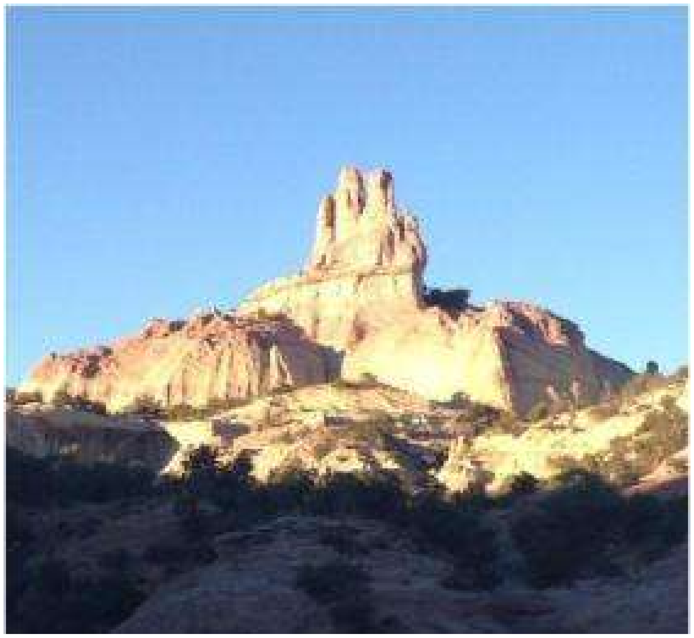
95% REVISED DRAFT

CONSOLIDATION AND GROUNDWATER EVALUATION REPORT



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Northeast Church Rock Site Closure

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EXECUTIVE SUMMARY

The Remedial Action (RA) referenced in the Administrative Settlement Agreement and Order on Consent (AOC) for the United Nuclear Corporation Superfund Site and Northeast Church Rock Mine Removal Site (AOC; USEPA, 2015) as described in the 2011 Action Memorandum (USEPA, 2011) and 2013 Record of Decision (ROD) (USEPA, 2013) calls for the excavation of approximately 1,000,000 cubic yards (cy) of mine waste from the Mine Site and placement at the Mill Site. Mine waste will be disposed of in a repository designed within the footprint of the existing tailings impoundment at the Mill Site. An Evapotranspiration (ET) cover composed of compacted soil overlain by a rock/soil admixture will then be placed over the mine waste (Dwyer 2017).

Placement of the mine spoils and subsequent ET Cover will place added weight and thus stress on the existing tailings material originally placed within the existing impoundment. This report presents an overview of the potential effect of this added weight on these tailings and subsequently on the underlying groundwater. That is, the report summarizes findings comparing the impact on groundwater before mine spoil placement and ET Cover versus after materials placement on the existing impoundment.

The results of the evaluation showed that there is a small amount of consolidation and thus reduction in porosity in the tailings due to the added weight from placement of the mine spoils and ET Cover on the existing impoundment. However, there is no drainage impact into the underlying groundwater. That is, there is no increase in flux into the underlying groundwater from the tailings impoundment.

Findings from the analyses show that the new ET Cover prevents flux while the existing cover potentially allows small amounts of percolation. Consequently, the addition of the mine spoils and new ET Cover should help reduce potential future groundwater impacts from the impoundment.

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ACRONYMS AND ABBREVIATIONS

AOC	Administrative Settlement Agreement and Order on Consent
ASTM	American Society for Testing and Materials
BGS	below ground surface
cm	centimeter
cy	cubic yards
DWYER	Dwyer Engineering, LLC
EP	evaporation
ET	evapotranspiration
LAI	leaf area index
MDD	maximum dry density
Mill Site	Church Rock Mill Site
Mine Site	Northeast Church Rock Mine Site
MWH	Montgomery Watson Harza
NECR	Northeast Church Rock
PET	potential evapotranspiration
PODR	Point of Diminishing Returns
RA	Removal Action
ROD	Record of Decision
RLD	root length density
SWCC	soil water characteristic curve
Tp	transpiration
UNC	United Nuclear Corporation
USEPA	United States Environmental Protection Agency

1.0 PURPOSE

United Nuclear Corporation (UNC) is evaluating the possibility of placing soils removed during the Mine Site Removal Action (RA) on the existing mill site tailings impoundments as per an Administrative Settlement Agreement Order on Consent for Design and Cost Recovery (AOC, USEPA, 2015). The purpose of this consolidation and modeling analysis on the UNC NECR mine tailings was to evaluate any potential impact on groundwater due to deposition of mine spoils and a new ET Cover on the existing impoundment. The weight from placement of these materials on the existing impoundment will add stress and some consolidation to the existing near saturated tailings. The designed ET Cover has adequate performance for 1,000-years to include limiting meteoric flux into the underlying mine waste, minimize erosion, provide a rooting medium for native vegetation, and attenuate emanation of radon-222 from the mine waste (Dwyer 2017).

1.1 Site Background

The existing ground surface and tailings thickness is shown on Figure 1. Figure 1 also shows the geometry of the proposed mine spoils placement and the boring locations for a geotechnical field investigation performed at the site (MWH 2014). This analysis evaluated the worst case areas; if these areas pose no significant impact to groundwater, it can be inferred that the rest of the repository poses no risk to groundwater.

1.2 Methods

The analysis evaluated the water balance and moisture status of the four profiles described in Section 2. Existing conditions ('before' condition) were compared to the same profiles with the proposed mine spoils and ET Cover placed on the impoundment (the 'after' condition) whereby the tailings experienced consolidation from the added weight of the placed materials. The consolidation and modeling analysis was performed to evaluate potential impact on groundwater from deposition of mine spoils and a new ET Cover on the existing mill tailings impoundment. The analysis described is composed of computations including consolidation and unsaturated flow modeling. The surcharge loading due to the weight of the mine spoils and new cover is expected to impact the existing tailings by consolidating the near saturated (greater than 90 percent of saturation) fine-grained materials. This consolidation will then impact the hydraulic properties of the tailings by reducing the porosity of the soil, albeit very small. Finally the potential impact to groundwater was evaluated due to the potential increase in drainage from wet fine-grained tailings (tailings of particular concern are generally greater than 90 percent degree of saturation).

The hydraulic properties of the existing materials (identified in a 2014 site investigation) were utilized as input parameters in unsaturated modeling to estimate the water balance of the profiles prior to placement of any additional materials on the existing repository. These soils hydraulic properties were then altered based on the reduction in porosity of the fine-grained tailings due to consolidation. The changed soil hydraulic properties were utilized as input parameters in the subsequent analysis of the same four profiles 'after' placement of the mine spoils and ET Cover. The results for the 'before' and 'after' conditions were compared to verify if an increase in drainage from the alluvium beneath the tailings could impact groundwater due to placement of the mine spoils and ET cover on the existing impoundment.

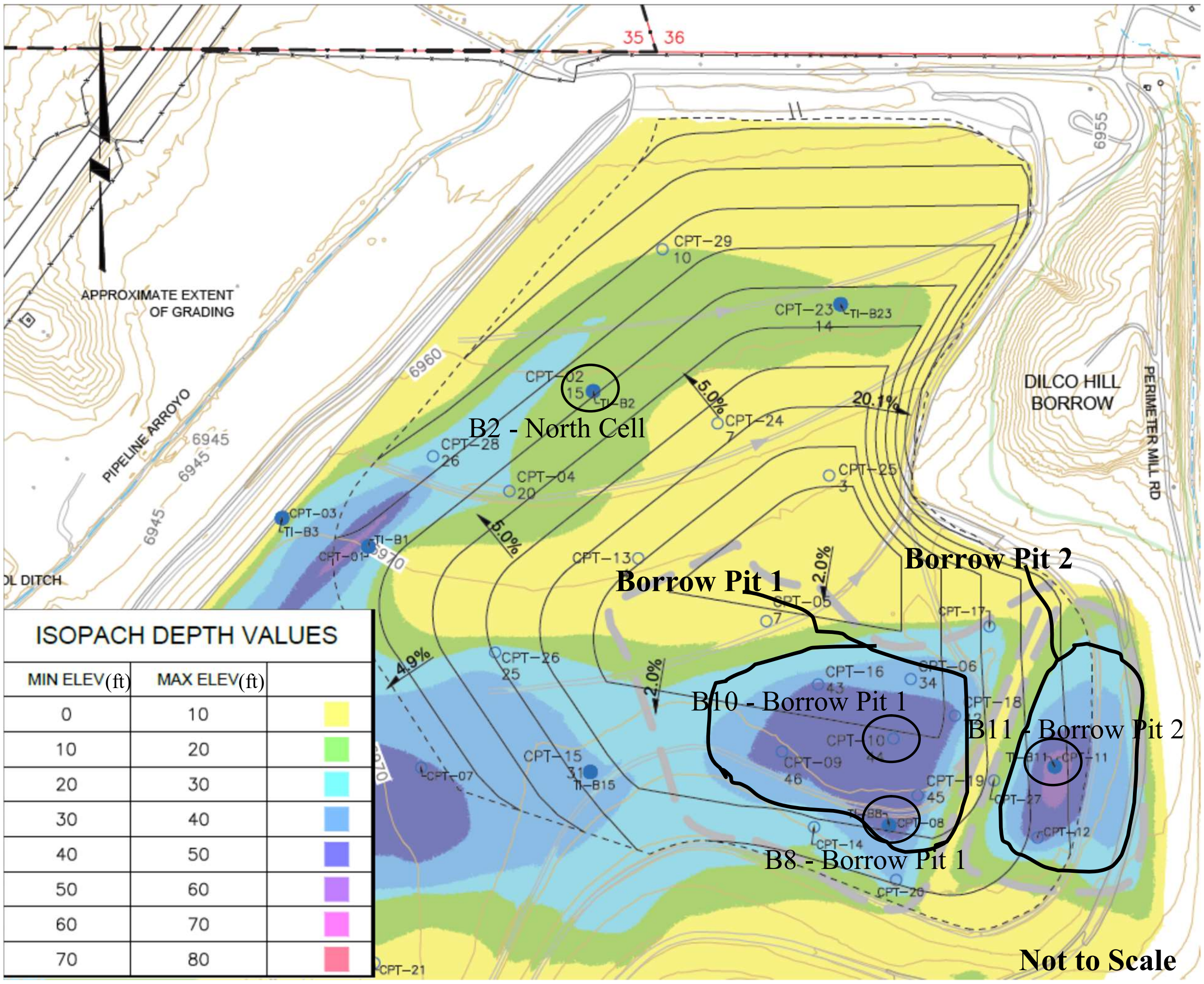

Figure 1. Existing Ground Surface and Tailings Thickness with Boring Locations and Repository Plan

2.0 PROFILES EVALUATED

According to historical documents (Canonie, 1987), the upper seven-feet (minimum) of the impoundment in the vicinity of the repository footprint consists of an existing cover and either fill or coarse-grained tailings. Beneath these layers is the fine-grained tailings layer (if any) (MWH 2014). Deep fine-grained tailings beneath the proposed repository are associated with Borrow Pits 1 and 2 (Figure 1).

A geotechnical investigation at the site (MWH 2014) assessed the volume, location, and properties of tailings (Figures 1 and 3). Results identified the presence of fine-grained tailings within the impoundment that have relatively high moisture content and a very low saturated hydraulic conductivity (about 10^{-8} cm/sec), which lessens their ability to drain the moisture. The overlying coarse-grained tailings were relatively dry compared to the fine-grained tailings. The saturated hydraulic conductivity of the coarse-materials is several orders of magnitude higher (about 10^{-4} cm/sec) than the fine-grained tailings.

The alluvium beneath the fine-grained tailings was much drier than the fine-grained tailings with a saturated hydraulic conductivity several orders of magnitude higher than the fine-grained tailings. The higher hydraulic conductivity of the alluvium allowed this material to drain after operations much faster than the fine-grained tailings. Thus the very low saturated hydraulic conductivity of the fine-grained tailings is controlling the drainage of the profile (Figure 2).

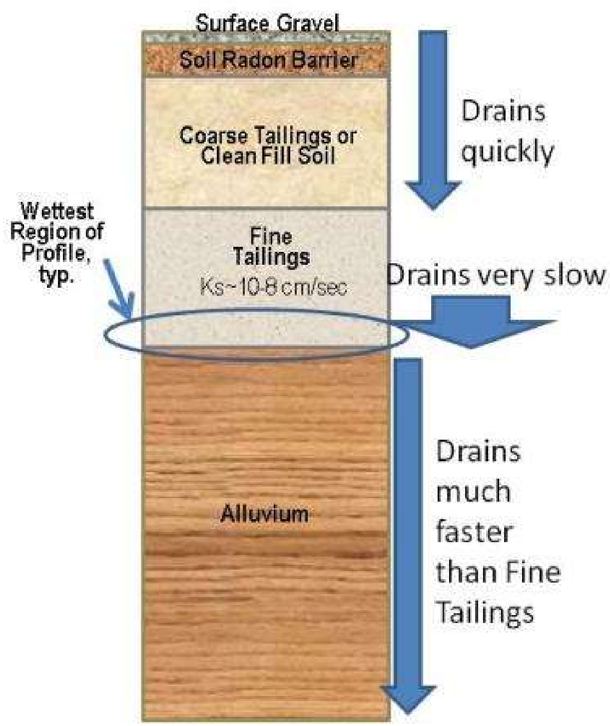

Figure 2. Typical Cross Section of Existing Impoundment

The profiles evaluated were chosen based on (1) general representativeness of the areas of most concern, and (2) completeness of field data available for those locations. These areas include the borrow pits where the deepest fine-grained tailings or slimes exist as well as other areas as described in MWH (2014). The areas evaluated include fine-grained tailings near to or exceeding 90 percent saturation. Cone penetrometer testing (CPT) was performed at these

locations along with physical sampling and laboratory measurements of soil textures and hydraulic properties.

This analysis evaluated the worst case areas: Borrow Pit 1 (Borings B8 and B10) and Borrow Pit 2 (Boring B11). A typical cross section in the North Cell (Boring B2) was also analyzed because it has fine-grained tailings near saturation.

The analysis evaluated the water balance and moisture status of the four profiles (B2, B8, B10, and B11). Figure 3 shows the depth from the top of the planned finished grade after placement of mine spoils and ET Cover to the base of the existing tailings. Deep tailings beneath the proposed repository are associated with Borrow Pit 1 and 2 (Figure 3).

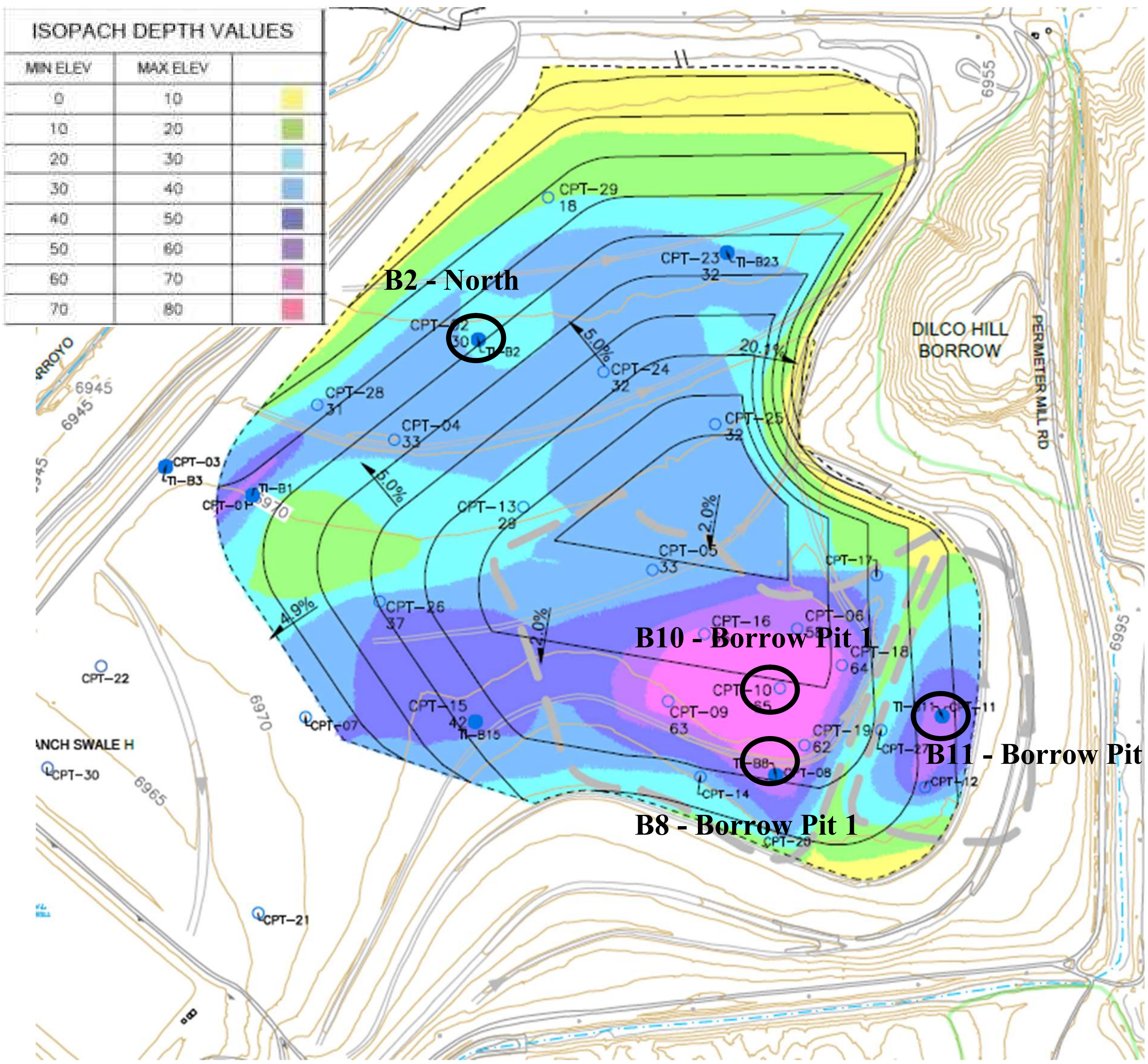

Figure 3. Repository Plan: Depth of Planned Finished Grade to Base of Tailings

3.0 CONSOLIDATION OF TAILINGS

Consolidation of the fine-grained tailings was performed to assess the potential impact on groundwater due to the addition of mine spoils on the existing impoundment at the NECR site. Consolidation is a concern because the fine-grained tailings are at or near saturation and consolidation will more strongly affect the hydraulic properties of these soils. The other materials within the profile are relatively dry and any consolidation should not force excess pore water from them.

Consolidation of soil occurs in three stages:

a. Immediate –takes place as the soil is placed
b. Primary – occurs after soil placement and impacts relatively fine-grained soils (such as the fine-grained tailings or slimes); involves the removal of excess pore water from the soil
c. Secondary – this stage is time dependent and occurs following primary consolidation

Immediate consolidation occurs as the load is applied or within about 7 days and is defined as elastic deformation of soils. Immediate consolidation was not considered relevant to this analysis because it is associated with consolidation that takes place **without change to soil moisture content** and it predominates in cohesion-less soils and unsaturated clay. Additionally, immediate consolidation analyses apply to fine-grained soils including silts and clays with a degree of saturation less than 90% and for coarse grained soils with a large coefficient of permeability (i.e. greater than $10x10^{-3}$ m/s) (Bowles 1996). The analysis summarized in this report focuses on the fine-grained tailings that generally have a degree of saturation greater than 90%.

Primary consolidation typically includes the largest volume change and dominates in saturated/nearly saturated fine-grained soils where consolidation theory applies (Figure 4). It is caused by a reduction in void space and subsequent squeezing of excess pore water from the materials. This analysis calculated the primary consolidation to quantify the impact on near-saturated fine-grained tailings given the placement of mine spoils and ET Cover on the existing impoundment. Canonie (1990 and 1992) stated primary consolidation completed within a few months for the fine-grained tailings when the existing cover was placed.

Secondary consolidation occurs after primary consolidation where excess pore water pressures have dissipated in the soil. Secondary consolidation was not considered in the analysis because it is time dependent and occurs under constant effective stress from continuous rearrangement of clay particles into a more stable configuration. Secondary consolidation is generally a significantly smaller amount of total deformation than primary consolation, and occurs more slowly than primary consolidation (Figure 4).

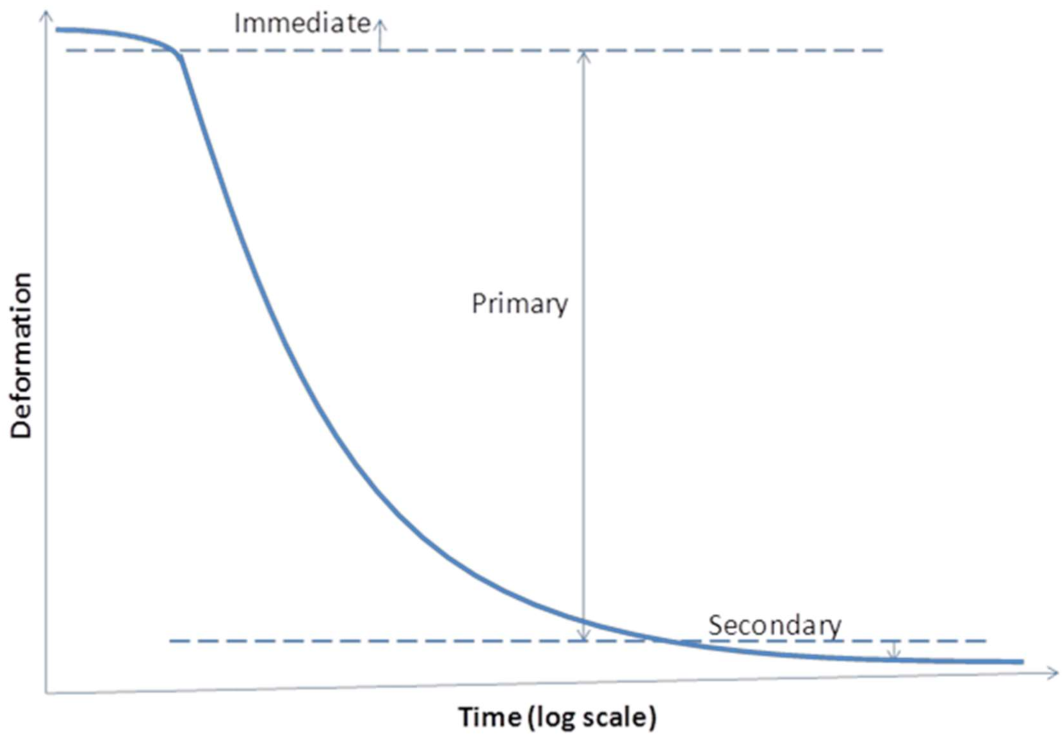

Figure 4. Consolidation Stages

3.1 CONSOLIDATION THEORY

Vanapalli and Oh (2010) showed that the use of saturated soil properties is appropriate for estimation of settlement in unsaturated fine-grained soils including the theory of consolidation by Terzaghi (1943).

Terzaghi's theory of consolidation is a common engineering concept utilized to compute primary consolidation in fine-grained soils. According to Karl Terzaghi "…consolidation is any process which involves a decrease in water content of saturated soil without replacement of water by air." Consolidation is the process in which reduction in volume takes place by reduction in void space under long-term static loads. It occurs when stress is applied to a soil and the soil particles pack together more tightly, reducing the bulk volume. When this occurs in saturated conditions, water will be squeezed out of the soil. The magnitude of consolidation can be predicted by many different methods. In the classical method, developed by Terzaghi, soils are tested in the laboratory to determine their one-dimensional compression index under vertical load. This was performed on soil samples from the tailings (MWH 2014). This change in void space can be used to predict the amount of consolidation that would occur under similar loading in the field. This is the method of consolidation analysis utilized for the tailings materials in this analysis.

Terzaghi’s theory of 1-D consolidation makes the following simplifying assumptions:

1. The soil is homogeneous
2. The soil is fully saturated
3. The solid particles and the pore water are incompressible

4. The flow of water and compression of soil is one-dimensional (vertical)
5. Strains are small
6. Darcy's law is valid at all hydraulic gradients
7. The coefficient of permeability and the coefficient of volume compressibility remain constant throughout the consolidation process
8. There is a unique relationship, independent of time, between void ratio and effective stress

Assumptions 1 to 5 are straightforward and generally pose no difficulties in applying Terzaghi's theory to practical problems. The analysis performed evaluated each relatively homogenous tailings layer independently while analyzing the profile as a whole thus satisfying assumption 1. Typical consolidation analyses assume a single compression index for the total fine-grained tailings thus treating all fine-grained tailings as a single layer. This analysis utilized a measured compression index for each soil texture change measured in each respective profile (MWH 2014) of the fine-grained tailings and thus evaluated each specific layer individually in calculating consolidation for that respective layer. Furthermore, each homogeneous layer within the fine-grained tailings had its respective hydraulic properties adjusted as input parameters for the subsequent unsaturated flow modeling performed for the cross section. This allowed for heterogeneity within the vertical profile to be evaluated in the modeling. Assumption 2 lends conservatism to the analysis given most of the tailings are unsaturated.

At very low hydraulic gradients, there is evidence that pore water flow doesn't take place according to Darcy's law as stated in Assumption 6. However, for most fine-grained soils, the hydraulic gradient is sufficiently high and therefore, this assumption is acceptable.

A limitation of Terzaghi's theory specific to this analysis is generally found in assumption 7. The coefficient of permeability and the coefficient volume compressibility generally decrease with increasing effective stress. That is, the coefficient of permeability is not constant through the consolidation process; rather the saturated permeability of soil generally decreases as density increases. The analysis presented here assumes a constant permeability in the tailings under consideration even after consolidation; the saturated hydraulic conductivity of the tailings at 'before' density in both the 'before' and 'after' scenarios. The modeling performed assumed a constant saturated hydraulic conductivity for tailings materials even though each layers' moisture retention or unsaturated hydraulic properties were adjusted to reduce the storage capacity. This adds conservatism to the analysis because as the tailings are compacted, typically the saturated hydraulic conductivity would also be reduced which would slow water movement and ultimately reduce the predicted annual flux through the base of the unsaturated alluvium.

Another limitation of Terzaghi's theory originates from Assumption 8. Experimental results have shown that the relationship between the void ratio and effective stress is not independent of time. Most fine-grained soils undergo a decrease in void ratio with time (called secondary consolidation or creep) at constant effective stress. Therefore, Terzaghi's theory is good only for the estimation of primary consolidation.

Terzaghi's theory of primary consolidation is represented by the following equation:

$$S_p = C_c \times \left(\frac{H}{1+e}\right) log\left(\frac{\sigma+\Delta\sigma}{\sigma}\right)$$ **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

Δσ = change in stress (additional weight due to spoils and ET Cover)

The use of this theory is intended to provide a conservative value of consolidation. This would in turn produce a conservatively high reduction in storage capacity of each tailings layer considered as well as a conservatively higher degree of saturation after loading. The use of the primary consolidation estimation is appropriate because the soils are fine-grained and are generally near saturation (90 percent saturated or higher) [Vanapalli and Oh 2010]. Saturated soils are generally more compressible than unsaturated soils under the same loading conditions and the approach is intended to account for the settlement that would occur under saturated loading.

3.2 CONSOLIDATION RESULTS

The settlement calculated in a fine-grained tailings layer allowed for respective reduction of the layer thickness when comparing existing conditions to the expected conditions after placement of the mine spoils and ET Cover. For example, the geometry representing the geologic cross-section of Profile B2 modeled for the existing conditions of the fine-grained tailings was 2.5-ft thick. The weight of the mine spoils and ET Cover placed on the impoundment directly above this profile caused the fine-grained tailings to settle 0.18 ft. Thus the geometry for the comparative profile modeled included this layer reduced to 2.32-ft thick.

Based on the consolidation estimated in the fine-grained tailings, the final void ratio and thus porosity of the respective layer was computed. Assuming the porosity and saturated moisture content are the same, the reduced porosity was used to adjust the saturated moisture content and moisture retention curve (Figure 6). Finally, the final degree of saturation of the fine-grained tailings layer(s) was calculated to allow for an adjustment to the initial suction value(s) for each respective layer based on the adjusted moisture characteristic curve for the soil layer similar to that seen in Figure 6 (refer to Section 4).

The ET Cover and mine spoils soil weight was calculated as follows (weights of soil for ET Cover and Mine Spoils derived in Appendix G, Attachment G.3 of the 95% Design Report):

1. Maximum dry density of cover soil [average value based on MWH (2014)] is 115 pounds per cubic foot (pcf). The moisture content of the soil is estimated at 10.8 percent (the average of the optimum moisture content less 3 percent) and is used to be consistent with MWH (2014). This is the likely moisture content of the soil installed. Thus the moist unit weight of the cover soil at 90 percent relative density is 114.68 pcf. Similarly, the soil/rock admixture unit weight is 130 pcf with 33 percent rock by volume. The moisture content taking into account the rock is 6.3 percent. This yields a moist unit weight of

129.64 pcf for the rock/soil admixture. Assuming the worst case or heaviest cover combination that would yield the most consolidation of underlying materials; the admixture consisting of 3-inch rock at a depth of 27 inches is used to quantify the consolidation. Given the cover is 4-ft thick and the admixture is 27-inches thick, the moist weight of the cover soil for the full cover thickness is then 492.4 psf.

2. Maximum dry density of mine spoils [average value based on MWH (2014)] is 118.3 pcf. The moisture content of the soil is 9.3 percent. This is the average of the optimum moisture content less 3 percent and used to be consistent with MWH (2014). This is the likely moisture content of the soil installed. The moist unit weight of the mine spoils soil at 90 percent relative density is 116.37 pcf. This unit weight was then multiplied by the respective depth of mine spoils in each profile evaluated.

The input data utilized to quantify the settlement in the wet/finer-grained tailings, the final void ratio, and the final degrees of saturation are summarized in Tables 1 to 4. These input data were measured values obtained during the pre-design study (MWH 2014). Results of the CPT (MWH 2014) for boring profiles B2, B8, B10, and B11 are included in Appendix B. Appendix B and MWH (2014) contain details on the measured values shown in Tables 1 to 4 for each layer or textural change in the geologic cross section and layer thicknesses of the existing materials at the impoundment. Other values shown in these tables were computed.

A spreadsheet was prepared to compute the settlement, final void ratio, and final degree of saturation after application of the mine spoils and new ET Cover. The total settlement of the fine-grained tailings estimated for Profile B2 was 0.18 ft with a final degree of saturation of 92.3 percent (Table 1). This profile is in the north cell where the fine-grained tailings are relatively thin; most areas of the north cell contain no fine-grained tailings (Figures 1, 3, and 8). There were no saturated tailings in this profile 'before' or 'after' placement of the mine spoils and ET Cover.

Profile B10 is in Borrow Pit 1 where the tailings of concern are 25.5 ft thick located from 37.1 ft below ground surface (BGS) to a depth beyond 62.6-ft BGS (Figure 10). The CPT instrumentation experienced refusal at this depth. The total settlement of the fine-grained tailings (and coarser-grained tailings sandwiched within them) estimated for Profile B10 was 0.93 ft (Table 3). Each unsaturated layer's moisture retention curve and the final degrees of saturation (degree of saturation was higher after consolidation) were adjusted and used to compute a revised *initial* suction value for the fine-grained tailings layers in the *'after'* condition. Any water 'squeezed' from a fine-grained layer within the profile was added to an adjacent tailings layer. This resulted in saturation of most of the fine-grained tailings in Profile B10 and thus an initial suction value of zero in the 'after' condition (Table 3).

The total settlement of the fine-grained tailings (and coarser-grained tailings sandwiched among them) estimated for Profile B11 was 0.1 ft (Table 4). There were no saturated tailings in this profile 'before' or 'after' placement of the mine spoils and ET Cover. Since each layer of the fine-grained tailings was unsaturated, each layer's moisture status was computed individually similarly to that described in the paragraph above. That is, each unsaturated individual layer's moisture retention curve and the final degree of saturation (degree of saturation was higher after consolidation) was adjusted and used to compute a revised *initial* suction value for the fine-grained tailings layers in the *'after'* condition. This profile is in Borrow Pit 2 where the tailings

of concern are 11.5 ft thick located from 41.3 ft BGS to a depth of about 52.8-ft BGS (Figure 11).

Since Profiles B2, B10, and B11 each had at least one unsaturated layer within the tailings 'after' consolidation, each unsaturated layer's adjusted suction value was computed accounting for the adjusted soil water characteristic curve (SWCC) with the reduced saturated moisture content from the estimated consolidation (Figure 6). Any saturated layer 'after' consolidation had an initial suction value of zero assigned to it. Soil suction at saturation is zero. Refer to Section 4.2.5 and Tables 11, 13, and 14 for these values.

The total settlement of the fine-grained tailings (and coarser-grained tailings sandwiched within them) estimated for Profile B8 was 0.65 ft with a final degree of saturation of 100 percent [weighted average] (Table 2). Any water 'squeezed' from a fine-grained layer within the profile was added to an adjacent tailings layer. Since the weighted average of these fine-grained tailings was saturated, all layers of fine-grained tailings and coarse-grained tailings sandwiched within them were assigned an initial soil suction of zero (Table 12). This profile is in Borrow Pit 1 where the tailings of concern are 18.5 ft thick located from 35.2 ft BGS to a depth of about 53.7 ft BGS (Figure 9). This was the only profile where the moisture status of fine-grained tailings after consolidation was calculated to be fully saturated due to placement of the mine spoils and ET Cover on the impoundment. The SWCC was adjusted similarly to the other profiles (Figure 6), but the new soil suction value for the tailings of concern used in the 'after' condition where the full profile included the mine spoils and ET cover along with consolidated tailings thicknesses was zero for all tailings of concern.

Table 1. B2: Soil Properties to Determine Fine-Grained Tailings Consolidation[b]

Layer	Layer Thickness (ft)	Dry Bulk Density (pcf)	Water Content (g/g)	Bulk Density (pcf)	Weight of Layer (lbs)	SG	Initial Saturation	Initial Void Ratio	Initial Stress (psf)	Change in stress (psf)	Cc	Settlement (ft)	Final Void Ratio	Final Saturation
ET Cover	4				492.4									
Mine Spoils	10.8			116.4	1257									
Fill	0.5	100.4	7.7%	108.1	54.1	2.68	31.0%	0.67	27.0	1749.2				
Fill	5.5	75.9	24.5%	94.5	519.7	2.73	53.7%	1.25	313.9	1749.2				
Fine Tailings	2.5	73.4	39.6%	100.8	251.97	2.78	80.7%[a]	1.36	699.8	1749.2	0.315	0.18	1.19	92.3%[a]

[a]The initial degree of saturation is less than 90 percent. However, it is the wettest soil in the profile and was conservatively treated as though it was wetter and that the Terzaghi consolidation theory applies. When applying the theory, the final degree of saturation after consolidation is wetter than 90 percent.

[b]The soil properties are taken from MWH (2014).

Table 2. B8: Soil Properties to Determine Fine-Grained Tailings Consolidation[c]

Layer	Layer Thickness (ft)	Dry Bulk Density (pcf)	Water Content (g/g)	Bulk Density (pcf)	Weight of Layer (lbs)	SG	Initial Saturation	Initial Void Ratio	Initial Stress (psf)	Change in stress (psf)	Cc	Settlement (ft)	Final Void Ratio	Final Saturation
ET Cover	4				492.4									
Mine Spoils	11.7				1361.5									
Coarse Tailings	18.5	103.7	9.0%	113.0	2091.1	2.72	38.4%	0.64	1045.6	1853.9				
Coarse Tailings	0.5	99.6	6.2%	105.8	52.9	2.72	23.9%	0.70	2117.6	1853.9				
Coarse Tailings	0.5	91.7	16.8%	107.1	53.6	2.72	53.7%	0.85	2170.8	1853.9				
Fine Tailings	4.5	62.7	61.8%	101.5	456.9	2.8	96.9%	1.79	2426.0	1853.9	0.426	0.17	1.68	Saturated
Fine Tailings	4	74.8	41.4%	105.7	423.0	2.6	92.0%	1.17	2865.9	1853.9	0.426	0.17	1.08	Saturated[a,b]
Coarse Tailings	0.5	90.9	14.3%	103.9	51.9	2.66	46.0%[a]	0.83	3103.4	1853.9	0.094	0.01	0.81	Saturated[a,b]
Coarse Tailings	0.5	89.6	16.5%	104.3	52.2	2.67	51.2%[a]	0.86	3155.5	1853.9	0.094	0.01	0.84	Saturated[a,b]
Fine Tailings	5.5	80.4	39.7%	112.30	617.7	2.63	Saturated	1.04	3490.4	1853.9	0.426	0.21	0.96	Saturated
Coarse/Fine Tailings	0.5	83.6	34.3%	112.3	56.1	2.72	90.5%	1.03	3827.3	1853.9	0.262	0.01	0.99	Saturated[a,b]
Coarse/Fine Tailings	2.5	92.3	29.3%	119.3	298.4	2.72	94.9%	0.84	4004.6	1853.9	0.262	0.06	0.80	Saturated
Fine Tailings	0.5	74.8	43.3%	107.2	53.6	2.6	96.2%	1.17	4180.5	1853.9	0.426	0.02	1.10	Saturated

[a]The initial degree of saturation is less than 90 percent. However, the layers are sandwiched between saturated or near saturated soils consequently these layers were treated as though they were wetter and that the Terzaghi consolidation theory applies. When applying the theory, the final degree of saturation after consolidation is wetter than 90 percent.

[b]The calculated value for this layer is less than saturation, but the calculated value for the entire fine-grained tailings layer inclusive of the sandwiched coarse-grained tailings was saturated. Water that is presumed to be squeezed from a previous saturated layer or near- saturated layer was included in an adjacent layer that was not saturated.

[c]The soil properties are taken from MWH (2014)

Table 3. B10: Soil Properties to Determine Fine-Grained Tailings Consolidation[c]

Layer	Layer Thickness (ft)	Dry Bulk Density (pcf)	Water Content (g/g)	Bulk Density (pcf)	Weight of Layer (lbs)	SG	Initial Saturation	Initial Void Ratio	Initial Stress (psf)	Change in stress (psf)	Cc	Settlement (ft)	Final Void Ratio	Final Saturation
ET Cover	4				492.4									
Mine Spoils	11.7				1361.5									
Coarse Tailings	5	96.8	9.0%	105.512	527.6	2.63	34.0%	0.70	263.8	3122.4				
Coarse Tailings	5.5	99.1	7.5%	106.5325	585.9	2.61	30.4%	0.64	820.5	3122.4				
Coarse/Fine Tailings	7.5	92.9	26.7%	117.7239	882.9	2.72	87.7% [a]	0.83	1555.0	3122.4	0.111	0.22	0.77	95.0% [a]
Fine Tailings	1	73.4	41.0%	103.4835	103.5	2.78	83.5% [a]	1.36	2048.2	3122.4	0.315	0.05	1.24	Saturated [a, b]
Fine Tailings	2	64.3	57.4%	101.2124	202.4	2.8	93.5%	1.72	2201.1	3122.4	0.315	0.09	1.60	Saturated
Fine Tailings	4	73.4	45.3%	106.6394	426.6	2.78	92.3%	1.36	2515.6	3122.4	0.315	0.19	1.25	Saturated
Coarse Tailings	1	100.1	15.4%	115.5154	115.5	2.67	61.8% [a]	0.67	2786.6	3122.4	0.094	0.02	0.63	Saturated [a,b]
Fine Tailings	2.5	72.5	47.7%	107.0926	267.7	2.78	95.2%	1.39	2978.3	3122.4	0.315	0.10	1.29	Saturated[b]
Fine Tailings	0.5	64.3	51.4%	97.36704	48.7	2.80	83.8% [a]	1.72	3136.5	3122.4	0.315	0.02	1.62	Saturated [a,b]
Coarse/Fine Tailings	1	87.8	32.2%	116.0913	116.1	2.72	93.8%	0.93	3218.9	3122.4	0.111	0.02	0.90	Saturated [b]
Fine Tailings	4	73.7	45.7%	107.3809	429.5	2.56	Saturated	1.17	3491.7	3122.4	0.315	0.16	1.08	Saturated
Fine Tailings	2	74.5	47.2%	109.7301	219.5	2.78	98.8%	1.33	3816.2	3122.4	0.315	0.07	1.25	Saturated

[a]The initial degree of saturation is less than 90 percent. However, the layers are relatively fine-grained and near 90 percent saturation or sandwiched between saturated or near saturated soils consequently treated as though it was wetter and that the Terzaghi consolidation theory applies. Water presumed to be squeezed from a previous saturated layer or near- saturated layer was included in an adjacent layer that was not saturated.

[b]The calculated value for this layer is less than saturation, but the calculated value for the entire fine-grained tailings layer inclusive of the sandwiched coarse-grained tailings was saturated. Water presumed to be squeezed from a previous saturated layer or near- saturated layer was included in an adjacent layer that was not saturated.

[c]The soil properties are taken from MWH (2014).

Table 4. B11: Soil Properties to Determine Fine-Grained Tailings Consolidation[a]

Layer	Layer Thickness (ft)	Dry Bulk Density (pcf)	Water Content (g/g)	Bulk Density (pcf)	Weight of Layer (lbs)	SG	Initial Saturation	Initial Void Ratio	Initial Stress (psf)	Change in stress (psf)	Cc	Settlement (ft)	Final Void Ratio	Final Saturation
ET Cover	4				492.4									
Mine Spoils	0.8				1361.5									
Fine Tailings	3.5	63.73087	59.9%	101.9	356.5625	2.84	95.3%	1.78	4495.2	585.5	0.482	0.03	1.76	96.7%
Fine Tailings	8	63.7	59.9%	101.9	815	2.84	95.3%	1.78	5081.0	585.5	0.482	0.07	1.76	96.6%

[a]The soil properties are taken from MWH (2014)

4.0 UNSATURATED MODELING OF PROFILES

Unsaturated soil is comprised of liquid, solid, and gas (Figure 5). That is, in an unsaturated volume of soil, there will be some air-filled voids, water-filled voids, and solid material. An unsaturated soil has a lower hydraulic conductivity than a saturated soil. 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. At this state, the hydraulic conductivity of the soil is at its lowest.

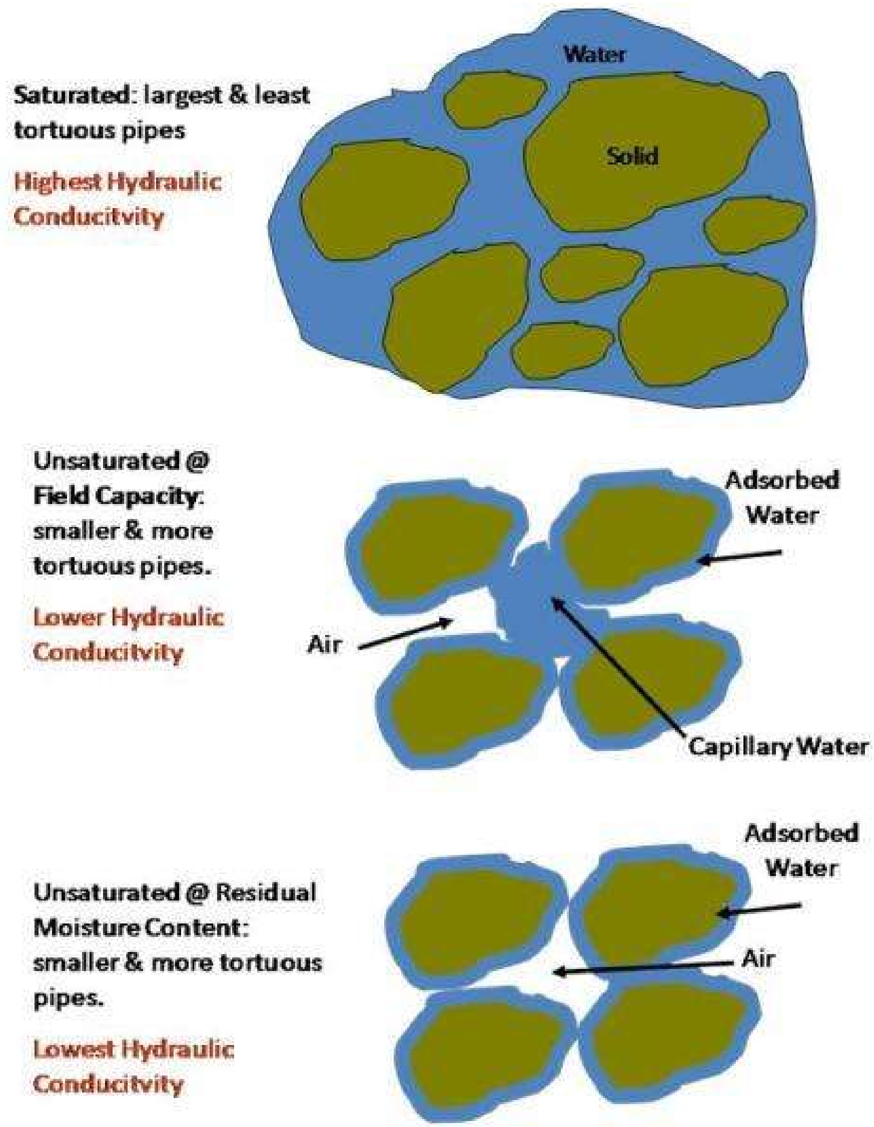

Figure 5. Components of Soil (Water, Air and Solid)

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 soil moisture content (Figure 6).

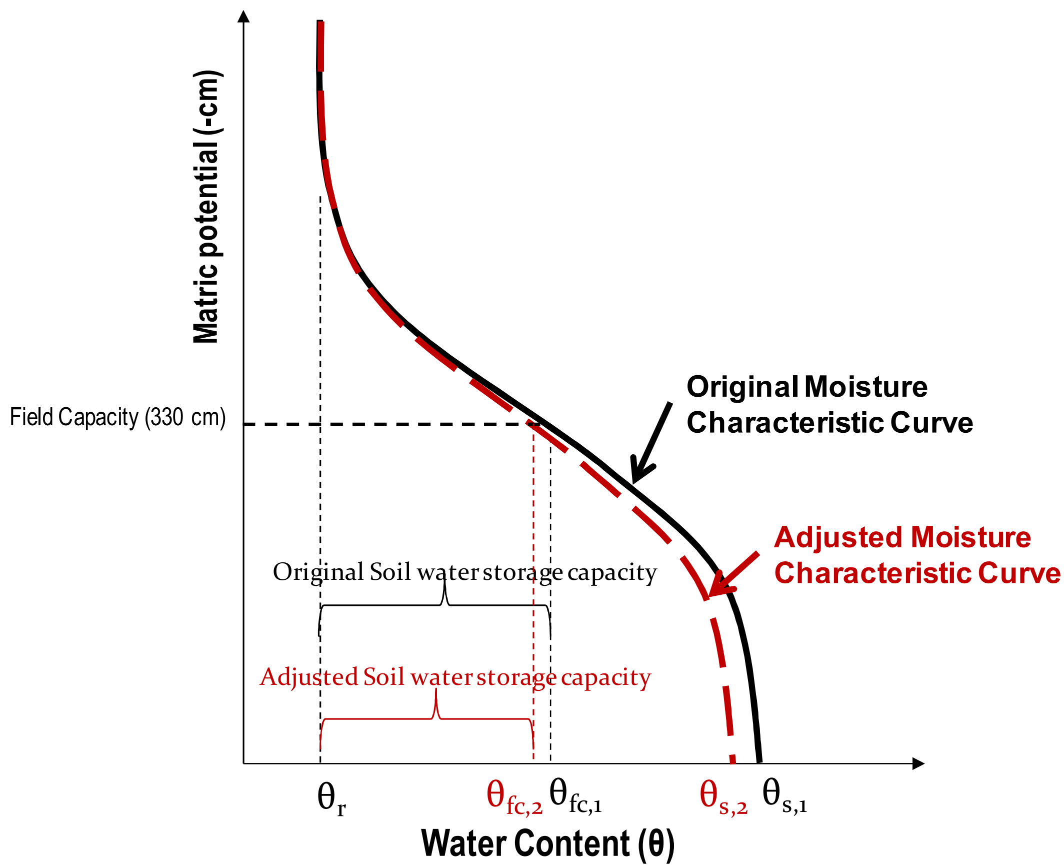

Figure 6. Change in Soil Hydraulic Properties due to Consolidation

The consolidation/modeling analysis is performed on the mill tailings to evaluate the potential change to groundwater quality due to the additional tailings seepage that might result from deposition of mine spoils and a new ET Cover on the existing impoundment. The surcharge loading due to the weight of the mine spoils and new ET Cover would compact the existing tailings by consolidating the underlying fine-grained materials. This consolidation would subsequently alter the hydraulic properties of these fine-grained tailings by reducing the storage capacity of the soil (Figure 5). Because the fine-grained tailings are wet (tailings of particular concern are generally wetter than 90 percent degree of saturation) the consolidation could potentially squeeze water from them. The hydraulic property changes affect the flow of water within each respective profile analyzed.

After consolidation of the tailings was computed (Section 3), the hydraulic properties of each fine-grained tailings layer was adjusted similar to that shown in Figure 6. The four selected profiles were then modeled to determine the annual flux at the base of the unsaturated alluvium.

4.1 OVERVIEW OF UNSAT-H

Historically, HELP (Schroeder et al, 1994) software was utilized to calculate the water balance in landfill systems. However, it is now recognized that this software has its limitations (ITRC 2003). Software more applicable for the analyses of water flow within an alternative earthen cover system is based on the Richard's Equation (ITRC 2003). A common software package in current use that is based on the Richard's equation is UNSAT-H (Fayer 2000). This unsaturated

flow modeling software was designed specifically for earthen covers and is recommended for use on alternative earthen covers in the ITRC (2003) design guidance documents. Consequently, UNSAT-H was used on this project.

UNSAT-H has been used for many recent alternative earthen cover designs (Dwyer 2003). UNSAT-H is a one-dimensional, finite-difference computer program developed at the Pacific Northwest National Laboratory by Fayer and Jones (1990). UNSAT-H can simulate the water balance of soil profiles as well as soil heat flow (Fayer 2000). UNSAT-H simulates water flow through soils by solving Richards' equation and simulates heat flow by solving Fourier's heat conduction equation.

An illustration showing how UNSAT-H computes the water balance is shown in Figure 7. 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 final cover soil. If the rate of precipitation exceeds the soil's infiltration capacity, the extra 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. This allows for conservative infiltration and percolation estimates since landfill cover systems are generally sloped to encourage runoff.

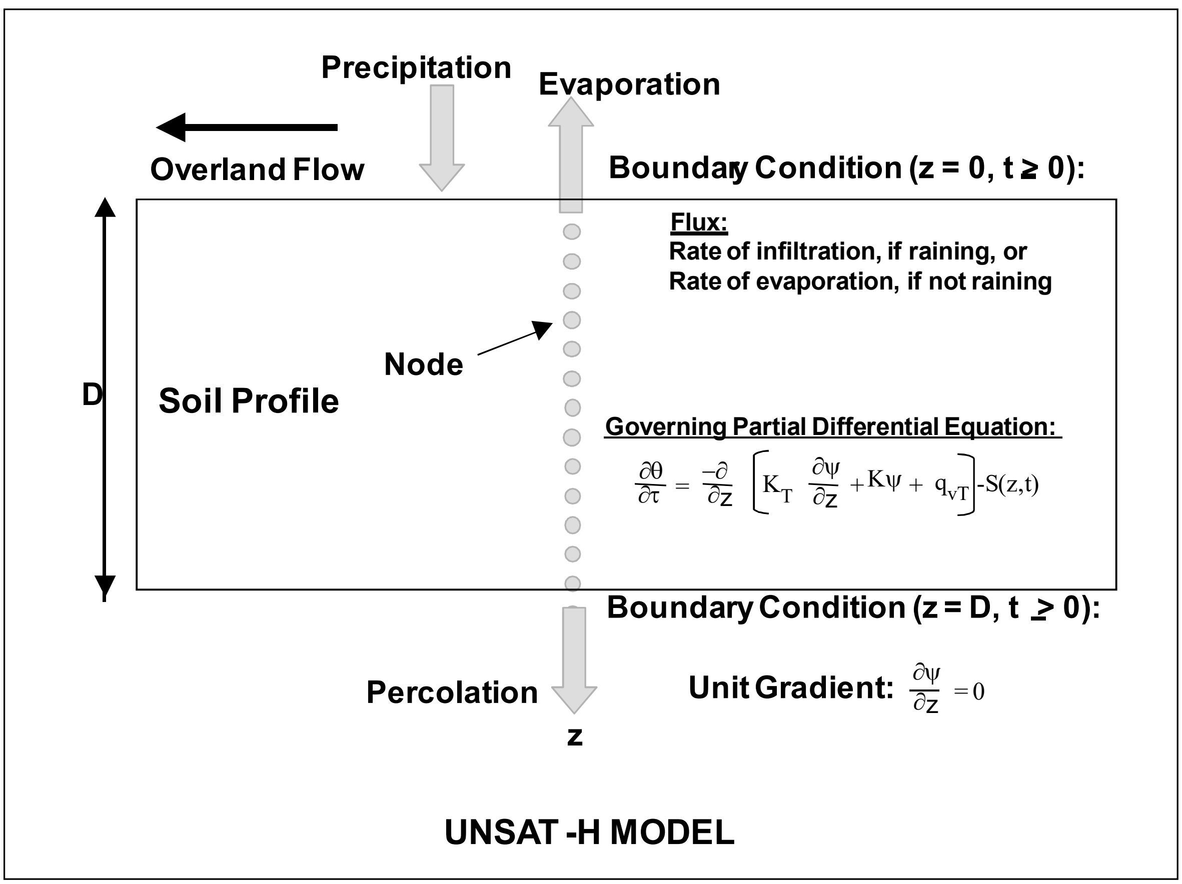

Figure 7. Schematic Representation of Water Balance Computation by UNSAT-H

Water that infiltrated a soil profile during an UNSAT-H simulation moves upward or downward as a consequence of gravity and matric potential gradients. 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. The upper boundary condition includes daily potential evapotranspiration (PET) and precipitation values. PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply. Actual evapotranspiration (ET) is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. ~~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 the water stored within the entire profile modeled. Flux from the lower boundary is via percolation. UNSAT-H, being a one-dimensional program, does not compute lateral drainage.

4.2 INPUT PARAMETERS

This section provides an overview of the parameters and boundary conditions used in water balance modeling of each respective profile 'before' and 'after' consolidation of the tailings were computed for addition of mine spoils and an ET Cover.

The input parameters include the cover soil properties (MWH 2014), vegetation (Cedar Creek 2014), and profile geometry. The upper boundary condition or climate was also evaluated from typical to extreme wet conditions.

The heaviest ET Cover profile that included the 3-inch rock mixed with cover soil to a depth of 27 inches with the remaining 4-ft thickness being the similar cover soil was used in the consolidation analysis. This cover profile is heavier than the admixture with the 1.5-inch (14 inches deep) or 2-inch rock (18 inches deep) because the admixture layer is thicker. Using the heaviest cover profile added conservatism to the analyses because additional weight increased consolidation.

Based on results of the cover design sensitivity analysis performed (Dwyer 2017), the most conservative profile for unsaturated flow is the cover profile utilizing the 1.5-inch rock mixed with soil to a depth of 14 inches, with the remainder of the cover being the similar cover soil. Consequently, this profile was used in the unsaturated flow modeling to add conservatism to the analyses. That is, the thinner 14-inch-thick admixture layer allowed a quicker infiltration than that with the 3-inch rock because the rock-adjusted effective saturated hydraulic conductivity of the 1.5-inch rock admixture is greater than that for the 3-inch rock admixture. The 3-inch rock is thicker and thus the reduced saturated hydraulic conductivity applies to a thicker region. The results from the design sensitivity analysis (Dwyer 2017) showed all profiles that included the new vegetated ET Cover produced no downward flux, thus the final cover system geometry has no significant sensitivity to the modeling results of the profiles inclusive of the mine spoils and ET Cover.

4.2.1 MODEL GEOMETRY

The model geometry for existing conditions was based on measured layer thicknesses as determined via the exploratory drilling program (MWH 2014). The four profiles evaluated are well defined based on both CPT and borehole investigations at each respective location. CPT results for boring profiles B2, B8, B10, and B11 are included in Appendix B.

The geometry for the subsequent analysis of 'after' conditions included a reduction in overall thickness of the wet tailings due to consolidation induced by the weight of the mine spoils and ET Cover. The profiles modeled also include the mine spoils and new ET Cover while removing the rock within the existing cover (this rock will be scavenged for inclusion in the final closure of the site).

The nodal spacing was set at a range narrow enough to accurately represent the modeled cover profile. For the profiles with the mine spoils and ET Cover, the total cover thickness is 4 feet. The surface admixture is 14 inches thick in the ET Cover. A general summary of the profiles modeled is included in Sections 4.2.1.1 through 4.2.1.4.

4.2.1.1 PROFILE B2

Profile B2 represents an area within the north cell with wet, fine-grained tailings (Figures 1 and 2). Much of the north cell has no fine-grained tailings (MWH 2014). Figure 8 summarizes the 'before' and 'after' profiles for B2 for potential impact on the underlying groundwater. The figure shows the profile for current conditions and the post- construction profile, taking into account the respective consolidation in the fine-grained tailings.

The borehole at location B2 stopped at 32 ft BGS. No saturated condition was encountered in this borehole.

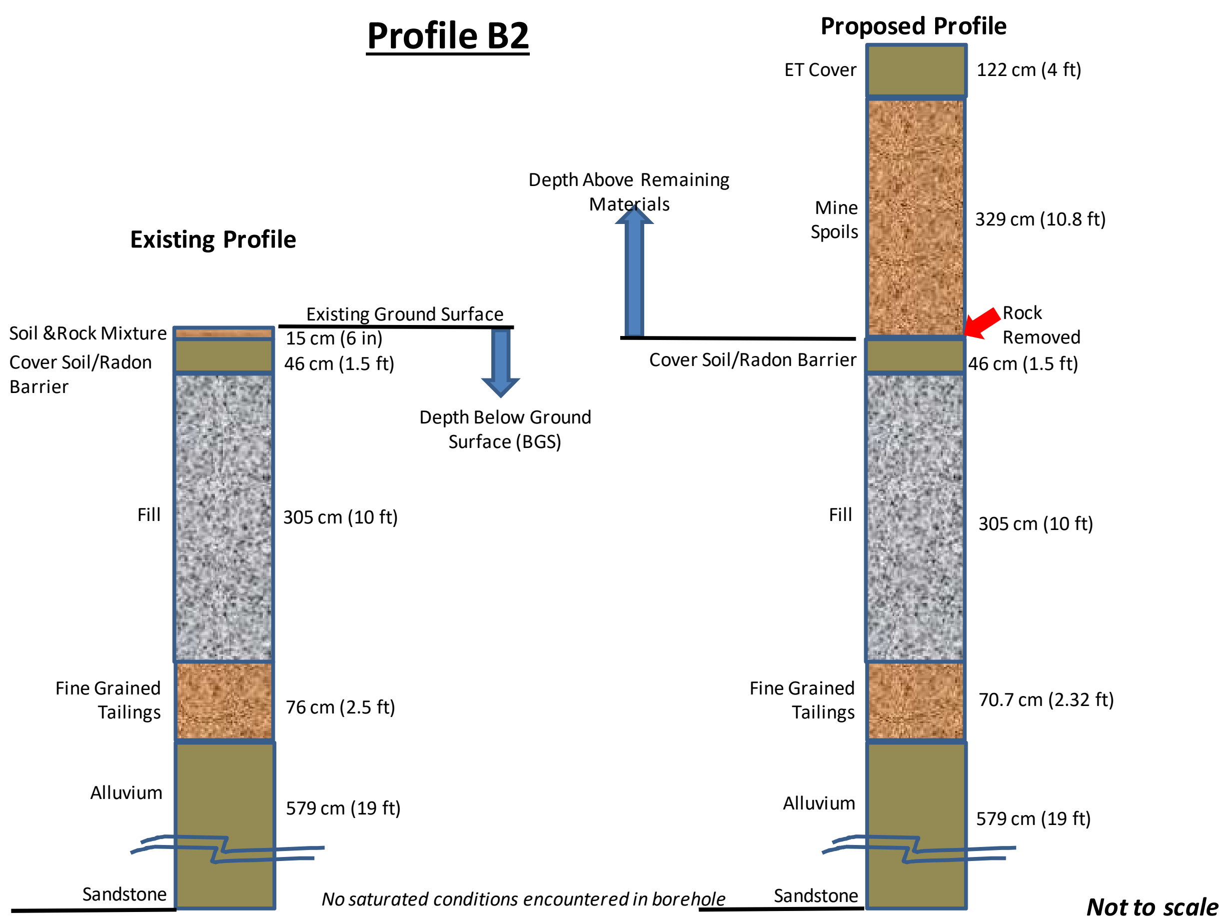

Figure 8. Profile B2

4.2.1.2 PROFILE B8

Profile B8 represents an area within Borrow Pit 1 where the fine-grained tailings are relatively thick and wet (Figures 1 and 2). Figure 9 summarizes the 'before' and 'after' profiles evaluated to assess the area for potential impact on the underlying groundwater, with the 'after' profile taking into account the respective consolidation in the fine-grained tailings. The coarse tailings, fine-grained tailings and coarse/fine-grained tailings layers have thinner distinctive layers within them that each had its own set of input parameters.

The borehole at location B10 stopped at 61 ft BGS. There was no saturated condition encountered in this borehole.

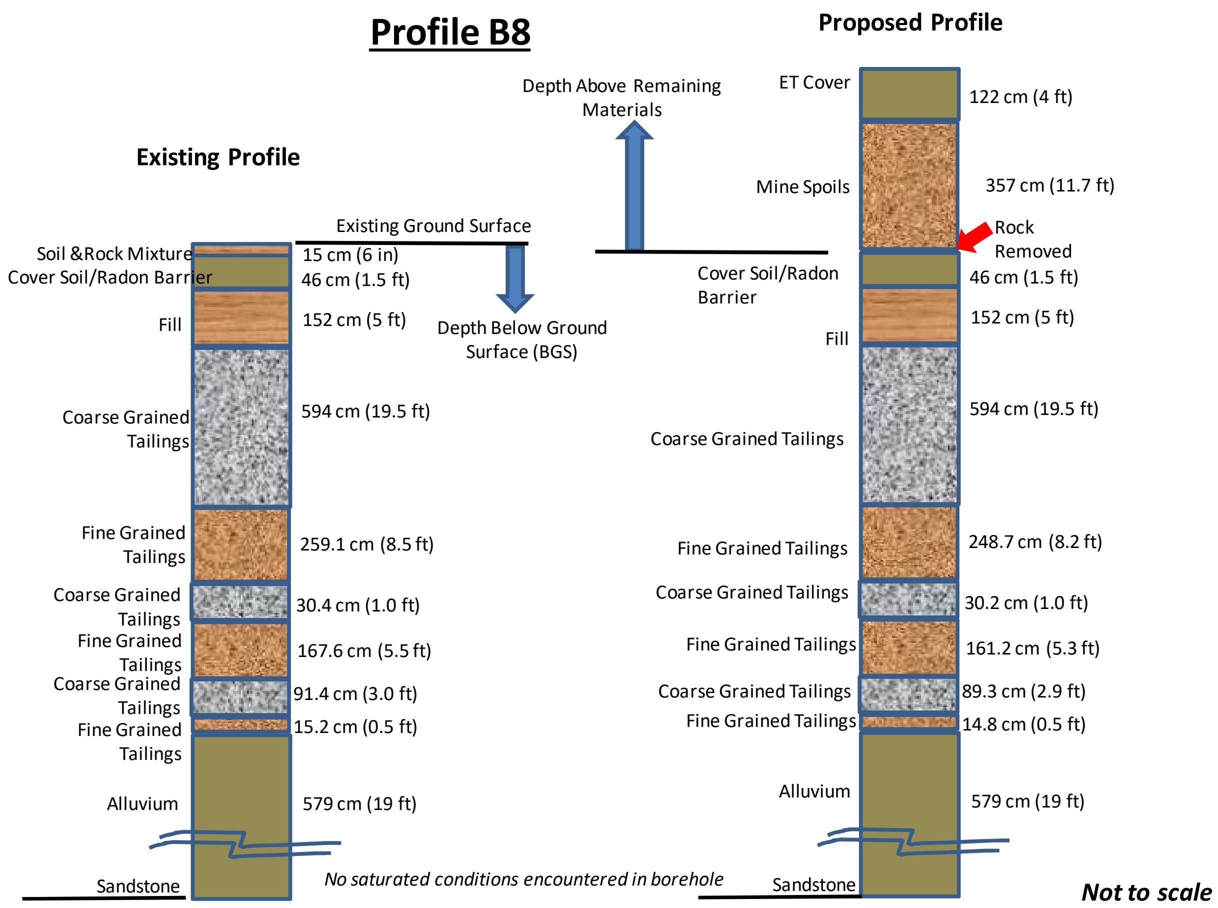

Figure 9. Profile B8

4.2.1.3 PROFILE B10

Profile B10 represents another area within Borrow Pit 1 where the fine-grained tailings are relatively thick and wet (Figures 1 and 2). Figure 10 summarizes the 'before' and 'after' profiles evaluated to assess the area for its potential impact on the underlying groundwater, with the 'after' profile taking into account the respective consolidation in the fine-grained tailings. The coarse tailings, fine-grained tailings and coarse/fine-grained tailings layers have thinner distinctive layers within them that each had its own set of input parameters.

The borehole at location B10 stopped at 105 ft BGS. The CPT penetration encountered refusal at a depth of 63 ft. Water was encountered in the borehole at a depth of 90 ft BGS (elevation 6883').

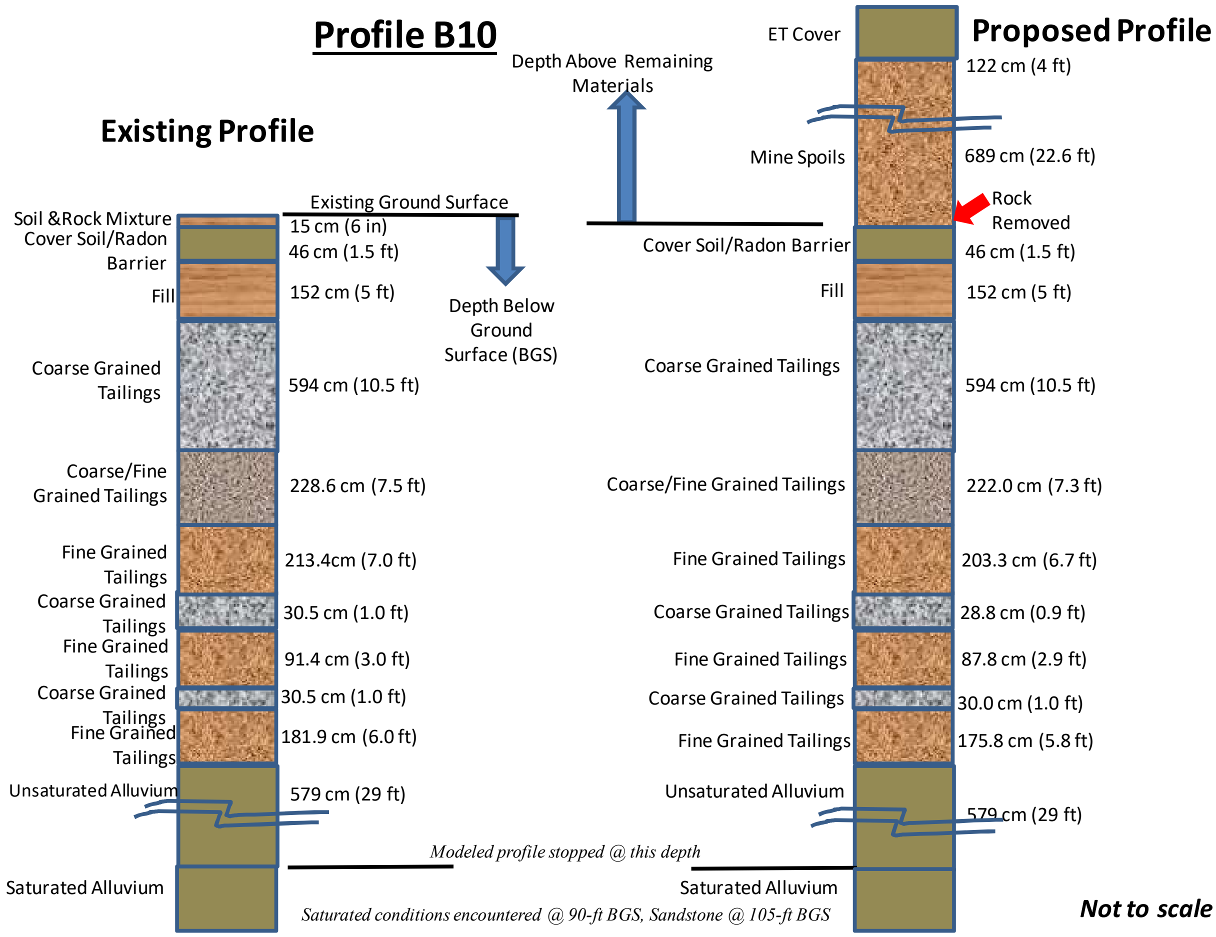

Figure 10. Profile B10

4.2.1.4 PROFILE B11

Profile B11 represents an area within Borrow Pit 2 where the fine-grained tailings are thick and wet (Figures 1 and 2). Figure 11 summarizes the 'before' and 'after' profiles evaluated to assess the area for its potential impact on the underlying groundwater. The 'after' profile takes into account the respective consolidation in the fine-grained tailings. The fine-grained tailings layers had thinner distinctive layers within them that each had its own set of input parameters.

The borehole at location B11 stopped at 97 ft BGS. Water was encountered in the borehole at a depth of 90 ft BGS (elevation 6887').

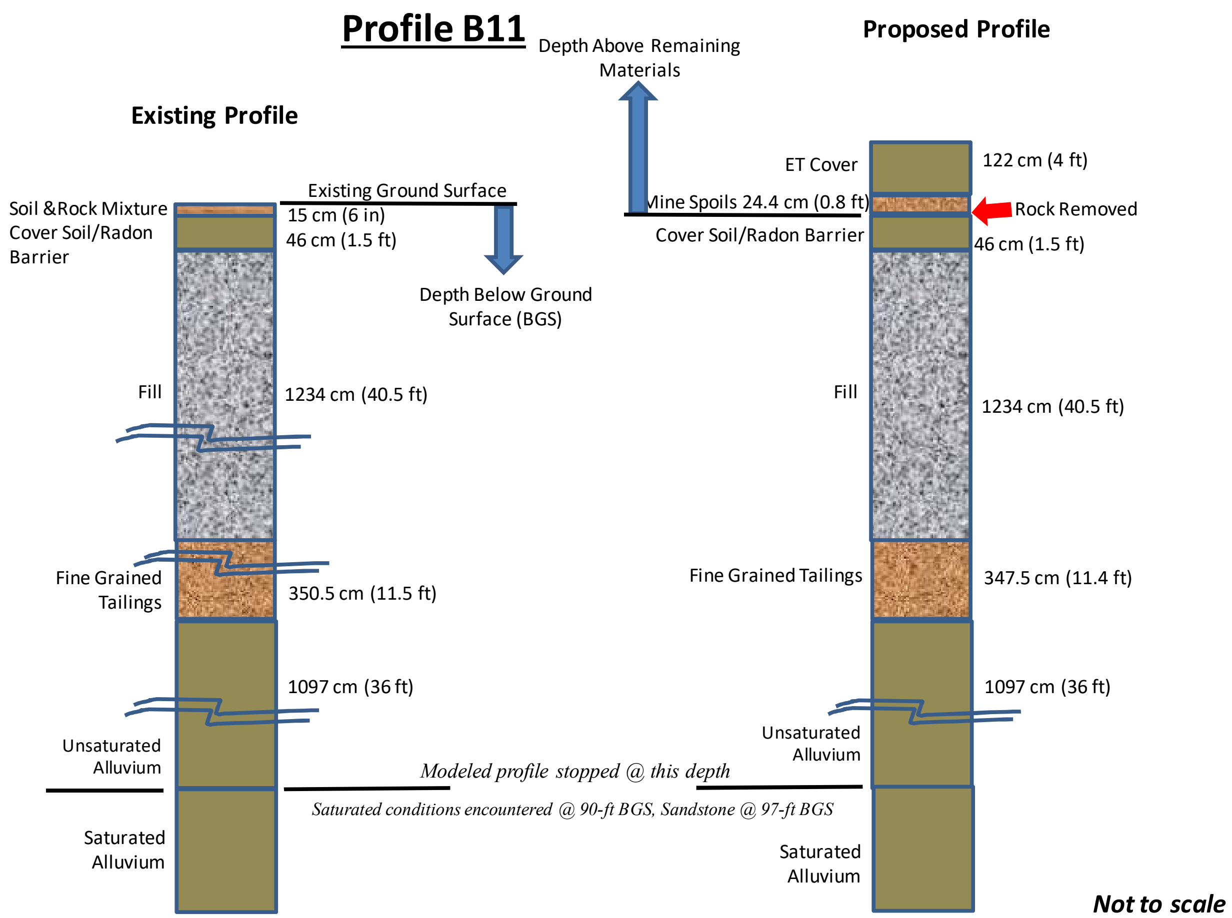

Figure 11. Profile B11

4.2.2 BOUNDARY CONDITIONS

The upper boundary condition for the UNSAT-H computer simulations used 20 years of local climate data. The 20 years consisted of 10 consecutive years of average or typical climate followed by the wettest year on record run consecutively for two years, followed by eight more years of typical climate conditions. This twenty-year time frame was chosen because it includes both average and extreme climate conditions; was significantly longer than the estimated time for completion of primary consolidation, and allowed adequate time to evaluate the sensitivity of the assigned initial conditions (including initial suction values). The 20-year period allows for an evaluation of the change in moisture status of the profile over multiple years to see if trends are established or annual flux is variable. The 20-year time-frame was hypothesized to be adequate to establish and evaluate long-term trends. Verification of this hypothesis is described in Section 6. The 20-year period did not include any dry years since this analysis was intended to evaluate whether liquid flux would increase with the addition of soil on the existing impoundment. Dry years would not provide a stress of the profiles. Refer to Section 6 for longer-term simulations.

The water balance results from these 20-year simulations reveal that after a couple of years of typical climate conditions, there is no significant year-to-year change to the annual water balance variables (Appendix A; also refer to Figures 16 to 19). Furthermore, the evaluation showed that

the existing cover (rock over soil radon barrier) allows for percolation and thus an increase of moisture within the profile; whereas the profile with mine spoils and an ET Cover allows no percolation and thus the profile is undergoing a drying trend. Based on this finding, the long-term drainage aspects from the tailings impoundment are improved by the addition of the mine spoils and ET Cover.

All available historical weather data for the Gallup, NM area and surrounding weather stations were evaluated. Ft. Wingate had historical weather data dating back to 1897 and the most complete set of data in the Gallup, NM area. Weather from Ft. Wingate, NM was utilized for the upper boundary condition due to its proximity to and similar elevation as the mill site repository. For the typical climate year; the weather from 1949 was utilized with an annual precipitation volume of 11.71 inches (29.74 cm) that was distributed as seen in Figure 12. For this year, it can be seen that for every month of the year, the demand for water referred to as potential evapotranspiration (PET) far exceeds the actual supply of water (precipitation). The annual PET is 83.4-inches (211.74 cm) or about 6.5 times more than the actual supply of water (precipitation). Consequently a "store and release" cover designed to take advantage of variances between the water demand and water supply (such as an ET Cover) is well suited for this climate.

It should be noted that the monthly values shown in Figures 12 and 13 are presented for the benefit of the reader and were not used in the actual analyses. Daily values are used in the boundary files for PET while hourly values are provided for precipitation. The daily precipitation total was spread through the day thus decreasing the precipitation rate to increase infiltration and reduce runoff to add conservatism to the analysis. The computer simulation is performed on an hourly basis.

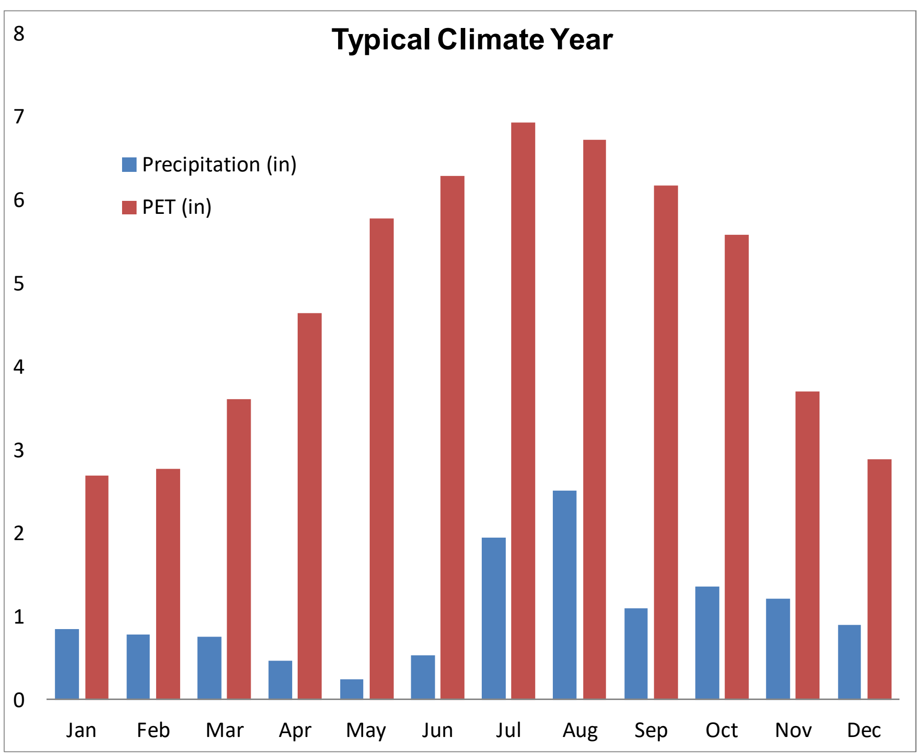

Figure 12. Typical Climate: Monthly Precip. vs. PET for Ft. Wingate, NM

Extreme climatic conditions were also evaluated. The Ft. Wingate weather data set contained the wettest year on record (1906), having an annual precipitation volume of 23.8 inches (84.8 cm). Much of the precipitation came in as snow from January to April and October to December. This is a period when PET is low and transpiration of moisture through vegetation is minimized or completely ceased in the modeling. The monthly precipitation and PET are presented in Figure 13 for the wettest year on record.

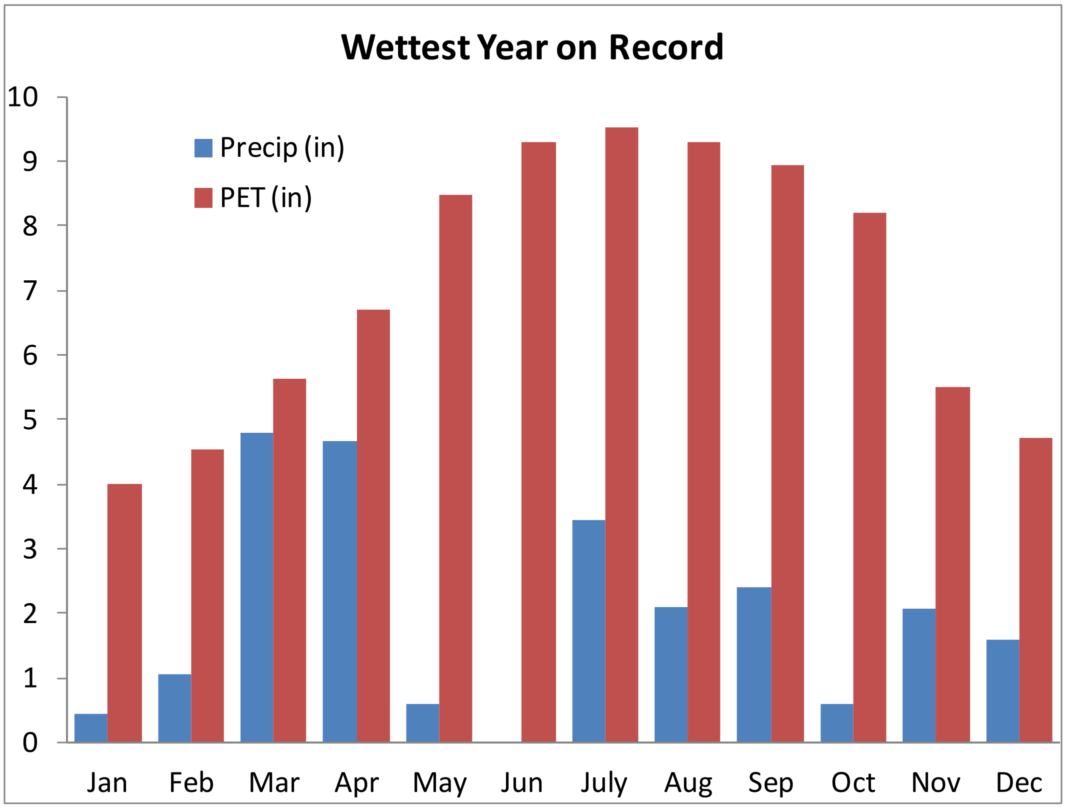

Figure 13. Wettest Year on Record: Monthly Precip. vs. PET for Ft. Wingate, NM

The water flow across the surface and lower boundary of the cover profile is determined by boundary condition specifications. For infiltration events, the upper boundary used in the simulation was conservatively set to a maximum hourly flux of 0.4 inches (1 cm) per hour. This value minimized runoff while maximizing infiltration. This is conservative because it is expected that, given the designed slopes at the site, a significant percentage of precipitation will run off without infiltrating into the cover profile.

The UNSAT-H program partitions PET into potential evaporation (Ep) and potential transpiration (Tp). Potential evaporation is estimated or derived from daily weather parameters (Fayer 2000). Potential transpiration is calculated using a function (Equation 4-1) based on the value of the assigned leaf area index (LAI) and an equation developed by Ritchie and Burnett (1971) as follows:

$T_p = PET\ [a + b(LAI)^c]$ where $d \le LAI \le e$ **Equation 4-1**

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 maximum and minimum daily temperatures, daily precipitation value, and site latitude were input parameters used to calculate PET (Samani and Pessarkli, 1986). The Samani method used to calculate PET correlates with the Penman method utilized within UNSAT-H (Samani and Pessarkli, 1986). The UNSAT-H program then partitioned the daily PET values into Ep and Tp. Tp was calculated using a function developed by Equation 4-1. Two separate files were written for each year modeled: one file represented the daily PET values and the other file consisted of the daily precipitation values.

The lower boundary condition (at base of profile evaluated - in these cases the base of the unsaturated alluvium) was a unit gradient. With the unit gradient, the calculated drainage flux depended on the hydraulic conductivity of the lower boundary node. The unit gradient corresponded to gravity-induced drainage and was most appropriate when drainage was not impeded. The base of the modeled profile was well below any significant transient activity. The large depth between the deepest roots and the lower boundary condition allowed for the assumption that the lower boundary was subject only to the drainage process (Fayer and Walter 1995). Therefore, the lower boundary condition was specified with a unit gradient condition (i.e. free drainage).

4.2.3 VEGETATION DATA

Vegetation will generally increase ET from the cover because a plant's matric potential or suction can be orders of magnitude higher than that of the soil (Figure 14).

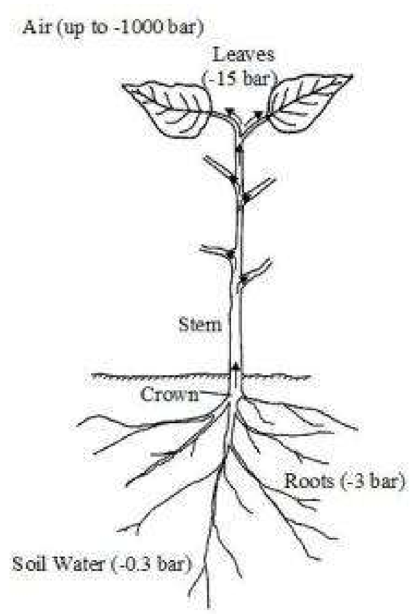

Figure 14. Typical Soil-Plant-Atmosphere Water Potential Variation (Hillel 1998)

The input parameters representing vegetation include the LAI, rooting depth and density, root growth rate, the suction head values that correspond 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. The maximum rooting depth is based on expected vegetation characteristics. The root length density (RLD) is assumed to follow an exponential function such as that defined in Equation 4-2 (Fayer 2000):

$$RLD = a \exp(-bz) + c \qquad \textbf{Equation 4-2}$$

where:

a,b, and c are fitting parameters

z = depth below surface

The cover profiles (Figures 8 to 11) were modeled with vegetation on the surface. The computer simulations of the various profiles evaluated for the existing conditions featured shrub land vegetation (Cedar Creek 2014). This best matched the current vegetation of the existing cover. The computer simulations for the profiles with mine spoils and ET Cover features reclaimed vegetation (Cedar Creek 2014). The reclaimed vegetation is the short-term condition (within the 20 years modeled) of vegetation after a site has been disturbed (Cedar Creek 2014). Canonie (1990 and 1992) stated the primary consolation occurred within a few months. The 20-year modeling period allowed for an evaluation of the site after consolidation takes place to assess potential changes in subsurface moisture movement due to the consolidated tailings.

Cedar Creek performed an analog study of the native vegetation at the site both in a disturbed setting and undisturbed settings (Cedar Creek 2014). Results from this study were utilized in the modeling to develop input parameters for vegetation. The following vegetation parameters (Table 5) related to rooting were utilized in the model (Cedar Creek 2014).

Table 5. Rooting Parameters (Cedar Creek 2014)

Parameter	Reclaimed Analog **(Profile with Mine Spoils and ET Cover)**	Shrub Analog **(Existing Condition Profile)**
a	556.28266872	0.42851959
b	-0.00000543	-0.03407481
c	-555.91871302	0.07781172

The LAI, percent bare area utilized, and maximum rooting depths for the respective vegetation used in a computer simulation are summarized in Table 6.

Table 6. Vegetation Parameters (Cedar Creek 2014)

Parameter	Reclaimed Analog **(Profile with Mine Spoils and ET Cover)**	Shrub Analog **(Existing Condition Profile)**
LAI	0.91	0.52
% Bare Area	52.3%	75.2%
Root Length	147 cm	155 cm

In the modeling simulations, the onset and termination of the growing season for the site were Julian days 63 and 343, respectively. This is based on the typical climate conditions for the site and the respective growing degree days computed and presented in Figure 15. The LAI was transitioned from 0 to the full LAI starting with Julian day 63 to 170. Day 171 through 266, the full LAI was utilized. The LAI was then transitioned down from the full LAI to 0 from Julian day 267 to 343.

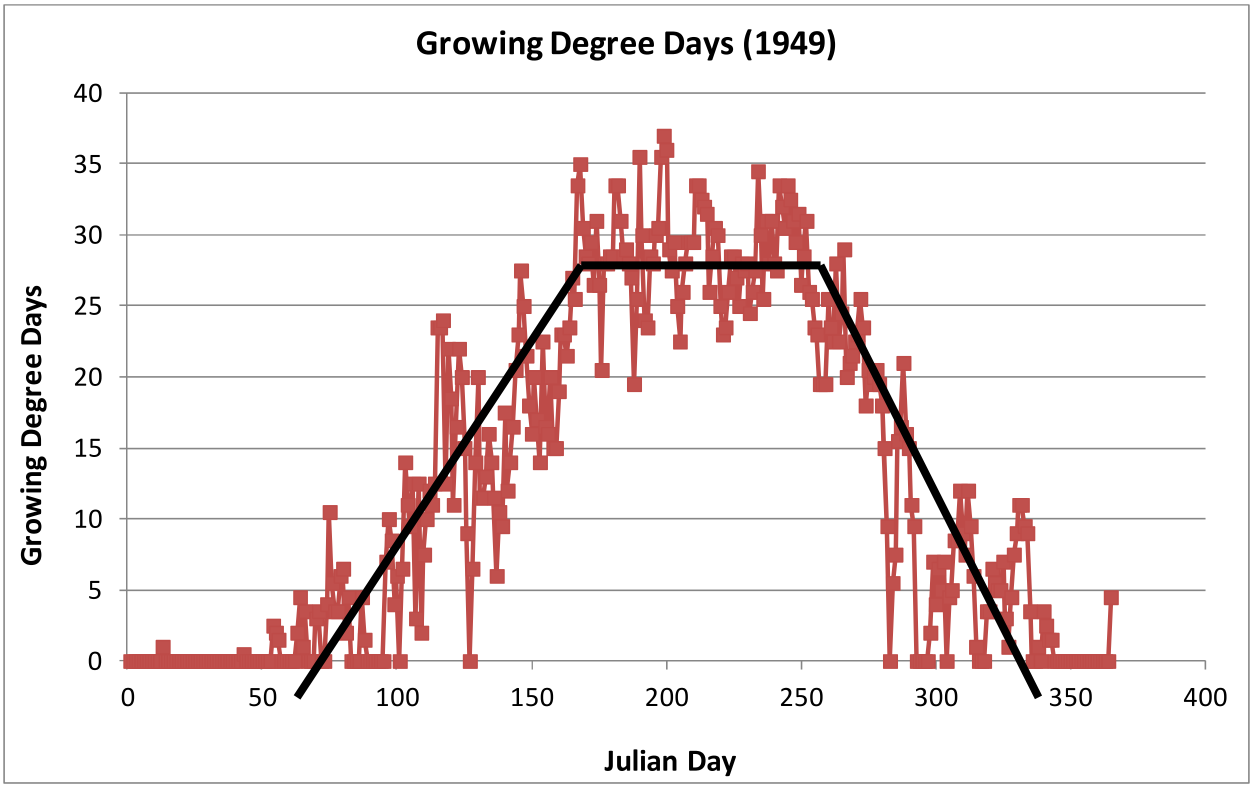

Figure 15. Leaf Area Index Transition During the Year

The UNSAT-H model adjusts the full LAI based on the percent bare area of vegetation. For example, for Shrub vegetation with an LAI of 0.52 and a percent bare area of 75.2 percent, the LAI is reduced to 0.752 * 0.52 = 0.39.

4.2.4 SOIL PROPERTIES RELATED TO VEGETATION

Soil properties related to vegetation utilized as model input parameters include suction head values corresponding to the wilting point, head corresponding to the water content below which plant transpiration starts to decrease, and a head value corresponding to the water content above which plants do not transpire because of anaerobic conditions were defined.

Not all 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. The suction head value for the wilting point for these simulations was set at 40,000 cm[1] for reclaimed vegetation (Fayer and Walters 1995) and 70,000 (Fayer and Walters 1995) for shrubland vegetation. These

[1] 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.

wilting point values are conservative given that nearby vegetation could remove water from the soil to a suction value of 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 ft (1000 cm) (Fayer and Walters 1995, Fayer 2000). The head value corresponding to the water content above which plants do not transpire because of anaerobic conditions was defined at 12 inches (30 cm) (Fayer and Walters 1995).

4.2.5 SOIL PROPERTIES

Soil mechanical and hydraulic properties were obtained from laboratory testing of soil samples collected on-site (MWH 2014). The soil input parameters for existing condition profiles are presented in Tables 7 to 10. The initial soil suction values were calculated based on the initial degree of saturation and moisture retention properties (van Genuchten 1978) and are also presented in Tables 7 to 10. The Mualem conductivity function (Mualem 1976) was calculated to describe the unsaturated hydraulic conductivity of the soils (van Genuchten et al. 1991). The van Genuchten 'm' parameter for this function is assumed to be'1-1/n'; 'n' being one of the established van Genuchten parameters. The initial soil conditions were expressed in terms of suction head or matric potential values calculated from the respective moisture content of each soil layer (van Genuchten et al. 1991). The moisture retention properties (van Genuchten parameters) were developed from the laboratory soil measurements (soil suction versus moisture content) using the RETC software (van Genuchten et al. 1991).

The input parameters summarized in Tables 7 to 10 are the best data available from measurements made during an extensive on-site drilling and laboratory measurements of existing conditions. Not all data for each layer was available via the MWH (2014) report to complete the analysis. Consequently, missing data were filled in with measured data from similar soils/tailings (MWH 2014). Engineering judgment was utilized to evaluate all of the available data and best fit the missing data with available data from MWH (2014).

The initial moisture content was calculated as follows:

$$\theta_i = S \times \theta_s$$ **Equation 4-3**

where:

$\theta_i = inital\ moisture\ content\ (vol.)$

$S =\ degree\ of\ saturation$

$\theta_s\ =\ saturated\ moisture\ content\ (vol.)$

The initial soil suction or matric potential value (h_i) is computed from the following equation (van Genuchten 1978):

$$\frac{\theta_i - \theta_r}{\theta_s - \theta_r} = [1 + (\propto h_i)^n]^{-m}$$ **Equation 4-4**

where:

$\theta_i = inital\ moisture\ content\ (vol.)$

$\theta_r\ =\ residual\ moisture\ content\ (vol.)$

$\theta_s\ =\ saturated\ moisture\ content\ (vol.)$

$\propto, m, n\ =\ van\ Genuchten\ et\ al$ (1991) $fitted\ parameters$

$h_i =\ inital\ soil\ suction\ or\ matric\ potential$ (cm)

$m =\ 1 - {}^{1}\!/_{n}$ (Mualem 1976)

Table 7. Profile B2 Existing Conditions: Soil Layer Input Parameters

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	S_0	van Genuchten parameters				Initial Suction[a] (-cm)
					θ_s	θ_r	α	n	
Cover – rock/soil	0 to 0.5’	Loamy sand (Carsel & Parrish 1998)	4.10×10^{-3}	30%	0.41	0.057	0.124	2.28	29.2
Cover - soil	0.5’ –2’	EB-B6-03	3.60×10^{-5}	30%	0.50926	0	0.01399	1.26891	6272.7
Fill	2’ – 6.5’	Use B11-03	2.50×10^{-5}	31%	0.30331	0	0.01632	1.06655	2692958106.4[b]
	6.5’ – 12’			53.70%	0.30331	0	0.01632	1.06655	699434.4
Fine Tailings	12’ – 14.5’	Use B10-14	2.90×10^{-8}	80.70%	0.58891	0	0.0011	1.16727	2636.5
Alluvium	14.5’ – 33.5’	Use B11-10	5.60×10^{-4}	22%	0.45752	0.06145	0.13956	1.31247	11741.6

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]It appears large, but this value was calculated from its degree of saturation.

Table 8. Profile B8 Existing Conditions: Soil Layer Input Parameters

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	S_0	van Genuchten parameters				Initial Suction[a] (-cm)
					θs	θr	α	n	
Cover – rock/soil	0 to 0.5’	Loamy sand (Carsel & Parrish 1998)	4.10×10^{-3}	30%	0.41	0.057	0.124	2.28	29.2
Cover - soil	0.5’ –2’	EB-B6-03	3.60×10^{-5}	30%	0.50926	0	0.01399	1.26891	6272.7
Fill	2’ – 7’	Use B11-03	2.50×10^{-5}	30%	0.30331	0	0.01632	1.06655	4407686039.0[b]
Coarse Tailings	7’ – 26.5’	B8-02	3.60×10^{-4}	38.4%	0.41023	0	0.47787	1.16163	779.9
Fine Tailings	26.5’ – 31’	Use B8-9	3.00×10^{-8}	96.9%	0.56534	0	0.00446	1.15784	70.0
Fine Tailings	31’ – 35’	Use B8-9	3.00×10^{-8}	92%	0.56534	0	0.00446	1.15784	193.6
Coarse/Fine Tailings	35’ - 35.5’	B8-06	1.60×10^{-5}	46%	0.48373	0	0.0009	1.37788	8299.9
Coarse/Fine Tailings	35.5’ – 36’	B8-06	$1.60E^{-5}$	51.20%	0.48373	0	0.0009	1.37788	6115.2
Fine Tailings	36’ – 41.5’	Use B8-9	$3.00E^{-8}$	Saturated	0.56534	0	0.00446	1.15784	0.0
Coarse/Fine	41.5’ – 42’	B8-08	1.30×10^{-7}	90.5%	0.4272	0	1.87772	1.16882	0.5

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	S_0	van Genuchten parameters				Initial Suction[a] (-cm)
					θs	θr	α	n	
Tailings									
Coarse/Fine Tailings	42' – 44.5'	B8-08	1.30 x10^{-7}	94.9%	0.4272	0	1.87772	1.16882	0.3
Fine Tailings	44.5' – 45'	Use B8-9	3.00 x10^{-8}	96.2%	0.56534	0	0.00446	1.15784	85.8
Alluvium	45' – 63'	Use B1-13A	1.70 x10^{-6}	50.6%	0.4951	0.0398	0.43246	1.20486	98.5

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]It appears large, but this value was calculated from its degree of saturation.

Table 9. Profile B10 Existing Conditions: Soil Layer Input Parameters

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	S_0	van Genuchten parameters				Initial Suction[a] (-cm)
					θ_s	θ_r	α	n	
Cover – rock/soil	0 to 0.5'	Loamy sand (Carsel & Parrish 1998)	4.10 x10^{-3}	30%	0.41	0.057	0.124	2.28	29.2
Cover - soil	0.5' – 2.0'	EB-B6-03	3.60 x10^{-5}	30%	0.50926	0	0.01399	1.26891	6272.7
Fill	2' – 7'	Use B11-03	2.50 x10^{-5}	30%	0.30331	0	0.01632	1.06655	4407686039.0[b]
Coarse Tailings	7' – 12'	B10-02	4.30 x10^{-4}	34%	0.3481	0	0.67277	1.13662	3994.5
Coarse Tailings	12' – 17.5'	B10-03	6.70 x10^{-5}	30.40%	0.4272	0	1.87772	1.16882	615.8
Coarse/Fine Tailings	17.5' – 25'	Use B8-08	1.30 x10^{-7}	87.70%	0.44786	0	0.00129	1.29116	645.6
Fine Tailing	25' – 26'	Use B10	3.00 x10^{-8}	83.50%	0.58891	0	0.0011	1.16727	2006.5
Fine Tailing	26' – 28'	Use B10	3.00 x10^{-8}	93.50%	0.58891	0	0.0011	1.16727	585.5
Fine Tailing	28' - 32'	Use B10	3.00 x10^{-8}	92.30%	0.58891	0	0.0011	1.16727	709.8
Coarse Tailings	32' – 33'	B8-08	6.70 x10^{-5}	61.80%	0.4272	0	1.87772	1.16882	8.9
Fine Tailings	33' – 35.5'	B8-08	3.00 x10^{-8}	95.20%	0.58891	0	0.0011	1.16727	423.1
Fine Tailings	35.5' – 36'	Use B8-9	3.00 x10^{-8}	83.80%	0.58891	0	0.0011	1.16727	1947.0
Coarse/Fine Tailings	36' – 37'	B10-03	1.30 x10^{-7}	93.80%	0.44786	0	0.00129	1.29116	327.1
Fine Tailings	37' – 41'	Use B10	3.00 x10^{-8}	100.10%	0.58891	0	0.0011	1.16727	0.0
Fine Tailings	41' – 43'	Use B10	3.00 x10^{-8}	98.80%	0.58891	0	0.0011	1.16727	113.2

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	S_0	van Genuchten parameters				Initial Suction[a] (-cm)
					θ_s	θ_r	α	n	
Alluvium	43' – 62'	B10-18	$2.40x10^{-5}$	48.86%	0.40301	0.00829	0.54078	1.1191	911.3

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]It appears large, but this value was calculated from its degree of saturation.

Table 10. Profile B11 Existing Conditions: Soil Layer Input Parameters

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	S_0	van Genuchten parameters				Initial Suction[a] (-cm)
					θ_s	θ_r	α	n	
Cover – rock/soil	0 to 0.5'	Loamy sand (Carsel & Parrish 1998)	$4.10x10^{-3}$	30%	0.41	0.057	0.124	2.28	29.2
Cover - soil	0.5' –2'	EB-B6-03	$3.60 x10^{-5}$	30%	0.50926	0	0.01399	1.26891	6272.7
Fill	2' – 15'	Use B11-03	$2.50 x10^{-5}$	29.30%	0.30331	0	0.01632	1.06655	6284703564.2[b]
	15' – 20'			42.90%	0.30331	0	0.01632	1.06655	20421368.8[b]
	20' – 30'			59.80%	0.30331	0	0.01632	1.06655	138843.8[2]
	30' – 42.5'			75.70%	0.30331	0	0.01632	1.06655	3974.6
Fine Tailings	42.5' – 54'	B8-09	$3.00 x10^{-8}$	95.30%	0.56534	0	0.00446	1.15784	106.8
Alluvium	54' - 90'	B11-10	$5.60 x10^{-4}$	50.10%	0.45752	0.06145	0.13956	1.31247	109.7

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]It appears large, but this value was calculated from its degree of saturation.

The input parameters for the respective profiles 'after' placement of mine spoils and new ET Cover are presented in Tables 11 to 14. The top layer or rock/soil admixture of the cover profile is composed of the mixture of rock (1.5-inch diameter for these simulations) mixed with soil. The admixture depth is 14 inches. The cover soil directly below the upper rock/soil admixture is composed of soil from the same borrow source. The cover soil properties are those from the south drainage area borrow (the largest borrow source). Results presented in Dwyer (2017) revealed that since no percolation is computed through the new ET Cover profile, the cover borrow source is insensitive to these modeling analyses results.

The hydraulic properties of the cover borrow soil modeled were obtained from laboratory testing (MWH 2014) of the various soil textures at a prescribed density of 90 percent of the maximum dry density (ASTM D698). This density approximately equates to the natural density of the borrow soils in their undisturbed setting. Because the density of the soil will migrate towards this natural density setting, it is warranted to install it as close to this density as possible. Therefore, the construction specifications for installation of the cover soil will require the installed density of the cover soil to be 90 percent of its maximum dry density (MDD) with a small tolerance allowance (+/- 5 pcf of MDD). The remolded samples are assumed to represent the soil as it is installed in the field.

The top admixture layer has rock mixed into it at a volumetric ratio of 33 percent rock to 67 percent soil. The mixture of rock into the soil alters its hydraulic properties. Consequently, the hydraulic properties were calculated for the admixture layer per ASTM D4718. Equation 4-5 was used to calculate the rock adjusted saturated hydraulic conductivity based on the addition of rock (Peck and Watson 1979).

$$K_b = [K_s * 2(1 - V_r)]/(2 + V_r) \qquad \textbf{Equation 4-5}$$
$$where: K_b = saturated\ hydraulic\ conductivty, bulk$$
$$K_s = saturated\ hydraulic\ conductivty, soil$$
$$V_r = volume\ of\ rock$$

The natural analog study performed on the cover borrow sources (Dwyer 2014) revealed that the upper foot of the undisturbed soil profile at each had a saturated hydraulic conductivity about one order of magnitude higher than the remaining of the soil profile evaluated. Consequently, the calculated bulk saturated hydraulic conductivity of the admixture layer was increased an order of magnitude from the calculated value to account for dynamic processes such as freeze/thaw cycles, wet/dry cycles, and biointrusion. Because the admixture depth is 14 inches thick, the entire depth of the admixture's saturated hydraulic conductivity was increased by an order of magnitude.

The moisture retention data for the cover soil was also altered to reflect the addition of the rock in the surface admixture layer and the subsequent loss of water storage capacity in the soil. The actual volumetric moisture content versus soil suction measurements made in the laboratory was utilized as the basis. Each respective measured volumetric moisture content used to determine the layer's moisture characteristic curve was reduced per Equation 4-6 [ASTM (2015) and Bouwer & Rice (1984)].

$$\theta_b = (1 - V_r)\theta_s$$ **Equation 4-6**

$where: \theta_b = bulk\ volumetric\ moisture\ content$

$\theta_s = \text{satuarated}\ volumetric\ moisture\ content$

$V_r = volume\ of\ rock$

The initial soil suction or matric potential value (h_i) for the fine-grained tailings (and coarser-grained tailings sandwiched within the fine-grained tailings) after consolidation is computed utilizing Equation 4-4 (van Genuchten 1978) with a modified (reduced) saturated moisture content (Figure 6) based on the computed final void ratio. The saturated moisture content is reduced because the void ratio was decreased due to consolidation of the layer, resulting in reduced storage capacity of the layer. The initial soil suction for the fine-grained tailings is therefore reduced. For Profile B8, all initial soil suction values for the fine-grained tailings layers were reduced to zero due to the saturated conditions created from their consolidation (refer to Tables 11 to 14).

Table 11. Profile B2 with Mine Spoils and ET Cover: Soil Layer Input Parameters

Soil Layer	Thickness (ft)	Data Sample (MWH 2014)	Ks (cm/sec)	van Genuchten parameters				Initial Suction[a] (-cm)
				θs	θr	α	n	
Cover Rock/Soil Admixture	1.17	SB-B4-01	4.26×10^{-4}	0.3478	0	0.0373	1.2243	2200.0
ET Cover	2.83	SB-B4-01	7.40×10^{-5}	0.5191	0	0.0373	1.2243	2200.0
Mine Spoils	10.8	Use TT-205-GT1	2.20×10^{-4}	0.3774	0	0.0525	1.2338	3278.4
Cover soil - Radon Barrier	1.5	EB-B6-03	3.60×10^{-5}	0.50926	0	0.01399	1.26891	6272.7
Fill	4.5	Use B11-03	2.50×10^{-5}	0.30331	0	0.01632	1.06655	2692958106.4[c]
	5.5			0.30331	0	0.01632	1.06655	699434.4
Fine Tailings	2.32[b]	Use B10-14	2.90×10^{-8}	0.555174	0	0.0011	1.16727	1617.0
Alluvium	19	Use B11-10	5.60×10^{-4}	0.45752	0.06145	0.13956	1.31247	11741.6

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]Thickness adjusted for consolidation, refer to Table 1
[c]It appears large, but this value was calculated from its degree of saturation.

Table 12. Profile B8 with Mine Spoils and ET Cover: Soil Layer Input Parameters

Soil Layer	Thickness (ft)	Data Sample (MWH 2014)	Ks (cm/sec)	van Genuchten parameters				Initial Suction[a] (-cm)
				θs	θr	α	n	
Cover Rock/Soil Admixture	1.17	SB-B4-01	4.26×10^{-4}	0.3478	0	0.0373	1.2243	2200.0
ET Cover	2.83	SB-B4-01	7.40×10^{-5}	0.5191	0	0.0373	1.2243	2200.0
Mine Spoils	11.7	Use TT-205-GT1	2.20×10^{-4}	0.3774	0	0.0525	1.2338	3278.4
Cover soil - Radon Barrier	1.5	EB-B6-03	3.60×10^{-5}	0.50926	0	0.014	1.26891	6272.7
Fill	5	Use B11-03	2.50×10^{-5}	0.30331	0	0.0163	1.06655	4407686039.0[c]
Coarse Tailings	19.50	B8-02	3.60×10^{-4}	0.41023	0	0.4779	1.16163	779.9
Fine Tailings	4.33[b]	Use B8-9	3.00×10^{-8}	0.54754	0	0.0045	1.15784	0
Fine Tailings	3.83[b]	Use B8-9	3.00×10^{-8}	0.54754	0	0.0045	1.15784	0
Coarse/Fine Tailings	0.49[b]	B8-06	1.60×10^{-5}	0.47776	0	0.0009	1.37788	0
Coarse/Fine Tailings	0.49[b]	B8-06	1.60×10^{-5}	0.47776	0	0.0009	1.37788	0

Soil Layer	Thickness (ft)	Data Sample (MWH 2014)	Ks (cm/sec)	van Genuchten parameters				Initial Suction[a] (-cm)
				θs	θr	α	n	
Fine Tailings	5.29[b]	Use B8-09	$3.00x10^{-8}$	0.54754	0	0.0045	1.15784	0
Coarse/Fine Tailings	0.49[b]	B8-08	$1.30 x10^{-7}$	0.41638	0	1.8777	1.16882	0
Coarse/Fine Tailings	2.44[b]	B8-08	$1.30 x10^{-7}$	0.41638	0	1.8777	1.16882	0
Fine Tailings	0.48[b]	Use B8-09	$3.00 x10^{-8}$	0.54754	0	0.0045	1.15784	0
Alluvium	18	Use B1-13A	$1.70 x10^{-6}$	0.4951	0.0398	0.4325	1.20486	98.5

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]Thickness adjusted for consolidation, refer to Table 2
[c]It appears large, but this value was calculated from its degree of saturation.

Table 13. Profile B10 with Mine Spoils and ET Cover: Soil Layer Input Parameters

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	van Genuchten parameters				Initial Suction[a] (-cm)
				θs	θr	α	n	
Cover Rock/Soil Admixture	1.17	SB-B4-01	$4.26 x10^{-4}$	0.3478	0	0.0373	1.2243	2200.0
ET Cover Soil	2.83	SB-B4-01	$7.40 x10^{-5}$	0.5191	0	0.0373	1.2243	2200.0
Mine Spoils	22.6	Use TT-205-GT1	$2.20 x10^{-4}$	0.3774	0	0.0525	1.2338	3278.4
Cover soil - Radon Barrier	1.5	EB-B6-03	$3.60 x10^{-5}$	0.50926	0	0.01399	1.26891	6272.7
Fill	5	Use B11-03	$2.50 x10^{-5}$	0.30331	0	0.01632	1.06655	4407686039.0[c]
Coarse Tailings	5	B10-02	$4.30 x10^{-4}$	0.3481	0	0.67277	1.13662	3662.8
Coarse Tailings	5.5	B10-03	$6.70 x10^{-5}$	0.4272	0	1.87772	1.16882	583.2
Coarse/Fine Tailings	7.28[b]	Use B8-08	$1.30 x10^{-7}$	0.43563	0	0.00129	1.29116	140.6
Fine Tailings	0.95[b]	Use B10-14	$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0
Fine Tailings	1.91[b]		$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0
Fine Tailings	3.81[b]		$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0
Coarse Tailings	0.98[b]	B10-03	6.70x10-7	0.41514	0	1.87772	1.16882	0
Fine Tailings	2.40[b]	Use B10-14	$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0
Fine Tailings	0.48[b]		$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	van Genuchten parameters				Initial Suction[a] (-cm)
				θs	θr	α	n	
Coarse Tailings	0.98[b]	Use B8-08	$1.30x10^{-7}$	0.43563	0	0.00129	1.29116	0
Fine Tailings	3.84[b]	Use B10-14	$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0
Fine Tailings	1.93[b]		$3.00 x10^{-8}$	0.57044	0	0.0011	1.16727	0
Alluvium	19	B10-18	$2.40x10^{-5}$	0.40301	0.00829	0.54078	1.1191	911.3

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]Thickness adjusted for consolidation, refer to Table 3
[c]It appears large, but this value was calculated from its degree of saturation.

Table 14. Profile B11 with Mine Spoils and ET Cover: Soil Layer Input Parameters

Soil Layer	Depth BGS	Data Sample (MWH 2014)	Ks (cm/sec)	van Genuchten parameters				Initial Suction[a] (-cm)
				θs	θr	α	n	
Cover Rock/Soil Admixture	1.1666667	SB-B4-01	$4.26x10^{-4}$	0.3478	0	0.0373	1.2243	2200.0
ET Cover Soil	2.8333333	SB-B4-01	$7.40 x10^{-5}$	0.5191	0	0.0373	1.2243	2200.0
Mine Spoils	0.8	Use TT-205-GT1	$2.20 x10^{-4}$	0.3774	0	0.0525	1.2338	3278.4
Cover soil - Radon Barrier	1.5	EB-B6-03	$3.60 x10^{-5}$	0.50926	0	0.014	1.26891	6272.7
Fill	13	Use B11-03	$2.50 x10^{-5}$	0.30331	0	0.0163	1.06655	6284703564.2[c]
	5			0.30331	0	0.0163	1.06655	20421368.8[c]
	10			0.30331	0	0.0163	1.06655	138843.8[c]
	12.5			0.30331	0	0.0163	1.06655	3974.6
Fine Tailings	11.40[b]	B8-09	$3.00 x10^{-8}$	0.56256	0	0.0045	1.15784	95.7
Alluvium	36	B11-10	$5.6 x10^{-4}$	0.45752	0.0615	0.1396	1.31247	109.7

[a]Initial suction values for each soil layer were computed utilizing the acquired van Genuchten parameters and measured moisture content (MWH 2014).
[b]Thickness adjusted for consolidation, refer to Table 4
[c]It appears large, but this value was calculated from its degree of saturation.

5.0 COMPUTER SIMULATION RESULTS

This section presents the modeling output from the profiles. Each respective profile was modeled in its existing condition and then again with the assumed mine spoils and new ET Cover based on the proposed design (Figures 8 to 11). The profiles were modeled for a period of 20 years consisting of typical climate for the first 10 years followed by the two wettest years on record, followed by eight more typical climate years. The results are intended to present a direct comparison of the difference between ‘before’ conditions and ‘after’ conditions. It is important to understand that the results are not intended to evaluate the flux which actually occurs for the existing condition, but rather to determine what the relative change in flux would be by conducting the proposed removal action.

The water balance results from these 20-year simulations reveal that after a few years of typical climate conditions, there is no significant year-to-year change to the annual water balance variables (Appendix A and Figures 16-19). This observation verifies that the 20-year timeframe is sufficient to determine if water movement through the profiles could reach the zone of saturation. Furthermore, the evaluation showed that the existing cover (rock over soil radon barrier) allows for percolation and thus an increase of moisture within the profile, whereas the profile with mine spoils and an ET Cover allows no percolation and thus the profile is undergoing a drying trend. Based on this finding, the long-term drainage aspects from the tailings of the impoundment are improved by the addition of the mine spoils and ET Cover.

The difference in flux (cumulative and average annual) between the existing cover and the ET Cover is shown in Table 15. Unsaturated alluvium is the bottom layer of each profile modeled. These analyses assumed that drainage though the base of the unsaturated alluvium is free to enter the underlying groundwater. Appendix A contains year-by-year water balance results for each profile evaluated. An important result of the evaluation is that the potential long-term drainage from the tailings to the base of the unsaturated alluvium is reduced by the addition of the mine spoils and ET Cover versus the existing cover.

The computer simulations revealed no difference in drainage through the base of the alluvium modeled for the 'before' and 'after' condition of profiles B2, B8, and B10. In these borings, the underlying alluvium was relatively dry compared to the overlying fine-grained tailings and had significant water storage capacity available compared to the volume of drainage. Thus, any drainage from the tailings will be captured and held within the alluvium. It is important to note that the drainage from the alluvium calculated in the modeling is likely due to the unit gradient condition applied to the base of each profile forcing drainage based on steady state conditions at the bottom node. It does not necessarily mean there is actually drainage from the alluvium.

There was a de minims difference between the simulations for Profile B11 in Borrow Pit 2. However, there are no mine spoils to be placed over B11, only a thin layer of clean fill.

Table 15. Cumulative and Average Annual Difference in Flux (cm/yr) between Existing Conditions Profiles and Proposed New Profiles with Mine Spoils and ET Cover

Profile		Layer Base	Difference (cm) for 20-year period	Average Annual Difference (cm)
B2	North Cell	Cover	+158	+7.89
		Base of Unsaturated Alluvium	0	0
B8	Borrow Pit 1	Cover	+136	+6.79
		Base of Unsaturated Alluvium	0	0
B10	Borrow Pit 1	Cover	+115	+5.75
		Base of Unsaturated Alluvium	0	0
B11	Borrow Pit 2	Cover	+127	+6.35
		Base of Unsaturated Alluvium	negligible[1]	negligible[1]

+ denotes the drainage in the existing condition profile is greater than that with the mine spoils and ET Cover.

- denotes the drainage in the existing condition profile is less than that with the mine spoils and ET Cover.

[1] Modeled values of -0.00004 and -0.000002 for the difference for 20 year period and average annual difference, respectively, are considered negligible values.

5.1 North Cell: Profile B2

Profile B2 represents an area in the North Cell with about 2.5 ft of fine-grained tailings or slimes, and is representative of the majority of the area where mine spoils are to be placed. The area is proposed to have about 10.8-ft of mine spoils placed on it in addition to a 4-ft ET Cover. About 6 inches of rock from the existing cover will be removed for later use prior to placement of the mine spoils (refer to Figures 1, 2 and 8).

Both the existing profile B2 and the profile with the mine spoils and new ET Cover added have an average annual drainage rate of 1.15×10^{-6} cm/year or a hydraulic conductivity at the base of the profile of 3.65×10^{-14} cm/sec given the steady state conditions assumed. Relative to the existing condition, the ET Cover allows for drying of the profile and reduces any theoretical recharge to groundwater via the conservative assumptions used in the calculations. In conclusion, there is no increase in drainage to the underlying groundwater over the existing condition due to the addition of mine spoils and new ET Cover in Profile B2. There is projected to be no release to groundwater associated with the proposed removal action.

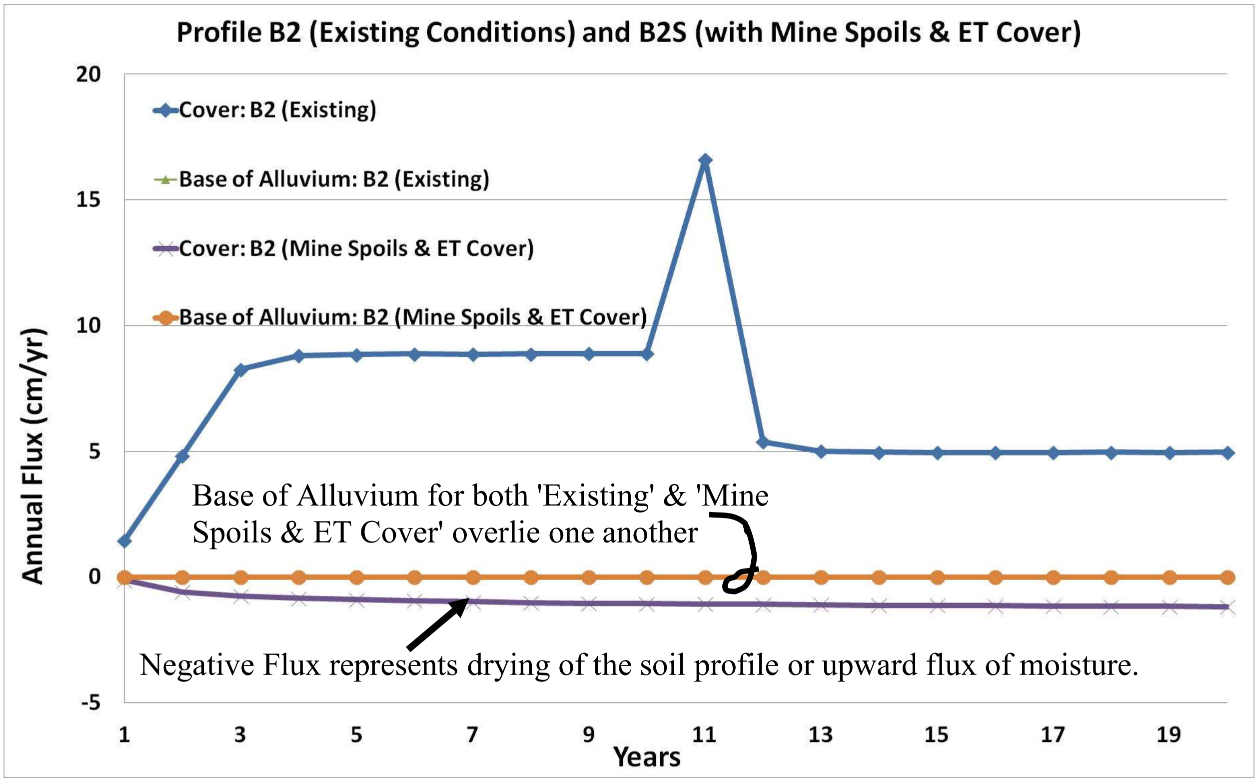

Figure 16. Profile B2 Computer Simulation Results

5.2 Borrow Pit 1: Profiles B8 and B10

Profile B8 represents an area in Borrow Pit 1 that has about 38 ft of combined coarse- and fine-grained tailings. This area is proposed to have about 11.7 ft of mine spoils placed on it in addition to a 4-ft ET Cover. About 6 inches of rock from the existing cover will be removed for later use prior to placement of the mine spoils (refer to Figures 1, 2 and 9).

Both the existing profile B8 and that with the mine spoils and new ET Cover added have an average annual drainage rate of 1.23×10^{-4} cm/year or a hydraulic conductivity given the steady state conditions assumed at the base of the profile of 3.91×10^{-12} cm/sec (Table 15, Figure 17). Relative to the existing condition, the ET Cover allows for drying of the profile and reduces any theoretical recharge to groundwater via the conservative assumptions used in the calculations. In conclusion, there is no increase in drainage to the underlying groundwater over the existing condition from the addition of mine spoils and new ET Cover in Profile B8.

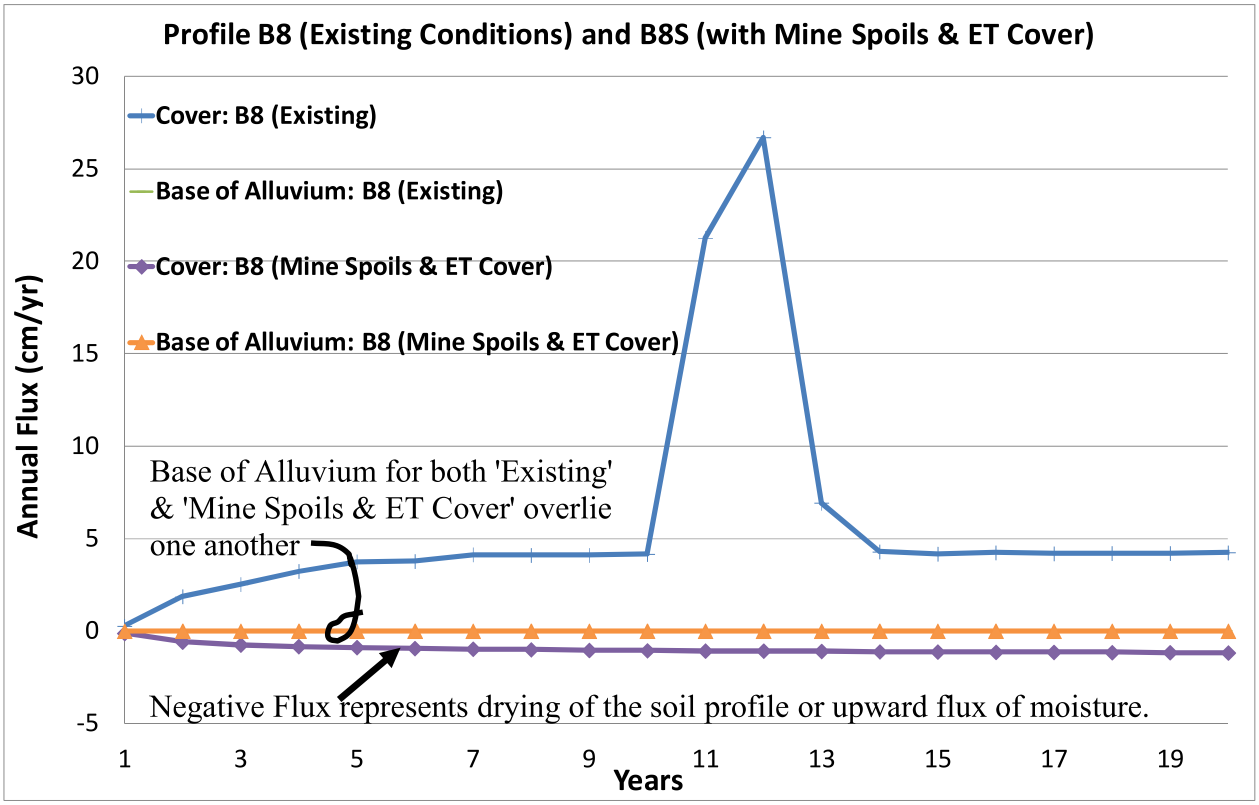

Figure 17. Profile B8 Computer Simulation Results

Profile B10 represents an area in Borrow Pit 1 that has about 36 ft of combined coarse- and fine-grained tailings. The area is proposed to have about 22.6 ft of mine spoils placed on it in addition to a 4-ft ET Cover. About 6 inches of rock from the existing cover will be removed for later use prior to placement of the mine spoils (refer to Figures 1, 2 and 10).

Both the existing and 'after' profile of B10 have an average annual drainage rate of 5.57×10^{-6} cm/year or a hydraulic conductivity given the steady state conditions assumed at the base of the profile of 1.77×10^{-13} cm/sec (Table 15, Figure 18).

Relative to the existing condition, the ET Cover allows for drying of the profile and reduces any theoretical recharge to groundwater via the conservative assumptions used in the calculations. In conclusion, there is no increase in drainage to the underlying groundwater over the existing condition due to the addition of mine spoils and new ET Cover in Profile B10.

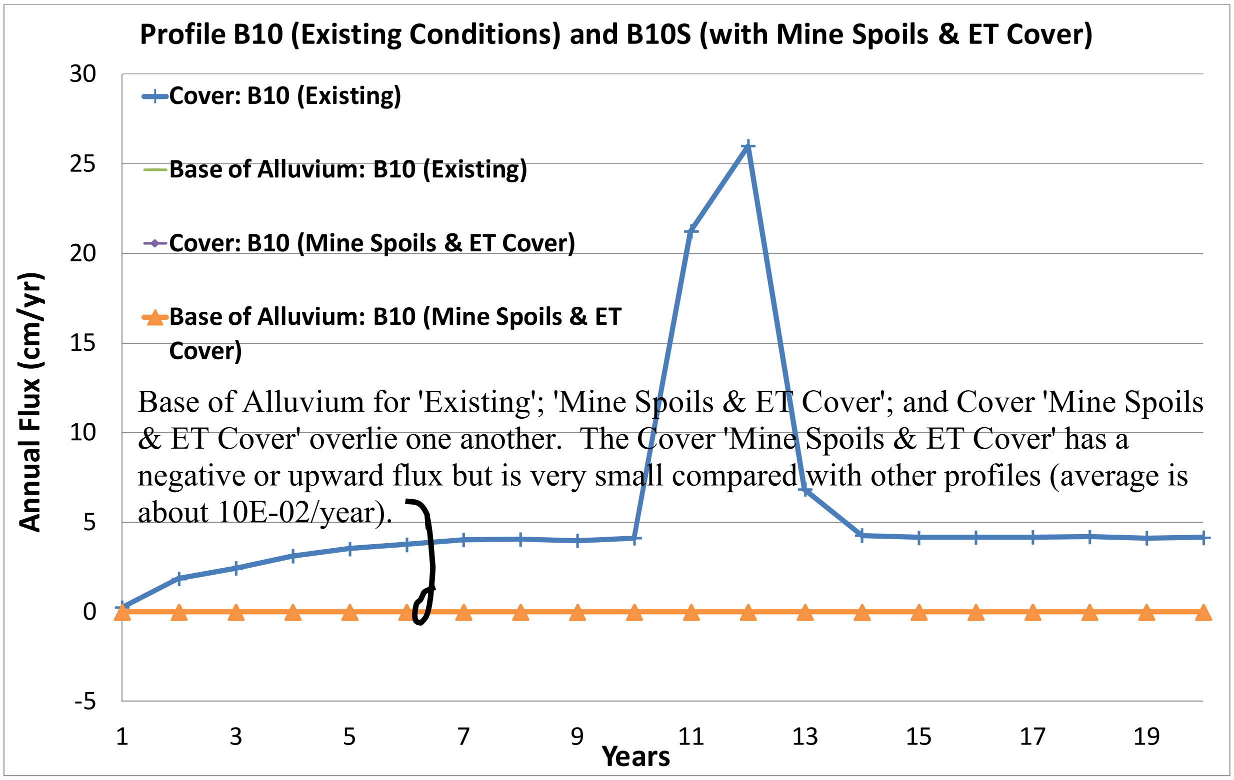

Figure 18. Profile B10 Computer Simulation Results

5.3 Borrow Pit 2: Profile B11

Profile B11 represents an area in Borrow Pit 2 that has about 36 ft of combined coarse- and fine-grained tailings. No mine spoils placement is planned for this area, just a thin layer of clean fill in addition to a 4-ft ET Cover. About 6 inches of rock from the existing cover will be removed for later use prior to placement of the mine spoils (refer to Figures 1, 2 and 11).

The existing profile B11 has an average annual drainage rate of 0.488508 cm/year or a hydraulic conductivity given the steady state conditions assumed at the base of the profile of 1.549×10^{-8} cm/sec. The profile B11 after placement of fill and new ET Cover has an average annual drainage rate of 0.488510 cm/year or a hydraulic conductivity given the steady state conditions assumed at the base of the profile of 1.549×10^{-8} cm/sec (Table 15, Figure 19).

Relative to the existing condition, the ET Cover allows for drying of the profile and reduces any theoretical recharge to groundwater via the conservative assumptions used in the calculations. In conclusion, there is no increase in drainage to the underlying groundwater over the existing condition due to the addition of soil over Profile B11.

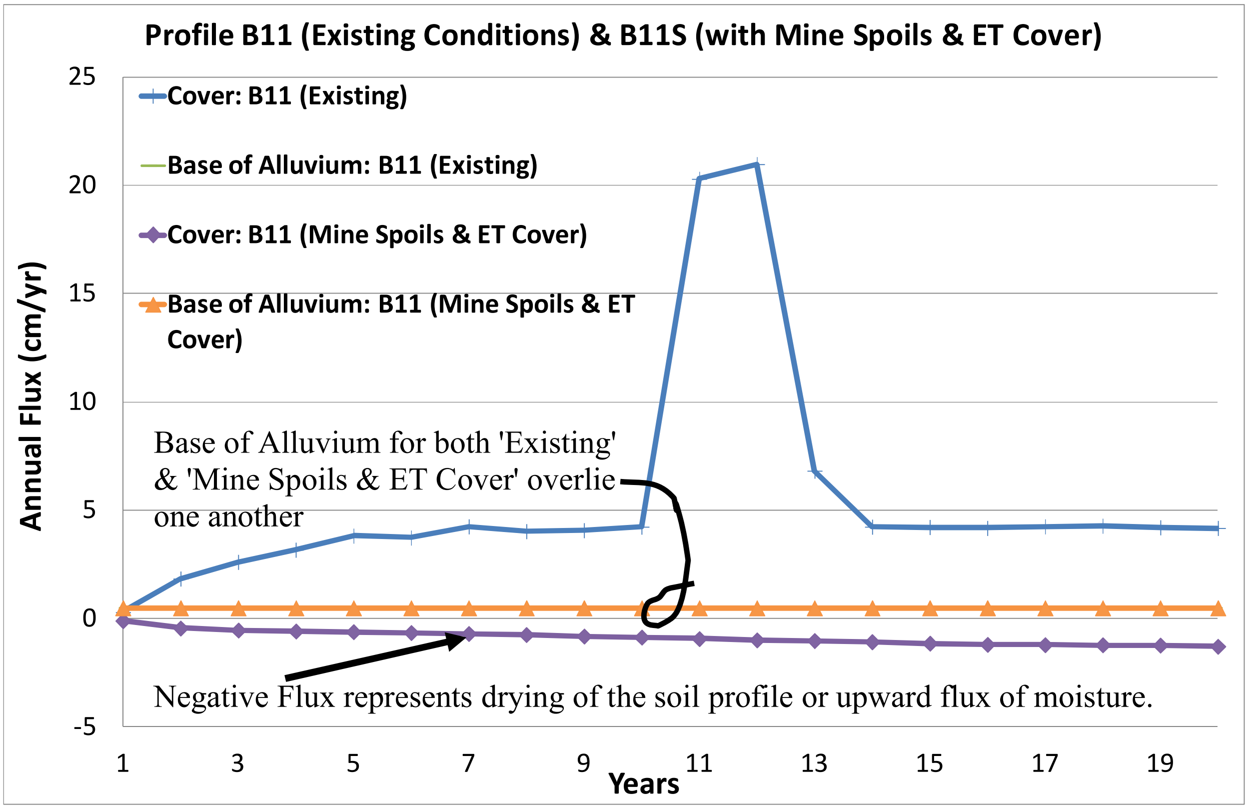

Figure 19. Profile B11 Computer Simulation Results

6.0 LONG-TERM SIMULATIONS: BORROW PIT 1: PROFILE B8

6.1 Overview of Long-Term Simulations

The profile analyses summarized in Section 5 were modeled for a 20-year period. These results each revealed no increased impact to groundwater due to the placement of the mine spoils and ET cover on the existing impoundment. The consolidation results (Section 3) of the four profiles analyzed estimated that only the fine-grained tailings in Profile B8 would actually reach full saturation after consolidation. Because Profile B8 after placement of the mine spoils is the only profile with fully saturated tailings, it is considered the worst case of the four profiles evaluated. An additional set of simulations was performed on this worst case profile to evaluate the long-term effects (Figure 9).

This long-term analysis is intended to evaluate the water balance of the entire profile and potential flux to groundwater over an extended period of time, accounting for the time-dependent variation in the input parameters (climate, soil, and vegetation). It is also meant to evaluate the potential for water accumulation above the existing radon barrier, and thereby, increase the risk of future side seeps. This long-term simulation used the wettest initial conditions resulting from the most allowable construction water placed in the mine spoils and ET Cover. The construction specifications for the installation of both the mine spoils and ET Cover shall limit the moisture content during installation to the optimum moisture content per ASTM D698. That is, each lift of soil placed of both the mine spoils and ET Cover on the impoundment shall be at or dry of its respective optimum moisture content prior to the installation of a subsequent lift of soil. Consequently, this set of simulations assumed the moisture content for ***all*** of the mine spoils and ET Cover were installed at the ***optimum moisture content***.

The UNSAT-H software cannot alter input parameters after the initiation of a given simulation. Consequently, running the long-term evaluation of Profile B8 involved multiple stages. That is, for the long-term evaluation, the initial simulation with an initial set of input parameters was performed for a specified time period and set of climatic upper boundary conditions. The last day of the last year of that initial simulation output - specifically, the matric potential values for each node from the previous simulation - was then used as the initial soil conditions for each node in the subsequent simulation with the altered input parameters. For example, the *final* soil suction values for each node in the model geometry for the ‘initial’ stage were used as the starting conditions for the next 'short-term' stage. There was no vegetation included in the 'initial' stage, but vegetation was included in subsequent stages (Cedar Creek 2014). The long-term simulations were performed in four sequential stages: 'initial', 'short-term', 'intermediate', and 'long-term' (Figure 20).

Time	Initial	Short-Term	Intermediate	Long-Term
Vegetation	None	Disturbed (Reclaimed)	Grassland	Shrubland
Soil	Remolded (Lab Measured)	Remolded (Lab Measured)	Remolded (Lab Measured)	Undisturbed (In Situ Measured)
Climate	Typical	Typical and Extreme	Typical and Extreme	Typical and Extreme

Figure 20. Input Based on Design Life for Computer Simulations

The first stage of the long-term simulations for Profile B8 assumed no vegetation for the first year. The soil from the south drainage borrow area was used for the ET Cover since it is the largest borrow source. The soil hydraulic input parameters from different borrow sources showed minimal variation in the predicted point of diminishing returns (PODR) for the cover profiles from the sensitivity analyses described in Dwyer (2017). THE PODR is defined as the depth of cover whereby additional cover thickness no longer reduces flux. The remolded values for the soil hydraulic properties based on laboratory measurements (Section 4) were used in the 'initial' stage. The input parameters are summarized in Table 12 with the exception of the initial suction values for the mine spoils and ET Cover. The initial soil suction values were revised to correlate with the optimum moisture content.

The initial suction values for the mine spoils and ET Cover were computed utilizing Equation 4-4 and the optimum moisture content (ASTM D698) for the respective soils. The optimum moisture content for the ET Cover (soil sample SB-B4-01) is 19.6 percent (vol.) (MWH 2014). The corresponding soil suction or matric potential is 2053.1 cm. The optimum moisture content for the mine spoils (soil sample TT-205-GT1) is 22.2 percent (vol.) (MWH 2014). The corresponding soil suction or matric potential is 175.2 cm.

Other soil input parameters for this set of simulations are contained in Table 12. These soil properties were also the soil input parameters used for the short- to intermediate- time periods. No vegetation is assumed for the 'initial' stage with average weather conditions. Average weather conditions were assumed because dry conditions would yield no flux while wet conditions would yield vegetation. The moisture condition (matric potential for each node in the model geometry) at the end of the initial year, was then taken and used as the initial moisture conditions (matric potential for each node in the modeled geometry) for the next 'short-term' stage.

The second stage of the long-term simulation included vegetation from the reclaimed vegetation analog (Cedar Creek 2014; refer to Section 4 for specifics on the input parameters). Tables 16 and 17 contain rooting vegetation input parameters used in this set of simulations. The reclaimed community of vegetation represents disturbed vegetation and generally considered from a time period shortly after seeding the installed ET Cover up to about 50 years (Cedar Creek 2014). The soil input parameters and geometries from the first stage of simulations were consistent with this stage of simulations. Typical climate conditions were used for ten consecutive years followed by the wettest year on record two years in a row, followed by eight more years of typical climate conditions. This is conservative to apply the wettest year on record in two

consecutive years every twenty years and include no dry years in the analysis. Applying two consecutive wettest years on record is assumed to be beyond the worst case infiltration event. The moisture condition (matric potential for each node in the model geometry) at the end of the last year of the respective 'short-term' stage for each admixture design, was then taken and used as the initial moisture conditions (matric potential for each node in the new model geometry) for the next 'intermediate' stage.

Table 16. Rooting Parameters (Cedar Creek 2014)

Parameter	Reclaimed Analog	Grass Analog	Shrub Analog
a	556.28266872	0.34471705	0.42851959
b	-0.00000543	-0.07151063	-0.03407481
c	-555.91871302	0.13639067	0.07781172

Table 17. Vegetation Parameters (Cedar Creek 2014)

Parameter	Reclaim Analog	Grass Analog	Shrub Analog
LAI	0.91	0.64	0.52
% Bare Area	52.3%	64.9%	75.2%
Root Length	147 cm	142 cm	155 cm

The third stage of the long-term simulation included vegetation from the grassland vegetation analog (Cedar Creek 2014; refer to Section 4 for specifics on the input parameters). The grassland community represents undisturbed vegetation and is assumed to represents the vegetation on the cover from about 25 to 100 years after construction (Cedar Creek 2014). The soil input parameters and geometries from the 'short-term' stage were consistent with this 'intermediate' stage. Typical climate conditions were used for ten consecutive years followed by the wettest year on record two years in a row, followed by eight more years of typical climate conditions. The wettest years run consecutively is assumed to be beyond the worst case infiltration event. The moisture condition (matric potential for each node in the model geometry) at the end of the last year of each respective 'intermediate' stage for each admixture design, was then taken and used as the initial moisture conditions (matric potential for each node in the new model geometry) for the next 'long-term' stage.

The fourth stage of the long-term simulation included vegetation from the shrubland vegetation analog (Cedar Creek 2014; refer to Section 4 for specifics on the input parameters). The shrubland community represents vegetation in an undisturbed setting and is assumed to represent vegetation on the cover from about 50 to 1,000 years following construction (Cedar Creek 2014). The geometries from the 'intermediate' stage were consistent with this 'long-term' stage. The soil input parameters were changed to the soil analog data obtained from the south drainage borrow area that represent an undisturbed soil structure or the long-term status of the soil (Dwyer 2014). Typical climate conditions were used for ten consecutive years followed by the wettest year on record two years in a row, followed by eight more years of typical climate conditions. The wettest years run consecutively is assumed to be the worst case infiltration event.

6.2 Long-Term Simulations Results with Respect to Groundwater

The first objective of the long-term analyses is to evaluate the water balance of the entire profile and potential effect on groundwater over an extended time period taking into account the time-dependent variation in the input parameters (climate, soil, and vegetation). The results of the analysis demonstrated that the de minims amount of water flux through the alluvium at Borrow Pit 2 (worst case profile) will not increase over time. The results indicate the soil profile has more than sufficient storage capacity in the existing fill and in the alluvium to contain any existing moisture or added moisture for the long-term. Although, this analysis only focused on the worst case location, its results can be transferred to the entire repository to demonstrate that addition of the mine waster and ET cover will not adversely impact groundwater over the long-term.

The soil suction values versus depth from the surface over a 63-year period was plotted for the entire Profile B8 in the 'before' and ‘after’ scenarios [refer to Figures 21 and 22]. It can be seen that the soils, including the tailings, are moving toward an equilibrium moisture status under both scenarios. The deepest and wetter fine-grained tailings are drying under both scenarios. That is, the suction values are increasing. Whereas the suction values of the coarser-grained tailings above these wetter tailings are moving to the left or decreasing. Wet tailings are drying while tailings materials that are drier are pulling moisture from the wetter soils.

It can also be seen that some moisture has moved down from the fine-grained tailings into the upper portion of the unsaturated alluvium under both scenarios. The moisture movement downward is controlled by the very low saturated hydraulic conductivity of the fine-grained tailings (about 10^{-8} cm/sec). There was no downward moisture movement after about 40 years for both the 'before' and 'after’ scenarios. That is, the base of the moisture movement into the alluvium or decrease in soil suction did not change from model years 2043 to 2062. Because the moisture is no longer moving downward, the moisture in the tailings is not a threat to the underlying groundwater.

The movement of water into the top of the alluvium from the fine tailings is identical in both the ‘before’ and ‘after’ scenarios. This movement is likely the consequence of the applied unit gradient condition in the modeling. A unit gradient bottom boundary forces water to be removed. This drainage from the base of the unsaturated alluvium albeit very small pulls moisture from the tailings into the alluvium. During the drilling program, two improvised piezometers that extended through the fine-grained tailings were installed in open CPT holes at locations B10 and B18. These piezometers experienced no seepage nor did the open holes experience any creep during the several weeks they were monitored (MWH 2014). This is consistent with the notion that *actual* drainage from the tailings is unlikely.

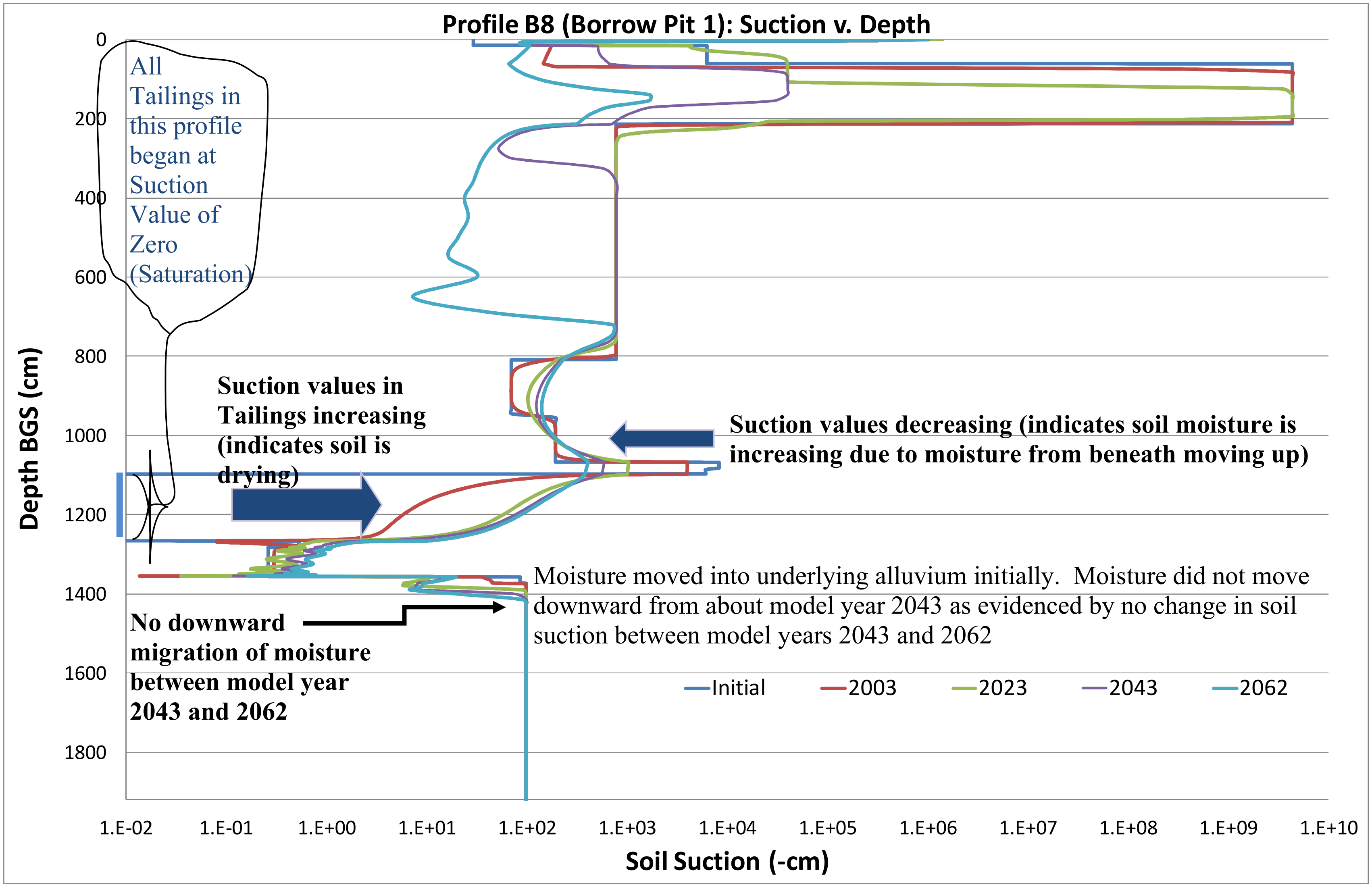

Figure 21. Profile B8 'Before' Condition: Soil Suction v. Depth

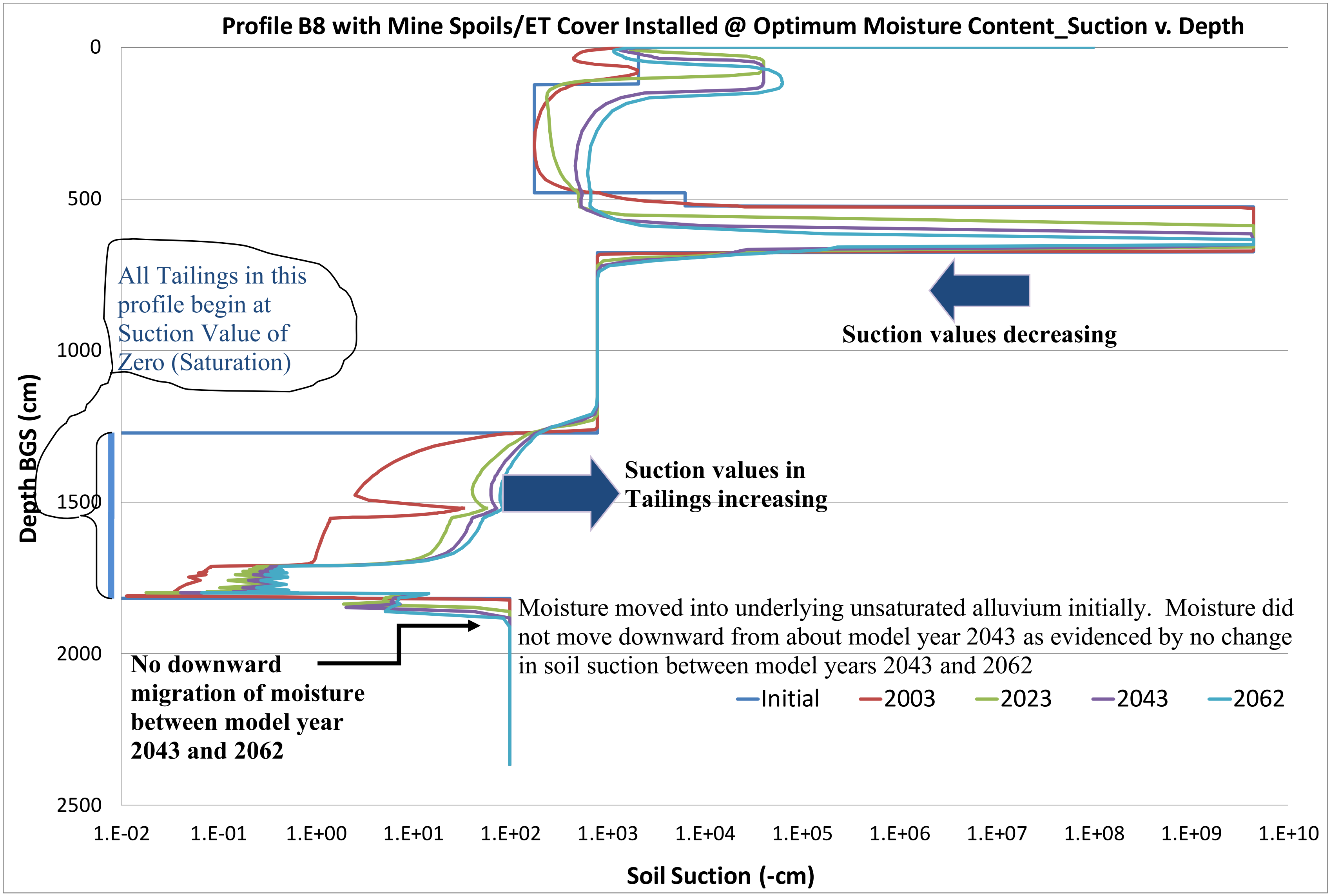

Figure 22. Profile B8 'After' Placement of Mine Spoils and ET Cover Installed @ Optimum Moisture Content

It has been noted that the initial suction values for the fill soil appear high even though these values were computed based on the field measured moisture content and corresponding laboratory measured moisture retention characteristics (MWH 2014). Figures 21 and 22 for profile B8 show that the higher initial soil suction in the *fill layers* actually makes the analysis more conservative. That is, the 'before' condition (Figure 21) shows that as percolation comes through the existing cover it moves into the fill soil and reduces the soil suction (increases the moisture content). Thus the initial condition for the 'before' condition provides more initial storage capacity for percolation through the existing cover. Eventually, this moisture works its way down the profile as can be seen with the suction graphic for the year 2063 where the suction has moved significantly to the left. This shows that moving forward past 2063, the percolation occurring in the existing cover may actually allow moisture into the tailings thus increasing the potential for future groundwater impacts. Conversely, Figure 22 indicates that the soil suction over time has little change other than to very slowly move toward steady state. There is no percolation coming from the new ET Cover and thus there is no potential future impact on groundwater. In other words, the impoundment has been improved by the installation of the new ET Cover and is evidenced by these two figures.

6.3 Long-Term Simulations Results with Respect to Lateral Seepage

The long-term modeling was also used to address the concern for potential water accumulation on the existing radon barrier, and thereby, increase the risk of future side seeps. The concern is that water from the placement of the mine waste will migrate vertically downward to the barrier, accumulate, and eventually travel laterally along the layer to cause side seeps at the perimeter of the repository. This modeling exercise was also used to address the concern regarding the sensitivity of moisture during placement of the mine spoils and ET Cover during construction.

To address these concerns, the long-term model focused on the matric potential of the soil profile as a function of time. The output features the base of the mine spoils and middle of the radon barrier. Two sets of long-term simulations performed considered different placement water contents for the mine spoils and ET Cover. The first water content used was the installed moisture condition of all of the mine spoils and ET Cover at the suction value corresponding to the respective optimum moisture content (ASTM D698). The optimum moisture content is the wettest condition that the materials can be installed. Per the design specifications, any wetter condition will require removal of the material and drying it or reworking the soil to dry it in place. However, no material will be allowed to be placed on top of a wet layer of soil until that underlying soil lift meets the specified conditions. The mine spoils are placed directly on the existing cover/radon barrier less the removal of the existing surface riprap that will be utilized elsewhere in the project. The next simulation set used an increased moisture in the mine spoils and ET Cover whereby they were ***entirely*** installed ***3 percent wet of the optimum moisture*** content per ASTM D698. This moisture content is higher than will be allowed during actual placement, but was modeled as a sensitivity analysis.

The initial suction values for the mine spoils and ET Cover in these simulations were computed utilizing Equation 4-4 and either the optimum moisture content or 3 percent wet of the optimum moisture content per ASTM D698 for the mine spoils and cover soil. The optimum moisture content (ASTM D 698) for the ET Cover (Soil sample SB-B4-01) is 19.6 percent (vol.); therefore 3 percent wet of optimum for the cover soil the moisture content is 22.6 percent (vol.). The corresponding soil suction or matric potential is 1083.0 cm. The optimum moisture content

for the mine spoils is (soil sample TT-205-GT1) is 22.2 percent (vol.); therefore 3 percent wet of optimum for the cover soil the moisture content is 25.2 percent (vol.). The corresponding soil suction or matric potential is 96.8 cm. Other soil input parameters for this set of simulations is contained in Table 12. The vegetation input parameters are those contained in Tables 16 and 17.

Under the optimum moisture content placement scenario, the model results indicated the mine spoils began drying immediately after installation. There is no flux that moves beneath the ET Cover (Dwyer 2017) and thus the net flux from Profile B8 is actually negative or upward with moisture from underlying wet soils moving upward and out of the profile. This trend will continue until a relative steady state is achieved. The adjacent soils of the mine spoils placed directly on the existing radon barrier soil have different soil textures and varied initial moisture contents. These adjacent soils are shown in Figure 23 moving toward equilibrium with respect to moisture as the soil suctions from each equilibrate about twenty to thirty years after installation of the wetter mine spoils. After the two soils equilibrate, both layers begin to dry. This drying trend will continue similarly to the mine spoils until a relative steady state condition is achieved at a suction value greater than that shown at the end of this set of simulations in the year 2062. The drying trend is assured given no recharge through the ET Cover (Dwyer 2017).

The results of this computer simulation for Profile B8 with all of the mine spoils and ET cover installed 3 percent wet of optimum (Figure 24) are similar to the previous analysis with the mine spoils and ET Cover installed at optimum moisture content (Figure 23). That is, the soil suction (Figure 24) and thus moisture content of the installed mine spoils and ET Cover will not cause any moisture build-up on the underlying radon barrier/liner while the radon barrier/liner continues to dry similar to that shown in Figure 23.

Even though the mine spoils initial suction value is very wet at 3 percent above optimum moisture content, it quickly dries and continues to dry during the full simulation (middle of mine spoils). The base of the mine spoils and adjacent radon barrier suction values move toward equilibrium (equal suction values) and then eventually all layers show a drying trend for the duration of the long-term simulation. This drying trend will continue until a steady state condition is reached, presumably at a suction value greater than the values shown for the base of the mine spoils or middle of the radon barrier. This is largely due to no recharge through the ET Cover system (Dwyer 2017) and the initial conditions are the wettest conditions; thus the profile will continue to dry as time passes while approaching steady state conditions.

Figure 24 also illustrates that there is no moisture buildup on the existing radon/barrier and thus no potential for future seepage from the impoundment even for mine spoils and cover material placed at 3 percent wet of optimum moisture content. Additionally, the moisture content of the mine spoils and cover soil is not a concern for future seepage form the impoundment.

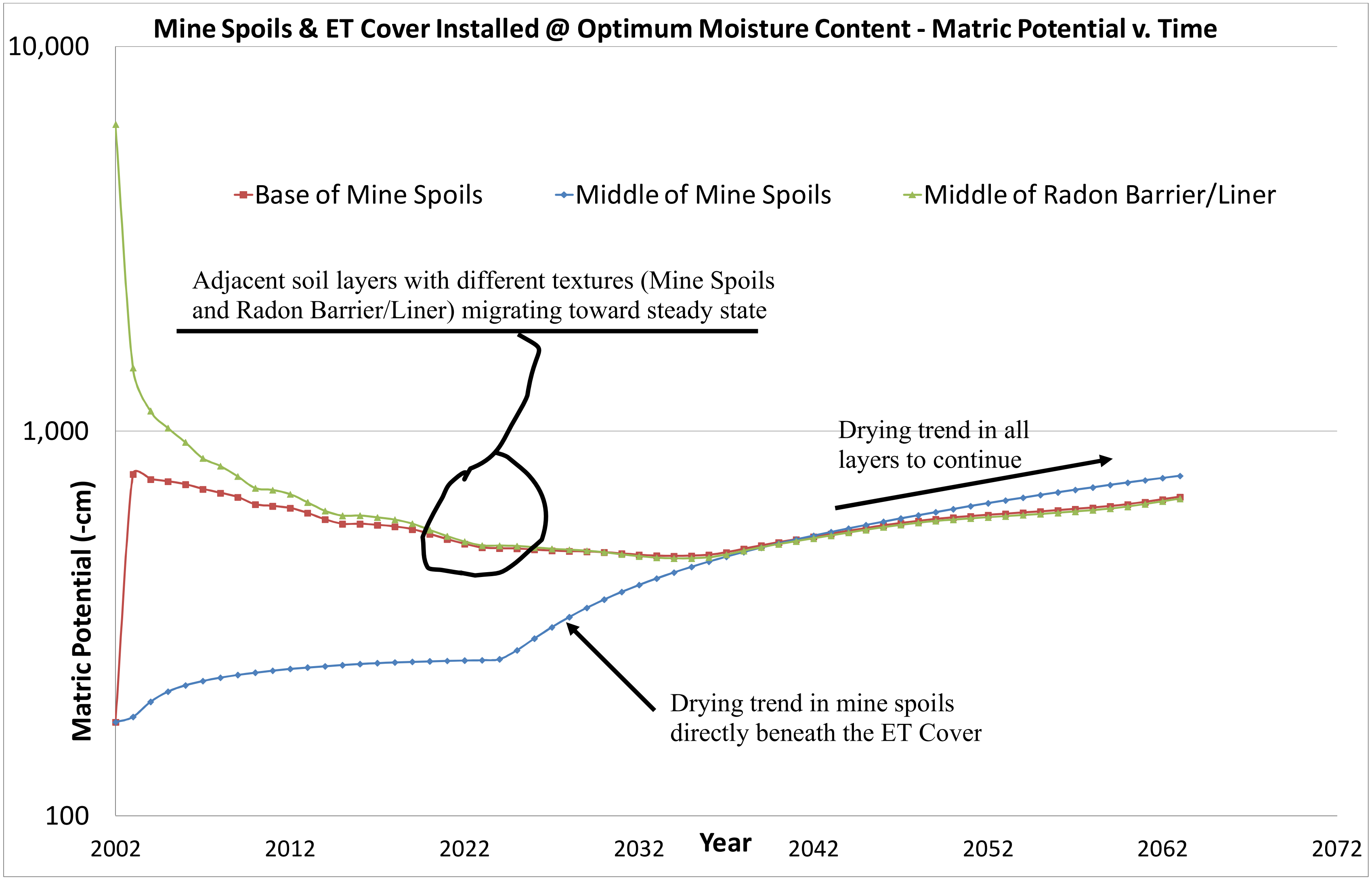

Figure 23. Suction Values with Respect to Depth vs. Time for Profile B with Mine Spoils & ET Cover Installed @ Optimum Moisture Content

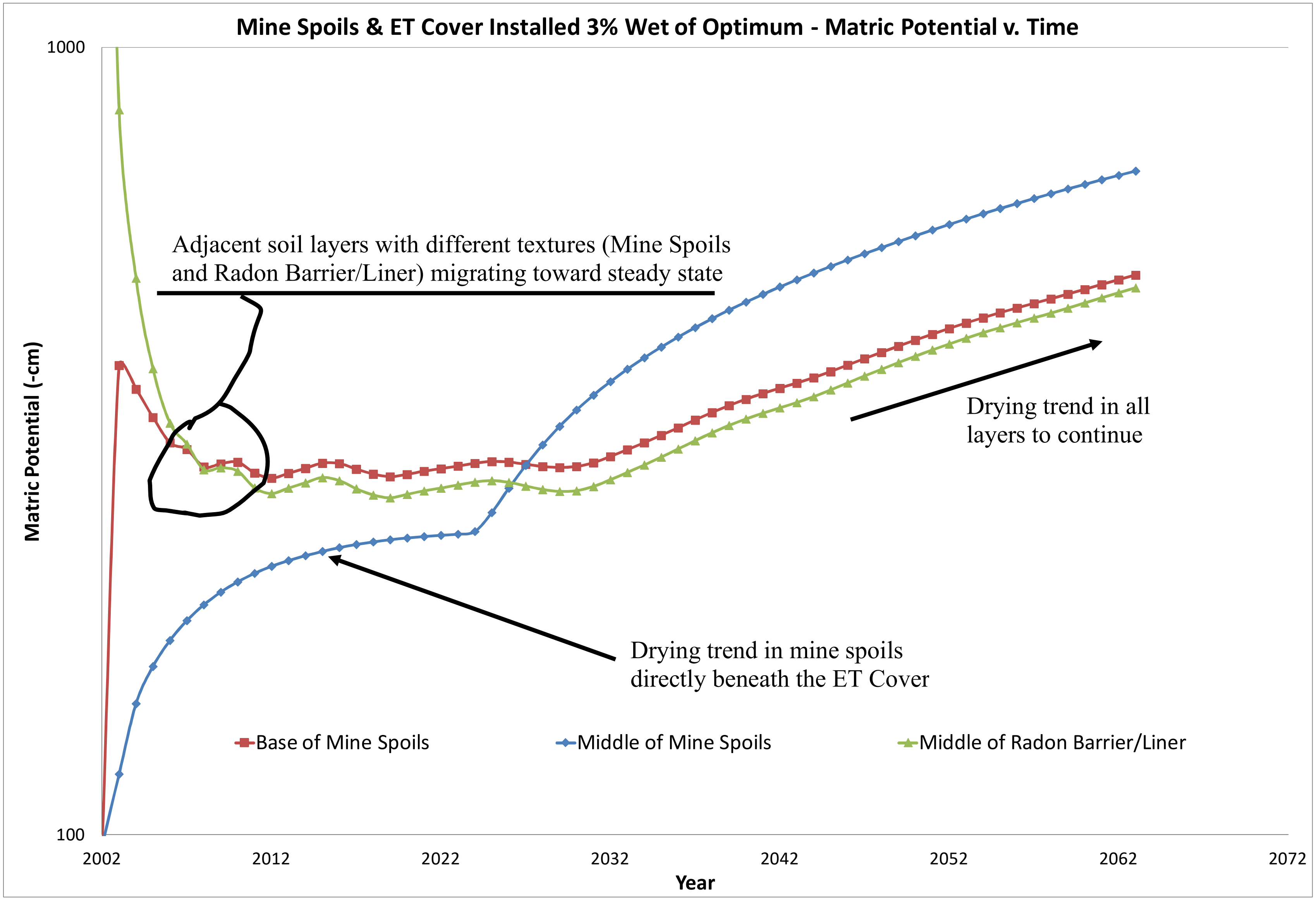

Figure 24. Suction Values with Respect to Depth vs. Time for Profile B with Mine Spoils & ET Cover Installed @ 3% Wet of Optimum Moisture Content

7.0 DISCUSSION OF RESULTS

Placement of the mine spoils and subsequent ET Cover will add weight and thus stress on the existing tailings placed within the current impoundment. Of particular interest is the consolidation on the fine-grained tailings with high water content. The purpose of the analysis was to evaluate if water currently stored in the fine-tailings would be 'squeezed' out with the additional weight and impact the underlying groundwater. Analyses presented in this report demonstrate that this added weight on these tailings will not adversely affect the quality of the underlying groundwater relative to current conditions. The modeling results demonstrate that the ET cover is better able to reduce tailings liquid fluxes at the base of the unsaturated alluvium than the existing condition. This is not to say that there is ongoing tailings seepage currently, rather whatever the current condition is, the proposed removal action would improve on it.

The analysis included computation of consolidation in the fine-grained tailings serving as input into subsequent model simulations using UNSAT-H. The analysis focused on two areas (the two borrow pits) with the highest potential for a release of water from the fine-tailings; and therefore, represents a conservative test case. These two areas have the thickest layers of near saturation (greater than 90 percent of saturation) fine-grained materials throughout the proposed repository footprint. In addition, they represent less than about 25 percent of the total proposed repository area (Figure 1). The remaining area has either no fine-grained tailings or a thinner layer of fine-grained tailings. Nonetheless, a representative boring in the North Cell was included to analyze potential to impact groundwater for the majority of the proposed repository area.

Consolidation was calculated for each fine-tailings layer in each profile, and a subsequent final saturation to represent saturation after placement of mine waste and the new ET cover was calculated. The hydraulic properties of the existing materials, identified in the field drilling and sampling project (MWH 2014), as well as the initial saturation values were utilized as input parameters in modeling to estimate the water balance of the profiles prior to placement of any additional materials on the existing repository. Subsequent simulations used the final saturation, which included any water squeezed from one tailings layer to an adjacent layer, to estimate the water balance of the profiles after placement of any additional materials on the existing repository.

The first set of computer simulations were for a 20-year period and looked at the calculated flux at the base of the cover and at the base of the unsaturated alluvium, both 'before' and 'after' implementing the proposed removal action. The simulations revealed no difference in drainage through the base of the unsaturated alluvium modeled for the 'before' and 'after' condition for the majority of the repository area, specifically any area outside Borrow Pit 2. Under the Borrow Pit 2 scenario, there was a de minims amount of additional flux calculated at the base of the unsaturated alluvium. With regard to Borrow Pit 2, there will be no mine spoils placed over the Borehole B11 area, just a thin layer of clean fill soil. The underlying alluvium in these areas was relatively dry compared to the overlying fine-grained tailings and had significant water storage capacity still available. Thus, any drainage from the tailings was captured within the alluvium. It should be noted that drainage from the alluvium calculated in the modeling is likely due to the unit gradient condition applied to the base of each profile forcing drainage based on steady state conditions at the bottom node and does not necessarily mean there is actually drainage from the alluvium. Given that the repository area will see no change in flux, it can be concluded that there will be no impact to water quality with the addition of the mine spoils and ET cover.

The second set of computer simulations focused on the worst case area, Borrow Pit 1, for a longer duration. Specially, Boring B8 which was the only profile computed to be at full saturation within the fine-grained tailings layer after consolidation. This long-term analysis was intended to evaluate the water balance over the entire thickness of the profile for an extended time period that accounted for the time-dependent variation in the input parameters (climate, soil, and vegetation). The results of the analysis demonstrated that drainage will not increase over time, i.e. there is no new ‘slug’ of water ‘squeezed out’ of the fine-tailings moving towards the underlying groundwater. The results also demonstrated that the wettest condition is the initial condition and that the long-term trend for the profile is drying. This analysis only focused on the worst case location, and so it has been demonstrated that the performance of the proposed removal action cannot adversely impact groundwater quality relative to the existing condition.

It is important to prevent the risk of future side seeps as well as the potential for recharge to groundwater. Therefore, the long-term simulations were also used to address a concern for water to accumulate on the radon barrier (see Section 6.3). The computer simulation results in these cases focused on the base of the mine waste and the middle of the radon barrier under two water contents for the mine waste. The first was at the maximum water content of the mine spoils as specified in the design and the second simulation used a wetter moisture content (3 percent wet of the optimum water content). The results of the computer simulation were similar. The soil suction and thus moisture content of the installed mine spoils and ET Cover will not cause moisture build-up on the underlying radon barrier while the radon barrier continues to dry. Thus there is no potential for seeps emerging from the impoundment.

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APPENDIX A

WATER BALANCE RESULTS

Appendix A contains water balance results for each simulation for all twenty years. The water balance variables included are annual values, with each value having the units in 'cm'. The water balance variables included are applied upper boundary conditions including precipitation and potential evapotranspiration (PET) applied, as well as, calculated output: evaporation, transpiration, runoff, and drainage. Evaporation, transpiration, and runoff are all surface values while drainage is the value at the base of the profile modeled.

Table A1. Profile B2 (Existing Condition) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	8.42	11.98	0	1.14910E-06
2	29.743	211.744	10.049	11.809	0	1.15220E-06
3	29.743	211.744	11.263	11.871	0	1.14910E-06
4	29.743	211.744	12.499	11.918	0	1.14910E-06
5	29.743	211.744	13.416	11.926	0	1.14910E-06
6	29.743	211.744	13.407	11.932	0	1.15220E-06
7	29.743	211.744	13.398	11.929	0	1.14910E-06
8	29.743	211.744	13.378	11.931	0	1.14910E-06
9	29.743	211.744	13.374	11.922	0	1.14910E-06
10	29.743	211.744	13.373	11.938	0	1.15220E-06
11	60.35	215.456	5.136	34.1	0.634	1.14910E-06
12	60.35	215.456	3.998	45.512	5.371	1.14910E-06
13	29.743	211.744	6.067	21.059	0	1.14910E-06
14	29.743	211.744	6.169	18.683	0	1.15220E-06
15	29.743	211.744	6.171	18.671	0	1.14910E-06
16	29.743	211.744	6.166	18.683	0	1.14910E-06
17	29.743	211.744	6.166	18.686	0	1.14910E-06
18	29.743	211.744	6.161	18.691	0	1.15220E-06
19	29.743	211.744	6.164	18.675	0	1.14910E-06
20	29.743	211.744	6.17	18.685	0	1.15220E-06

Table 18A2. Profile B2 (Mine Spoils & ET Cover) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	16.147	18.937	0.097	1.14910E-06
2	29.743	211.744	10.691	18.819	0.091	1.15220E-06
3	29.743	211.744	10.201	18.857	0.093	1.14910E-06
4	29.743	211.744	10.318	18.946	0.088	1.14910E-06
5	29.743	211.744	10.288	18.862	0.095	1.14910E-06
6	29.743	211.744	10.26	18.763	0.095	1.15220E-06
7	29.743	211.744	10.359	18.778	0.092	1.14910E-06
8	29.743	211.744	10.397	18.753	0.099	1.14910E-06
9	29.743	211.744	10.662	18.927	0.091	1.14910E-06
10	29.743	211.744	10.459	18.729	0.094	1.15220E-06
11	60.35	215.456	19.82	35.552	0.735	1.14910E-06
12	60.35	215.456	21.741	37.68	0.345	1.14910E-06
13	29.743	211.744	13.548	20.349	0.087	1.14910E-06
14	29.743	211.744	10.755	18.843	0.09	1.15220E-06
15	29.743	211.744	10.551	18.733	0.087	1.14910E-06
16	29.743	211.744	10.641	18.793	0.085	1.14910E-06
17	29.743	211.744	10.875	18.955	0.101	1.14910E-06
18	29.743	211.744	10.78	18.882	0.092	1.15220E-06
19	29.743	211.744	10.642	18.767	0.091	1.14910E-06
20	29.743	211.744	10.668	18.781	0.09	1.15220E-06

Table A3. Profile B8 (Existing Condition) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	6.688	17.647	0.306	1.23350E-04
2	29.743	211.744	8.005	17.514	0.37	1.23690E-04
3	29.743	211.744	8.563	17.508	0.317	1.23350E-04
4	29.743	211.744	9.179	17.528	0.351	1.23350E-04
5	29.743	211.744	9.567	17.519	0.312	1.23350E-04
6	29.743	211.744	10.17	17.573	0.287	1.23690E-04
7	29.743	211.744	10.54	17.54	0.352	1.23350E-04
8	29.743	211.744	11.015	17.544	0.3	1.23350E-04
9	29.743	211.744	11.016	17.58	0.332	1.23350E-04
10	29.743	211.744	11.316	17.573	0.335	1.23690E-04
11	60.35	215.456	11.181	27.932	0.029	1.23350E-04
12	60.35	215.456	11.239	25.795	0.241	1.23350E-04
13	29.743	211.744	13.124	17.848	0.316	1.23350E-04
14	29.743	211.744	13.133	17.617	0.341	1.23690E-04
15	29.743	211.744	13.15	17.598	0.336	1.23350E-04
16	29.743	211.744	13.138	17.573	0.302	1.23350E-04
17	29.743	211.744	13.054	17.582	0.332	1.23350E-04
18	29.743	211.744	12.835	17.583	0.341	1.23690E-04
19	29.743	211.744	12.624	17.561	0.345	1.23350E-04
20	29.743	211.744	12.474	17.554	0.336	1.23690E-04

Table A4. Profile B8 (Mine Spoils & ET Cover) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	16.169	18.953	0.088	1.23350E-04
2	29.743	211.744	10.602	18.746	0.09	1.23690E-04
3	29.743	211.744	10.148	18.811	0.086	1.23350E-04
4	29.743	211.744	10.122	18.793	0.087	1.23350E-04
5	29.743	211.744	10.334	18.897	0.087	1.23350E-04
6	29.743	211.744	10.516	18.962	0.09	1.23690E-04
7	29.743	211.744	10.477	18.87	0.093	1.23350E-04
8	29.743	211.744	10.551	18.884	0.087	1.23350E-04
9	29.743	211.744	10.468	18.769	0.096	1.23350E-04
10	29.743	211.744	10.732	18.956	0.088	1.23690E-04
11	60.35	215.456	19.789	35.604	0.728	1.23350E-04
12	60.35	215.456	21.769	37.682	0.344	1.23350E-04
13	29.743	211.744	13.443	20.277	0.092	1.23350E-04
14	29.743	211.744	10.692	18.797	0.089	1.23690E-04
15	29.743	211.744	10.635	18.796	0.091	1.23350E-04
16	29.743	211.744	10.653	18.797	0.093	1.23350E-04
17	29.743	211.744	10.686	18.822	0.093	1.23350E-04
18	29.743	211.744	10.747	18.873	0.091	1.23690E-04
19	29.743	211.744	10.877	18.956	0.088	1.23350E-04
20	29.743	211.744	10.569	18.694	0.089	1.23690E-04

Table A5. Profile B10 (Existing Condition) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	6.682	17.624	0.379	5.56550E-06
2	29.743	211.744	7.998	17.505	0.397	5.58080E-06
3	29.743	211.744	8.54	17.518	0.343	5.56550E-06
4	29.743	211.744	9.102	17.533	0.328	5.56550E-06
5	29.743	211.744	9.479	17.517	0.352	5.56550E-06
6	29.743	211.744	10.156	17.533	0.405	5.58080E-06
7	29.743	211.744	10.345	17.541	0.344	5.56550E-06
8	29.743	211.744	11.005	17.546	0.313	5.56550E-06
9	29.743	211.744	11.011	17.556	0.341	5.56550E-06
10	29.743	211.744	11.113	17.555	0.406	5.58080E-06
11	60.35	215.456	11.166	27.874	0.053	5.56550E-06
12	60.35	215.456	11.191	26.454	0.233	5.56550E-06
13	29.743	211.744	13.111	17.835	0.376	5.56550E-06
14	29.743	211.744	13.128	17.589	0.32	5.58080E-06
15	29.743	211.744	13.149	17.566	0.351	5.56550E-06
16	29.743	211.744	13.138	17.575	0.359	5.56550E-06
17	29.743	211.744	13.003	17.577	0.368	5.56550E-06
18	29.743	211.744	12.761	17.552	0.344	5.58080E-06
19	29.743	211.744	12.562	17.545	0.352	5.56550E-06
20	29.743	211.744	12.395	17.554	0.394	5.58080E-06

Table A6. Profile B10 (Mine Spoils & ET Cover) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	17.365	19.187	0.091	5.56550E-06
2	29.743	211.744	12.161	18.996	0.087	5.58080E-06
3	29.743	211.744	11.513	19.02	0.088	5.56550E-06
4	29.743	211.744	11.105	18.829	0.089	5.56550E-06
5	29.743	211.744	11.208	18.964	0.095	5.56550E-06
6	29.743	211.744	11.152	18.953	0.093	5.58080E-06
7	29.743	211.744	11.081	18.908	0.088	5.56550E-06
8	29.743	211.744	11.079	18.914	0.09	5.56550E-06
9	29.743	211.744	11.256	19.066	0.088	5.56550E-06
10	29.743	211.744	11.231	19.046	0.089	5.58080E-06
11	60.35	215.456	20.229	35.861	0.685	5.56550E-06
12	60.35	215.456	22.04	37.873	0.335	5.56550E-06
13	29.743	211.744	13.968	20.434	0.092	5.56550E-06
14	29.743	211.744	11.239	18.998	0.09	5.58080E-06
15	29.743	211.744	11.025	18.889	0.09	5.56550E-06
16	29.743	211.744	11.034	18.904	0.09	5.56550E-06
17	29.743	211.744	11.059	18.925	0.091	5.56550E-06
18	29.743	211.744	10.984	18.867	0.09	5.58080E-06
19	29.743	211.744	11.125	18.99	0.089	5.56550E-06
20	29.743	211.744	11.112	18.978	0.09	5.58080E-06

Table A7. Profile B11 (Existing Condition) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	6.634	17.619	0.336	0.488
2	29.743	211.744	7.946	17.475	0.352	0.49
3	29.743	211.744	8.572	17.507	0.365	0.488
4	29.743	211.744	9.138	17.516	0.361	0.488
5	29.743	211.744	9.599	17.517	0.352	0.488
6	29.743	211.744	9.943	17.523	0.323	0.49
7	29.743	211.744	10.544	17.547	0.363	0.488
8	29.743	211.744	10.855	17.55	0.364	0.488
9	29.743	211.744	10.855	17.563	0.361	0.488
10	29.743	211.744	10.899	17.59	0.38	0.49
11	60.35	215.456	10.76	29.121	0.039	0.488
12	60.35	215.456	10.416	30.582	1.412	0.488
13	29.743	211.744	13.14	17.848	0.332	0.488
14	29.743	211.744	13.156	17.587	0.326	0.49
15	29.743	211.744	13.138	17.566	0.355	0.488
16	29.743	211.744	12.951	17.574	0.364	0.488
17	29.743	211.744	12.656	17.559	0.307	0.488
18	29.743	211.744	12.467	17.548	0.358	0.489
19	29.743	211.744	12.358	17.56	0.331	0.488
20	29.743	211.744	12.255	17.564	0.344	0.489

Table A8. Profile B11 (Mine Spoils & ET Cover) - all units are cm

Year	Precip	PET	Transp	Evap	Runoff	Drain
1	29.743	211.744	16.16	19.004	0.088	0.488
2	29.743	211.744	10.531	18.888	0.086	0.49
3	29.743	211.744	9.723	18.739	0.088	0.488
4	29.743	211.744	9.635	18.725	0.086	0.488
5	29.743	211.744	9.894	18.919	0.086	0.488
6	29.743	211.744	9.842	18.834	0.086	0.49
7	29.743	211.744	9.968	18.904	0.087	0.488
8	29.743	211.744	10.016	18.905	0.089	0.488
9	29.743	211.744	10.067	18.899	0.086	0.488
10	29.743	211.744	9.918	18.732	0.088	0.49
11	60.35	215.456	19.25	35.433	0.745	0.488
12	60.35	215.456	21.21	37.538	0.356	0.488
13	29.743	211.744	12.829	20.157	0.092	0.488
14	29.743	211.744	10.264	18.764	0.089	0.49
15	29.743	211.744	10.357	18.863	0.09	0.488
16	29.743	211.744	10.308	18.775	0.085	0.488
17	29.743	211.744	10.471	18.868	0.086	0.488
18	29.743	211.744	10.427	18.798	0.085	0.489
19	29.743	211.744	10.395	18.755	0.088	0.488
20	29.743	211.744	10.543	18.859	0.091	0.489

APPENDIX B

Cone Penetrometer Results for Applicable Borings (from MWH 2014)

The following are graphical summaries of results for applicable borings (Profiles B2, B8, B10, and B11) from the on-site field drilling performed of the existing impoundment. Specifically, they are graphical summaries of the cone penetrometer findings for the full depth drilled in each profile. These findings are part of the full suite of data presented in MWH (2014).

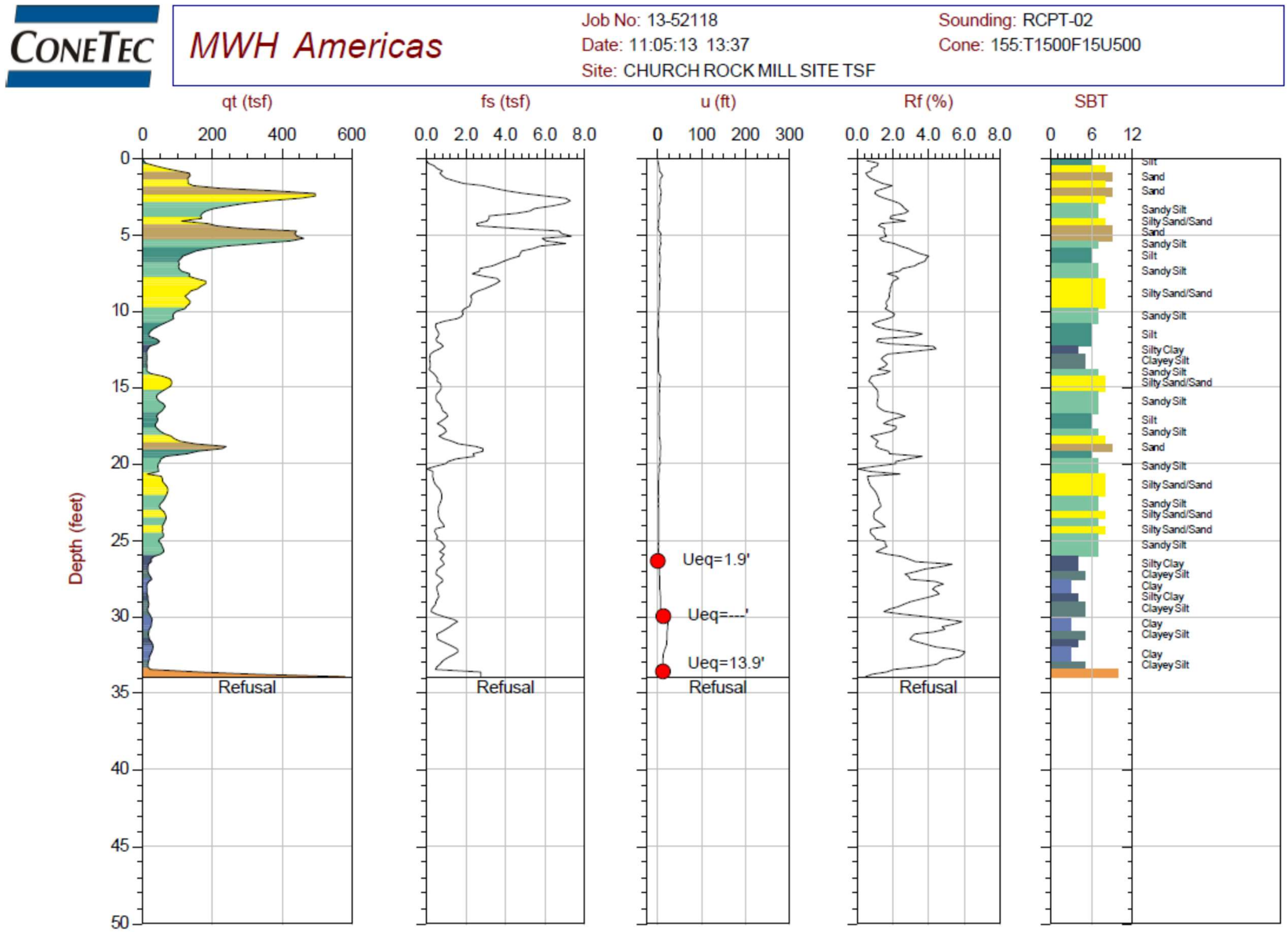

Figure B1 CPT for Boring B2

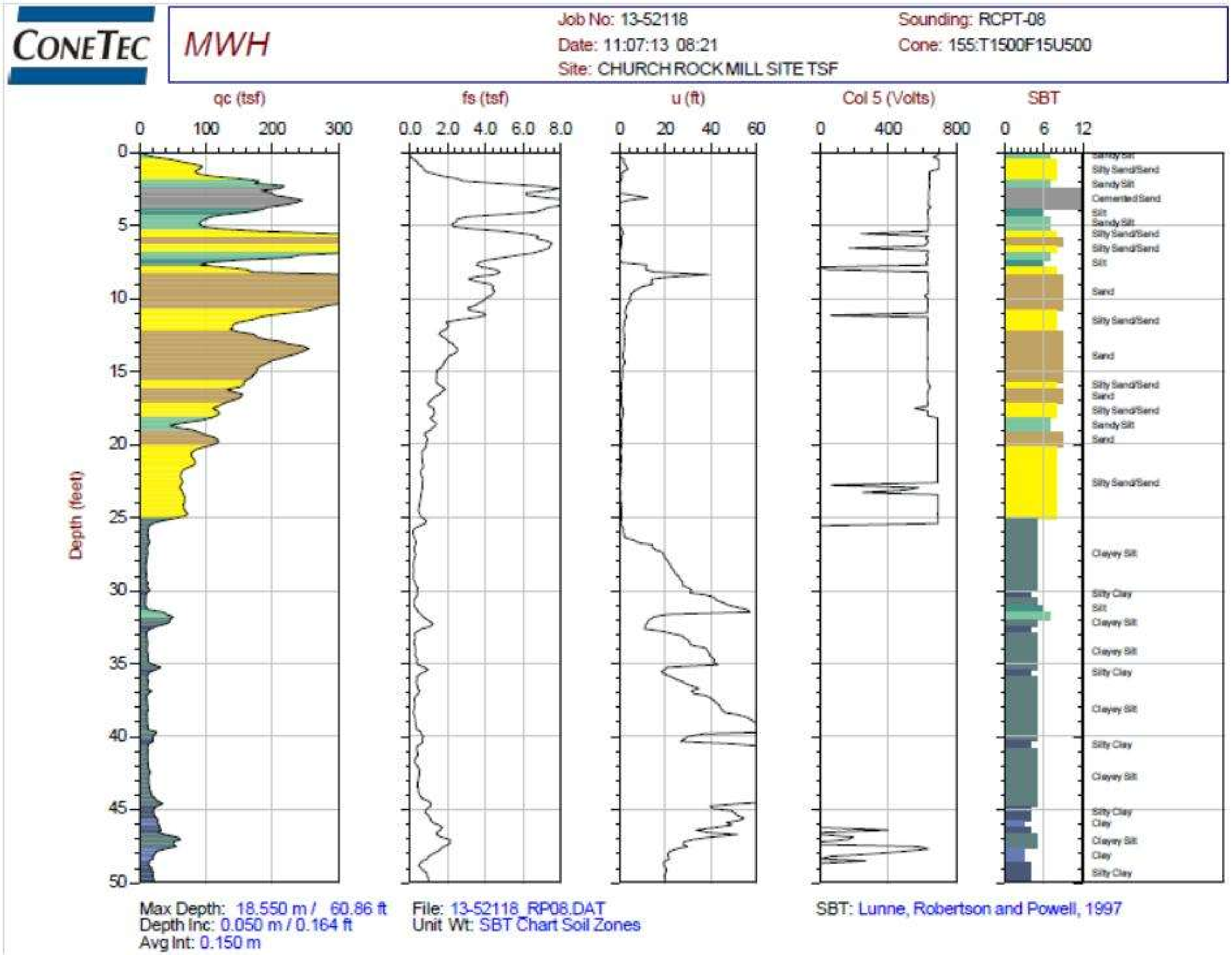

Figure B2 CPT for Boring B8

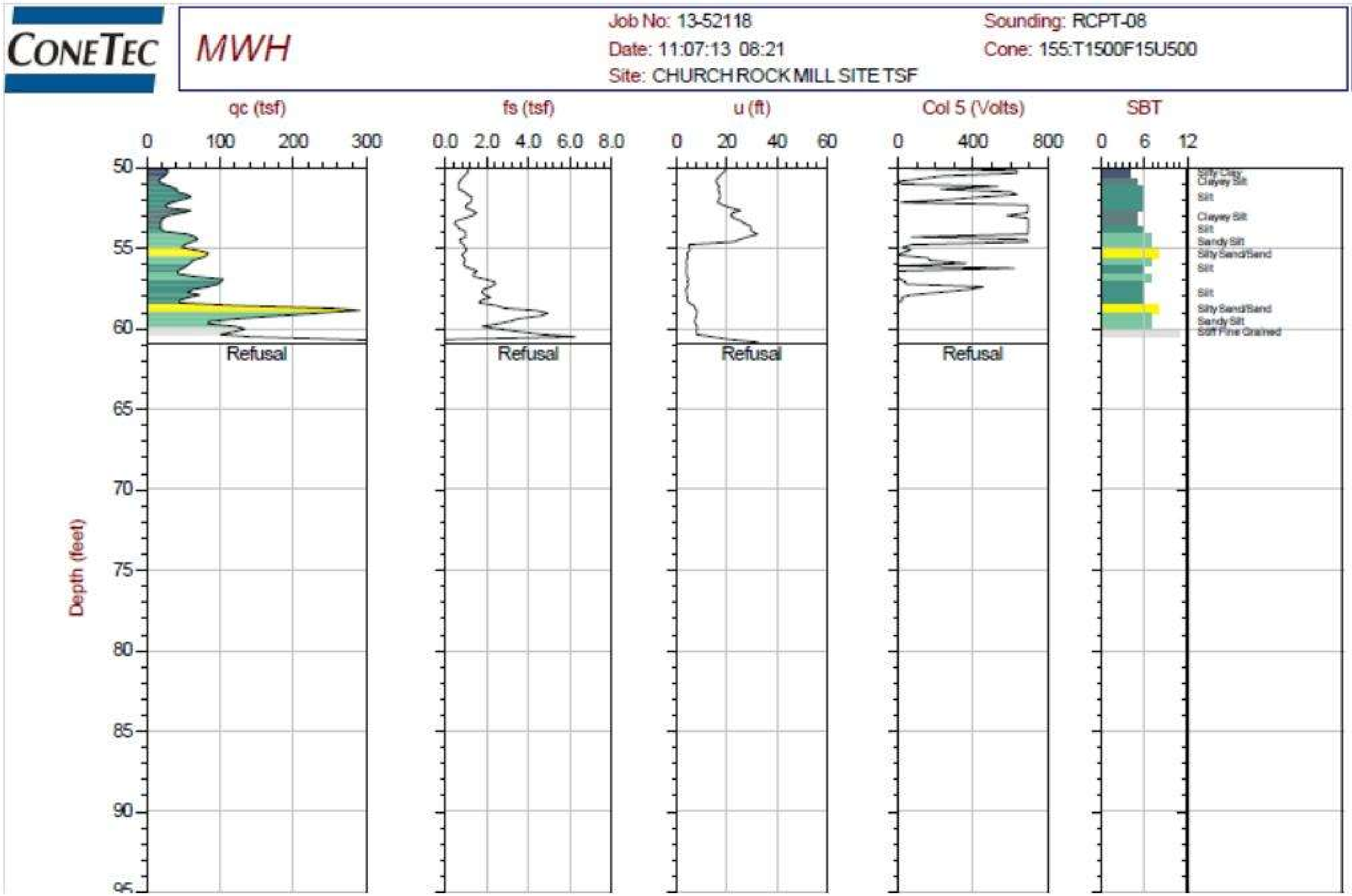

Figure B3. CPT for Boring B8 (continued)

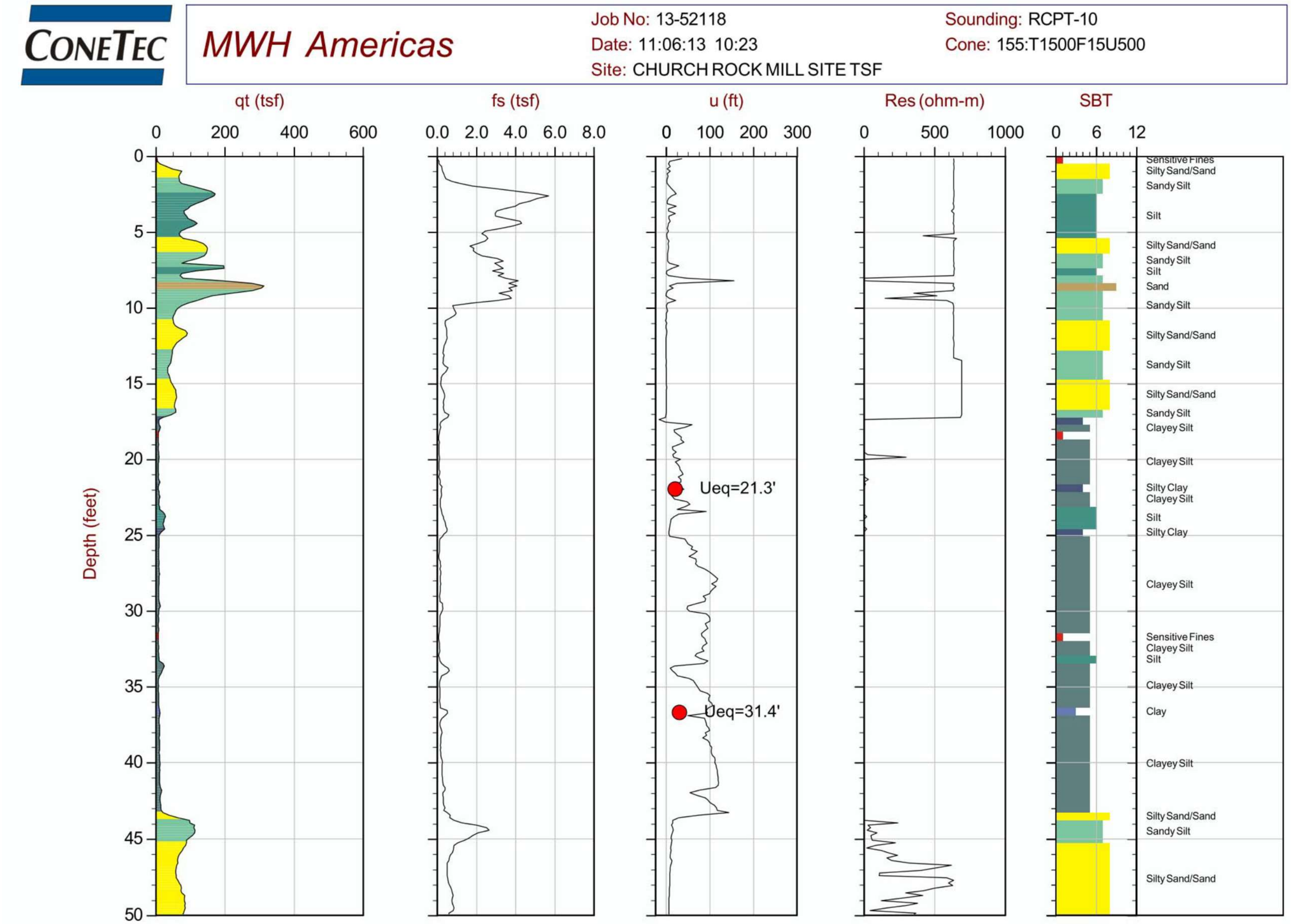

Figure B4 CPT for Boring B10

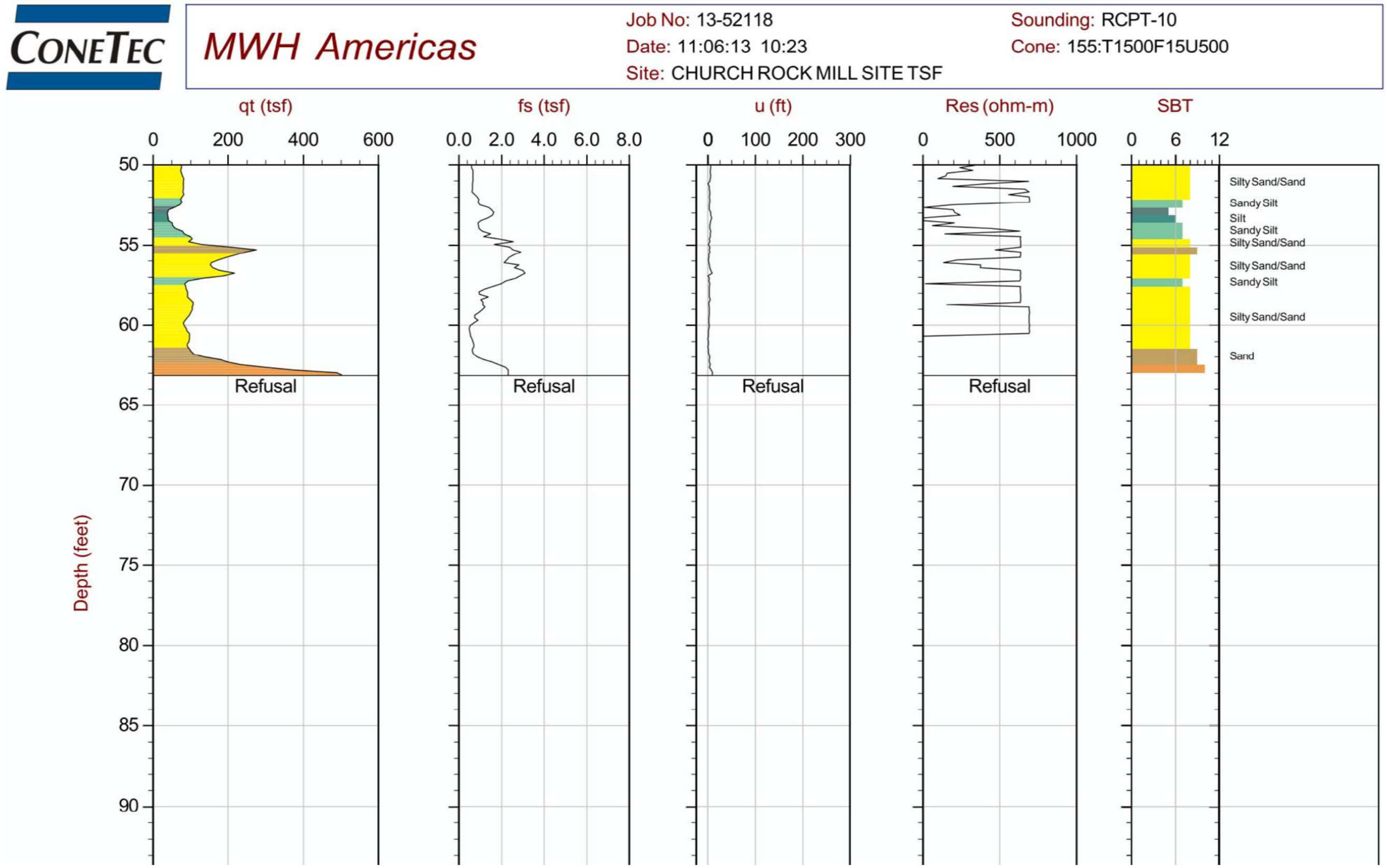

Figure B5. CPT for Boring B10 (continued)

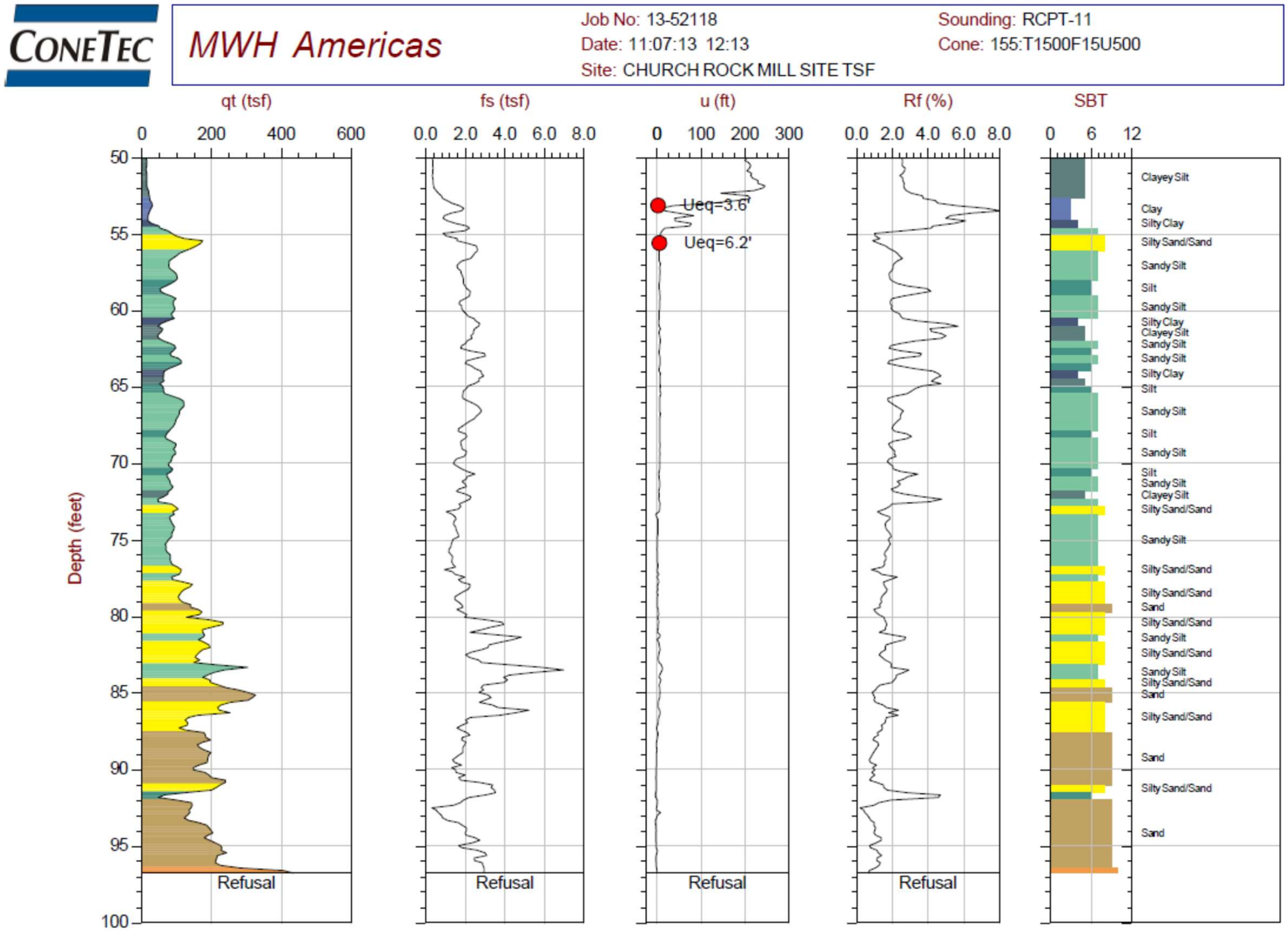

Figure B6. CPT for Boring B11