APPENDIX E
COVER INFILTRATION ANALYSES

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1.0 INTRODUCTION

This appendix presents information related to the historic and future analyses to evaluate infiltration through the cover system selected for reclamation of the tailings impoundments at the Cotter Corporation Canon City Milling Facility. A previous version of the historic information was presented in the 2005 Decommissioning and Reclamation Plan (MFG, 2005), wherein two different cover systems were evaluated for reclamation of the tailings impoundments. MFG (2005) provided a comparison of a multi-layered cover system and a uniform, alternative cover, including results of analyses related to infiltration, radon attenuation, and construction costs. Subsequently, the alternative cover system was selected as the preferred cover alternative.

A site investigation is currently being performed to evaluate potential borrow sources for the cover material. In addition, an evaluation of in-place interim cover and random fill is currently being conducted. Laboratory testing on collected samples will be used to update values used for infiltration modeling for initial water contents, porosity, hydraulic conductivities, and soil water characteristic curves (SWCCs) for the final cover material, as well as the in-place interim cover on the Secondary Impoundment and in-place random fill on the Primary Impoundment. The results of the updated infiltration analyses will be provided in a future submittal of this appendix.

1.1 Background

The evaluation of infiltration through the approved cover system for the reclaimed Primary and Secondary Impoundments at the Canon City Milling Facility was initially conducted by ESCI and presented in the 1995 reclamation plan (ESCI, 1995). These analyses were conducted utilizing the Hydrologic Evaluation of Landfill Performance (HELP) computer model (Schroeder and Aziz, 1997). For the approved cover system, rates of infiltration averaged less than 0.5 inches per year (roughly 3 percent of annual precipitation).

The approved cover system was modified in the 2003 reclamation plan to include a random fill zone at the base of the cover (MFG, 2003). This modified cover system was referred to as the multi-layered cover in MFG, 2005. Infiltration rates through the multi-layered cover were calculated (with the HELP model) to be approximately 0.15 inches per year or less. Estimated HELP model values from MFG (2003) for individual years ranged from 0.06 to 1.90 inches per year.

The MFG (2005) report provided results of an evaluation of both the multi-layered cover and an alternative, uniform cover. MFG (2005) presents the following conclusions regarding the two cover systems:

- The average moisture flux over a 20-year simulation period is not significantly different between the multi-layered cover and the alternative uniform cover with the same overall thickness. For an average precipitation year, both cover scenarios show an average upward moisture flux. For a wet year, both cover scenarios show an average downward moisture flux, with a higher average for the multi-layered cover. The actual infiltration shown on a daily basis for an average precipitation year and a wet year shows larger pulses of infiltration for the alternative cover.
- The alternative, uniform cover provides the same level of infiltration reduction as the multi-layered cover with similar overall total thickness.
- A capillary barrier, represented by coarser material in the random fill layer immediately below the cover, provides benefit in reducing downward migration of moisture in the cover.

- Results of the evaluation of the effectiveness of radon attenuation by each cover indicate the maximum calculated radon emanation rate from the multi-layered cover is 14 pCi/m^2-sec, and the maximum calculated radon emanation rate from the uniform alternative cover is 9 pCi/m^2-sec.
- The cost of constructing an alternative cover would be less than or similar to the cost of constructing a multi-layered cover of the same cover thickness.
- The uniform alternative cover is consistent with covers that have been successfully approved and constructed over uranium mill tailings and other 113.(2) byproduct materials in the Western United States (Blacklaw and others, 1998; McClendon and others, 1997; Range, 1989; Jacobs, 1995, USDOE, 1995).

The uniform alternative cover system is the preferred alternative for the final reclamation plan for its preferred constructability characteristics as well as not having to rely on long-term performance of a compacted clay layer. This appendix summarizes the results of previous analyses conducted for the alternative cover and presented in MFG (2005). This appendix also outlines future analyses that will be performed to further evaluate the long-term performance of the chosen cover system and to address comments from Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division (CDPHE) (2011).

1.2 Description of Model

The infiltration analyses presented in MFG (2005) were conducted using the computer program VADOSE/W (GEO-SLOPE, 2002). VADOSE/W is a finite element method of analysis that can be used to model movement and distribution of pore water within porous materials. VADOSE/W can model both saturated and unsaturated flow in response to atmospheric conditions, making it possible to analyze seepage as a function of time while considering infiltration, precipitation, surface water runoff and ponding, plant transpiration and actual evaporation based on computed soil water stress conditions. The physical relationships required for rigorous calculation of actual evaporation include fully coupled heat and mass transfer with vapor flow in the soil and across the soil-atmosphere continuum. Although the finite-element model can accommodate two-dimensional flow, the lateral component of flow was not a critical aspect of these analyses. Therefore, one-dimensional forms of the model were used to analyze infiltration through the cover systems. The one-dimensional analyses were conservatively based on no surface runoff of precipitation.

Future analyses conducted to further evaluate the alternative cover will be performed in accordance with the same methods described in MFG, 2005, and will be performed with the most current version of the VADOSE/W model or an equivalent computer model.

1.3 Climate Data

Daily climate data was used for the analyses performed by MFG in 2005. Actual daily precipitation and maximum and minimum temperatures were obtained from the National Climatic Data Center (EarthInfo, Inc. 1999) for Canon City, Colorado (Station 051294). A period of 20 years of daily data was selected from the years of 1967 to 1998 for these analyses. Future analyses conducted to further evaluate the alternative cover will incorporate an expanded climate dataset to include climate data through 2010, in addition to the data from the the Cotter site meteorological station. Other climate data used in the MFG 2005 model included average annual wind speed and average quarterly values for relative humidity obtained from the HELP model database for Pueblo, Colorado (Schroeder and Aziz, 1997). This data will be updated for future analyses from the Pueblo meteorological station (Station 056740) and/or the

Cotter site meteorological station, depending on the time period used for analysis, and will include maximum and minimum daily relative humidity and average daily wind speed.

MFG (2005) conducted analyses for infiltration through the covers for three different precipitation conditions including the 20-year precipation record, the 20-year precipitation record followed by a typical precipitation year, and the 20-year precipitation record followed by a wet year. For the wet year, the second wettest year during the period of record was selected for the analyses. In future analyses, the time periods used for modeling both typical and wet precipitation conditions will be based on current recommendations for water balance cover modeling (Albright, et al., 2010) and review of the updated climate data.

1.4 Material Properties

The soil parameters of the materials used in the analyses conducted by MFG (2005) are summarized in Table E.1. The soil parameters for the materials shown in Table E.1 are also the same as those used in previous HELP modeling (Appendix G of MFG, 2003).

Table E.1 Summary of Soil Parameters Used in the Infiltration Analyses for the Alternative Cover (MFG, 2005)

Soil Type	Saturated Hydraulic Conductivity (cm/sec)	Saturated Volumetric Water Content (vol./vol.)	Field Capacity Volumetric Water Content (vol./vol.)	Residual Volumetric Water Content (vol./vol.)
Topsoil	7.2 × 10-4	0.453	0.19	0.085
Old Pond Area Sand	1.5 × 10-3	0.35	0.22	0.12
Random Fill/Tailings	4.2 × 10-5	0.471	0.342	0.21
Random Fill/Tailings (coarse)	1.0 x 10-2	0.35	0.22	0.11

Functions for volumetric water content were estimated by MFG (2005) using the values listed above and the Fredlund and Xing curve fit given in the VADOSE/W model. Functions for hydraulic conductivity were estimated by MFG (2005) using the saturated hydraulic conductivity values listed above and the estimated volumetric water content curves. Thermal functions for thermal conductivity and specific volumetric heat were estimated by MFG (2005) using typical values from VADOSE/W and the estimated volumetric water content profiles.

Initial water content values used in the analyses conducted by MFG (2005) were obtained from MFG (2003). The modeling was conservatively conducted assuming no runoff of meteoric water from the cover surface, such that all precipitation entered the cover system.

Samples of borrow material for the alternative cover are currently being collected, and laboratory testing will be performed to develop geotechnical parameters for further evaluation of the alternative cover. The parameters presented in Table E.1 will be modified based on the results of the additional laboratory testing.

1.5 Previous Evaluation of the Alternative Cover System (MFG, 2005)

The configuration of the uniform alternative cover is described below, and was previously described in MFG, 2005. Figure E.1 presents the profile of the alternative cover system, as evaluated by MFG (2005).

The layers comprising the alternative cover system and underlying materials are listed below (from top to bottom).

1. Topsoil layer (0.5 feet thick)
2. Vegetative cover layer consisting of sand (4.0 feet thick) from any source
3. Compacted random fill layer (1.5 feet thick)
4. Random fill/tailings (varying thickness).

This cover system consists of 4.5 feet of cover materials and 1.5 feet of random fill. Future analyses will also evaluate this configuration of the alternative cover system.

Results of the previous analyses conducted for the alternative cover scenario by MFG (2005) are presented in Section 2 below.

2.0 EVALUATION OF ALTERNATIVE COVER SYSTEM (MFG, 2005)

A summary of the conditions and results of the previous evaluation performed by MFG (2005) is presented below. Infiltration modeling was conducted over a simulation period of 20 years using daily climate data. This period of simulation was used to represent long-term conditions and evaluate variations in actual precipitation as well as allow moisture contents and flow gradients to stabilize within the cover system. In addition, one-year simulations were made for average and wet-year conditions (MFG, 2005).

2.1 Cases Analyzed

The alternative cover was analyzed for five cases to evaluate the effect of cover thickness, leaf area index (LAI), root depth, and presence of a coarse random fill layer (for a capillary barrier). The cases analyzed are listed below.

1. Cover thickness 4 feet, rooting depth 4.5 feet, leaf area index 2.
2. Cover thickness 6 feet, rooting depth 4.5 feet, leaf area index 2.
3. Cover thickness 4 feet, rooting depth 2.0 feet, leaf area index 2.
4. Cover thickness 4 feet, rooting depth 2.0 feet, leaf area index 2, coarse random fill.
5. Cover thickness 4 feet, rooting depth 2.0 feet, leaf area index 1.

2.2 Discussion of Results

The results of the infiltration analyses presented in MFG (2005) are summarized as follows:

1. The average moisture flux through the bottom of the cover is less than 0.1 inches per year.
2. Infiltration occurs as specific downward pulses of moisture in response to precipitation events. The remaining selected days show slight upward moisture movement.
3. Smaller pulses of infiltration are shown for the coarse random fill case (capillary barrier) and the 6-foot thick cover case.
4. Root depth does not have a significant impact on the downward pulses of infiltration.

Conditions for an average year were modeled using climate data from 1998 and the final conditions from the 20-year simulations as initial conditions. Results of the analyses indicate three general annual periods of infiltration in late February, late March, and mid-April.

Conditions for a wet year were modeled using climate data from 1997 and the final conditions from the 20-year simulations as initial conditions. Results of the analyses indicate six general periods of infiltration which correspond with precipitation events throughout the wet year.

Results of the sensitivity analyses conducted by MFG (2005) for the alternative cover indicate that increasing total cover thickness and rooting depth do not significantly reduce infiltration. MFG (2005) further shows that the coarse random fill layer acts as a capillary barrier and reduces downward moisture migration. The following results are presented in MFG (2005):

- Average rates of flux over 20 years range from 0.01 inches per year downward to 0.04 inches per year upward.
- For an average climate year, the average flux rates are all upward, ranging from 0.43 to 2.22 inches per year.
- For a wet year, the average flux rates are all downward, ranging from 0.14 to 1.30 inches per year.

3.0 CONCLUSIONS

The following conclusions provided by MFG (2005) support final reclamation of the tailings impoundments at the Cotter Corporation Canon City Milling Facility by covering with the alternative, uniform cover:

- The average moisture flux over a 20-year simulation period is not significantly different between the multi-layered cover and the uniform cover with the same overall thickness. The upward average flux for the two covers ranges from 0.01 to 0.07 inches per year.
- During a modeled average precipitation year, both the multi-layered and the alternative covers show an average upward moisture flux ranging from 0.74 to 1.61 inches per year.
- For a wet year, both cover scenarios show an average downward moisture flux, with a higher average for the multi-layered cover. The downward moisture flux ranges from 0.06 to 0.80 inches per year for the two cover systems.
- The alternative, uniform cover provides the same level of infiltration reduction as a multi-layered cover with similar overall total thickness.
- A capillary barrier, represented by coarser material in the random fill layer immediately below the cover, provides benefit in reducing downward migration of moisture in the cover.
- Results of the evaluation of the effectiveness of radon attenuation by each cover indicate the maximum calculated radon emanation rate from the multi-layered cover is 14pCi/m^2-sec, and the maximum calculated radon emanation rate from the uniform alternative cover is 9pCi/m^2-sec.
- The cost of constructing an alternative cover would be less than or similar to the cost of constructing a multi-layered cover of the same cover thickness.
- The uniform, alternative cover is consistent with covers that have been successfully approved and constructed over uranium mill tailings and other 113.(2) byproduct materials in the Western United States (Blacklaw and others, 1998; McClendon and others, 1997; Range, 1989; Jacobs, 1995, USDOE, 1995).

Samples of borrow material for the alternative cover are currently being collected, and laboratory testing will be performed to develop geotechnical parameters for further evaluation of the alternative cover. The soil parameters used in the future analyses may be modified from those presented by MFG (2005) based on the results of the pending laboratory testing. Further

analyses will be conducted based on the results of the laboratory testing, and will include analyses to optimize the cover design and address comments from CDPHE (2011).

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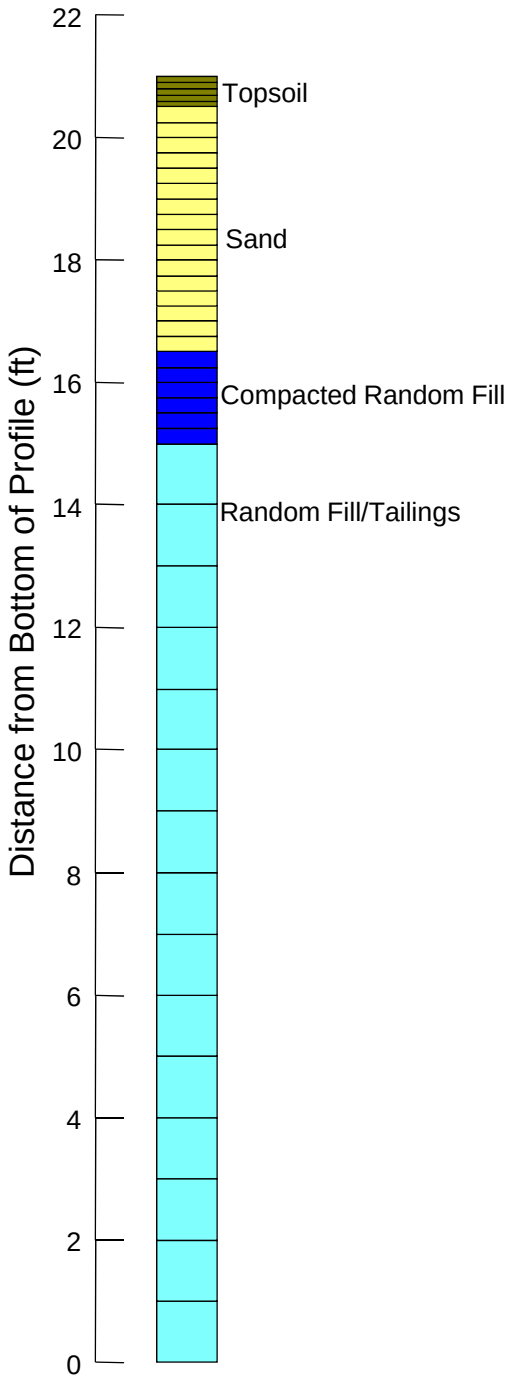

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