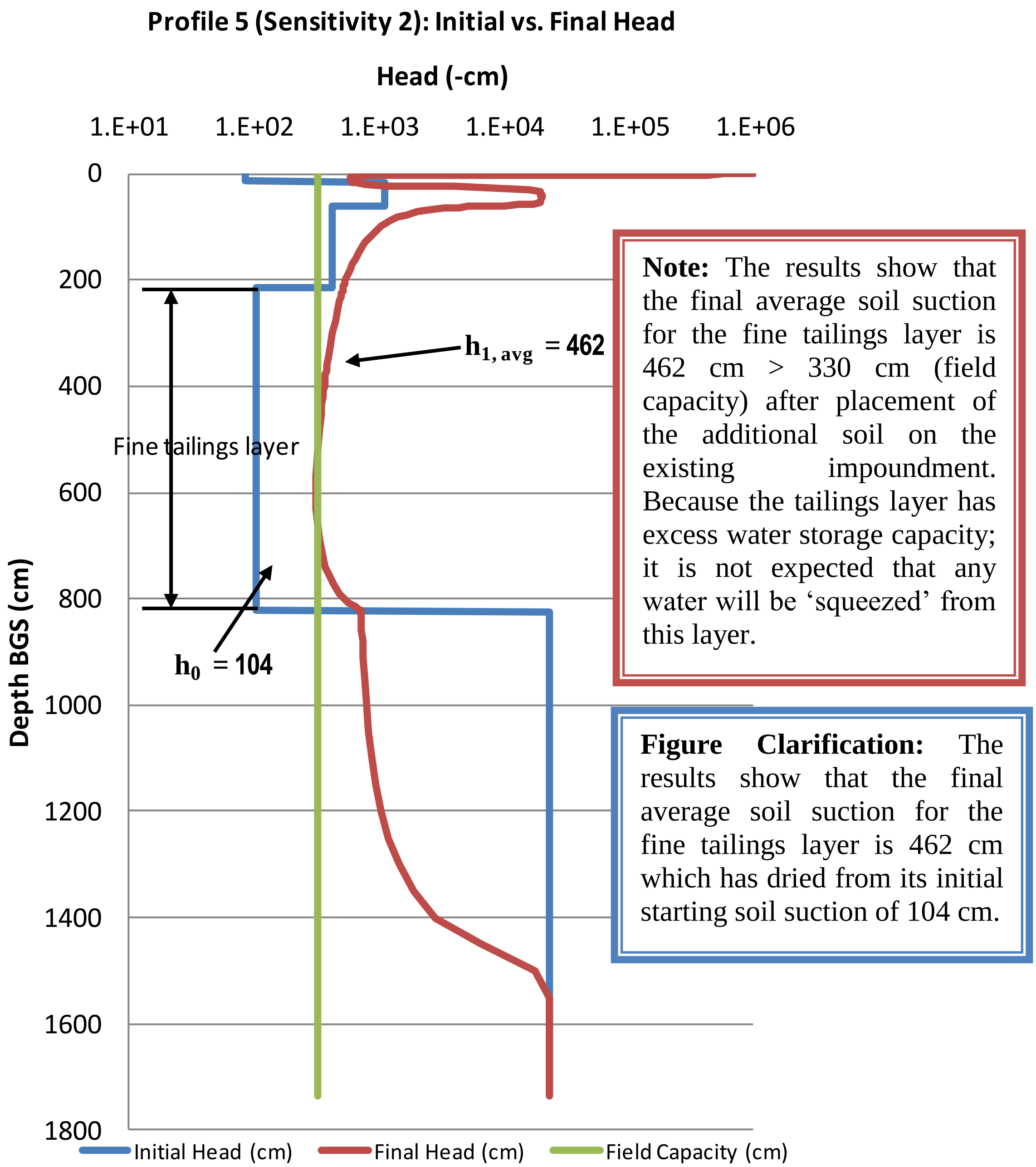


Figure C38. Profile 5 Initial and Final Soil Suction values compared to Field Capacity; Sensitivity Analysis 2

- Determine the primary consolidation to the fine tailings given the placement of mine spoils and waste rock directly on the tailings impoundment.

  Assumption: 900,000 CY of mine spoils and waste rock covers the entire 65 acres of the Central Cell. The height of this material is therefore 8.6 ft, assuming uniform coverage for simplicity. These assumptions are conservative as the estimated volume includes a 20 percent contingency and the placement area may be greater than 65 acres. The density of material is 105.9 pcf. Additionally it is assumed a final cover 3-ft thick will be placed over the mine spoils and waste

rock. The density of material is 105.9 pcf. Based on the assumed height and density of material the pressure will be 1226.6 psf.

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma + \Delta\sigma}{\sigma}\right) = 0.243 \times \left(\frac{19.725ft}{1+1.098}\right) log\left(\frac{3012.7 + 1226.6}{3012.7}\right) = 0.34ft$$

- Determine the revised porosity (n_2) and void ratio (e_2) as a result of the additional primary consolidation.

$$e_2 = e_1 - \frac{S(1+e_1)}{H} = 1.098 - \frac{0.244(1+1.098)}{19.725} = 1.06$$

$$n_2 = \frac{e_2}{1+e_2} = 0.515$$

- Develop new Moisture Characteristic Curve (Figure C39) with $\theta_s = n_2$

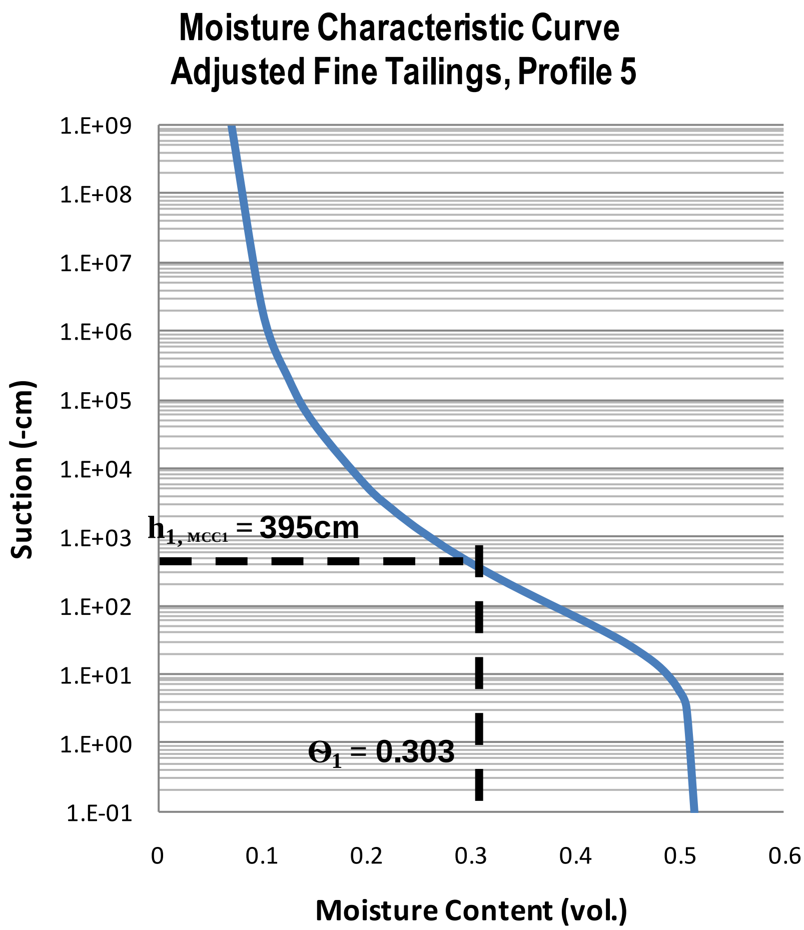


Figure C39. Profile 5, MCC adjusted for Reduced Porosity, Sensitivity Analysis 2

- Conclusion. The final soil suction value ($h_{1,\ MCC1}$) is 395 cm > 330 cm (field capacity); therefore the fine soil layer is drier than field capacity and thus any moisture will be held within its storage capacity and not be 'squeezed' out due to the surcharge pressure from the addition of mine spoils and waste rock on the impoundment.