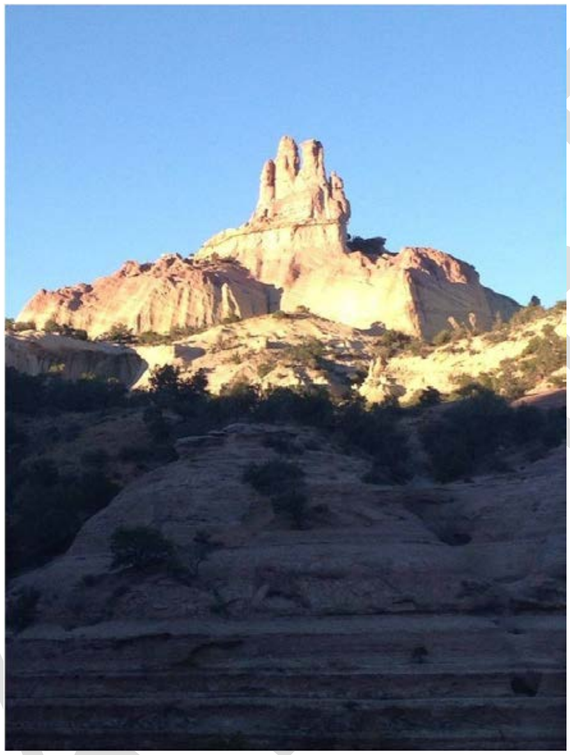
**30% DRAFT**

# CONSOLIDATION AND GROUNDWATER EVALUATION REPORT



7/29/2016

Northeast Church Rock Site Closure

*Prepared by:*
Dwyer Engineering LLC
Stephen F Dwyer, PhD, PE
1813 Stagecoach Rd. SE
Albuquerque, NM 87123

*Prepared for:*
United Nuclear Corporation
640 Freedom Business Center
King of Prussia, PA 19406

## EXECUTIVE SUMMARY

The Remedial Action (RA) referenced in the Administrative Settlement Agreement and Order on Consent for the United Nuclear Corporation Superfund Site and Northeast Church Rock Mine Removal Site (AOC; USEPA, 2015) as described in the 2011 Action Memo (USEPA, 2011) and 2013 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 2016).

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 subsequent affect of drainage on the underlying groundwater.

The existing tailings are expected to incur a small amount of consolidation and thus reduction in porosity due to the added weight. An evaluation was performed comparing the existing condition of the tailings impoundment to the proposed condition with mine spoils and new ET Cover added. The results show that although there is a small amount of consolidation in the tailings, there is no significant drainage impact into the underlying groundwater. That is, there is no significant increase in flux into the underlying groundwater from the tailings impoundment. In fact it appears that the improvement in final cover system with the addition of the ET Cover compared to the existing should help reduce future drainage impacts on the groundwater from the existing tailings.

# Table of Contents



# FIGURES

## TABLES

# 1.0 INTRODUCTION

The Northeast Church Rock (NECR) Mine Site was an underground uranium mine active from 1968 to 1982, when it was placed in stand-by status. The primary ore mined was coffinite. Mine reclamation is warranted as a result of these mining operations.

The site is located about 16 miles northeast of Gallup in McKinley County, New Mexico. The site is in a semi-arid climate averaging about 11-inches of precipitation per year at an elevation of about 7000-ft above sea level. The vegetation is generally categorized as a pinyon-juniper landscape with shrubs and native grasses.

United Nuclear is evaluating the possibility of placing soils removed during the Removal Action on the existing tailings impoundments rather than creating a new repository on-site to effectively minimize the waste footprint. This report provides an evaluation of the potential impact of drainage from the impoundment on the underlying groundwater.

# 2.0 PROFILES EVALUATED

The purpose of the consolidation/modeling analysis performed on the NECR mine tailings is to evaluate the potential impact on groundwater due to the deposition of mine spoils and a new ET Cover on the existing impoundment. Briefly, the analysis described in this report 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% of saturation) fine-grained materials. The consolidation will then impact the hydraulic properties of the tailings by reducing the porosity of the soil, albeit very small. Because the fine-grained tailings are wet (tailings of particular concern are generally greater than 90% degree of saturation) the consolidation could increase drainage from them that could potentially impact groundwater.

Profiles evaluated consist of specific areas prior to placement of any additional mine spoils and the same areas after deposition of mine spoils and an ET Cover. This allowed for a "before and after" evaluation of the respective areas to evaluate whether placement of mine spoils on the existing impoundment has any significant and detrimental impact on the underlying groundwater.

The profiles evaluated were chosen because they have the most complete set of field data available (where both cone penetrometer testing (CPT) was performed as well as physical sampling and laboratory measurements of soil textures and hydraulic properties) and generally represent the worst areas or areas of most concern that 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 four profiles where fine-grained tailings exist and they are near or exceed 90% saturation.

The four sets of profiles evaluated (Figure 1) include two in borrow pit 1 (B10 and B8), one in borrow pit 2 (B11). The borrow pits are generally the areas with the deepest layers of fine-grained tailings. Another area within the north cell (B2) was also evaluated that had fine-grained tailings near saturation. Other areas where complete sets of field data were available contained tailings that were drier than 90% of saturation or had less fine-grained tailings.

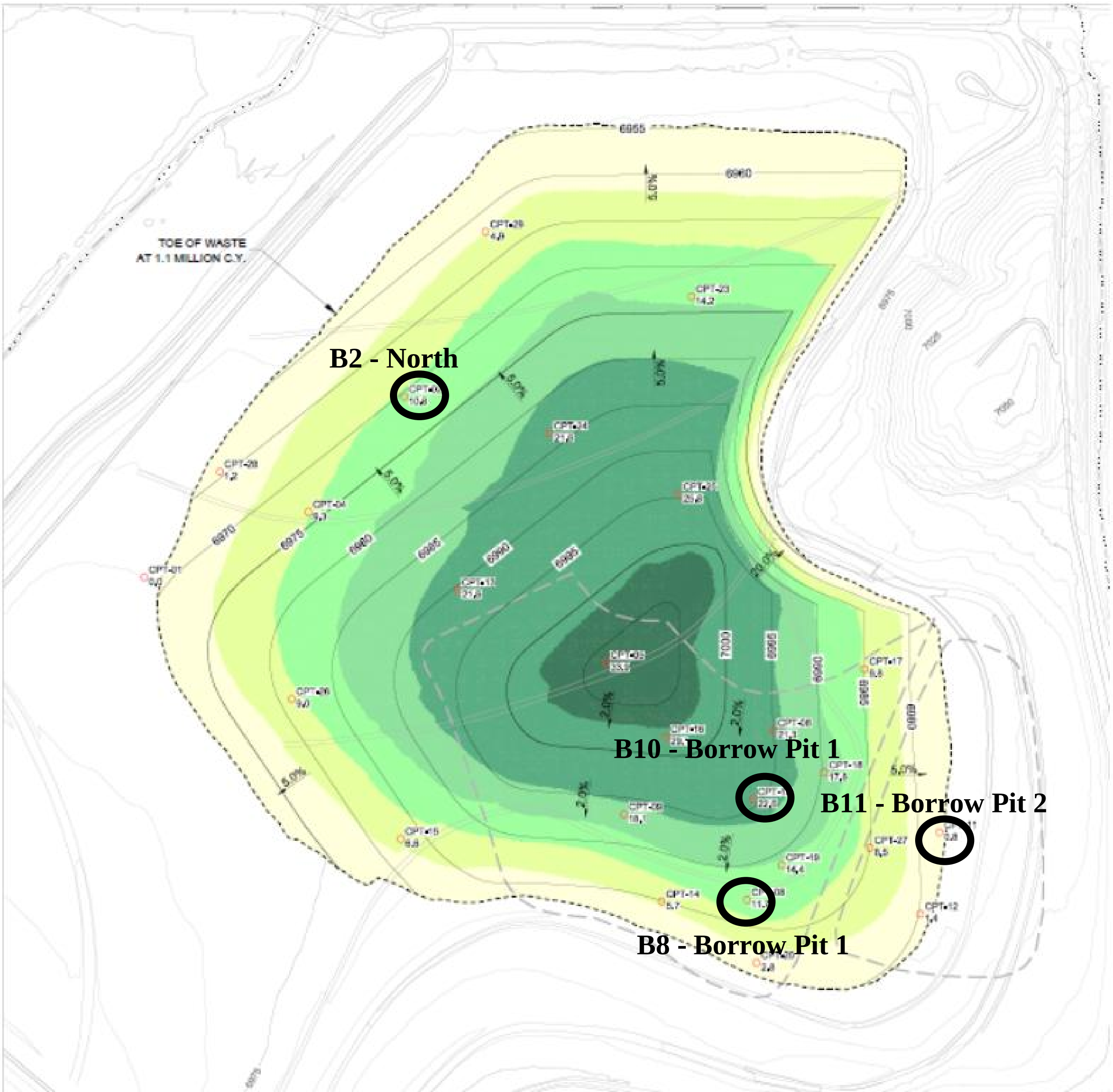



**Figure 1. Location of Profiles Evaluated**

## 3.0 CONSOLIDATION OF TAILINGS

Consolidation of tailings is part of this analysis to assess the potential impact on groundwater due to the addition of mine spoils on the existing impoundment at the NECR site. A drilling and laboratory testing program conducted at the site (MWH 2014) was performed to assess the volume and location of underlying tailings within the impoundment. Results identified existing fine-grained tailings within the impoundment are relatively wet and have a very low saturated hydraulic conductivity (about $10^{-8}$ cm/sec) thus limiting their ability to drain this moisture. The coarse-grained tailings were found to be 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) and thus allowed for moisture within them from mining operations to drain much quicker than the fine-grained tailings.

The intent of the analysis was to assess the potential impact of drainage from the existing impoundment on underlying groundwater, consequently the fine-grained tailings are featured in this analysis. This is because the fine-grained tailings are at or near saturation and consolidation will 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 within those soils.

Consolidation occurs in three stages:

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

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

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

Immediate consolidation was not considered in this analysis because it is generally associated with consolidation that takes place **without change to soil moisture content** and it predominates in cohesion-less soils and unsaturated clay. Immediate consolidation occurs as the load is applied or within a time period of about 7 days. Immediate settlement is defined as elastic deformation of soils and thus has no impact on the water displacement that this analysis is intended to evaluate. Immediate settlement is not time dependent and occurs more so in near surface soils. Immediate settlement analyses are used for fine-grained soils including silts and clays with a degree of saturation less than 90% and for coarse grained soils with large coefficient of permeability (i.e. greater than $10x10^{-3}$ m/s) (Bowles 1996).

Primary consolidation is generally the largest portion of all consolidation in terms of volume change that occurs and dominates in saturated/nearly saturated fine grained soils where consolidation theory applies (Figure 2). It is caused by a reduction in void space and subsequent squeezing of excess pore water from the materials. This is the primary consolidation that was calculated to quantify the impact on the wet, fine-grained tailings given the placement of mine spoils and ET Cover on the existing impoundment. Canonie (1990 and 1992) stated primary consolidation generally occurred in about 100 days for the fine-grained tailings.

Secondary consolidation was not considered because it is time dependent and occurs under constant effective stress due to continuous rearrangement of clay particles into a more stable configuration. It occurs after primary consolidation and thus in unsaturated soils that would not have water forced from their volume that could potentially impact the underlying groundwater. Secondary consolidation occurs after excess pore water pressures have dissipated in the soil and is typically caused by the realignment of soil particles that can occur over long periods of time. It is generally a significantly smaller amount of settlement than primary consolation, and continues at a much slower rate than primary consolidation (Figure 2).

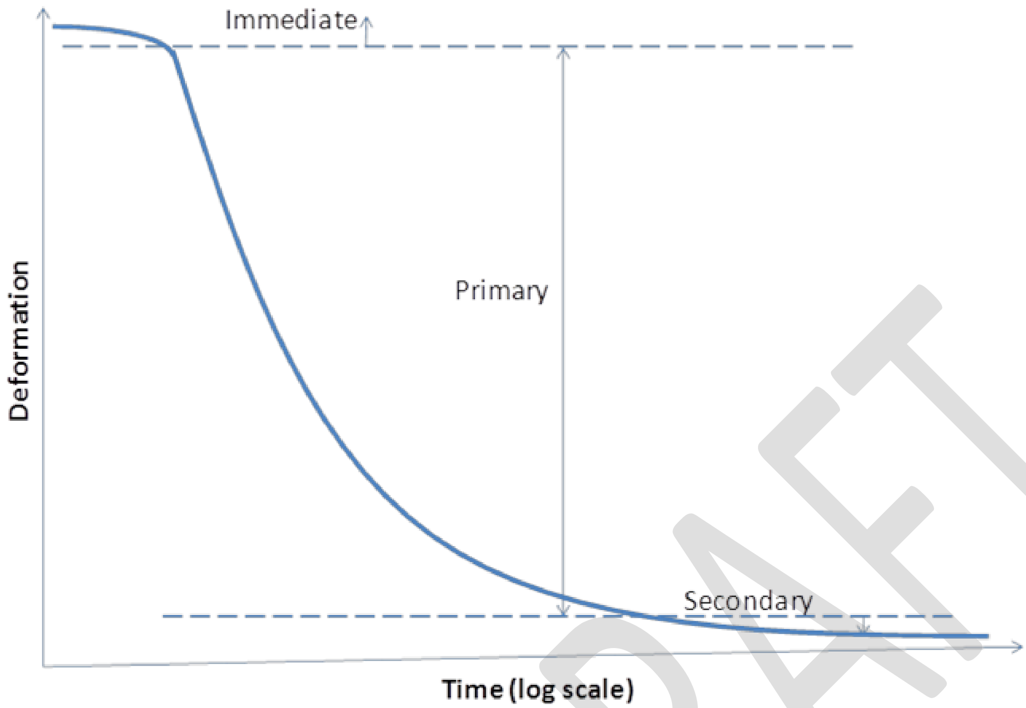



Figure 2. Consolidation Stages

## 3.1 TERZAGHI CONSOLIDATION THEORY

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 for 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 are 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.

These assumptions are generally assumed by the engineering community to be satisfied. The analysis went to great strides to evaluate each relatively homogenous tailings layer independently while analyzing the profile as a whole thus satisfying assumption 1. Typical consolidation analyses assumes a single compression index for the total fine-grained tailings and treats all of the fine-grained tailings as a single layer. This analysis utilized a measured compression index for every texture change measured in each respective profile (MWH 2014) of the fine-grained tailings and thus evaluated each specific layer individually when calculating consolidation for that respective layer. Furthermore, each layer had its hydraulic properties adjusted based on these myriad calculations and thus the unsaturated modeling also broke up any textural change in a given profile and assigned separate properties to each so that the heterogeneity in the vertical profile could be fully evaluated. Assumption 2 lends conservatism to the analysis given the tailings although very wet are not necessarily saturated. Limitations of Terzaghi's theory specific to this analysis is generally found in assumption 7. With regard to assumption 7, it is now recognized that the coefficient of permeability is not constant through the consolidation process; rather the saturated permeability of soil generally decreases as density increases. Because the analysis presented in this report assumes a constant permeability in the tailings under consideration even after consolidation, this lends for some conservatism in the analysis.

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; and
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 that 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% saturated or higher). 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.

The modeling performed assumed a constant saturated hydraulic conductivity for tailings materials even though each layers' unsaturated hydraulic properties were adjusted to reduce the storage capacity. This adds conservatism because as the tailings are compacted, the saturated hydraulic conductivity is actually reduced which would slow the movement of water and ultimately reduce the predicted annual flux through the base of the underlying alluvium. The analysis is intended to evaluate the potential impact of water from the tailings moving downward toward groundwater. The impact on this flux is greatest initially during primary consolidation and decreases with time as the available water decreases.

## 3.2 CONSOLIDATION RESULTS

The input data utilized to quantify the settlement in the wet, finer-grained tailings, the final void ratio, and the subsequent or final degree of saturation are summarized in Tables 1 to 4. These input data were obtained during the pre-design study performed at the site where soil samples were obtained from the respective soil layers and measured (MWH 2014).

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

The final void ratio of the tailings layer was also computed and used to adjust the saturated moisture content (Figure 4) and thus van Genuchten parameters (van Genuchten et al 1991) utilized in the unsaturated modeling (Refer to Section 4 for more details). Finally, the final degree of saturation of the fine-grained tailings layer(s) was calculated that allowed 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 4 (Refer to Section 4 for more details).

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 30% Design Report):

1. Maximum dry density of cover soil [average value based on pre-design study data (MWH 2014)] is 115 pcf. The long-term moisture content of the soil is estimated to be 10.8%. This is the average of the optimum moisture content less 3% (MWH 2014). Thus the moist unit weight of the cover soil at 90% relative density is 114.68 pcf. Similarly, the soil/rock admixture unit weight is 130 pcf with 33% rock by volume. The long-term moisture content taking into account the rock is then 6.3%. 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 deep and the admixture is 27-inches deep, the moist weight of the cover soil for the full cover thickness is then 492.4 psf.
2. Maximum dry density of mine spoils soil [average value based on pre-design study data (MWH 2014)] is 118.3 pcf. The long-term moisture content of the soil is 9.3%. This is the average of the optimum moisture content less 3% (MWH 2014). Thus the moist unit weight of the mine spoils soil at 90% relative density is 116.37 pcf. This unit weight was then multiplied by the respective depth of mine spoils in each profile evaluated.

Tables1 to 4 summarize the input parameters and consolidation results for each profile evaluated. A spreadsheet was assembled to provide the actual calculations for each profile.

Refer to (MWH 2014) for measured values for each layer or textural change in the geologic cross section (i.e. density, water content, specific gravity, and consolidation coefficient) and layer thicknesses of the existing materials at the impoundment and represented in the following tables. Other values shown in the tables were computed.

### Table 1. B2: Soil Properties to Determine Fine-Grained Tailings Consolidation (MWH 2014)

| 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%, 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, it can be seen that the final degree of saturation after consolidation is wetter than 90%.

### Table 2. B8: Soil Properties to Determine Fine-Grained Tailings Consolidation (MWH 2014)

| 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 | 99.8% |

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 47.1% [a] |
| 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 | 52.4% [a] |
| 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 | 94.6% |
| 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%, 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, it can be seen that the final degree of saturation after consolidation is wetter than 90%.

**Table 3. B10: Soil Properties to Determine Fine-Grained Tailings Consolidation (MWH 2014)**

| 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 | 93.7% [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 | 92.1% [a] |
| 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 | 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 | 64.8% [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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tailings** | | | | | | | | | | | | | | |
| **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 |
| **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 | 88.6% [a] |
| **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 | 97.2% |
| **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%, however the layers are relatively fine-grained and near 90% Saturation or sandwiched between saturated or near saturated soils consequently treated as though it was wetter and that the Terzaghi consolidation theory applies.

### Table 4. B11: Soil Properties to Determine Fine-Grained Tailings Consolidation (MWH 2014)

| 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 | | | | | | | | | |
| **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% |

## 4.0 UNSATURATED MODELING OF PROFILES

Unsaturated soil is comprised of liquid, solid, and gas (Figure 3). 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 higher hydraulic conductivity than a saturated soil. In a saturated volume of soil ($\theta_s$), 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 ($\theta_r$) where only adsorbed water remains. At this state, the hydraulic conductivity of the soil is at its lowest.

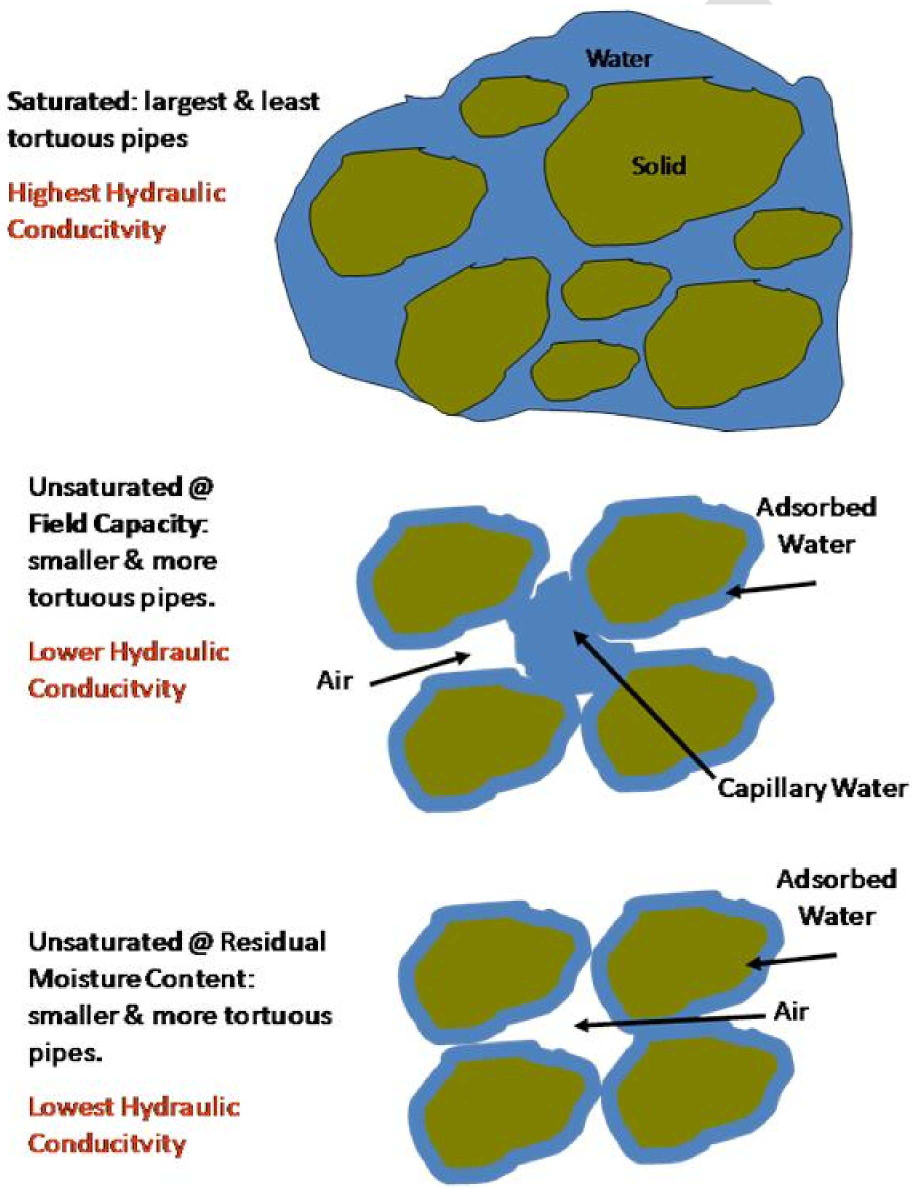



**Figure 3. Components of Soil (Water, Air and Solid)**

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

The purpose of the consolidation/modeling analysis performed on the NECR mine tailings is to evaluate the potential impact on groundwater due to the 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 cover would impact the existing tailings by consolidating the fine-grained materials. The consolidation would subsequently impact the hydraulic properties of the tailings by reducing the storage capacity of the soil as shown below (Figure 4). Because the fine-grained tailings are wet (tailings of particular concern are generally wetter than 90% degree of saturation) the consolidation could squeeze water from them that could potentially impact groundwater. These hydraulic property changes would then affect the flow of water within each respective profile analyzed.

After consolidation of the tailings was computed, the hydraulic properties of each tailings layer were adjusted similar to that shown in Figure 4. Multiple profiles were then modeled to determine the annual flux at the base of the alluvium directly beneath tailings.

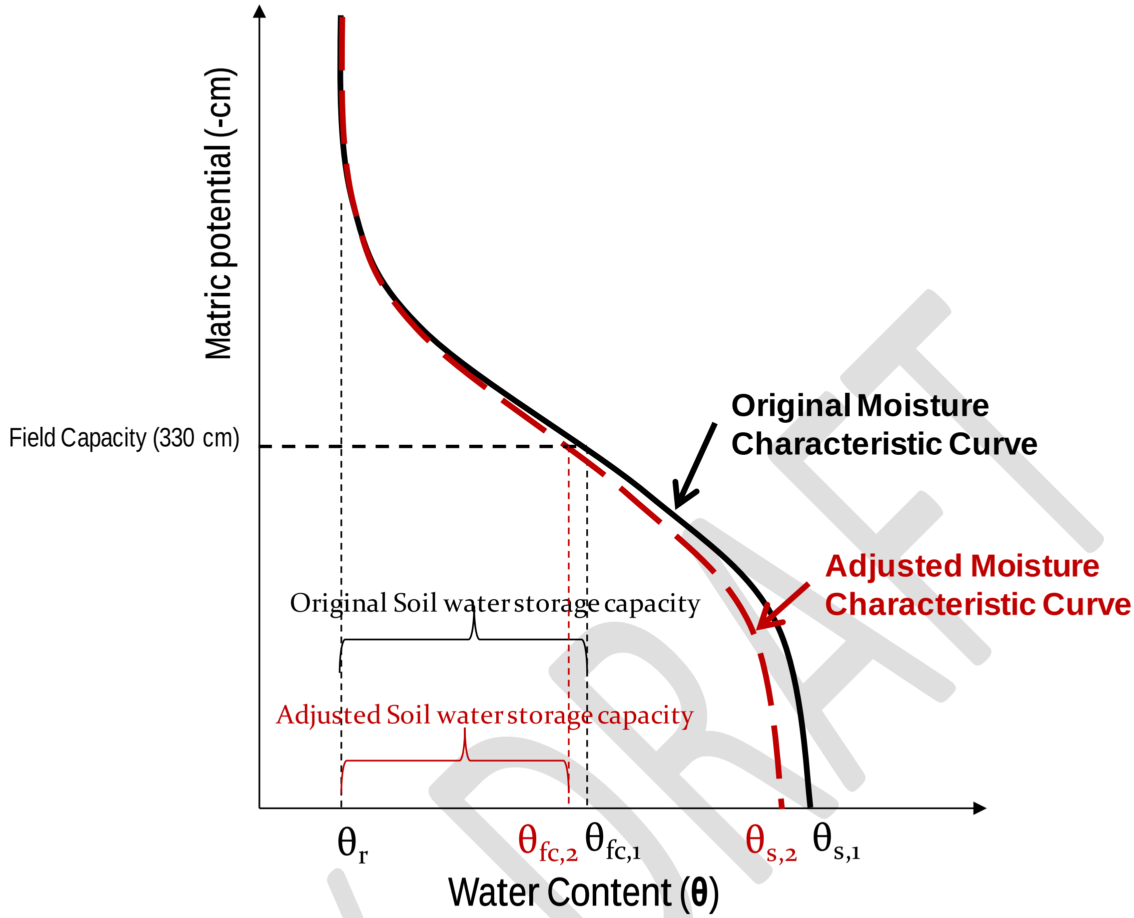



**Figure 4. Change in Soil Hydraulic Properties due to Consolidation**

## 4.1 OVERVIEW OF UNSAT-H

Historically, HELP (Schroeder et al, 1994) has been the software utilized to predict water balance in landfill systems including the final cover. 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). One of the most common software (ITRC 2003) that is based on the Richard's equation used today is UNSAT H (Fayer 2000). This unsaturated modeling software was designed specifically for earthen covers. It has been 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 to design 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 be used to 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.

A schematic illustration showing how UNSAT-H computes the water balance is shown in Figure 5. 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 soils characteristic of the final cover. 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.

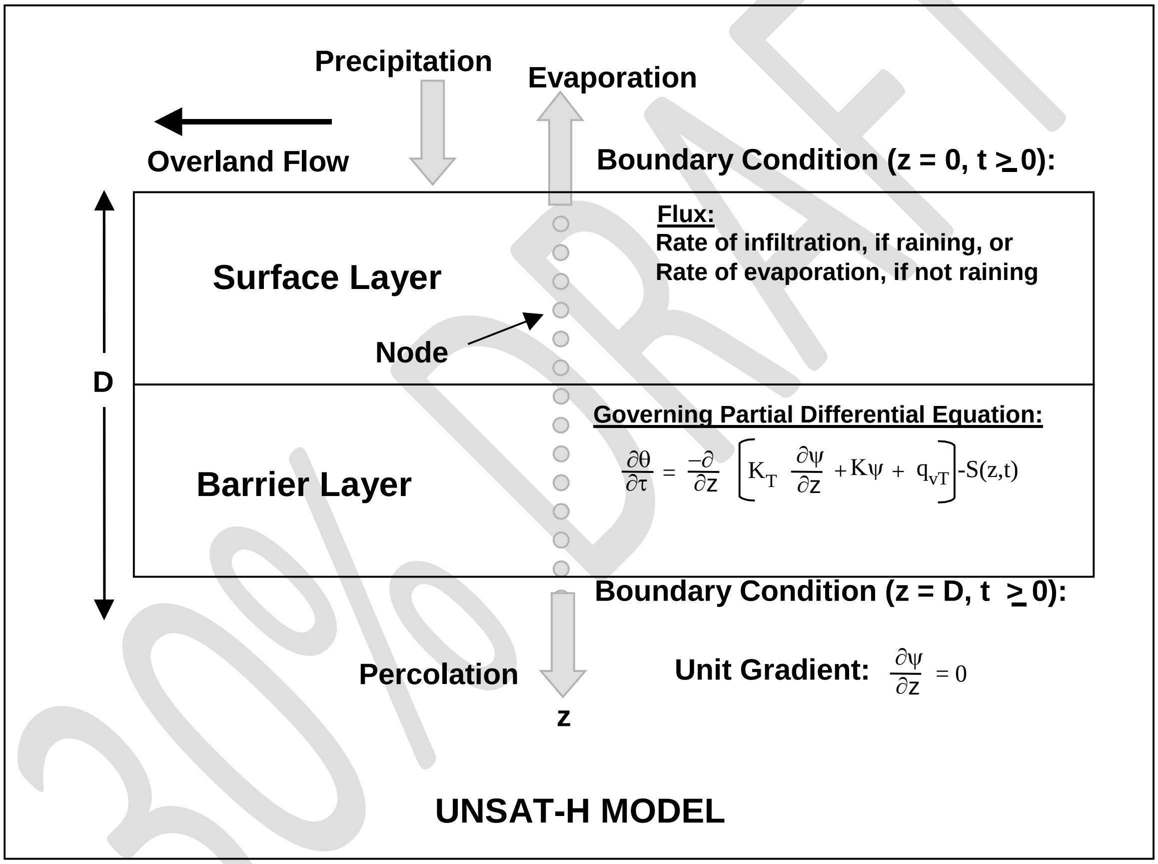



**Figure 5. Schematic Representation of Water Balance Computation by UNSAT-H**

Water that has 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. Potential evapotranspiration (PET) is computed from the daily wind speed, relative humidity, net solar radiation, and daily minimum and maximum air temperatures using a modified form of Penman's equation given by Doorenbos and Pruitt (1977). Soil water storage is computed by integrating the water content profile. Flux from the lower boundary is via percolation. 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 modeling each respective profile before and after consolidation of the tailings was computed due to the addition of mine spoils and an ET Cover.

The input parameters included the cover borrow soil, vegetation, and profile geometry (surface erosion protection layer composed of rock and soil). The upper boundary condition or climate was also evaluated from typical to extreme wet conditions.

The ET Cover with the heaviest combination that included the 3-inch rock mixed with cover soil to a depth of 27-inches with the remaining 4-ft depth being the similar cover soil was used to ensure conservatism in the consolidation analysis because it is heavier than the admixture with the 1.5-inch (14-inches deep) or 2-inch rock (18-inches deep) because the layer is thicker. However, based on results of the cover design sensitivity analysis performed (Dwyer 2016), the most conservative profile for unsaturated flow is the cover 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 was used in this analysis again to attempt some conservatism. That is, this layer allows 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. Again, this is because 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 2016) showed that all profiles utilized that included vegetation produced no downward flux, thus the cover geometry has no significant sensitivity to the results of the profiles inclusive of the mine spoils and ET Cover.

### 4.2.1 MODEL GEOMETRY

The model geometry for the existing conditions was based on actual layer thicknesses as determined via the exploratory drilling program performed at the site (MWH 2014). Complete profiles are well defined for each profile evaluated based on both CPT and borehole investigations performed at each respective location. The geometry for the subsequent analysis whereby the mine spoils and ET Cover are assumed to have been placed on the impoundment include 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 that is assumed to 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 cover is 4-feet thick in total. The surface admixture is 14-inches thick in the ET Cover, while all cover soil beneath this erosion protection surface layer is simply cover soil from approved borrow sources. The admixture soil is similar soil from the same approved borrow sources. The rock is from approved on-site stockpiles or approved vendors meeting durability requirement to ensure adequate performance for the 1000-year design life of the cover system. A general summary of the profiles modeled is included in Sections 4.1.2.1 through 4.1.2.4.

#### 4.2.1.1 PROFILE B2

Profile B2 represents a typical area within the north cell where wet, fine-grained tailings exist. Figure 6 summarizes the profiles evaluated to assess the area for its potential impact on the underlying groundwater. The figure shows the profile as it currently exists without the added mine spoils or ET Cover. It also shows the respective profile with the added mine spoils and ET Cover taking into account the respective consolidation in the fine-grained tailings.

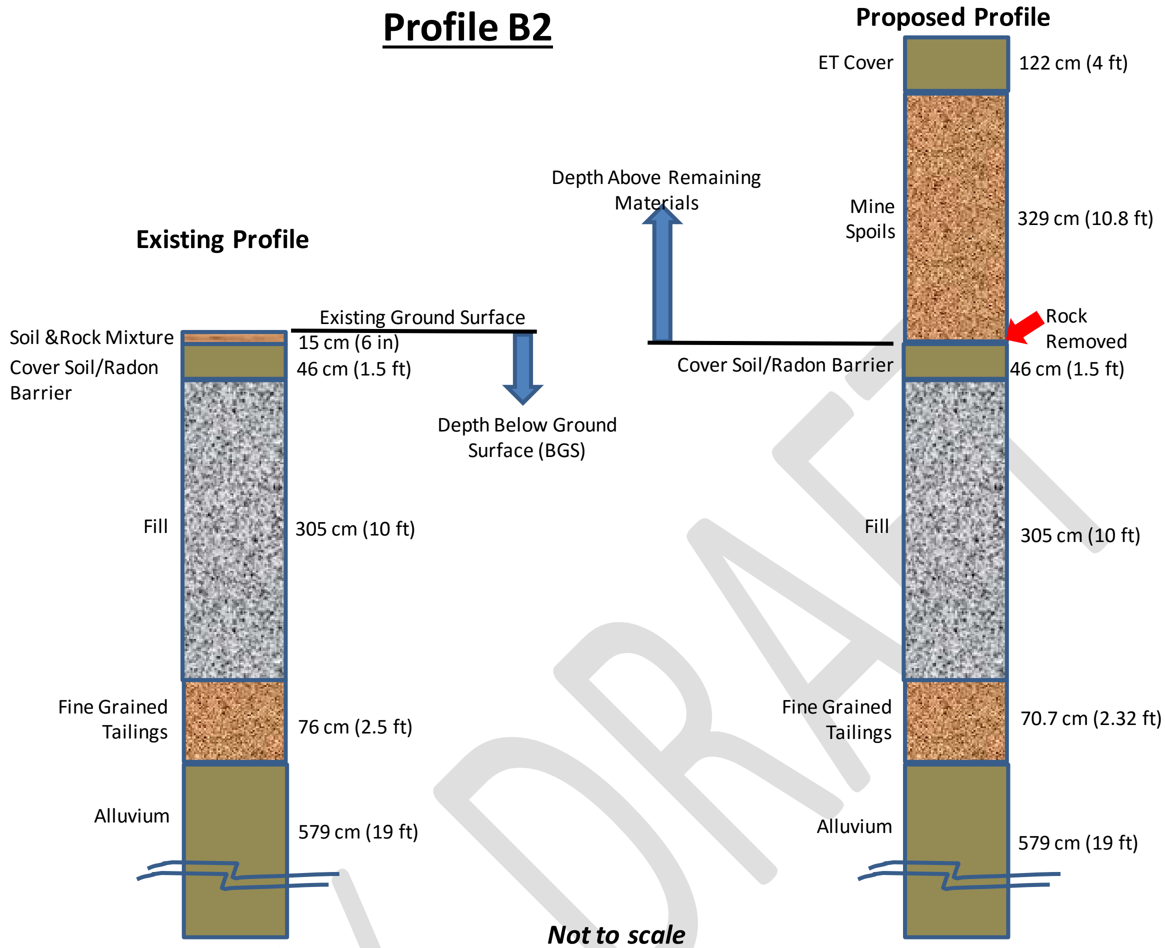



**Figure 6. Profile B2**

### 4.2.1.2 PROFILE B8

Profile B8 represents an area within Borrow Pit 1 where the fine-grained tailings are relatively deep and very wet. Figure 7 summarizes the profiles evaluated to assess the area for its potential impact on the underlying groundwater. The figure shows the profile as it currently exists without the added mine spoils or ET Cover. It also shows the respective profile with the added mine spoils and ET Cover 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 each that each had its own set of input parameters.

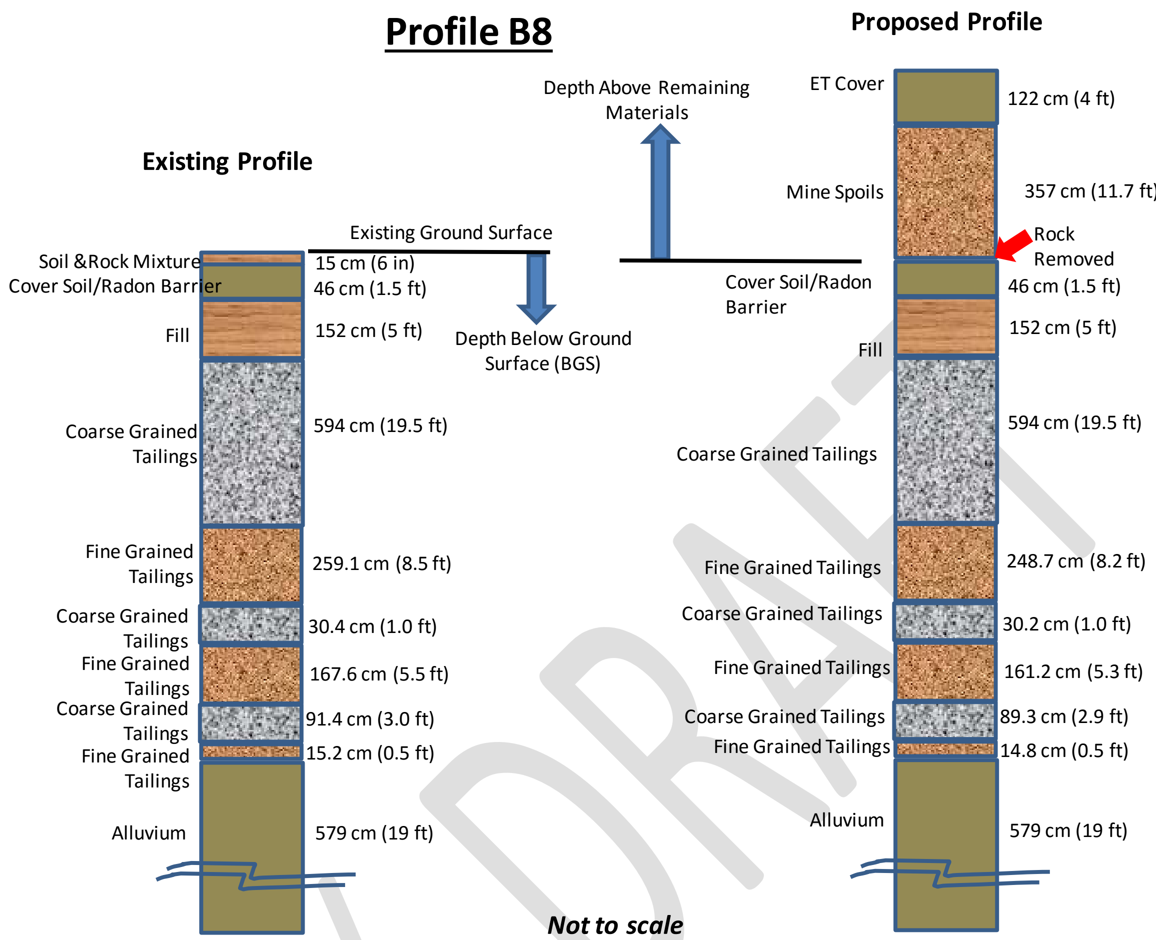



**Figure 7. Profile B8**

### 4.2.1.3 PROFILE B10

Profile B10 represents another area within Borrow Pit 1 where the fine grained tailings are relatively deep and very wet. Figure 8 summarizes the profiles evaluated to assess the area for its potential impact on the underlying groundwater. The figure shows the profile as it currently exist without the added mine spoils or ET Cover. It also shows the respective profile with the added mine spoils and ET Cover 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 each that each had its own set of input parameters.

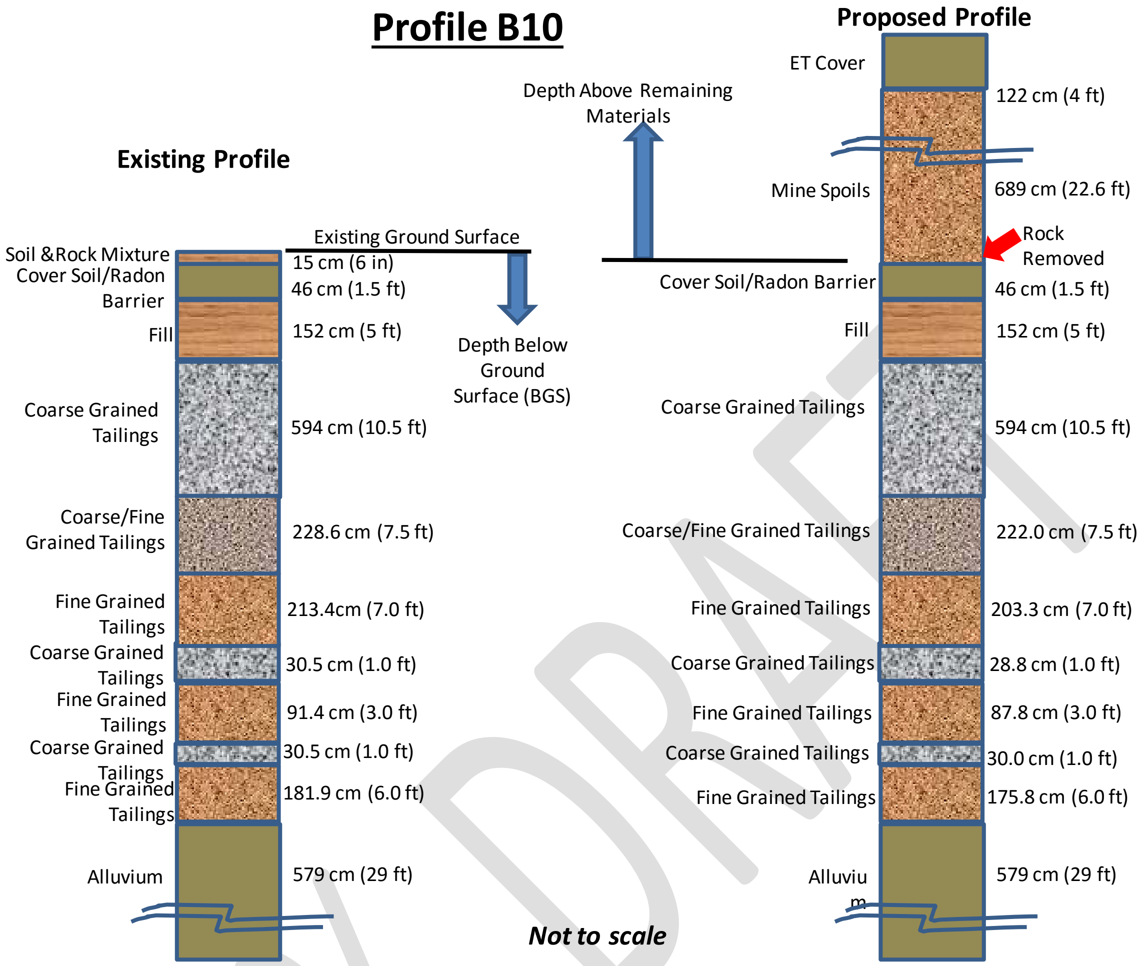



Figure 8. Profile B10

### 4.2.1.4 PROFILE B11

Profile B11 represents another area within Borrow Pit 2 where the fine grained tailings are deep and very wet. Figure 9 summarizes the profiles evaluated to assess the area for its potential impact on the underlying groundwater. The figure shows the profile as it currently exist without the added mine spoils or ET Cover. It also shows the respective profile with the added mine spoils and ET Cover taking into account the respective consolidation in the fine-grained tailings. The fine-grained tailings layers had thinner distinctive layers within it that each had its own set of input parameters.

**Profile B11**

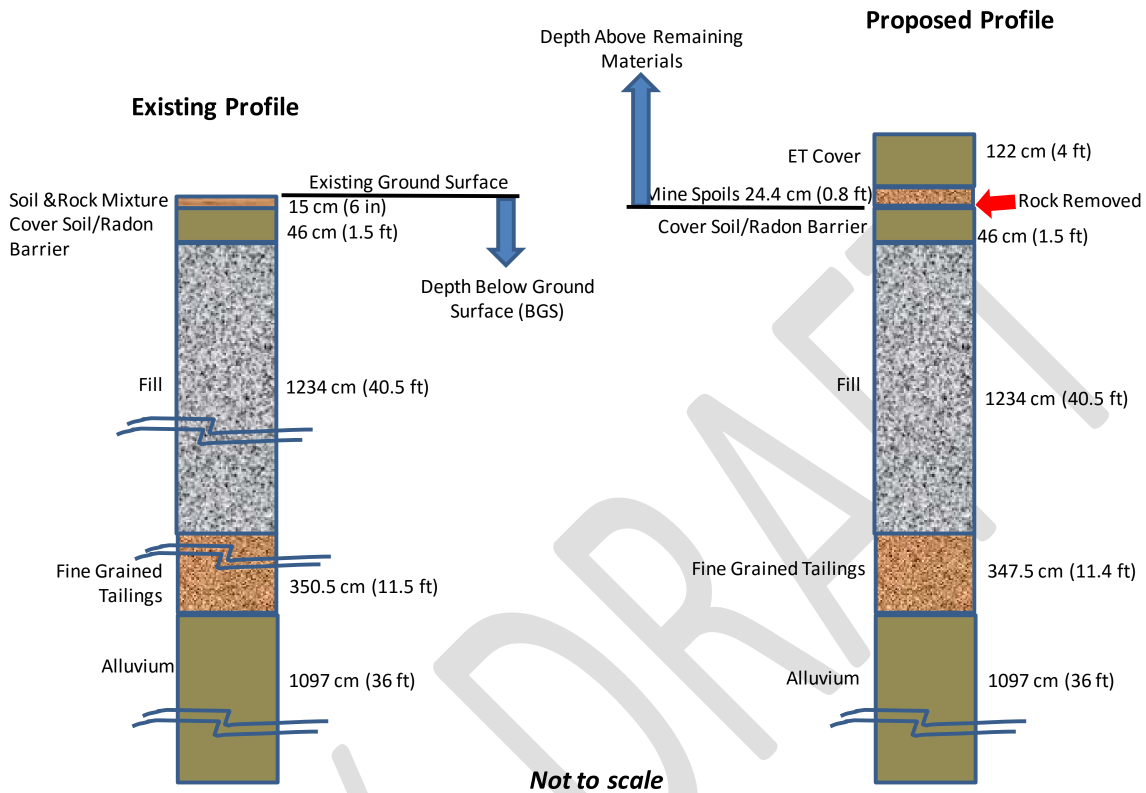



**Figure 9. Profile B11**



## 4.2.2 BOUNDARY CONDITIONS

The upper boundary condition for the UNSAT H computer simulations consist of climate data. The upper boundary conditions for these computer simulations are composed of twenty years of local climate. The twenty years consisted of ten consecutive years of average or typical climate followed by the wettest year on record run consecutively, followed by eight more years of typical climate. This twenty year time frame was chosen because it includes both average and extreme climate conditions. It did not include any dry years because the purpose of this analysis was 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. The twenty year period allows for an evaluation of the change in moisture status of the profile over multiple years to see if any trends are established or annual flux is variable. The water balance results show that after a couple of years of typical climate conditions, there is not significant change to the annual water balance variables (Appendix A). Also refer to Figures 14 to 17 where trends of flux through the cover (up or down) and the alluvium are established within a couple of years. Furthermore, an important result of the evaluation performed showed that the existing cover allows for percolation and thus an increase of moisture within the profile; while the profile with mine spoils and an ET Cover does not allow for percolation and thus the profile is undergoing a drying trend. An evaluation of a longer period of time would not reveal additional useful information for decision making. 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.

Historical weather data for the Gallup, NM area and surrounding weather stations were evaluated from 1897 to present. Weather from Ft. Wingate, NM was utilized as the upper boundary condition due to its proximity and similar elevation as the NECR mill site. Ft. Wingate had historical weather data dating back to 1897 and the most complete set of data in the Gallup, NM area. For the typical climate year used to evaluate the cover performance; 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 10.

For this year, it can be seen that for every month of the year (Figure 10), the climate's demand for water (PET) far exceeds the actual supply of water (precipitation). The climate's annual demand for water referred to as potential evapotranspiration (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" type cover designed to take advantage of variances between the demand for water and actual supply of water such as an ET Covers is well suited for this climate.

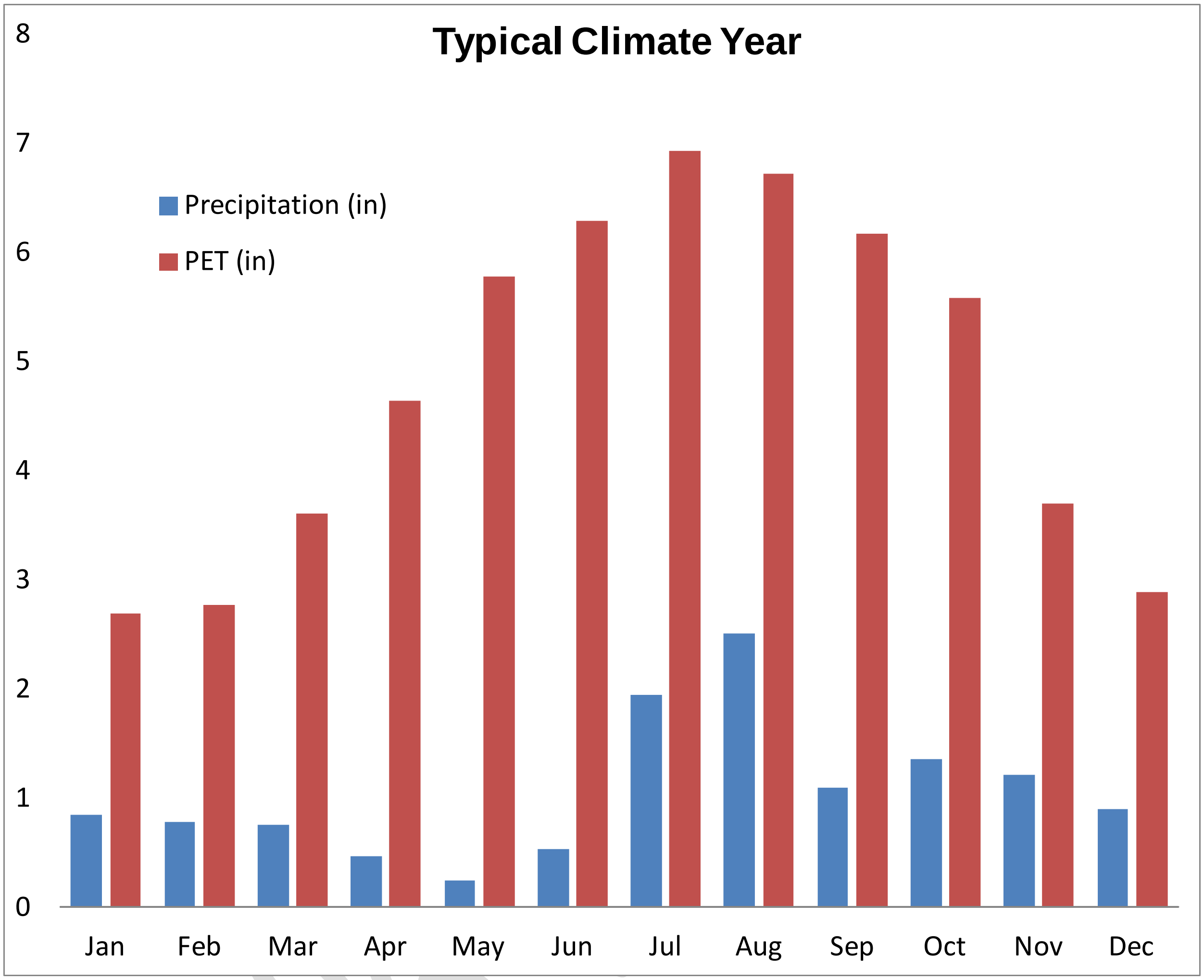



**Figure 10. Typical Climate: Monthly Precip. vs. PET for Ft. Wingate, NM**

Extreme climatic conditions were also evaluated. The Ft. Wingate weather data set also had the most extreme weather with the wettest year on record occurring in 1906 with an annual precipitation volume of 23.8-inches (84.8 cm). Much of that moisture coming in the form of 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 11 for the wettest year on record.

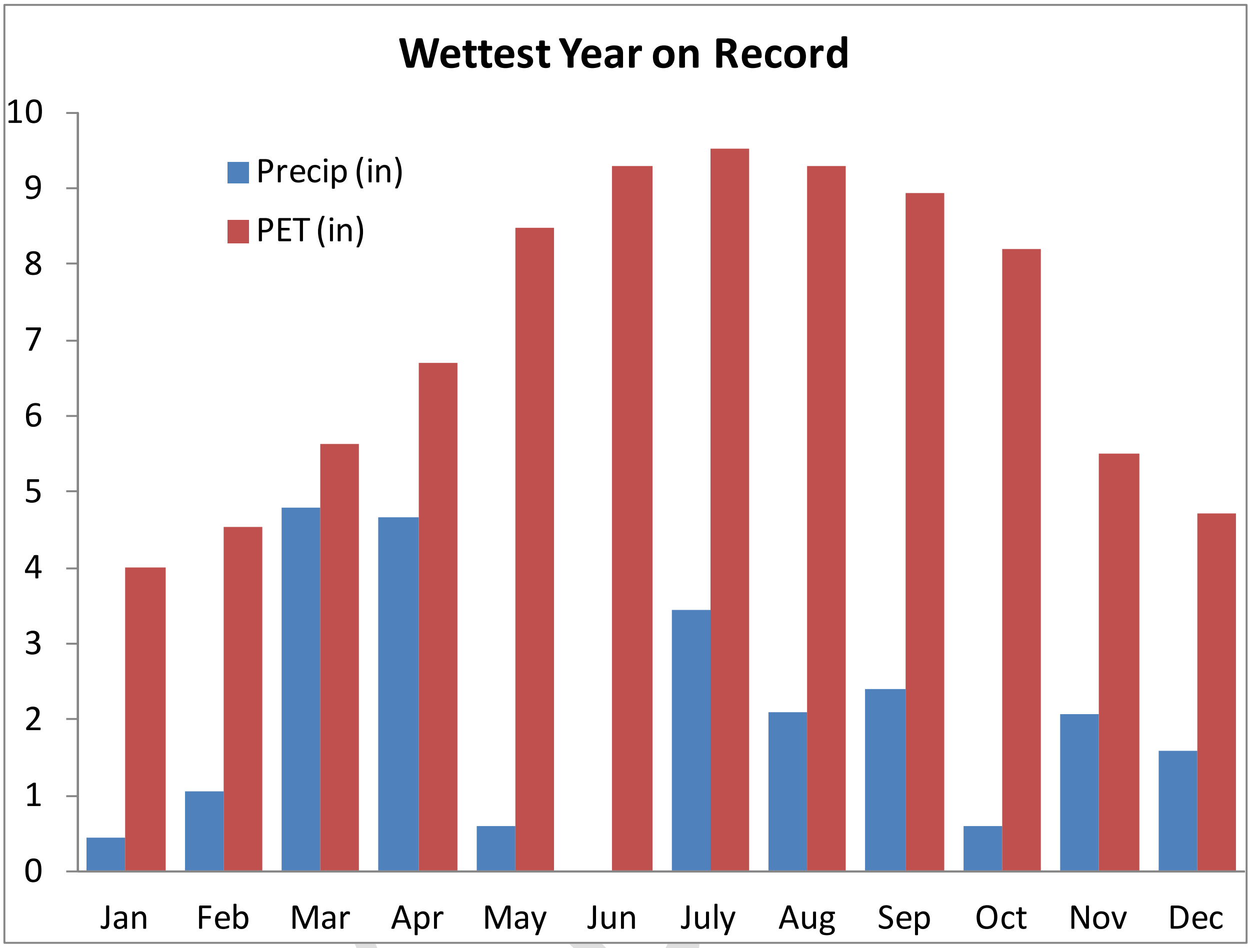



**Figure 11. Wettest Year on Record: Monthly Precip. vs. PET for Ft. Wingate, NM**

The flow of water across the surface and lower boundary of the cover profile of interest is determined by boundary condition specifications. For infiltration events, the upper boundary was conservatively set to a maximum hourly flux for these computer simulations of 0.4 inches (1 cm) per hour that produced effectively no runoff while maximizing infiltration. This is conservative because it is expected at the site given the designed slopes that a significant percentage of precipitation will runoff the site without infiltrating into the cover profile.

The UNSAT-H program partitions PET into potential evaporation ($E_p$) and potential transpiration ($T_p$). Potential evaporation is estimated or derived from daily weather parameters (Fayer 2000). Potential transpiration is calculated using a function (Equation 12) that is based on the value of the assigned leaf area index (LAI) and an equation developed by Ritchie and Burnett (1971) as follows:

$T_p = PET\,[a + b(LAI)^c]$ 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 very well with the Penman method utilized within UNSAT H (Samani and Pessarkli, 1986). The UNSAT-H program then partitioned the daily PET values into $E_p$ and $T_p$. $T_p$ was calculated using a function developed by Equation 4-1 above. The PET or climatic demand for water versus the amount of rain is graphically presented for an average year above in Figure 10 and wettest year on record in Figure 11. 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 alluvium) was a unit gradient. With the unit gradient, the calculated drainage flux depended upon 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 the rooting zone and 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 12).

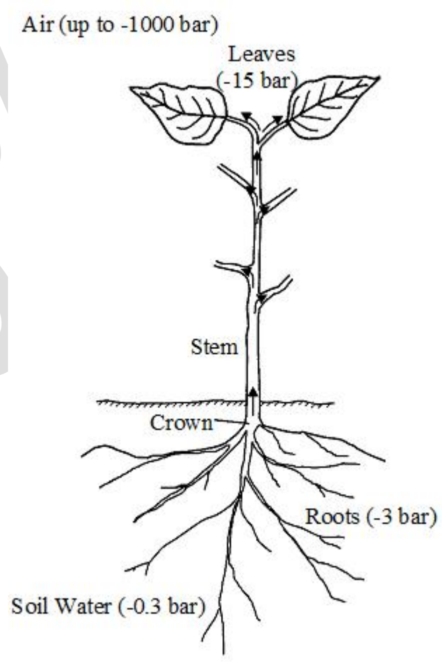



**Figure 12. Typical Soil-Plant-Atmosphere Water Potential Variation (Hillel 1998)**

The input parameters representing vegetation include the LAI, rooting depth and density, root growth rate, the suction head values that corresponds to the soil's field capacity, wilting point, and water content above which plants do not transpire because of anaerobic conditions. The onset and termination of the growing season for the site are defined in terms of Julian days. 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:

$$RLD = a \exp(-bz) + c$$ **Equation 4-2**

where:

a,b, and c are fitting parameters

z = depth below surface

The cover profiles (Figures 6 to 9) were modeled with vegetation on the surface. The computer simulations of the various profiles evaluated for the existing conditions (without mine spoils and new ET Cover) 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 on them features reclaimed vegetation (Cedar Creek 2014). The reclaimed vegetation is the short-term condition (within the twenty years modeled) of vegetation after a site has been disturbed (Cedar Creek 2014). Canonie (1990 and 1992) measured the primary consolation will generally occur in about 100 days. The twenty year modeling period allows for an evaluation of the site after the consolidation takes place to evaluate any potential changes in subsurface moisture movement due to the consolidated tailings.

Cedar Creek performed an analog study of the native vegetation at the NECR site both in a disturbed setting and an undisturbed setting (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 leaf area index (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 NECR site and the respective growing degree days graphically presented in Figure 13. 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. This was conservative since it is realistic that plants can transpire longer than indicated at this site.

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

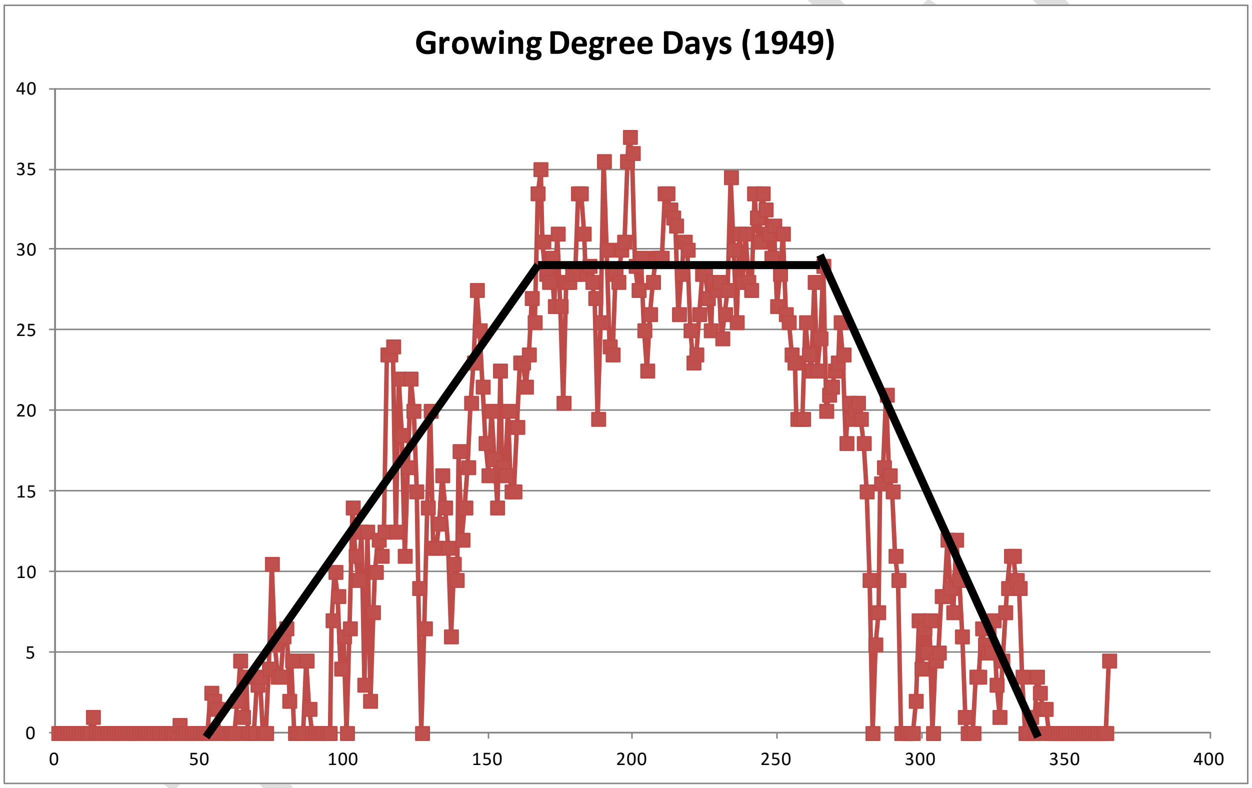



Figure 13. Leaf Area Index Transition during the Year

### 4.2.4 SOIL PROPERTIES RELATED TO VEGETATION

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. 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.

Not all of the water stored in the soil can be removed via transpiration. Vegetation is generally assumed to reduce the soil moisture content to the permanent wilting point. The wilting point for these computer simulations was set at 40,000 cm for reclaimed vegetation (Fayer and Walters 1995) and 70,000 (Fayer and Walters 1995) for shrubland vegetation. This was conservatively used although some shrubs present near the site could remove water from the soil to a suction 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 32.2-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 4-in (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 for each respective layer is also presented in Tables 7 to 10. These soil suction values were calculated based on the initial degree of saturation and hydraulic properties (van Genuchten et al 1991). The Mualem conductivity function was used 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 values calculated from the respective moisture content of each soil layer (van Genuchten et al 1991). The van Genuchten parameters were developed from the laboratory soil measurements (soil suction versus moisture content) using the RETC software (van Genuchten et al 1991).

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | θs | θr | α | n | |
| **Cover – rock/soil** | 0 to 0.5’ | Loamy sand (Carsel & Parrish 1998) | $4.10\times10^{-3}$ | 30% | 0.41 | 0.057 | 0.124 | 2.28 | 29 |
| **Cover - soil** | 0.5’ –2’ | EB-B6-03 | $3.60\times10^{-5}$ | 30% | 0.50926 | 0 | 0.01399 | 1.26891 | 6273 |
| **Fill** | 2’ – 6.5’ | Use B11-03 | $2.50\times10^{-5}$ | 31% | 0.30331 | 0 | 0.01632 | 1.06655 | 2692958106 |
| | 6.5’ – 12’ | | | 53.70% | 0.30331 | 0 | 0.01632 | 1.06655 | 699434 |
| **Fine Tailings** | 12’ – 14.5’ | Use B10-14 | $2.90\times10^{-8}$ | 80.70% | 0.58891 | 0 | 0.0011 | 1.16727 | 2636 |
| **Alluvium** | 14.5’ – 33.5’ | Use B11-10 | $5.60\times10^{-4}$ | 22% | 0.45752 | 0.06145 | 0.13956 | 1.31247 | 11742 |

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | θs | θr | α | n | |
| **Cover – rock/soil** | 0 to 0.5’ | Loamy sand (Carsel & Parrish 1998) | $4.10\times10^{-3}$ | 30% | 0.41 | 0.057 | 0.124 | 2.28 | 29.2 |
| **Cover - soil** | 0.5’ –2’ | EB-B6-03 | $3.60\times10^{-5}$ | 30% | 0.50926 | 0 | 0.01399 | 1.26891 | 6272.7 |
| **Fill** | 2’ – 7’ | Use B11-03 | $2.50\times10^{-5}$ | 30% | 0.30331 | 0 | 0.01632 | 1.06655 | 4407686039.0 |
| Coarse Tailings | 7’ – 26.5’ | B8-02 | $3.60\times10^{-4}$ | 38.4% | 0.41023 | 0 | 0.47787 | 1.16163 | 779.9 |
| **Fine Tailings** | 26.5’ – 31’ | Use B8-9 | $3.00\times10^{-8}$ | 96.9% | 0.56534 | 0 | 0.00446 | 1.15784 | 70.0 |
| **Fine Tailings** | 31’ – 35’ | Use B8-9 | $3.00\times10^{-8}$ | 92% | 0.56534 | 0 | 0.00446 | 1.15784 | 193.6 |
| **Coarse/Fine Tailings** | 35’ - 35.5’ | B8-06 | $1.60\times10^{-5}$ | 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 | $3.00E^{-8}$ | Saturat | 0.56534 | 0 | 0.00446 | 1.15784 | 0.0 |

| Soil Layer | Depth BGS | Data Sample (MWH 2014) | Ks (cm/sec) | $S_0$ | van Genuchten parameters | | | | Initial Suction (-cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | θs | θr | α | n | |
| | | | | ed | | | | | |
| **Coarse/Fine Tailings** | 41.5' – 42' | B8-08 | 1.30 x10$^{-7}$ | 90.5% | 0.4272 | 0 | 1.87772 | 1.16882 | 0.5 |
| **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 |

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | θs | θr | 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 |
| **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 |

| Soil Layer | Depth BGS | Data Sample (MWH 2014) | Ks (cm/sec) | $S_0$ | van Genuchten parameters | | | | Initial Suction (-cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | θs | θr | α | n | |
| **Coarse/Fine Tailings** | 36’ – 37’ | B10-03 | $1.30 \times 10^{-7}$ | 93.80% | 0.44786 | 0 | 0.00129 | 1.29116 | 327.1 |
| **Fine Tailings** | 37’ – 41’ | Use B10 | $3.00 \times 10^{-8}$ | 100.10% | 0.58891 | 0 | 0.0011 | 1.16727 | 0.0 |
| **Fine Tailings** | 41’ – 43’ | Use B10 | $3.00 \times 10^{-8}$ | 98.80% | 0.58891 | 0 | 0.0011 | 1.16727 | 113.2 |
| **Alluvium** | 43’ – 62’ | B10-18 | $2.40 \times 10^{-5}$ | 48.86% | 0.40301 | 0.00829 | 0.54078 | 1.1191 | 911.3 |

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | θs | θr | α | n | |
| **Cover – rock/soil** | 0 to 0.5’ | Loamy sand (Carsel & Parrish 1998) | $4.10 \times 10^{-3}$ | 30% | 0.41 | 0.057 | 0.124 | 2.28 | 29.2 |
| **Cover - soil** | 0.5’ –2’ | EB-B6-03 | $3.60 \times 10^{-5}$ | 30% | 0.50926 | 0 | 0.01399 | 1.26891 | 6272.7 |
| **Fill** | 2’ – 15’ | Use B11-03 | $2.50 \times 10^{-5}$ | 29.30% | 0.30331 | 0 | 0.01632 | 1.06655 | 6284703564.2 |
| | 15’ – 20’ | | | 42.90% | 0.30331 | 0 | 0.01632 | 1.06655 | 20421368.8 |
| | 20’ – 30’ | | | 59.80% | 0.30331 | 0 | 0.01632 | 1.06655 | 138843.8 |
| **Fine Tailings** | 30’ – 42.5’ | B8-09 | $3.00 \times 10^{-8}$ | 75.70% | 0.30331 | 0 | 0.01632 | 1.06655 | 3974.6 |
| **Alluvium** | 42.5’ – 54’ | B11-10 | $5.60 \times 10^{-4}$ | 95.30% | 0.56534 | 0 | 0.00446 | 1.15784 | 106.8 |

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 which is the largest borrow source.

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% 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% 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 have rock mixed into it at a volumetric ratio of 33% rock to 67% 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. The following equation (Equation 4-3) was used to calculate the rock adjusted saturated hydraulic conductivity based on the addition of rock (Peck and Watson 1979).

$$K_b = [K_s * 2(1 - V_r)]/(2 + V_r) \quad \textbf{Equation 4-3}$$

$$where{:}\ K_b = saturated\ hydraulic\ conductivty, bulk$$

$$K_s = saturated\ hydraulic\ conductivty, soil$$

$$V_r = volume\ of\ rock$$

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 admixture depth'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 were utilized as the basis. Each respective measured volumetric moisture content was reduced per Equation 4-4 [ASTM D4718 and Bouwer & Rice (1984)].

$$\theta_b = (1 - V_r)\theta_s \quad \textbf{Equation 4-4}$$

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

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

$$V_r = volume\ of\ rock$$

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|
| | | | | θs | θr | α | n | |
| **Cover Rock/Soil Admixture** | 1.17 | SB-B4-01 | $4.26x10^{-4}$ | 0.3478 | 0 | 0.0373 | 1.2243 | 2200.0 |
| **ET Cover** | 2.83 | SB-B4-01 | $7.40\ x10^{-5}$ | 0.5191 | 0 | 0.0373 | 1.2243 | 2200.0 |
| **Mine Spoils** | 10.8 | 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 | 0.01399 | 1.26891 | 6272.7 |
| **Fill** | 4.5 | Use B11-03 | $2.50\ x10^{-5}$ | 0.30331 | 0 | 0.01632 | 1.06655 | 2692958106.4 |
| | 5.5 | | | 0.30331 | 0 | 0.01632 | 1.06655 | 699434.4 |
| **Fine Tailings** | 2.32** | Use B10-14 | $2.90\ x10^{-8}$ | 0.555174 | 0 | 0.0011 | 1.16727 | 1617.0 |
| **Alluvium** | 19 | Use B11-10 | $5.60\ x10^{-4}$ | 0.45752 | 0.06145 | 0.13956 | 1.31247 | 11741.6 |

** thickness adjusted for consolidation, refer to Table 1

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|
| | | | | θs | θr | α | n | |
| **Cover Rock/Soil Admixture** | 1.17 | SB-B4-01 | $4.26x10^{-4}$ | 0.3478 | 0 | 0.0373 | 1.2243 | 2200.0 |
| **ET Cover** | 2.83 | SB-B4-01 | $7.40\ x10^{-5}$ | 0.5191 | 0 | 0.0373 | 1.2243 | 2200.0 |
| **Mine Spoils** | 11.7 | Use TT-205-GT1 | $2.20\ x10^{-4}$ | 0.3774 | 0 | 0.0525 | 1.2338 | 3278.412007 |

| Soil Layer | Thickness (ft) | Data Sample (MWH 2014) | Ks (cm/sec) | van Genuchten parameters | | | | Initial Suction (-cm) |
|---|---|---|---|---|---|---|---|---|
| | | | | θs | θr | α | n | |
| **Cover soil - Radon Barrier** | 1.5 | EB-B6-03 | $3.60 x 10^{-5}$ | 0.50926 | 0 | 0.014 | 1.26891 | 6272.650572 |
| **Fill** | 5 | Use B11-03 | $2.50 x 10^{-5}$ | 0.30331 | 0 | 0.0163 | 1.06655 | 4407686039 |
| **Coarse Tailings** | 19.50 | B8-02 | $3.60 x 10^{-4}$ | 0.41023 | 0 | 0.4779 | 1.16163 | 779.9 |
| **Fine Tailings** | 4.33** | Use B8-9 | $3.00 x 10^{-8}$ | 0.54754 | 0 | 0.0045 | 1.15784 | 0 |
| **Fine Tailings** | 3.83** | Use B8-9 | $3.00 x 10^{-8}$ | 0.54754 | 0 | 0.0045 | 1.15784 | 114.2 |
| **Coarse/Fine Tailings** | 0.49** | B8-06 | $1.60 x 10^{-5}$ | 0.47776 | 0 | 0.0009 | 1.37788 | 8014.4 |
| **Coarse/Fine Tailings** | 0.49** | B8-06 | $1.60 x 10^{-5}$ | 0.47776 | 0 | 0.0009 | 1.37788 | 5898.4 |
| **Fine Tailings** | 5.29** | Use B8-09 | $3.00 x 10^{-8}$ | 0.54754 | 0 | 0.0045 | 1.15784 | 0.0 |
| **Coarse/Fine Tailings** | 0.49** | B8-08 | $1.30 x 10^{-7}$ | 0.41638 | 0 | 1.8777 | 1.16882 | 0.4 |
| **Coarse/Fine Tailings** | 2.44** | B8-08 | $1.30 x 10^{-7}$ | 0.41638 | 0 | 1.8777 | 1.16882 | 0.1 |
| **Fine Tailings** | 0.48** | Use B8-09 | $3.00 x 10^{-8}$ | 0.54754 | 0 | 0.0045 | 1.15784 | 17.1 |
| **Alluvium** | 18 | Use B1-13A | $1.70 x 10^{-6}$ | 0.4951 | 0.0398 | 0.4325 | 1.20486 | 98.5 |

** thickness adjusted for consolidation, refer to Table 2

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|
| | | | | θs | θr | α | n | |
| **Cover Rock/Soil Admixture** | 1.17 | SB-B4-01 | $4.26 x 10^{-4}$ | 0.3478 | **0** | 0.0373 | 1.2243 | 2200.0 |
| **ET Cover Soil** | 2.83 | SB-B4-01 | $7.40 x 10^{-5}$ | 0.5191 | **0** | 0.0373 | 1.2243 | 2200.0 |
| **Mine Spoils** | 22.6 | Use TT-205-GT1 | $2.20 x 10^{-4}$ | 0.3774 | 0 | 0.0525 | 1.2338 | 3278.4 |

| Soil Layer | Depth BGS | Data Sample (MWH 2014) | Ks (cm/sec) | van Genuchten parameters | | | | Initial Suction (-cm) |
|---|---|---|---|---|---|---|---|---|
| | | | | θs | θr | α | n | |
| **Cover soil - Radon Barrier** | 1.5 | EB-B6-03 | 3.60 x$10^{-5}$ | 0.50926 | 0 | 0.01399 | 1.26891 | 6272.7 |
| **Fill** | 5 | Use B11-03 | 2.50 x$10^{-5}$ | 0.30331 | 0 | 0.01632 | 1.06655 | 4407686039.0 |
| **Coarse Tailings** | 5 | B10-02 | 4.30 x$10^{-4}$ | 0.3481 | 0 | 0.67277 | 1.13662 | 3662.8 |
| **Coarse Tailings** | 5.5 | B10-03 | 6.70 x$10^{-5}$ | 0.4272 | 0 | 1.87772 | 1.16882 | 583.2 |
| **Coarse/Fine Tailings** | 7.28** | Use B8-08 | 1.30 x$10^{-7}$ | 0.43563 | 0 | 0.00129 | 1.29116 | 510.3 |
| **Fine Tailings** | 0.95** | Use B10-14 | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 1517.0 |
| **Fine Tailings** | 1.91** | | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 305.2 |
| **Fine Tailings** | 3.81** | | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 415.1 |
| **Coarse Tailings** | 0.98** | B10-03 | 6.70x10-7 | 0.41514 | 0 | 1.87772 | 1.16882 | 7.5 |
| **Fine Tailings** | 2.40** | Use B10-14 | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 156.8 |
| **Fine Tailings** | 0.48** | | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 1467.1 |
| **Coarse Tailings** | 0.98** | Use B8-08 | 1.30x$10^{-7}$ | 0.43563 | 0 | 0.00129 | 1.29116 | 200.7 |
| **Fine Tailings** | 3.84** | Use B10-14 | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 0 |
| **Fine Tailings** | 1.93** | | 3.00 x$10^{-8}$ | 0.57044 | 0 | 0.0011 | 1.16727 | 0 |
| **Alluvium** | 19 | B10-18 | 2.40x$10^{-5}$ | 0.40301 | 0.00829 | 0.54078 | 1.1191 | 911.3 |

** thickness adjusted for consolidation, refer to Table 3

**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 (-cm) |
|---|---|---|---|---|---|---|---|---|
| | | | | θs | θr | α | n | |
| **Cover Rock/Soil Admixture** | 1.1666667 | SB-B4-01 | 4.26x$10^{-4}$ | 0.3478 | 0 | 0.0373 | 1.2243 | 2200.0 |

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

** thickness adjusted for consolidation, refer to Table 4

## 5.0 COMPUTER SIMULATION RESULTS

The output from the profiles modeled as described in Section 4.2.1 are presented in this section. Each respective profile was modeled in its existing condition and then again with the assumed mine spoils and new ET Cover placed on it based on the proposed design. The profiles were modeled for a period of twenty years consisting of typical climate for the first ten years followed by the two wettest years on records followed by eight more typical climate years. The results are intended to present a direct comparison of existing conditions with the same location after installation of the mine spoils and new ET Cover.

Table 15 presents the cumulative results of the annual flux though the cover and base of the profile for each computer simulation. Figures 6 to 9 provide a graphical summary of each profile modeled including each layer's thickness. Alluvium is the bottom layer of each profile modeled and located above the groundwater table. This analysis assumes that drainage though the base of the alluvium is free to enter the underlying groundwater. Appendix A contains a year-by-year water balance results for each profile evaluated.

The computer simulations revealed there is no difference in drainage through the base of the alluvium modeled for profiles B2, B8, and B10. In these profiles, the underlying alluvium was measured to be 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. The fact that any drainage from the alluvium was 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.

There was a very small difference between the simulations for Profile B11 in Borrow Pit 2. The profile with mine spoils and new ET Cover induced an average annual flux increase of 2E-06 cm/year. This equates to a hydraulic conductivity difference of 6.34E-14 cm/sec. It is believed the reason that there is a slight difference here is the initial assumed conditions of the alluvium was very wet (95.3% degree of saturation) and was wetter than field capacity. That is, there was no excess water storage capacity in the alluvium. The initial soil suction in this alluvium layer was 106.8 cm. Field capacity is generally assumed to be 330 cm (Jury et al 1991). Drainage through soils with a soil suction less (more negative) than field capacity are controlled by gravity.

**Table 15. Cumulative 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 Alluvium | 0 | 0 |
| **B8** | **Borrow Pit 1** | Cover | +136 | +6.79 |

| Profile | | Layer Base | Difference (cm) for 20 year period | Average Annual Difference (cm) |
|---|---|---|---|---|
| | | Base of Alluvium | 0 | 0 |
| **B10** | **Borrow Pit 1** | Cover | +115 | +5.75 |
| | | Base of Alluvium | 0 | 0 |
| **B11** | **Borrow Pit 2** | Cover | +127 | +6.35 |
| | | Base of Alluvium | -0.00004 | -0.000002 |

\+ 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.

## 5.1 North Cell: Profile B2

Profile B2 represents an area in the North Cell that has about 2.5-ft of fine-grained tailings or slimes, and is representative of the majority of the area where the mine wastes are to be placed. The area is slated 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 Figure 6.

Both the existing profile B2 and the profile with the mine spoils and new ET Cover added have an average annual drainage rate of $1.15 \times 10^{-6}$ cm/year converted to a hydraulic conductivity given the steady state conditions assumed at the base of the profile of $3.65 \times 10^{-14}$ cm/sec. It can also be seen that the existing cover allows a significant amount of percolation through it each year, while the new ET Cover allows none (Figure 14). The ET Cover allows for drying of the profile via a significant amount of evaporation as well as transpiration.

In conclusion, there is no increase in drainage to the underlying groundwater due to the addition of mine spoils and new ET Cover in Profile B2. Furthermore, it is anticipated due to the elimination of downward liquid flux through the ET Cover (the cover on the existing profile appears to be allowing flux) that the long-term drainage condition of the impoundment below the ET Cover footprint will be improved when compared to the existing conditions.

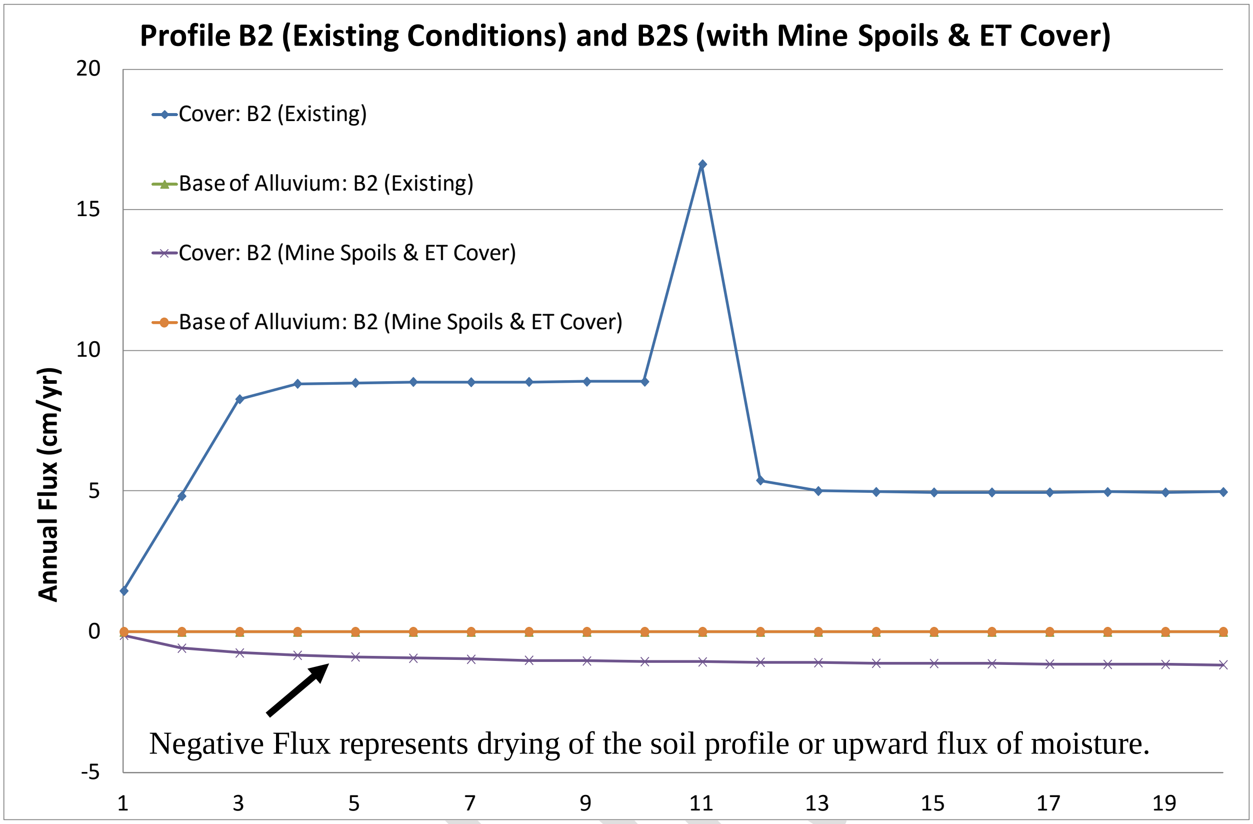



**Figure 14. Profile B2 Computer Simulation Results**

## 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 slated 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 Figure 7.

Both the existing profile B8 and that with the mine spoils and new ET Cover added have an average annual drainage rate of $1.23 \times 10^{-4}$ cm/year or a hydraulic conductivity given the steady state conditions assumed at the base of the profile of $3.91 \times 10^{-12}$ cm/sec. It can also be seen that the existing cover allows a significant amount of percolation through it each year, while the new ET Cover allows none (Figure 15). The ET Cover allows for drying of the profile via a significant amount of evaporation as well as transpiration.

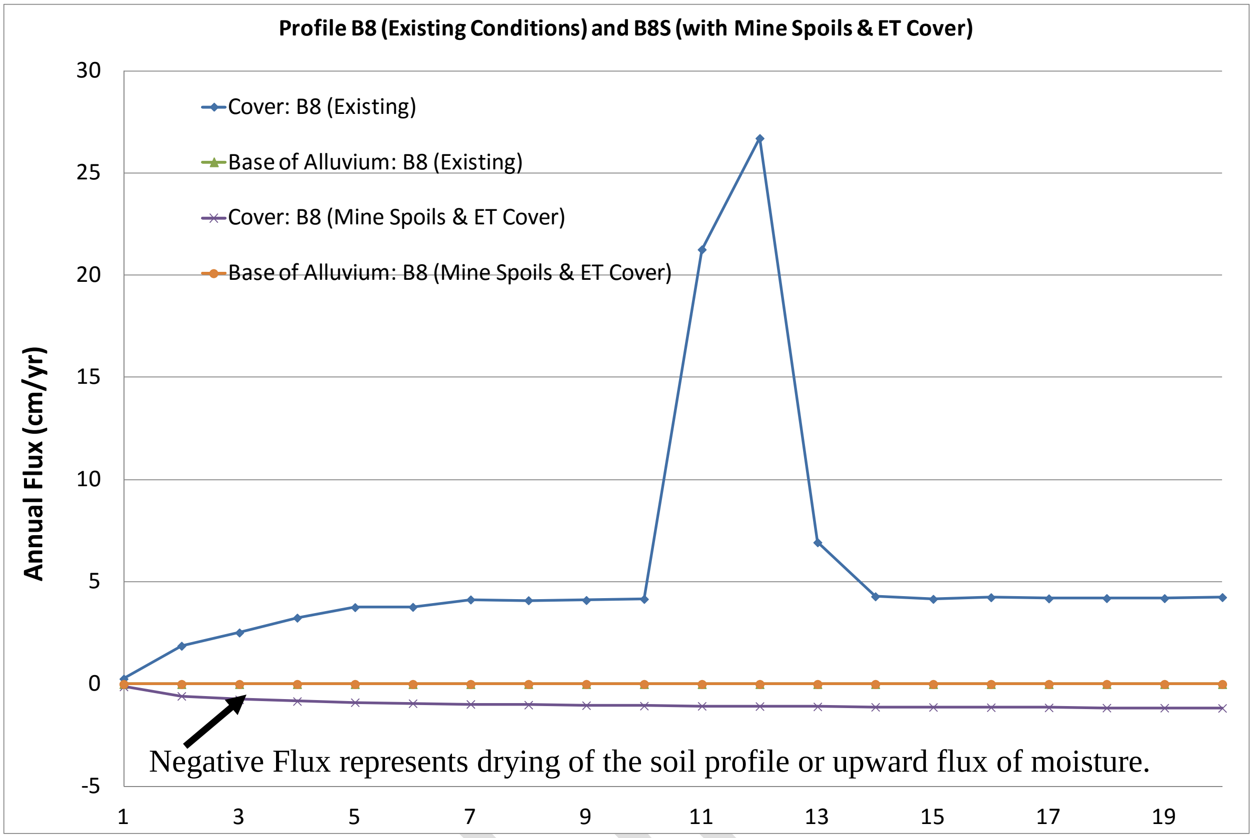



**Figure 15. Profile B8 Computer Simulation Results**

Profile B10 represents an area in Borrow Pit 1 that has about 36-ft of combined coarse and fine-grained tailings. The area is slated 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 Figure 8.

Both the existing profile B10 and that with the mine spoils and new ET Cover added have an average annual drainage rate of $5.57 \times 10^{-6}$ cm/year or a hydraulic conductivity given the steady state conditions assumed at the base of the profile of $1.77 \times 10^{-13}$ cm/sec. It can also be seen that the existing cover allows a significant amount of percolation through it each year, while the new ET Cover allows none (Figure 16).

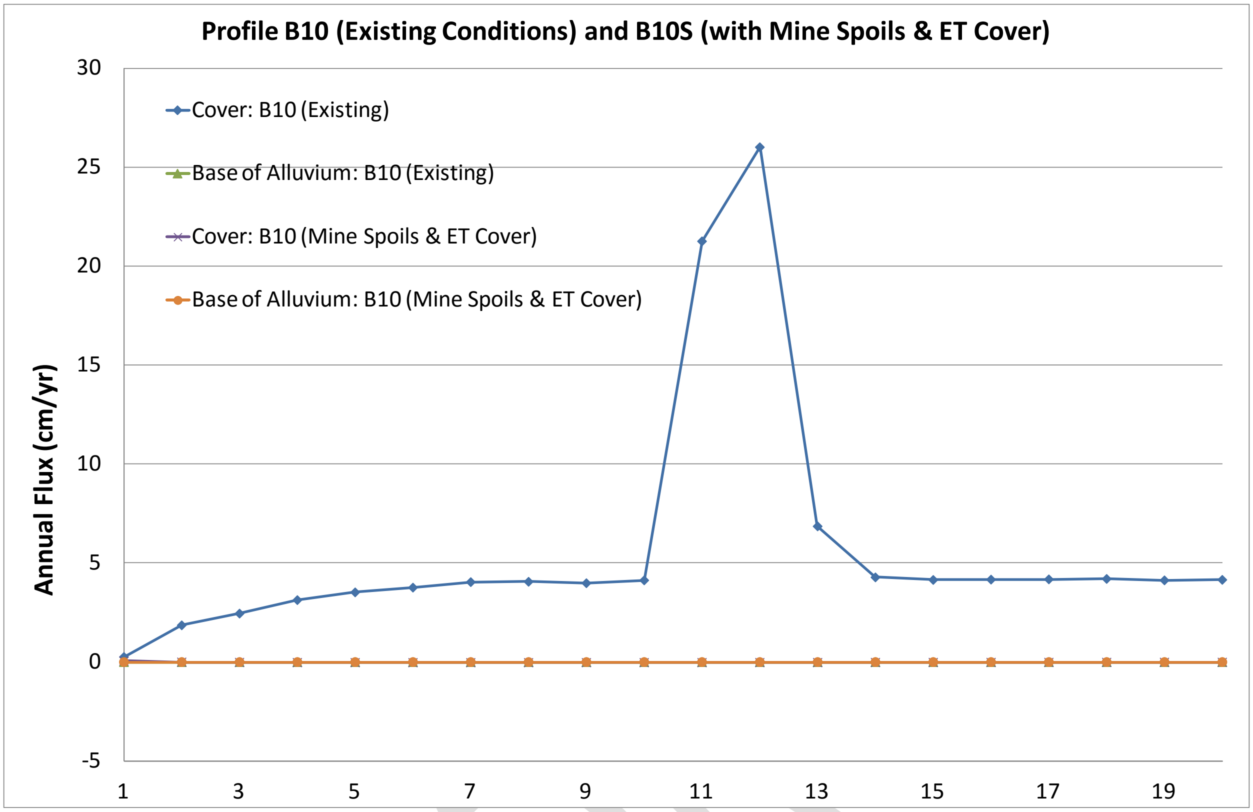



**Figure 16. Profile B10 Computer Simulation Results**

In conclusion, there is no increase in drainage to the underlying groundwater due to the addition of mine spoils and new ET Cover in Borrow Pit 1. Furthermore, it is anticipated due to the elimination of downward liquid flux through the ET Cover (the cover on the existing profile appears to be allowing flux) that the long-term drainage condition of the impoundment below the ET Cover footprint will be improved when compared to the existing conditions.

## 5.2 Borrow Pit 2: Profile B11

Profile B11 represents an area in Borrow Pit 1 that has about 36-ft of combined coarse and fine-grained tailings. The area is slated 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 Figure 9.

The existing profile B11 added 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 $1.549 \times 10^{-8}$ cm/sec. The profile B11 with the mine spoils 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 $1.549 \times 10^{-8}$ cm/sec. The difference between the two is considered insignificant. It can also be seen that the existing cover allows a significant amount of percolation through it each year, while the new ET Cover allows none (Figure 17). The ET Cover allows for drying of the profile via a significant amount of evaporation as well as transpiration.

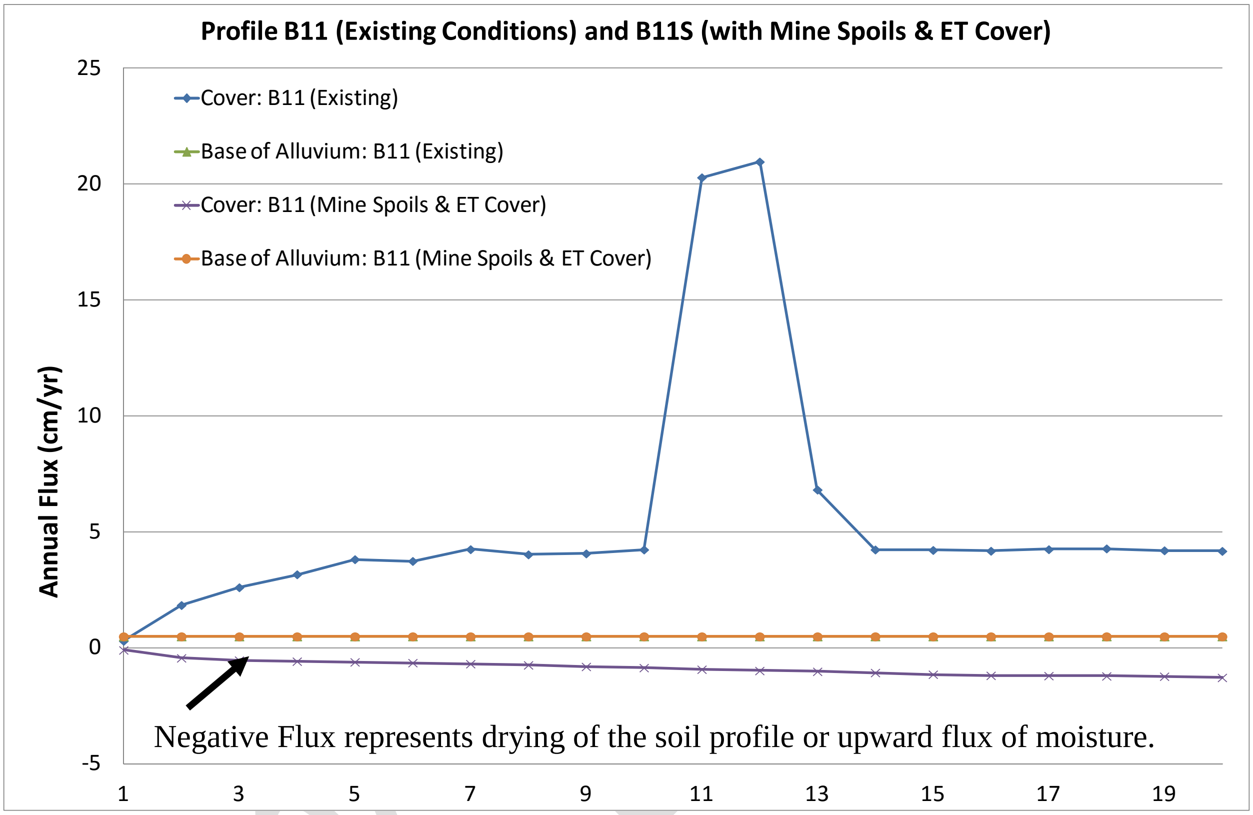



**Figure 17. Profile B11 Computer Simulation Results**

In conclusion, there is no significant increase in drainage to the underlying groundwater due to the addition of mine spoils and new ET Cover in Borrow Pit 2.

## 6.0 Overview of Results

Results presented in Section 5 demonstrate that there is no significant difference in drainage from the respective profiles into the underlying groundwater by placing mine spoils and a new ET Cover on the existing tailings impoundment. Appendix A contains the year-by-year water balance results for each profile evaluated.

Perhaps more important to consider than the annual flux difference presented in Table 15, is the change in storage capacity between the cover and base of the tailings of each profile presented in Table 16. It can be seen that for each profile evaluated, there is a significant build-up of water within the existing condition from as high as about 200 cm of water within the B2 Profile to about 114 cm of water in Profile B10. This build-up will eventually lead to an increase and prolonged drained rate from the existing profile. Conversely, since there is no new moisture entering the profile with the mine spoils and ET Cover added, the drainage will continue to decrease until it stops.

**Table 16. Change in Storage Capacity between Cover & Base of Tailings**

| Profile | | Increase in Water Stored in Profile between Cover & Base of Tailings in Existing Profile Compared to Same Profile with Mine Spoils and ET Cover |
|---|---|---|
| **B2** | **North Cell** | 200.1 cm |
| **B8** | **Borrow Pit 1** | 134.3 cm |
| **B10** | **Borrow Pit 1** | 114.2 cm |
| **B11** | **Borrow Pit 2** | 126.9 cm |

## 7.0 REFERENCES


1. ASTM 4718-2007. Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversized Particles.
2. ASTM 698-12. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.
3. Bouwer H. and R. Rice, 1984. Hydraulic Properties of Stony Vadose Zones. Ground Water, 22 (6) (1984), pp. 696–705.
4. Bowles, Joseph E. 1996. Foundation Analysis and Design. 5th Edition. McGraw-Hill Companies, Inc.
5. Canonie Environmental. 1990. North Cell Interim Stabilization, As-Built Report. January 1990.
6. Canonie Environmental. 1992. Central Cell Interim Stabilization, As-Built Report Addendum. April 1992.
7. Cedar Creek Associates. 2014. Vegetation Characterization and Biointrusion Surveys Church Rock Mill Site. July 2014.
8. Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for prediction crop water requirements. FAO Irrig. and Drain. Paper No. 24, 2nd ed., FAO Rome, Italy.
9. Dwyer, SF. 2003. Water Balance Measurements and Computer Simulations of Landfill Closures. PhD Dissertation. University of New Mexico, Albuquerque, NM.
10. Dwyer, SF. 2014. Natural Analog Study of Cover Soil Borrow Sources Using a Tension Infiltrometer. Northeast Churchrock Mine, Gallup, NM. August 20, 2014.
11. Dwyer, SF. 2016. Cover System Design Report - 30% Design Draft. July 2016.
12. Fayer, M. J., and T. L. Jones. 1990. UNSAT-H version 2.0: Unsaturated soil water and heat flow model. PNL-6779, Pacific Northwest Laboratory, Richland, WA.
13. Fayer, M.J. 2000. UNSAT-H Version 3.0: Unsaturated Soil Water and Heat Flow Model, Theory, User Manual, and Examples. Pacific Northwest Laboratory, Richland, WA.
14. Fayer, MJ and TB Walters. 1995. Estimated Recharge Rates at the Hanford Site. PNL-10285, Pacific Northwest Laboratory, Richland, WA.
15. Hillel, D. 1998. Environmental Soil Physics. Academic Press, San Diego, CA.
16. ITRC. 2003. Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers. Interstate Technology and Regulatory Council, Alternative Landfill Technologies Team, Washington DC.
17. Jury, W.A., W.R. Gardner, and W.H. Gardner. 1991. Soil Physics, 5$^{th}$ Edition, John Wiley & Sons, Inc., New York, NY.
18. MWH. 2014. Pre-Design Studies Northeast Church Rock Mine Site Removal Action/Church Rock Mill Site. October 31, 2014.

19. Peck, A.J., and J.D. Watson. 1979. Hydraulic Conductivity and Flow in Non-uniform Soil. In Workshop on Soil Physics and Field Heterogeneity. CSIRO Division of Environmental Mechanics, Canberra, Australia.

20. Ritchie, J.T., and E. Burnett. (1971). Dryland Evaporative Flux in a Semi-humid Climate, 2, Plant Influences. Agron. J. 63:56-62.

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

22. Schroeder, P., C. Lloyd and P. Zappi. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3.0. U.S. Environmental Protection Agency, EPA/600/R-94/168a, Cincinnati, OH.

23. U.S. Environmental Protection Agency (USEPA), Region 6 and Region 9. 2015. Administrative Settlement Agreement and Order on Consent for Design and Cost Recovery. April 27.Johnson (2002).

24. U.S. Environmental Protection Agency (USEPA), Region 6 and Region 9, 2011. Action Memorandum: Request for a Non-Time-Critical Removal Action at the Northeast Church Rock Site, McKinley County, New Mexico, Pinedale Chapter of the Navajo Nation. September 29.

25. U.S. Environmental Protection Agency (USEPA), Region 6. 2013. Record of Decision, United Nuclear Corporation Site, McKinley County, New Mexico. March 29.

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

27.

# APPENDIX A

## WATER BALANCE RESULTS

**Table 17. ProfileB2 (Existing Condition) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 143.532 |
| 1 | 29.743 | 211.744 | 8.42 | 11.98 | 0 | 1.14910E-06 | 152.876 |
| 2 | 29.743 | 211.744 | 10.049 | 11.809 | 0 | 1.15220E-06 | 160.763 |
| 3 | 29.743 | 211.744 | 11.263 | 11.871 | 0 | 1.14910E-06 | 167.371 |
| 4 | 29.743 | 211.744 | 12.499 | 11.918 | 0 | 1.14910E-06 | 172.695 |
| 5 | 29.743 | 211.744 | 13.416 | 11.926 | 0 | 1.14910E-06 | 177.095 |
| 6 | 29.743 | 211.744 | 13.407 | 11.932 | 0 | 1.15220E-06 | 181.496 |
| 7 | 29.743 | 211.744 | 13.398 | 11.929 | 0 | 1.14910E-06 | 185.91 |
| 8 | 29.743 | 211.744 | 13.378 | 11.931 | 0 | 1.14910E-06 | 190.341 |
| 9 | 29.743 | 211.744 | 13.374 | 11.922 | 0 | 1.14910E-06 | 194.785 |
| 10 | 29.743 | 211.744 | 13.373 | 11.938 | 0 | 1.15220E-06 | 199.214 |
| 11 | 60.35 | 215.456 | 5.136 | 34.1 | 0.634 | 1.14910E-06 | 219.61 |
| 12 | 60.35 | 215.456 | 3.998 | 45.512 | 5.371 | 1.14910E-06 | 225.086 |
| 13 | 29.743 | 211.744 | 6.067 | 21.059 | 0 | 1.14910E-06 | 227.705 |
| 14 | 29.743 | 211.744 | 6.169 | 18.683 | 0 | 1.15220E-06 | 232.597 |
| 15 | 29.743 | 211.744 | 6.171 | 18.671 | 0 | 1.14910E-06 | 237.5 |
| 16 | 29.743 | 211.744 | 6.166 | 18.683 | 0 | 1.14910E-06 | 242.396 |
| 17 | 29.743 | 211.744 | 6.166 | 18.686 | 0 | 1.14910E-06 | 247.289 |
| 18 | 29.743 | 211.744 | 6.161 | 18.691 | 0 | 1.15220E-06 | 252.182 |
| 19 | 29.743 | 211.744 | 6.164 | 18.675 | 0 | 1.14910E-06 | 257.088 |
| 20 | 29.743 | 211.744 | 6.17 | 18.685 | 0 | 1.15220E-06 | 261.978 |

**Table 18. ProfileB2 (Mine Spoils & ET Cover) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial Storage = | | | | | | | 197.342 |
| 1 | 29.743 | 211.744 | 16.147 | 18.937 | 0.097 | 1.14910E-06 | 192.251 |
| 2 | 29.743 | 211.744 | 10.691 | 18.819 | 0.091 | 1.15220E-06 | 192.749 |
| 3 | 29.743 | 211.744 | 10.201 | 18.857 | 0.093 | 1.14910E-06 | 193.778 |
| 4 | 29.743 | 211.744 | 10.318 | 18.946 | 0.088 | 1.14910E-06 | 194.821 |
| 5 | 29.743 | 211.744 | 10.288 | 18.862 | 0.095 | 1.14910E-06 | 195.772 |
| 6 | 29.743 | 211.744 | 10.26 | 18.763 | 0.095 | 1.15220E-06 | 196.626 |
| 7 | 29.743 | 211.744 | 10.359 | 18.778 | 0.092 | 1.14910E-06 | 197.404 |
| 8 | 29.743 | 211.744 | 10.397 | 18.753 | 0.099 | 1.14910E-06 | 198.116 |
| 9 | 29.743 | 211.744 | 10.662 | 18.927 | 0.091 | 1.14910E-06 | 198.789 |
| 10 | 29.743 | 211.744 | 10.459 | 18.729 | 0.094 | 1.15220E-06 | 199.41 |
| 11 | 60.35 | 215.456 | 19.82 | 35.552 | 0.735 | 1.14910E-06 | 203.884 |
| 12 | 60.35 | 215.456 | 21.741 | 37.68 | 0.345 | 1.14910E-06 | 204.808 |
| 13 | 29.743 | 211.744 | 13.548 | 20.349 | 0.087 | 1.14910E-06 | 201.205 |
| 14 | 29.743 | 211.744 | 10.755 | 18.843 | 0.09 | 1.15220E-06 | 201.669 |
| 15 | 29.743 | 211.744 | 10.551 | 18.733 | 0.087 | 1.14910E-06 | 202.186 |
| 16 | 29.743 | 211.744 | 10.641 | 18.793 | 0.085 | 1.14910E-06 | 202.702 |
| 17 | 29.743 | 211.744 | 10.875 | 18.955 | 0.101 | 1.14910E-06 | 203.21 |
| 18 | 29.743 | 211.744 | 10.78 | 18.882 | 0.092 | 1.15220E-06 | 203.697 |
| 19 | 29.743 | 211.744 | 10.642 | 18.767 | 0.091 | 1.14910E-06 | 204.173 |
| 20 | 29.743 | 211.744 | 10.668 | 18.781 | 0.09 | 1.15220E-06 | 204.646 |

**Table 19. ProfileB8 (Existing Condition) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 539.383 |
| 1 | 29.743 | 211.744 | 6.688 | 17.647 | 0.306 | 1.23350E-04 | 544.54 |
| 2 | 29.743 | 211.744 | 8.005 | 17.514 | 0.37 | 1.23690E-04 | 548.561 |
| 3 | 29.743 | 211.744 | 8.563 | 17.508 | 0.317 | 1.23350E-04 | 552.124 |
| 4 | 29.743 | 211.744 | 9.179 | 17.528 | 0.351 | 1.23350E-04 | 554.944 |
| 5 | 29.743 | 211.744 | 9.567 | 17.519 | 0.312 | 1.23350E-04 | 557.504 |
| 6 | 29.743 | 211.744 | 10.17 | 17.573 | 0.287 | 1.23690E-04 | 559.272 |
| 7 | 29.743 | 211.744 | 10.54 | 17.54 | 0.352 | 1.23350E-04 | 560.741 |
| 8 | 29.743 | 211.744 | 11.015 | 17.544 | 0.3 | 1.23350E-04 | 561.733 |
| 9 | 29.743 | 211.744 | 11.016 | 17.58 | 0.332 | 1.23350E-04 | 562.692 |
| 10 | 29.743 | 211.744 | 11.316 | 17.573 | 0.335 | 1.23690E-04 | 563.336 |
| 11 | 60.35 | 215.456 | 11.181 | 27.932 | 0.029 | 1.23350E-04 | 584.184 |
| 12 | 60.35 | 215.456 | 11.239 | 25.795 | 0.241 | 1.23350E-04 | 603.987 |
| 13 | 29.743 | 211.744 | 13.124 | 17.848 | 0.316 | 1.23350E-04 | 602.639 |
| 14 | 29.743 | 211.744 | 13.133 | 17.617 | 0.341 | 1.23690E-04 | 601.498 |
| 15 | 29.743 | 211.744 | 13.15 | 17.598 | 0.336 | 1.23350E-04 | 600.248 |
| 16 | 29.743 | 211.744 | 13.138 | 17.573 | 0.302 | 1.23350E-04 | 599.181 |
| 17 | 29.743 | 211.744 | 13.054 | 17.582 | 0.332 | 1.23350E-04 | 598.072 |
| 18 | 29.743 | 211.744 | 12.835 | 17.583 | 0.341 | 1.23690E-04 | 597.249 |
| 19 | 29.743 | 211.744 | 12.624 | 17.561 | 0.345 | 1.23350E-04 | 596.651 |
| 20 | 29.743 | 211.744 | 12.474 | 17.554 | 0.336 | 1.23690E-04 | 596.276 |

**Table 20. ProfileB8 (Mine Spoils & ET Cover) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 599.336 |
| 1 | 29.743 | 211.744 | 16.293 | 19.057 | 0.089 | 1.23350E-04 | 594.248 |
| 2 | 29.743 | 211.744 | 10.767 | 18.883 | 0.089 | 1.23690E-04 | 594.744 |
| 3 | 29.743 | 211.744 | 10.332 | 18.958 | 0.09 | 1.23350E-04 | 595.775 |
| 4 | 29.743 | 211.744 | 10.061 | 18.742 | 0.091 | 1.23350E-04 | 596.806 |
| 5 | 29.743 | 211.744 | 10.134 | 18.744 | 0.089 | 1.23350E-04 | 597.761 |
| 6 | 29.743 | 211.744 | 10.185 | 18.699 | 0.088 | 1.23690E-04 | 598.618 |
| 7 | 29.743 | 211.744 | 10.419 | 18.83 | 0.091 | 1.23350E-04 | 599.398 |
| 8 | 29.743 | 211.744 | 10.465 | 18.811 | 0.089 | 1.23350E-04 | 600.111 |
| 9 | 29.743 | 211.744 | 10.603 | 18.887 | 0.088 | 1.23350E-04 | 600.779 |
| 10 | 29.743 | 211.744 | 10.466 | 18.744 | 0.084 | 1.23690E-04 | 601.403 |
| 11 | 60.35 | 215.456 | 19.774 | 35.594 | 0.737 | 1.23350E-04 | 605.983 |
| 12 | 60.35 | 215.456 | 21.798 | 37.729 | 0.355 | 1.23350E-04 | 606.807 |
| 13 | 29.743 | 211.744 | 13.292 | 20.144 | 0.089 | 1.23350E-04 | 603.191 |
| 14 | 29.743 | 211.744 | 10.837 | 18.919 | 0.09 | 1.23690E-04 | 603.664 |
| 15 | 29.743 | 211.744 | 10.721 | 18.866 | 0.094 | 1.23350E-04 | 604.185 |
| 16 | 29.743 | 211.744 | 10.762 | 18.891 | 0.088 | 1.23350E-04 | 604.699 |
| 17 | 29.743 | 211.744 | 10.594 | 18.745 | 0.088 | 1.23350E-04 | 605.196 |
| 18 | 29.743 | 211.744 | 10.627 | 18.761 | 0.091 | 1.23690E-04 | 605.688 |
| 19 | 29.743 | 211.744 | 10.716 | 18.828 | 0.091 | 1.23350E-04 | 606.17 |
| 20 | 29.743 | 211.744 | 10.673 | 18.784 | 0.09 | 1.23690E-04 | 606.641 |

**Table 21. ProfileB10 (Existing Condition) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 557.638 |
| 1 | 29.743 | 211.744 | 6.682 | 17.624 | 0.379 | 5.56550E-06 | 562.769 |
| 2 | 29.743 | 211.744 | 7.998 | 17.505 | 0.397 | 5.58080E-06 | 566.761 |
| 3 | 29.743 | 211.744 | 8.54 | 17.518 | 0.343 | 5.56550E-06 | 570.117 |
| 4 | 29.743 | 211.744 | 9.102 | 17.533 | 0.328 | 5.56550E-06 | 572.905 |
| 5 | 29.743 | 211.744 | 9.479 | 17.517 | 0.352 | 5.56550E-06 | 575.335 |
| 6 | 29.743 | 211.744 | 10.156 | 17.533 | 0.405 | 5.58080E-06 | 577.188 |
| 7 | 29.743 | 211.744 | 10.345 | 17.541 | 0.344 | 5.56550E-06 | 578.774 |
| 8 | 29.743 | 211.744 | 11.005 | 17.546 | 0.313 | 5.56550E-06 | 579.662 |
| 9 | 29.743 | 211.744 | 11.011 | 17.556 | 0.341 | 5.56550E-06 | 580.512 |
| 10 | 29.743 | 211.744 | 11.113 | 17.555 | 0.406 | 5.58080E-06 | 581.382 |
| 11 | 60.35 | 215.456 | 11.166 | 27.874 | 0.053 | 5.56550E-06 | 602.63 |
| 12 | 60.35 | 215.456 | 11.191 | 26.454 | 0.233 | 5.56550E-06 | 624.273 |
| 13 | 29.743 | 211.744 | 13.111 | 17.835 | 0.376 | 5.56550E-06 | 622.831 |
| 14 | 29.743 | 211.744 | 13.128 | 17.589 | 0.32 | 5.58080E-06 | 621.687 |
| 15 | 29.743 | 211.744 | 13.149 | 17.566 | 0.351 | 5.56550E-06 | 620.412 |
| 16 | 29.743 | 211.744 | 13.138 | 17.575 | 0.359 | 5.56550E-06 | 619.216 |
| 17 | 29.743 | 211.744 | 13.003 | 17.577 | 0.368 | 5.56550E-06 | 618.192 |
| 18 | 29.743 | 211.744 | 12.761 | 17.552 | 0.344 | 5.58080E-06 | 617.434 |
| 19 | 29.743 | 211.744 | 12.562 | 17.545 | 0.352 | 5.56550E-06 | 616.783 |
| 20 | 29.743 | 211.744 | 12.395 | 17.554 | 0.394 | 5.58080E-06 | 616.37 |

**Table 22. ProfileB10 (Mine Spoils & ET Cover) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 640.017 |
| 1 | 29.743 | 211.744 | 17.235 | 19.082 | 0.092 | 5.56550E-06 | 633.717 |
| 2 | 29.743 | 211.744 | 12.043 | 18.898 | 0.089 | 5.58080E-06 | 632.646 |
| 3 | 29.743 | 211.744 | 11.337 | 18.875 | 0.09 | 5.56550E-06 | 632.251 |
| 4 | 29.743 | 211.744 | 11.146 | 18.868 | 0.091 | 5.56550E-06 | 632.035 |
| 5 | 29.743 | 211.744 | 11.307 | 19.05 | 0.089 | 5.56550E-06 | 631.896 |
| 6 | 29.743 | 211.744 | 11.264 | 19.044 | 0.09 | 5.58080E-06 | 631.779 |
| 7 | 29.743 | 211.744 | 11.307 | 19.085 | 0.088 | 5.56550E-06 | 631.684 |
| 8 | 29.743 | 211.744 | 11.238 | 19.046 | 0.089 | 5.56550E-06 | 631.595 |
| 9 | 29.743 | 211.744 | 11.118 | 18.959 | 0.089 | 5.56550E-06 | 631.512 |
| 10 | 29.743 | 211.744 | 11.099 | 18.943 | 0.091 | 5.58080E-06 | 631.44 |
| 11 | 60.35 | 215.456 | 20.117 | 35.837 | 0.666 | 5.56550E-06 | 635.39 |
| 12 | 60.35 | 215.456 | 22.035 | 37.901 | 0.362 | 5.56550E-06 | 635.555 |
| 13 | 29.743 | 211.744 | 13.842 | 20.339 | 0.092 | 5.56550E-06 | 631.342 |
| 14 | 29.743 | 211.744 | 11.254 | 19.013 | 0.088 | 5.58080E-06 | 631.199 |
| 15 | 29.743 | 211.744 | 11.161 | 19.001 | 0.089 | 5.56550E-06 | 631.138 |
| 16 | 29.743 | 211.744 | 11.011 | 18.883 | 0.088 | 5.56550E-06 | 631.079 |
| 17 | 29.743 | 211.744 | 11.143 | 19.003 | 0.09 | 5.56550E-06 | 631.033 |
| 18 | 29.743 | 211.744 | 11.064 | 18.933 | 0.092 | 5.58080E-06 | 630.981 |
| 19 | 29.743 | 211.744 | 11.089 | 18.957 | 0.091 | 5.56550E-06 | 630.935 |
| 20 | 29.743 | 211.744 | 11.121 | 18.983 | 0.089 | 5.58080E-06 | 630.891 |

**Table 23. ProfileB11 (Existing Condition) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 645.56 |
| 1 | 29.743 | 211.744 | 6.634 | 17.619 | 0.336 | 0.488 | 650.234 |
| 2 | 29.743 | 211.744 | 7.946 | 17.475 | 0.352 | 0.49 | 653.9 |
| 3 | 29.743 | 211.744 | 8.572 | 17.507 | 0.365 | 0.488 | 656.804 |
| 4 | 29.743 | 211.744 | 9.138 | 17.516 | 0.361 | 0.488 | 659.131 |
| 5 | 29.743 | 211.744 | 9.599 | 17.517 | 0.352 | 0.488 | 660.991 |
| 6 | 29.743 | 211.744 | 9.943 | 17.523 | 0.323 | 0.49 | 662.576 |
| 7 | 29.743 | 211.744 | 10.544 | 17.547 | 0.363 | 0.488 | 663.527 |
| 8 | 29.743 | 211.744 | 10.855 | 17.55 | 0.364 | 0.488 | 664.085 |
| 9 | 29.743 | 211.744 | 10.855 | 17.563 | 0.361 | 0.488 | 664.645 |
| 10 | 29.743 | 211.744 | 10.899 | 17.59 | 0.38 | 0.49 | 665.27 |
| 11 | 60.35 | 215.456 | 10.76 | 29.121 | 0.039 | 0.488 | 685.188 |
| 12 | 60.35 | 215.456 | 10.416 | 30.582 | 1.412 | 0.488 | 702.615 |
| 13 | 29.743 | 211.744 | 13.14 | 17.848 | 0.332 | 0.488 | 700.56 |
| 14 | 29.743 | 211.744 | 13.156 | 17.587 | 0.326 | 0.49 | 698.753 |
| 15 | 29.743 | 211.744 | 13.138 | 17.566 | 0.355 | 0.488 | 697.043 |
| 16 | 29.743 | 211.744 | 12.951 | 17.574 | 0.364 | 0.488 | 695.482 |
| 17 | 29.743 | 211.744 | 12.656 | 17.559 | 0.307 | 0.488 | 694.369 |
| 18 | 29.743 | 211.744 | 12.467 | 17.548 | 0.358 | 0.489 | 693.469 |
| 19 | 29.743 | 211.744 | 12.358 | 17.56 | 0.331 | 0.488 | 692.547 |
| 20 | 29.743 | 211.744 | 12.255 | 17.564 | 0.344 | 0.489 | 691.719 |

**Table 24. ProfileB11 (Mine Spoils & ET Cover) - all units are cm**

| Year | Precip | PET | Transp | Evap | Runoff | Drain | Store |
|---|---|---|---|---|---|---|---|
| Initial storage = | | | | | | | 667.243 |
| 1 | 29.743 | 211.744 | 16.16 | 19.004 | 0.088 | 0.488 | 661.812 |
| 2 | 29.743 | 211.744 | 10.531 | 18.888 | 0.086 | 0.49 | 662.149 |
| 3 | 29.743 | 211.744 | 9.723 | 18.739 | 0.088 | 0.488 | 663.101 |
| 4 | 29.743 | 211.744 | 9.635 | 18.725 | 0.086 | 0.488 | 664.13 |
| 5 | 29.743 | 211.744 | 9.894 | 18.919 | 0.086 | 0.488 | 665.14 |
| 6 | 29.743 | 211.744 | 9.842 | 18.834 | 0.086 | 0.49 | 666.097 |
| 7 | 29.743 | 211.744 | 9.968 | 18.904 | 0.087 | 0.488 | 667.013 |
| 8 | 29.743 | 211.744 | 10.016 | 18.905 | 0.089 | 0.488 | 667.881 |
| 9 | 29.743 | 211.744 | 10.067 | 18.899 | 0.086 | 0.488 | 668.697 |
| 10 | 29.743 | 211.744 | 9.918 | 18.732 | 0.088 | 0.49 | 669.447 |
| 11 | 60.35 | 215.456 | 19.25 | 35.433 | 0.745 | 0.488 | 673.938 |
| 12 | 60.35 | 215.456 | 21.21 | 37.538 | 0.356 | 0.488 | 674.835 |
| 13 | 29.743 | 211.744 | 12.829 | 20.157 | 0.092 | 0.488 | 671.381 |
| 14 | 29.743 | 211.744 | 10.264 | 18.764 | 0.089 | 0.49 | 671.833 |
| 15 | 29.743 | 211.744 | 10.357 | 18.863 | 0.09 | 0.488 | 672.306 |
| 16 | 29.743 | 211.744 | 10.308 | 18.775 | 0.085 | 0.488 | 672.722 |
| 17 | 29.743 | 211.744 | 10.471 | 18.868 | 0.086 | 0.488 | 673.091 |
| 18 | 29.743 | 211.744 | 10.427 | 18.798 | 0.085 | 0.489 | 673.418 |
| 19 | 29.743 | 211.744 | 10.395 | 18.755 | 0.088 | 0.488 | 673.72 |
| 20 | 29.743 | 211.744 | 10.543 | 18.859 | 0.091 | 0.489 | 674.005 |