WSRC-MS-95-0084
CONF-950788--8

Effect of Roof Slope and Thickness on the Performance of a Saltstone Vault

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A document prepared for INTERNATIONAL CONFERENCE ON COMPUTATIONAL ENGINEERING SCIENCES at Mauna Lani from 07/30/95 - 08/03/95.

DOE Contract No. DE-AC09-89SR18035

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A paper for presentation at the
International Conference on Computational Engineering Sciences
Mauna Lani, Big Island of Hawaii, USA
July 30-August 3, 1995

and for publication in the proceedings.

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1. INTRODUCTION

At the Savannah River Site, low-level radioactive decontaminated salt solution is mixed with slag, flyash, and cement to form a grout-like material called "Saltstone." The Saltstone is poured into concrete vaults constructed at the Saltstone Disposal Facility (SDF) [1]. The SDF is designed for the release of contaminants in a slow, controlled manner over thousands of years. The impact of SDF on groundwater has been studied in a radiological performance assessment (PA) [2, 3]. The PA addresses the performance requirements or objectives mandated by DOE Order 5820.2A [4]. One of the performance objectives is to show that the impacted groundwater will be in compliance with the Safe Drinking Water Act (SDWA) [5].

Groundwater models were used to predict the fluid flow and contaminant transport at SDF [6]. Nitrate was a key contaminant. The models predicted a spatial contaminant concentration distribution in groundwater as a function of time. The SDWA mandates that the predicted concentration for any contaminant be lower than its maximum concentration limit (MCL) at a compliance point, over a performance period of 10,000 years. The MCL for nitrate is 45 mg/L. A compliance point is 100 m or farther from the disposal facility.

This study focuses on the roof configuration of Saltstone vault, with special interests in cost-effectiveness. We conducted a sensitivity study to evaluate the effect of roof slope and thickness on the performance of a Saltstone vault. Four roof configurations were simulated: 1) flat roof with a uniform thickness of 2 ft, 2) flat roof with a uniform thickness of 4 ft, 3) 2% slope roof with an average thickness of 2 ft; 4) 2% slope roof with an average thickness of 4 ft. Substituting the 4-ft roof with a 2-ft roof will reduce the project cost by approximately \$2,000,000 per vault.

The tool used for the simulation was ECLIPSE, a finite-difference petroleum reservoir engineering code with an environmental tracer option. Nitrate was used as the "tracer" contaminant. In this study, ECLIPSE solves the two-phase (air-water) two-dimensional (x-z vertical slice) flow and transport problem up to 10,000 years. The properties of all materials are assumed to remain unchanged. This paper describes a modeling study used to evaluate roof design options for the Saltstone vault.

2. The Saltstone Disposal Facility

The SDF will consist of 15 concrete vaults. The first vault, completed in 1990, is 100-ft wide by 600-ft long by 25-ft high (30.5 m × 183 m × 7.6 m). It contains six 100 ft × 100 ft (30.5 m × 30.5 m) cells. Thickness of the Saltstone vault bottom slab is 2 ft (0.61 m). The side walls are 1.5 ft (0.46 m) thick. The vaults will be filled with a monolith of Saltstone up to a height of 24 ft (7.3 m). A layer of clean concrete will then be poured above the Saltstone as the roof. The original design for the Saltstone roof has a slope of 2% and an average thickness of 4 ft (1.2 m). This corresponds to heights of 4.5 ft (1.8 m) at the center ridge and 3.5 ft (1.4 m) at the edges. Prior to closure, the bottom of the vaults is at the ground level which is at least 20 ft (6.1 m) above the historical high water table.

After all the vaults are filled, the SDF will undergo closure. The closure plan has not been completed. The current closure concept includes the placement, from the top of the vault to the ground surface, of two feet of clay, one foot of gravel, two feet of backfill soil, two feet of clay, one foot of gravel, and two feet of top soil. The purpose of the closure is to reduce rain water infiltration, to prevent an inadvertent intruder from exposure to the waste, and to minimize the probability of waste exposure by erosion.

3. MODELING METHODOLOGY

A two-dimensional vertical cross-section of a Saltstone vault was modeled. The closure cap was included in the simulation domain. The bottom of the simulation domain was a "numerical aquifer." The elevation at this level was arbitrarily chosen to be zero. The Saltstone and the concrete vault were assumed to be initially saturated with water. The initial nitrate concentration in the Saltstone pore fluid was 0.16 g/cm^3. Nitrate in the vault and the backfill soil was assumed to be negligible.

The boundary conditions used for the simulation were: 1) constant water influx of 40 cm/yr at the top of the domain; 2) a 1-ft air layer at the top; 3) a 1-ft numerical aquifer layer at the bottom; 4) a vertical barrier and gravel drain to one side of the domain; and, 5) zero convective and diffusive fluxes at the vertical boundaries due to symmetry. The 40 cm/yr water influx was the average infiltration rate at SRS. The air layer was maintained at 1.0 atmospheric pressure. The numerical aquifer was connected to a relatively large aquifer to maintain a stable water table condition. The vertical barrier and gravel drain were an approximation that allowed the removal of run-off water without modeling the whole SDF.

The ECLIPSE code [7] was used for the simulation. ECLIPSE is a finite-difference petroleum reservoir engineering code with an "environmental tracer" option. We used ECLIPSE for this study because of its robust equation solver and the "corner point geometry" option. This option allows us to use non-rectangular grids for the sloped roof and closure. The conceptual model and simulation grid for a 2% slope, 4 ft-roof is depicted in Figure 1.

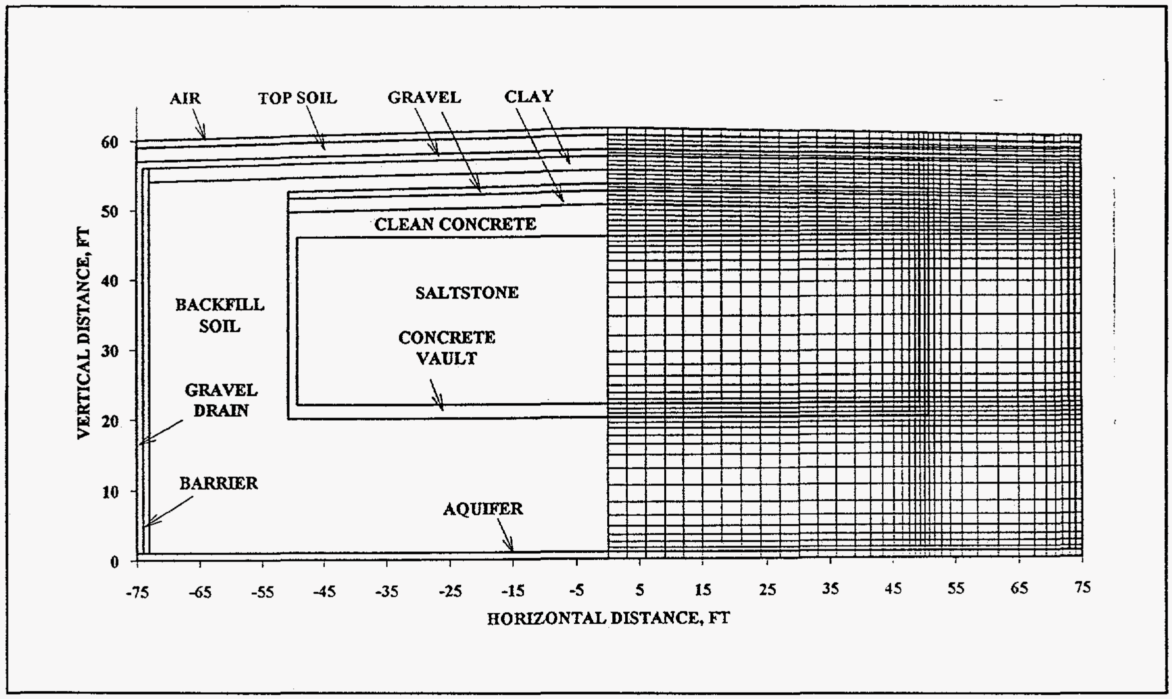

Fig. 1 Conceptual Model and Simulation Grid, 2% Slope, 4 ft Roof.

Only half a vault was used for the simulation model to take advantage of symmetry. Nitrate was chosen as the contaminant because it does not absorb or decay and is most abundant in the decontaminated salt solution. Nitrate was initially in the Saltstone and then migrated to the surroundings by convection and diffusion. In this study, ECLIPSE solves the two-phase (air-water) two-dimensional (x-z vertical slice) flow and transport problem up to 10,000 years. The properties of all materials are assumed to remain unchanged.

4. TRANSPORT MECHANISM

The dominant mechanisms for nitrate release from the Saltstone are convection and diffusion. Convection results from a very small amount of perched water flowing through the vault and acts to leach out nitrate. Diffusion results from the concentration gradient between the Saltstone and the model boundaries. Simultaneous transient flow and transport were simulated.

The relative importance between convection and diffusion is governed by the flow and transport properties of the porous media. It was assumed that the properties of the materials remain unchanged during the entire modeled period. For this study, the hydraulic conductivities of and the diffusivities for nitrate in Saltstone, concrete, backfill soil and clay are as follows:

Material	Conductivity (cm/sec)	Diffusivity (cm^2/sec)
Saltstone	1.0×10^{-10}	1.0×10^{-8}
Concrete	1.0×10^{-10}	1.0×10^{-8}
Backfill Soil	1.0×10^{-4}	5.0×10^{-6}
Clay	1.0×10^{-7}	1.5×10^{-6}

The conductivities of Saltstone and concrete used are somewhat higher than laboratory measurements [8] for conservatism. The characteristics (capillary pressure and relative permeability) of the materials could also affect the convective transport. Additional sensitivity studies showed they were not as important as the conductivities and diffusivities. Other mechanisms that may affect contaminant transport are absorption, decay, chemical reactions, and solubility limits. They were believed to be unimportant for nitrate because nitrate is non-absorbing, non-decaying, non-reactive and highly soluble.

5 RESULTS AND DISCUSSIONS

The predicted rate of nitrate released to the water table (g/yr) was divided by the total initial nitrate inventory in the modeling domain to obtain the fractional release rate (yr^{-1}). The fractional releases for the four scenarios are shown in Figure 2. In this figure, the 0% slope, 2 ft roof case (Case 1) showed highest nitrate fractional release rates. The curve peaked to 9.0×10^{-6} per year at about 3,800 years after waste disposal. In the 2% slope, 2 ft roof case, predicted peak nitrate release was 4.4×10^{-6} per year at about 8,000 years. The performance was improved by 50% at essentially no additional cost to Case 1. Increasing the roof thickness to 4 ft will also improve the performance. However, we believe this action will not justify its additional cost.

The release rate histories were used as source terms for the saturated-zone model to calculate the nitrate concentrations in the groundwater. Predicted groundwater peak concentration was proportional to the peak fractional release rate. It happened shortly after the peak fractional release because the groundwater velocity in the shallow aquifer was approximately 300 m/yr and the compliance point was only 100 m from the facility boundary. The regulatory maximum concentration limit (MCL) for nitrate is 45 mg/L. Predicted nitrate peak fractional releases and peak groundwater concentrations (C_{max}) at the compliance points are summarized in Table 1.

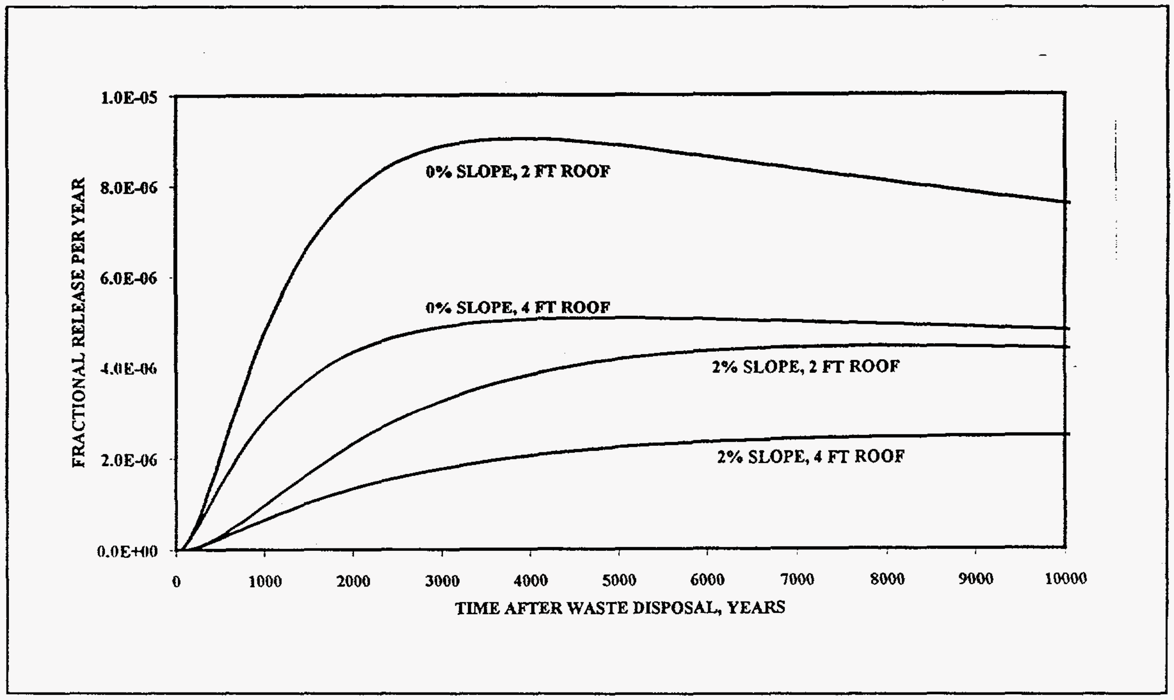

Fig. 2. Predicted Fractional Release Rates.

Cases	Maximum Fractional Release (per year)		C_{max} (mg/L)
	Value	At Year	Value
0% slope, 2 ft	9.0×10^{-6}	3,800	2.1
0% slope, 4 ft	5.1×10^{-6}	4,700	1.2
2% slope, 2 ft	4.4×10^{-6}	8,000	1.0
2% slope, 4 ft	2.5×10^{-6}	10,000	0.6
Maximum Concentration Limit			45.

Table 1. Predicted Peak Nitrate Fractional Releases and Groundwater Concentrations.

Based on the modeling results, we found: 1) Increasing the roof thickness from 2 ft to 4 ft only improves the SDF performance by 40%. 2) Changing the slope of the roof from 0% to 2% improves the SDF performance by 50%. The time of the peak is also doubled. 3) A reduction of roof thickness from 4 ft (original design) to 2 ft can result in project cost saving of approximately $2,000,000 per vault. 4) Predicted peak nitrate concentrations in the groundwater for all four cases are well below the 45 mg/L MCL. This probably results from the assumptions of intact Saltstone and vault.

ACKNOWLEDGMENT

This work was sponsored by the U.S. Department of Energy Office of Environmental Restoration and Waste Management under DOE Savannah River Field Office Contract No. DE-AC09-89SR18035.

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