SOIL WATER IMPACTS FROM USING VEGETATION AND ROCK COVERS FOR SURFACE STABILIZATION OF URANIUM MILL TAILINGS

David W. Mayer
Peter A. Beedlow
Larry L. Cadwell

Pacific Northwest Laboratory
Richland, Washington 99352

INTRODUCTION

Uranium mill tailings are typically slurried into large ponds that eventually dry out and leave a tailings pile. Since tailings contain significant quantities of radium, the tailings piles emit radon gas (a decay product of radium). Exposure to radon gas has been linked to lung cancer and concern has thus been expressed over the health and environmental aspects of open tailings piles. A number of sealant or barrier systems are being considered to contain radon and other toxic materials in inactive uranium mill tailings piles.

To maintain long-term effectiveness, a sealant/barrier system must be protected from wind, water, ultraviolet radiation, frost, chemical reaction, and biological degradation. Soil placed over a sealant/barrier system can provide a protective mantle if the soil is not lost by erosion. Vegetation is an attractive choice for controlling wind and water erosion since it is economical and self-renewing. In extremely arid regions, vegetation may not adequately stabilize the surface layer. In these areas rock covers may be required. However, by reducing evapotranspiration, rock covers may cause the moisture content of the tailings to increase.

This paper presents the results from an analysis of vegetated and rock covers and their effect on the moisture content in a covered uranium mill tailings system. This work was performed at the Pacific Northwest Laboratory (PNL)(a) under a contract with the Department of Energy's Uranium Mill Tailings Remedial Action Program (UMTRAP).(b)

SYSTEM CONFIGURATION

The multilayer cover system investigated is one of three being developed at the Grand Junction, Colorado site. This particular system was simulated because the water content in the seal affects its performance as a radon barrier.[1,2] The system consists of a 618-cm deep tailings layer covered with 15 cm of a clay/gravel mix, 30-cm of rock, and 100 cm of overburden. The porosities of these layers are 0.46, 0.27, 0.32 and 0.47,

---

(a) Operated by Battelle Memorial Institute.
(b) Contract DE-AC06-76RLO 1830.

respectively. The tailings pile is above the water table and therefore occupies the unsaturated flow zone--the transition region between the groundwater system and the soil surface.

A one-dimensional unsaturated flow model, UNSATV[3,4,5], was used to simulate moisture movement. Input parameters were obtained for an existing site at Grand Junction, Colorado. Since moisture profiles were not available it was necessary to synthesize the moisture conditions for the start of the simulation. This was achieved by specifying near-equilibrium conditions between the clay/gravel layer and the 763-cm-deep water table. The clay/gravel layer was designed to be initially saturated and was therefore assumed to be saturated in these simulations. The moisture conditions above the clay/gravel layer were the result of repeated simulations using recorded climatic conditions(a) and could represent the initial conditions from a long-term climatic history.

The soil water characteristics reported by Simmons and Gee[5] for the overburden, rock, and tailings layers have been used. The soil water characteristics for the clay/gravel mix have been reported by Mayer et al.[3]

For both cover systems, UNSATV was run for one year using the climatic data for 1979 (wettest year on record). The purpose of this one-year simulation was to allow the moisture content in the soil to adjust to the actual climate. Since this is simply an initialization procedure, the results for this year are not discussed here. The moisture content profile at the end of the one-year simulation was next used as the initial condition for a two-year simulation using repeated 1979 climate data and for a two-year simulation using repeated 1976 climate data (driest year on record). This approach provides two dry years and two wet years for comparison of the effects of climate on each surface treatment. The surface treatments can also be compared with each other, thereby illustrating the effects of vegetation and rock covers.

VEGETATED COVER CASE

The purpose of this phase of the research effort is to examine how vegetation influences the moisture content of a covered uranium mill tailings pile. A plant community consisting of the following plant species (percentages are cover values) was modeled:

- 29% Artemisia tridentata (Big Sagebrush)
- 2% Atriplex confertifolia (Four-wing Saltbush)
- 2.5% Agropyron (Wheatgrass)
- 2.5% Bromus tectorum (Cheatgrass).

Thus, the plant community consisted of 36% plants and 64% bare soil which is representative of the Grand Junction area.

(a) Published by the U.S. Department of Commerce, National Climatic Center, Asheville, North Carolina.

Because UNSATV was originally developed for a single plant species, the above plant community was modeled as a single composite plant with the root density data and evapotranspiration (ET) data for each plant weighted appropriately. The data obtained for root density and ET for each plant are based on a plant community that consists of typical amounts of bare soil. The composite plant characteristics are obtained by averaging the individual plant characteristics. The weighting factors for each plant are obtained by dividing the percent of plant cover for each species by the total percent of plant cover.

The root density must be specified so that the loss of moisture due to plant transpiration can be distributed appropriately throughout the root zones. The root densities for each plant were developed from data on root biomass and root weights reported in the literature.[6,7] The two shrubs Artemisia tridentata and Atriplex confertifolia were assumed to have constant maximum root depths of 180 cm and 110 cm, respectively, and the perennial grass (Agropyron) was assumed to have a constant maximum root depth of 80 cm. The root depth of the annual grass (B. tectorum) was a specified function of the number of growing days. The two shrubs were assumed to have an active growing season starting on the 90th day of the year and ending on the 320th day of the year. The grasses were assumed to be actively growing from day 120 to day 190. It should be noted that the plant root model does not take into account the effects of climate or soil conditions on root growth.

Modeling plant transpiration requires that the potential evapotranspiration (PET) be divided into its component parts: potential evaporation (PE) and potential transpiration (PT). This information was lacking for the shrubs, but results reported by Branson et al.[8] indicate that the PT is approximately 85% of the PET. This relationship was assumed to hold for both shrubs throughout the growing season. An available relationship that accounts for the variation of PT with growing season and PET for cheatgrass has been used for both grasses.[5]

Using this information, the simulations were performed as previously discussed. Fig. 1 is a plot of the moisture content for selected days from the final year of the simulation using the wet climate data. An important feature to note is that, although the moisture content in the surface layer varies dramatically, the lower layers exhibit very little change in moisture content.

The water balance for the wet and dry years is summarized in Table I. The initial storage values represent the amount of water stored in all four layers on day one for each year. The rainfall value is the amount of water from precipitation that is available for infiltration. The runoff values indicate the amount of precipitation that did not infiltrate but flows over the soil surface and eventually provides input to a stream or lake. The total amount of water lost by evaporation from the soil surface and the amount lost by transpiration are also given. The water that drains through the soil profile and out the bottom is listed. The final storage values indicate the amount of

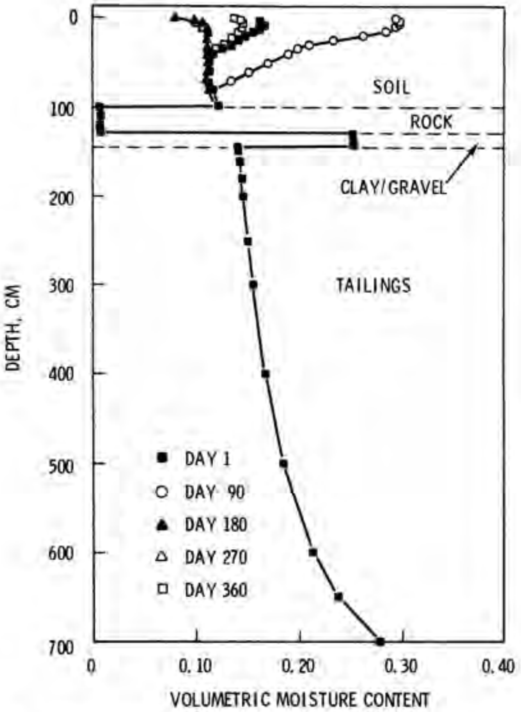

Fig. 1. Moisture Content Profiles with Vegetated Cover--3rd Simulation Year, Wet Climate

Table I. Water Balance--Vegetated Cover System

	Wet Simulation Year		Dry Simulation Year	
Water (cm)	2	3	2	3
Initial Storage	139.3	139.2	139.3	137.1
Rainfall	22.6	22.6	13.4	13.4
Runoff	0.0	0.0	0.0	0.0
Evaporation	5.8	5.8	6.0	5.1
Transpiration	16.2	16.3	8.8	7.5
Drainage	0.0	0.0	0.0	0.0
Final Storage	139.2	139.1	137.1	137.1
Mass Balance Error	0.6	0.6	0.8	0.9

moisture stored in all four layers on the last day of each year. The mass balance error, a measure of the accuracy of the model results, is computed by comparing the change in water storage computed as the difference in initial and final water storage or by summing the rainfall, runoff, evaporation, transpiration, and drainage values (values must be added or subtracted as appropriate).

It is apparent from Table I that storage during the wet years has changed negligibly. The two dry years result in a slight drying of the soil profile (approximately 2 cm of water). Note that no runoff or drainage occurred for either the wet or the dry years.

ROCK COVER CASE

This phase of the study examines the effect of rock on moisture storage in a covered uranium mill tailings pile. This analysis is essentially identical to the analysis for the vegetated cover except that the plants have been removed, and 50 cm of rock has been added to the top of the tailings pile.

Moisture will move through the rock primarily by a vapor diffusion process. The movement of the water vapor through the relatively thick rock layer considered here has been modeled with the following equation:

$$E = D_a (P - \theta) \alpha (\rho_{air} - \rho_{soil}) / \Delta Z$$

where

D_a = water vapor diffusivity in air (typical value: 0.24 cm^2/sec)

P = material porosity on a volume basis

θ = moisture content on a volume basis

α = tortuosity (often assumed to be 0.5 for gravels)

ρ_{air} = water-vapor density in the air (typical units: g/cm^3)

ρ_{soil} = water-vapor density in the soil immediately below the rock (typical units: g/cm^3)

ΔZ = thickness of the rock layer (typical units: cm).

Note that this equation does not account for the influence of wind, which tends to increase the evaporation rate. The water-vapor densities in air and soil depend on the temperatures of the air and soil and are related to the respective vapor pressures by the ideal gas law. The vapor pressure at the soil surface (which is nearly saturated until the soil becomes very dry) is calculated from the water-vapor-adsorption-isotherm equation discussed by Simmons and Gee.[5]

$$\ln \theta = A + B \ln [(RH)^{-C} - 1]$$

where

A, B and C are empirically determined coefficients and
RH is the relative humidity.

Values of the coefficients for Grand Junction clay soil are $A = -2.916$, $B = -0.185$ and $C = 1.49$.[5]

Since the moisture movement in the rock layer is not directly modeled, it is necessary to assume a value for the moisture content, θ. For this study, it was assumed that the moisture from precipitation would move instantaneously to the soil surface; therefore, θ was taken to be zero. The material used for the surface rock layer was the same as the lower rock layer, so the porosity was fixed at 0.32.

The resulting moisture content profile is shown in Fig. 2 for the final wet climate year simulation. Note that the rock cover is not shown on these plots, because the liquid water movement was not modeled for the rock cover. It is apparent from this plot that the rock cover has had a significant effect on the moisture content in the tailings pile in comparison to the vegetation cover treatment. The moisture content in the soil layer is much higher, and the seasonal variation in moisture content is not as great (compared with Fig. 1). The major difference, however, is that the tailings layer is becoming wetter, meaning that water is now draining from the upper layers. Note also that the moisture content throughout the tailings pile is now being affected by the climatic conditions (i.e., the moisture content is also changing in the lower rock, clay/gravel, and tailings layers).

Clearly, more moisture is stored under rock covers than under vegetated covers, because evaporative losses through rock are less. As Table II shows, moisture loss from the rock cover is approximately 1 cm of water per year. The moisture loss due to evapotranspiration from the vegetated cover is between 10 and 20 cm of water per year. The moisture input to a tailings pile with a rock cover in Grand Junction, Colorado could exceed the moisture input with a vegetated cover by more than 10 cm of water. Significantly, the moisture input for the rock cover case exceeds the ability of the soil profile to store water; hence, drainage from the system occurs.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study are based on a one-dimensional analysis of moisture movement. (Actual moisture flow occurs in three dimensions.) The results indicate that care must be taken when selecting a surface stabilization system for a tailings pile. The moisture-content response of the tailings pile and cover system can be radically altered by different surface treatments. The two cases considered in this study indicate that (under climatic conditions occurring at Grand Junction, Colorado) the evapotranspiration from a vegetated cover can result in a

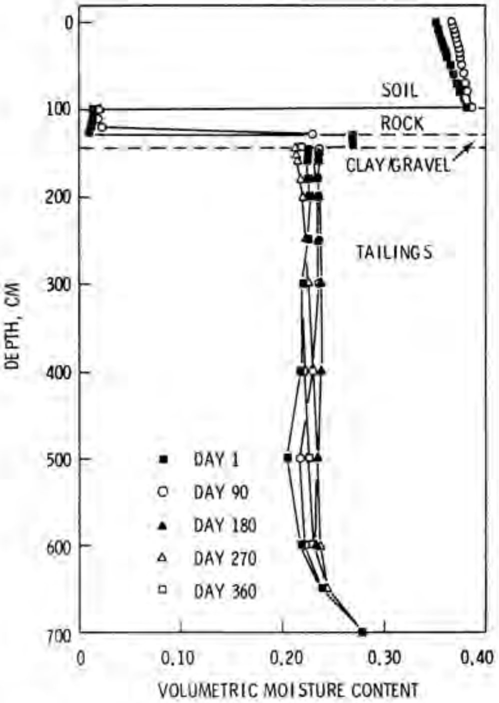

Fig. 2. Moisture Content Profiles with Rock Cover--
3rd Simulation Year, Wet Climate

Table II. Water Balance--Rock Cover System

Water (cm)	Wet Simulation Year 2	Wet Simulation Year 3	Dry Simulation Year 2	Dry Simulation Year 3
Initial Storage	167.5	185.8	167.5	179.9
Rainfall	22.6	22.6	13.4	13.4
Runoff	0.8	0.8	0.4	0.4
Evaporation	0.2	0.2	0.2	0.2
Transpiration	0.0	0.0	0.0	0.0
Drainage	0.4	15.1	0.1	5.4
Final Storage	185.8	189.4	179.9	186.8
Mass Balance Error	2.8	2.8	0.4	0.4

relatively stable moisture content. A rock cover, however, may increase the moisture content of the tailings pile by significantly reducing evaporation. In fact, moisture storage may increase to the point that drainage occurs. If drainage does occur, the potential for groundwater pollution is increased. These results suggest that vegetation, thinner rock covers, engineered drainage systems, and/or liner systems may be needed to reduce drainage and potential leaching of contaminants.

Additional work is needed to improve the description of the surface boundary condition and provide a more accurate moisture sink term. This work should focus on better descriptions of plant growth and moisture extraction behavior as a function of climatological and soil conditions. Additional work is required to more accurately describe the diffusion of water vapor through rock covers, and to quantify the effects of wind.

REFERENCES

1. Nelson, R. W., G. W. Gee and C. A. Oster. 1980. "Radon Control by Multilayer Earth Barriers, 1. Modeling of Moisture and Density Effects on Radon Diffusion from Uranium Mill Tailaings." In: Uranium Mill Tailings Management, Proceedings of the Third Symposium, November 24-25, 1980, pp. 79-88. Geotechnical Engineering Program, Civil Engineering Department, Colorado State University.

2. Mayer, D. W., C. A. Oster, R. W. Nelson and G. W. Gee. 1981. Radon Diffusion Through Multilayer Earthen Covers: Models and Simulations. PNL-3989, Pacific Northwest Laboratory, Richland, Washington.

3. Mayer, D. W., P. A. Beedlow and L. L. Cadwell. 1981. Moisture Content Analysis of Covered Uranium Mill Tailings. PNL-4132, Pacific Northwest Laboratory, Richland, Washington.

4. Gupta, S. K., K. K. Tanji, D. R. Nielsen, J. W. Biggar, C. S. Simmons and J. L. MacIntyre. 1978. Field Simulation of Soil-Water Movement with Crop Water Extraction. Water Science and Engineering Papers No. 4013, Department of Land, Air, and Water Resources, University of California, Davis, California.

5. Simmons, C. S., and G. W. Gee. 1981. Simulation of Water Flow and Retention in Cover Materials Overlaying Uranium Mill Tailings. PNL-3877, Pacific Northwest Laboratory, Richland, Washington.

6. Branson, F. A., R. F. Miller and I. S. McQueen. 1976. "Moisture Relationships in Twelve Northern Desert Shrub Communities Near Grand Junction, Colorado." Ecology, Vol. 57, pp. 1104-1124.

7. Cline, J. F., and W. H. Rickard. "Belowground Plant Biomass in the Shrub-Steppe Ecosystem." In: Pacific Northwest Laboratory Annual Report of 1973. Vol. 1, Part 2, pp. 161-162. BNWL-1850, Pacific Northwest Laboratory, Richland, Washington.

8. Branson, F. A., R. F. Miller and I. S. McQueen. 1970. "Plant Communities and Associated Soil and Water Factors on Shale-Derived Soils in Northeastern Montana." Ecology, Vol. 51, No. 3, pp. 391-407.