

## **Potential Groundwater Recharge and the Effects of Soil Heterogeneity on Flow at Two Radioactive Waste Management Sites at the Nevada Test Site**

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### Abstract

Two low-level Radioactive Waste Management Sites (RWMSs), consisting of shallow land burial disposal units at the Nevada Test Site (NTS), are managed by Bechtel Nevada for the U.S. Department of Energy, National Nuclear Security Administration. The NTS has an arid climate with annual average precipitation of about 17 cm at the Area 3 RWMS and about 13 cm at the Area 5 RWMS. The vadose zone is about 490 m thick at the Area 3 RWMS, and about 235 m thick at the Area 5 RWMS. Numerous studies indicate that under current climatic conditions, there is generally no groundwater recharge at these sites. Groundwater recharge may occur at isolated locations surrounding the RWMSs, such as in large drainage washes. However, groundwater recharge scenarios (and radionuclide transport) at the RWMSs are modeled in support of Performance Assessment (PA) documents required for operation of each RWMS. Recharge scenarios include conditions of massive subsidence and flooding, and recharge resulting from deep infiltration through bare-soil waste covers. This paper summarizes the groundwater recharge scenarios and travel time estimates that have been conducted in support of the PAs, and examines the effects of soil hydraulic property heterogeneity on flow.

### Introduction

Scenarios for potential groundwater recharge and associated radionuclide transport are modeled in support of the PAs for the two low-level RWMSs at the NTS. Radionuclide travel times through the vadose zone, and via a groundwater pathway are modeled to calculate radionuclide doses to the public using conservative assumptions.

In the Area 5 PA (Shott et al., 1998), travel time estimates of flow through the vadose zone to the groundwater were conducted assuming extremely conservative assumptions of landfill subsidence, maximum catastrophic subsidence, and flooding, and using the flow code ODIRE (Lindstrom et al., 1995). These scenarios were repeated in a later study to verify the results of ODIRE using VS2DT (Healy, 1990), and to predict the travel time to groundwater beneath the Area 5 RWMS if buried waste packages were assumed to be completely water-saturated (Crowe et al., 1998).

Recent studies indicate that under bare-soil conditions such as those found at the operational waste cell covers, some drainage may eventually occur through the waste covers into the waste zone. This drainage is estimated to be about one percent of the annual rainfall at Area 5, and 10 percent of annual rainfall at Area 3, based on conservative one-dimensional modeling results using UNSAT-H (Fayer and Jones, 1990) and HYDRUS-2D (Simunek and van Genuchten, 1996). These results are summarized in Levitt et al. (1999). If this drainage is assumed to flow downward by gravity without any influence from evapotranspiration, then this drainage will result eventually in groundwater recharge. Travel time of water flow at the Area 3 RWMS was modeled for this scenario using VS2DT (Healy, 1990).

The effects of soil hydraulic property heterogeneity on redistribution of vadose zone water was discussed in the Area 3 PA (Shott et al., 1997) and an Area 3 vadose zone characterization report

(Bechtel Nevada, 1998), and is summarized in this paper. Data are presented suggesting that the effects of heterogeneous hydraulic properties on water flow are significant, and that all of the modeling studies described are overly conservative, and resulted in underestimated travel times.

### Site Descriptions

The Area 3 RWMS is located on Yucca Flat at an elevation of 1225 m (Figure 1). Yucca Flat is a closed intermontane basin located in the northeastern portion of the NTS. The thickness of the unsaturated zone at the Area 3 RWMS is estimated to be 488 m, and the water table is assumed to occur in Tertiary tuff, based on data from surrounding boreholes. The tuff-alluvium contact is estimated to occur at a depth of between 305 and 457 m below land surface.

The Area 5 RWMS is located on northern Frenchman Flat at an elevation of 971 m (Figure 1). Frenchman Flat is a closed intermontane basin located in the southeastern portion of the NTS. The thickness of the unsaturated zone at the Area 5 RWMS ranges from approximately 235 m at the southeast corner of the site to 256 m at the northeast corner of the site. The uppermost aquifer beneath the RWMS is alluvial.

The climate of Yucca Flat and Frenchman Flat is arid. The average annual precipitation is 165 mm and 126 mm at the Area 3 and Area 5 sites, respectively. The average annual potential evapotranspiration (ET), is calculated to be approximately 1625 mm at both sites, or about 10 and 13 times the annual average precipitation at the Area 3 and Area 5 sites, respectively.

### Vadose Zone Hydrologic Conceptual Model

Climate and vegetation strongly control the movement of water in the upper few meters of the alluvium. The magnitude and direction of both liquid and vapor fluxes vary seasonally and often daily. Except for periods following precipitation events, water contents in this near-surface region are quite low. Below this is a region where relatively steady upward movement of water is occurring. In this region of slow upward water movement, stable isotope compositions of soil pore water confirm that evaporation is the dominant process (Tyler et al., 1996). This region extends to depths ranging from approximately 3 to 49 m (10 to 160 ft) in Area 3, and from approximately 3 to 40 m (10 to 131 ft) in Area 5. Below this region, water potential measurements indicate the existence of a static region, which begins between approximately 49 to 119 m (160 to 390 ft) in Area 3, and between approximately 40 to 90 m (131 to 295 ft) in Area 5 (Shott et al., 1997, 1998). In this static region, essentially no vertical liquid flow is currently occurring. Below this static region, flow is steady and downward due to gravity. Stable isotope compositions of pore water from the interval of downward flow depths indicate that infiltration into this region must have occurred under cooler, past climate conditions (Tyler et al., 1996). If water were to migrate below the currently static region, movement to the groundwater would be extremely slow due to the low water content of the alluvium. Refer to Figure 2 for a diagram of the vadose zone hydrologic conceptual models at the Area 3 and Area 5 RWMSs.

Based on the results of field studies, modeling results, and monitoring data, which are summarized in the Area 3 and Area 5 Performance Assessments (Shott et al., 1997, 1998), Tyler et al. (1996), Levitt et al., (1999), and Bechtel Nevada (2001), groundwater recharge is not occurring under current climatic conditions at these two disposal sites. Deep drainage and potential groundwater recharge may be occurring in isolated valley locations at the NTS, such as large drainage washes, where soil permeabilities are high and vegetation is sparse.

### Recharge from Subsidence and Flooding Scenarios

Simulations of water flow at the Area 5 RWMS were conducted assuming that the waste cells in the RWMS subsided to a uniform depth of 2 m (caused primarily by collapse of void spaces in the waste), and then completely filled with flood waters from three consecutive 200-year floods in three consecutive years. The probability of occurrence of such flooding in 10,000 years is approximately 1 in 800. This modeling was conducted as a bounding assessment of recharge for the Area 5 PA (Shott et al., 1998). The modeling was conducted using ODIRE (Lindstrom et al., 1995), a one-dimensional vadose zone flow model that accounts for the falling head of floodwaters in the subsided waste cells. This simulation resulted in a travel time of floodwater through the vadose zone to groundwater of 146 years (Shott et al., 1998).

This modeling scenario was repeated using VS2DT (Healy, 1990) to examine the effects of buried waste moisture content on travel time. ODIRE was not selected for the simulations in this report because of its lack of widespread use and therefore validation, and the lack of any experienced operators of this model. Details of this modeling study are documented in Crowe et al. (1998). The initial conditions, boundary conditions, and hydraulic properties used for the ODIRE model runs were used with VS2DT. Simulations indicate that ODIRE and VS2DT yield comparable results. Travel times of the wetting front to the groundwater table ranged from 190 years (if waste is assumed to be dry) to 140 years (if waste is assumed to be saturated) (Figure 3). One reason for the difference between model results is that the travel time to groundwater of 146 years reported in the Area 5 PA was calculated when the wetting front was actually about 15 m above the groundwater table after 146 years.

### Recharge from Deep Infiltration through Waste Covers

Conservative one-dimensional modeling studies have been conducted to predict flow through monolayer-ET waste covers at the RWMSs. These studies indicate that some drainage (10 percent of rainfall at Area 3, and 1 percent of rainfall at Area 5) may occur under non-vegetated conditions (Levitt et al., 1999). Redistribution of that infiltrated water was modeled using VS2DT (Healy, 1990) to estimate travel times to groundwater. These simulations resulted in travel times of water through the vadose zone to groundwater of 500,000 years at the Area 3 site (Figure 4).

Simulations were also conducted to calculate travel times of water through the vadose zone to groundwater at the Area 5 site under ambient conditions for the Area 5 RWMS PA (Shott et al., 1998). These simulations were conducted using stochastic distributions of soil hydraulic properties, and Darcy's law, and assuming no influence from evapotranspiration. 7,500 Monte Carlo realizations were conducted, resulting in a wide distribution of travel times. The mean travel time to groundwater was approximately 52,000 years. No realization resulted in a travel time less than 19,000 years. These model simulations are described in detail in Shott et al. (1998).

For simplicity, and to incorporate conservatism, each of these simulations of water flow travel time to groundwater assumes no effect from evapotranspiration. However, the surface boundary effects are significant and extend to depths of at least 40 m, as described in the hydrologic conceptual model. The calculation of upward liquid advection (and potential upward transport of radionuclides) at the NTS is the subject of Yucel and Levitt (2002 [this conference]).

## Effects of Hydraulic Property Heterogeneity on Flow

Simulations of flow were also conducted using data from boreholes drilled into the floor of a nuclear subsidence crater (U-3bh) at the Area 3 RWMS. Nuclear subsidence craters are used for waste disposal at the Area 3 site. (Refer to Shott et al. (1997) for details of the Area 3 RWMS.) Redistribution of soil water beneath the U-3bh crater was modeled using two scenarios: a homogeneous soil profile, and a layered-soil profile in which soil layers consisted of subtle yet distinct differences in hydraulic properties. For both modeling scenarios, initial water content conditions were taken from the actual water content profile data from soil core collected from beneath the U-3bh crater. The model runs simulated 100 years of redistribution. For the homogeneous profile scenario, one set of van Genuchten hydraulic parameters (van Genuchten, 1980) were calculated from the mean of the van Genuchten parameters (log-mean for Ksat and alpha). For the layered-soil scenario, 10 sets of van Genuchten hydraulic parameters were calculated by grouping all the U-3bh data into 10 categories, where each category included soil layers having similar water retention curve shapes.

Results of the model runs indicate significantly different rates of redistribution between the two scenarios (Figure 5). For the homogeneous profile scenario, a wetting front moved to a depth of 80 m below U-3bh in about 100 years. For the layered-soil scenario, although some redistribution occurred between soil layers, there was no significant downward movement of a wetting front out of the layered section of the profile.

Neutron logging data were collected in the two cased boreholes that were drilled to supply the core data for determination of hydraulic properties. Soil water content profiles from neutron logs in 1996 and 2000 are shown in Figure 5 with the model results. Although soil water content measurements from neutron logs are higher than water contents from core samples, the neutron logs can detect relative wetting front movement and soil water redistribution. Note that profiles collected in 1996 included measurements taken every 30 cm, while profiles collected in 2000 used measurements taken every 60 cm. Also note that the crater floor was irrigated heavily for dust control between 1996 and 2000, resulting in elevated soil water contents about 8 m below the 1996 crater floor. The crater floor has risen between 1996 and 2000 due to waste disposed in this crater. These data indicate that redistribution of soil water beneath U-3bh is slow, and very little or no redistribution is visible between 1996 and 2000.

These simulations, and the neutron logging data, indicate that subtle layering of hydraulic properties cause water flow to be significantly less than if a single set of hydraulic properties are used. These results suggest that some of the modeling studies described in this paper, which used single sets of hydraulic properties, are overly conservative, and likely have underestimated travel times to groundwater. Limitations of these studies include the use of one-dimensional modeling geometries. However, preferential vertical pathways through faults and fractures are unlikely since the vadose zone at these sites consists of homogeneous alluvium, except just above the uppermost aquifer beneath the Area 3 site.

## Summary

Simulations of groundwater recharge at two low-level RWMSs indicate that recharge, and potential radionuclide transport to groundwater, can occur under conditions of extreme landfill subsidence and subsequent frequent massive flooding. Under these conditions, the travel time of

water through the vadose zone is approximately 190 years, or 140 years if the buried waste is assumed to be completely saturated.

Simulations of groundwater recharge were also conducted for scenarios involving deep infiltration of water through bare-soil, non-vegetated, waste covers, and assuming zero ET. These simulations resulted in travel times of water through the vadose zone to groundwater of 500,000 years at the Area 3 RWMS. Simulations conducted for the Area 5 PA indicate that the travel time to groundwater of water infiltrated below the root zone, and assuming zero ET, is approximately 50,000 years at the Area 5 RWMS (Shott et al., 1998).

Simulations of flow were also conducted using heterogeneous and homogeneous soil hydraulic properties using data from boreholes drilled into the floor of a nuclear subsidence crater at the Area 3 RWMS. These simulations, and neutron logging data collected from these same boreholes over a period of five years, indicate that subtle layering of hydraulic properties cause water flow to be much less than if a single set of hydraulic properties are used. These results suggest that some of the modeling studies described in this paper, which used single sets of hydraulic properties, are overly conservative, and likely have resulted in underestimated travel times to groundwater.

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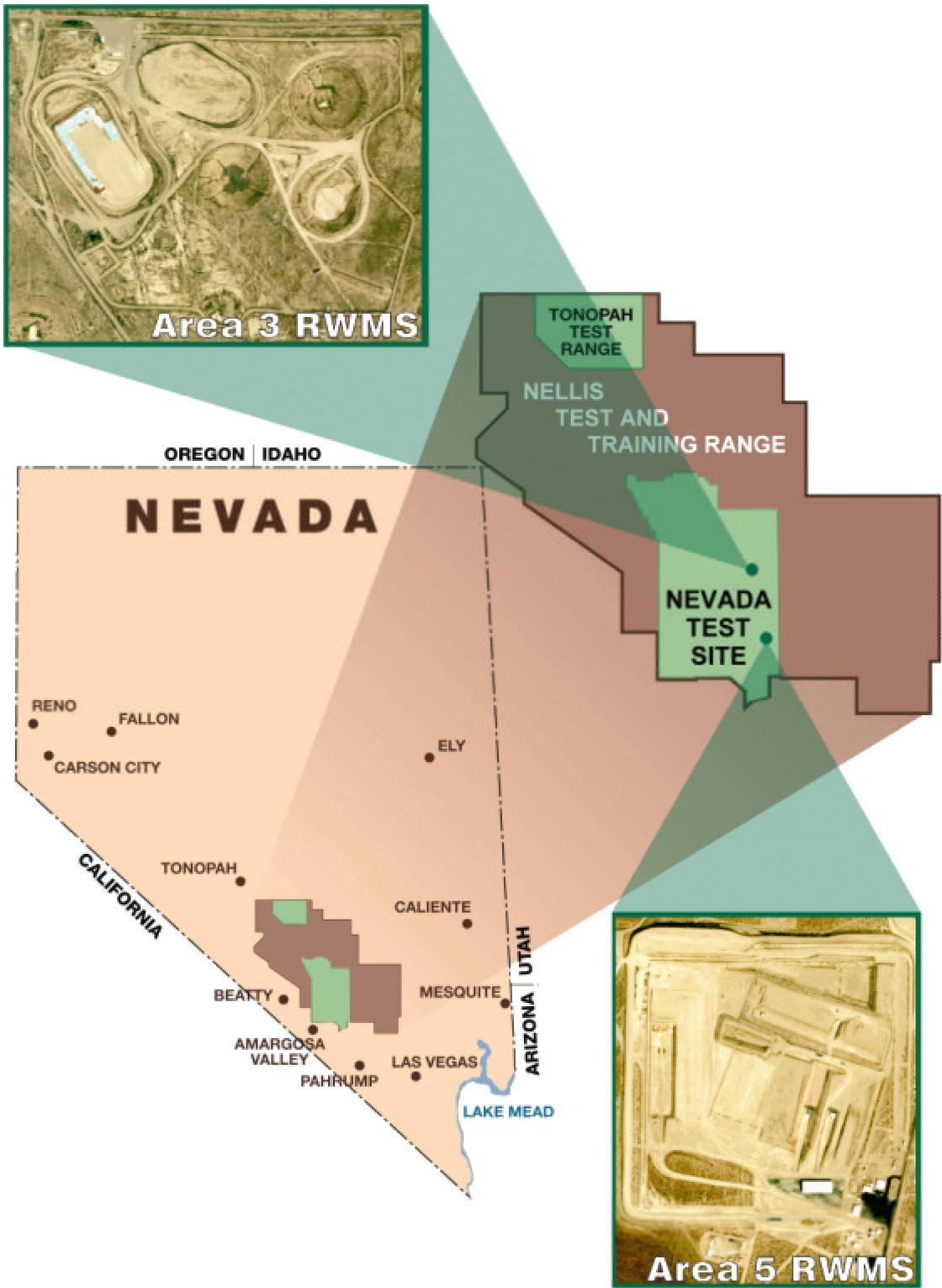


Figure 1. Location of the Area 3 and Area 5 RWMSs within the Nevada Test Site and Nevada.

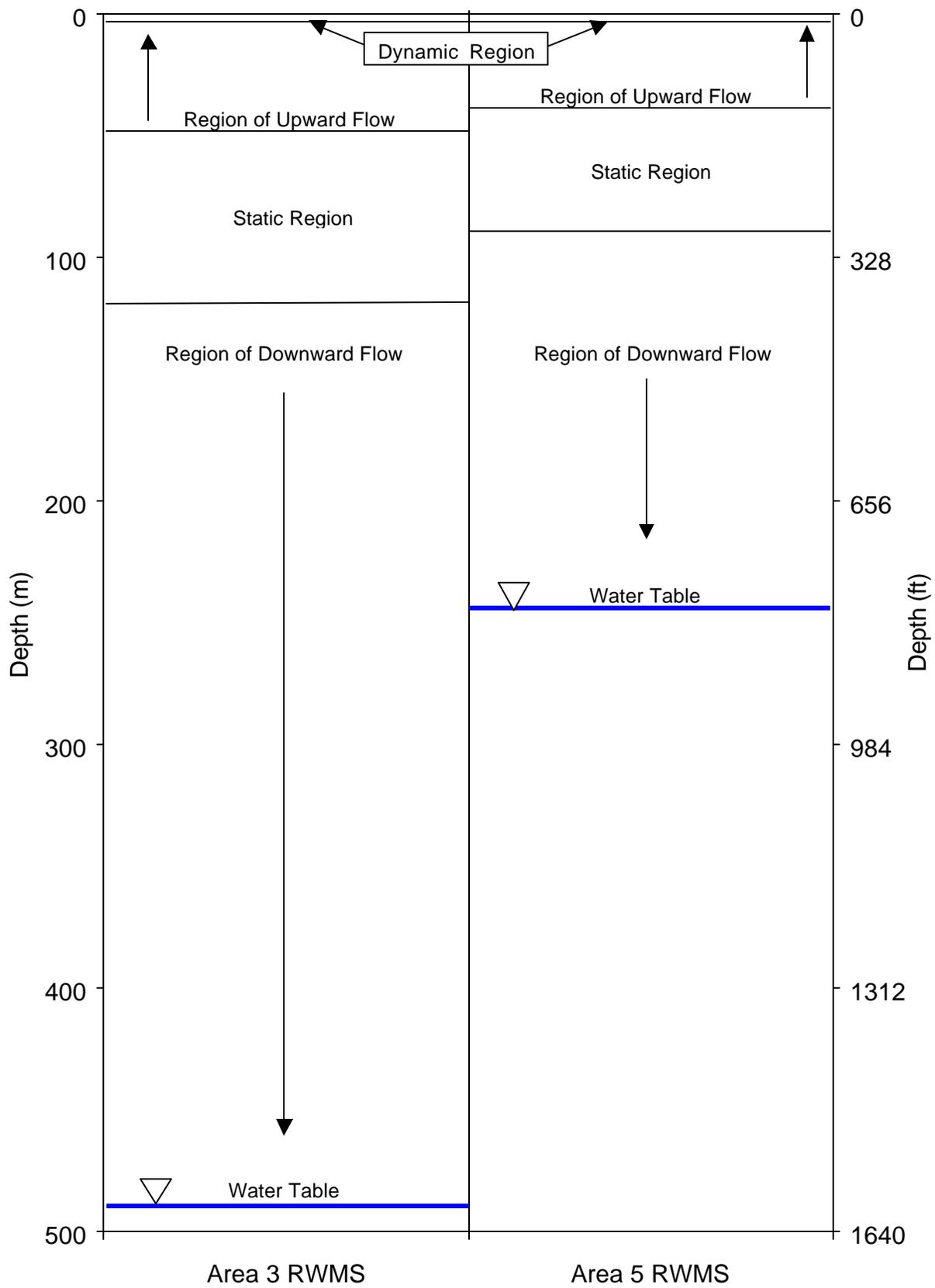


Figure 2. Vadose zone hydrologic conceptual model of the Area 3 and Area 5 RWMSs.

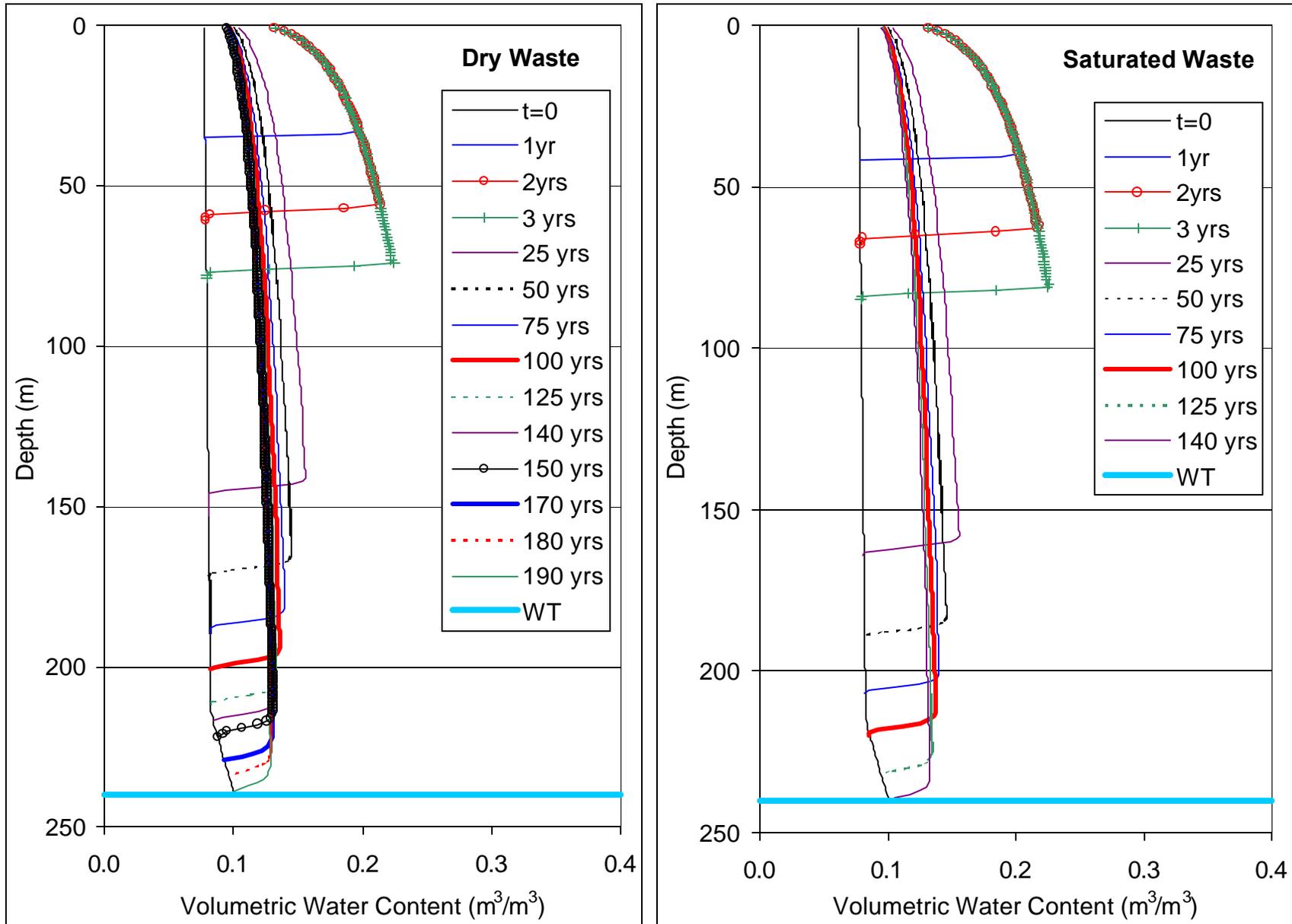


Figure 3. VS2DT simulations of redistribution of deep infiltration from subsidence and flooding for cases of dry and saturated buried waste.

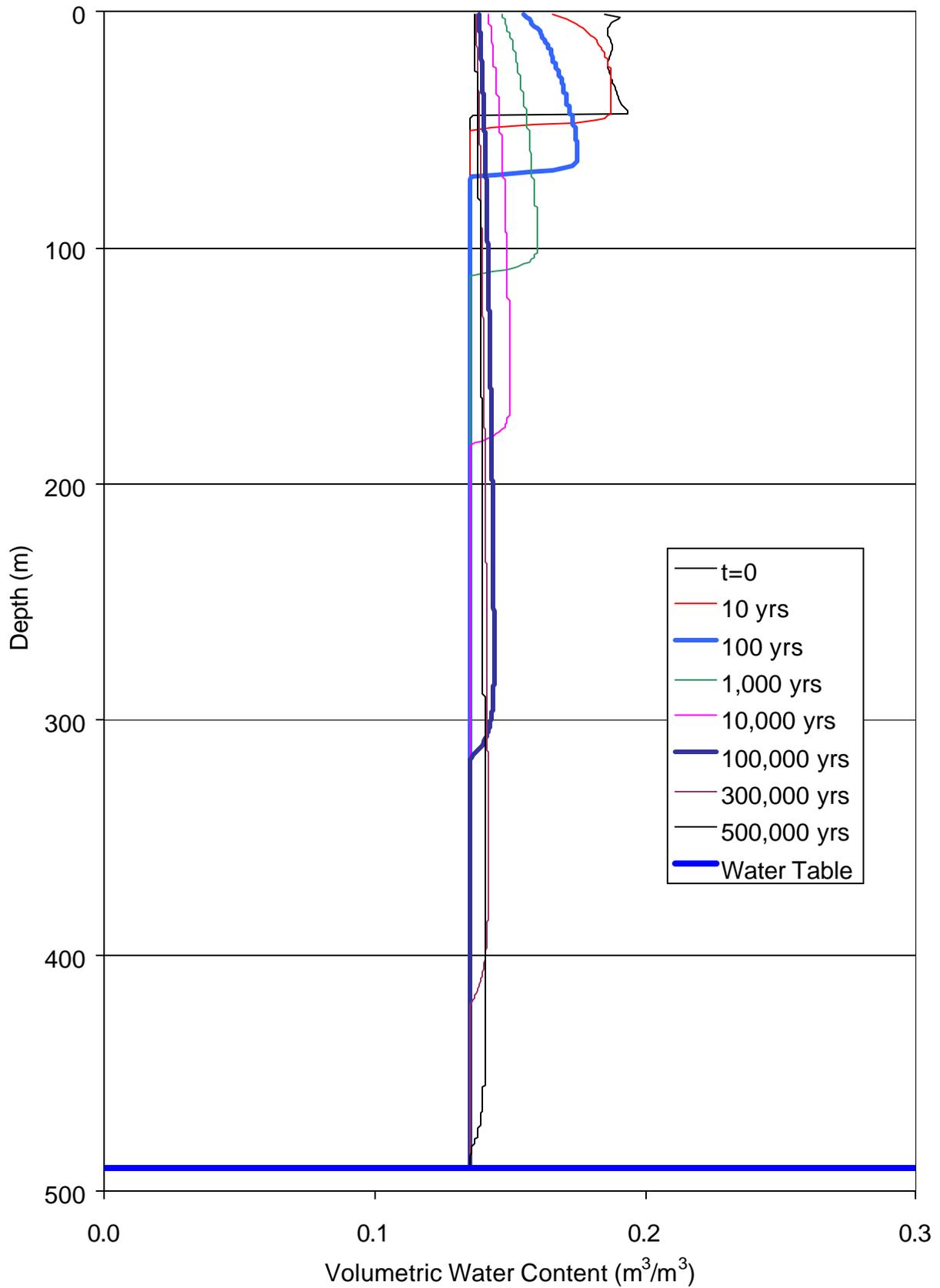


Figure 4. VS2DT simulations of redistribution of deep infiltration through bare-soil waste covers at the Area 3 RWMS.

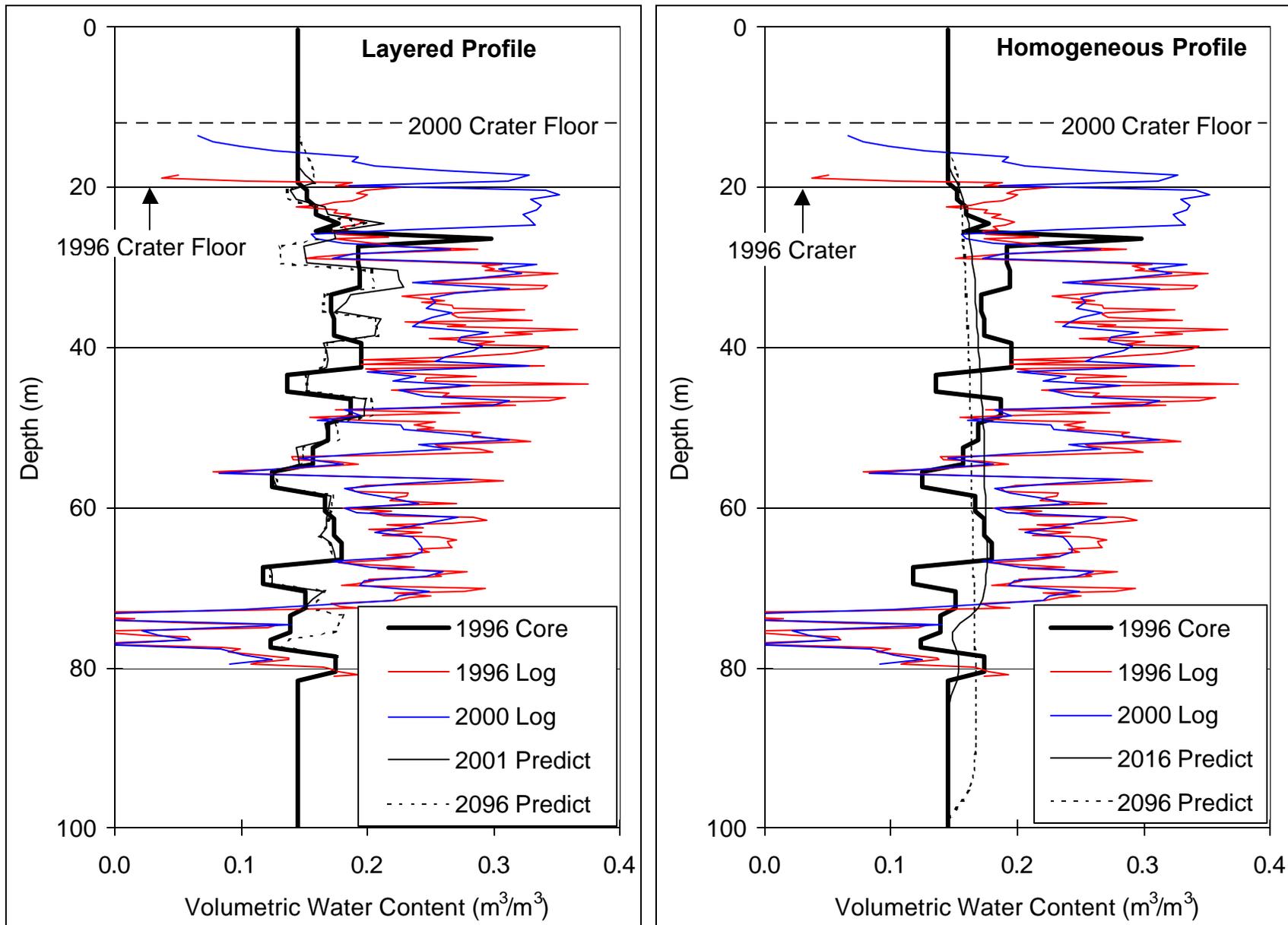


Figure 5. Modeled and measured soil water content profiles at nuclear subsidence crater U-3bh.