Determining the Performance of an Arid Zone Radioactive Waste Site Through Site Characterization, Modeling and Monitoring

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ABSTRACT

A strategy of site characterization, modeling and monitoring are used to evaluate the performance of an interim cover at a low-level radioactive waste management site. The soil water migration pathway must be evaluated to assure the long-term isolation of low-level radioactive waste. Water balance studies using precision weighing lysimeters have been conducted for five years near the radioactive waste site at the Nevada Test Site. The numerical flow models UNSAT-H and HYDRUS-2D were tested using the weighing lysimeter data and then used to evaluate various cover design issues including cover thickness, presence of vegetation, and monitoring system design. The modeling was conducted to examine the expected behavior of a cover under realistic climate conditions by simulating flow over a 24-year period using site-specific historical data. Modeling results indicate that the current interim cover, a single layer of unvegetated recompacted native alluvium in excess of 2.4 m thick, adequately isolates the waste during the operational period. Total soil water storage never exceeded 17.6 cm per meter of soil, and total drainage through the bottom of the cover was 4.8 cm, or 1.6 percent of the total rainfall for that period. In addition, modeling results indicate that for a 3 m thick unvegetated cover, total soil water storage never exceeded 16.3 cm per meter of soil, and total drainage through the bottom of the cover was 1.8 cm, or 0.6 percent of the total rainfall for that period. Therefore the potential for transport of radioactive and hazardous constituents through the soil water pathway to the uppermost aquifer (at a depth of 235 m), should be judged to be negligible. Results also indicate that any cover thickness in conjunction with partial vegetative cover completely eliminates drainage. The performance of instrumentation in the lysimeters and modeling of moisture profiles in the cover provided insight into instrument selection, instrument location, and monitoring frequency for the design of a cover monitoring system. This type of an evaluation strategy of cover performance and monitoring system design can be easily applied to other sites.

INTRODUCTION

A strategy of site characterization, modeling and monitoring are used to evaluate the performance of an interim cover at a low-level radioactive waste management site. The site is a mixed waste disposal unit (Pit 3) located in the Area 5 Radioactive Waste Management Site (RWMS) at the Nevada Test Site (NTS). A 2.4 to 3.7 m thick operational cover consisting of recompacted local alluvial soil has been placed over the existing waste. Water balance studies using precision weighing lysimeters have been conducted for five years near the Area 5 RWMS (1). The numerical flow models

UNSAT-H (2) and HYDRUS-2D (3) were tested using the precision weighing lysimeter data and then used to evaluate various cover design issues including cover thickness, presence of vegetation, and monitoring system design. Simulations were conducted for a 24-year period using site-specific historical precipitation data from 1974 to 1997. Simulations using UNSAT-H were conducted for bare cover thicknesses of 2.44 m (8 ft) and 3.05 m (10 ft), and a vegetated cover thickness of 3.05 m, and simulations using HYDRUS-2D were conducted for a bare cover thickness of 3.05 m only in order to compare the two flow models.

SITE DESCRIPTION

The Area 5 RWMS is located in the northern Frenchman Flat on the NTS in southern Nevada. Frenchman Flat is a closed basin. The RWMS is at an elevation of 976 m on a bajada of the Massachusetts Mountains at the intersection of three alluvial fans on a slope of about 1° (4).

The NTS lies in a region that is transitional between the Great Basin Desert and the Mohave Desert. The climate of the area is characterized by a large number of cloudless days, low precipitation, and high daily temperatures, especially in the summer. Annual average precipitation is approximately 12.5 cm. The majority of rain falls during two peak seasons, with a greater peak in the winter and a lesser one occurring during the summer months. Potential evapotranspiration is calculated to be approximately 1.6 to 1.7 m/year.

Pit 3 is an unlined trench approximately 320 m long, 9 to 85 m wide at the floor, and 9 m deep. It has a capacity of approximately 129,000 m^3, of which about 39,000 m^3 at the eastern end has been used at the present time.

MODEL SIMULATIONS

Simulations using both UNSAT-H and HYDRUS-2D were one-dimensional. Nodal discretization had very fine spacing near the surface boundary (0.1 cm), and wider spacing (up to 20 cm) near the lower boundary. The 3.05 m cover simulations using UNSAT-H were run with a total of 68 nodes, and the 2.44 m cover simulations were run with a total of 66 nodes. The HYDRUS-2D simulations were run with a total of 43 nodes.

Saturated hydraulic conductivity and porosity of samples obtained at the Area 5 RWMS were determined in the laboratory on recompacted soil samples. The saturated hydraulic conductivity used was 1.0E-4 cm/sec. Porosity was 0.320. Hydraulic parameters α, n, and residual water content (θr) for the van Genuchten retention and conductivity model (5) were determined by Istok et al. (4) on samples from an observed fine texture layer in Pit 3. These hydraulic parameters are 0.029, 1.543, and 0.080 for α (cm^{-1}), n, and θr, respectively.

For bare-soil simulations, initial conditions were set to a uniform soil matric potential of 3,348 cm tension, which corresponds to a volumetric water content of 0.100 using the van Genuchten hydraulic parameters given above and using a residual water content of 0.080. For vegetated simulations, initial conditions were also set to a uniform soil matric potential of 3,348 cm tension, using a residual water content of 0.080 and an initial leaf area index (LAI) set to 0.2. After 2 years, revegetation was assumed to occur, and the residual water content was reduced to 0.020, LAI was increased to 2.0, and vegetation coverage was assumed to be 50 percent. These plant parameters were derived from the calibration of UNSAT-H using vegetated weighing lysimeter data. The reduction in residual water content due to incorporation of plants is based on actual residual water contents observed in the vegetated weighing lysimeter.

A 24-year precipitation record of daily totals was acquired from the National Oceanic and Atmospheric Administration (NOAA) for a rain gauge at Well 5B located about 6.6 km south of the Area 5 RWMS. The elevation of the RWMS is 975 m (3,200 ft) while that of the rain gauge is 942 m (3,090 ft). While it would be preferable to have a rain gauge closer to Pit 3, this rain record is reliable and continuous from 1974 to present. Average annual precipitation for the 24-year period is 12.8 cm, and the total precipitation for the 24-year period is 308.2 cm.

Potential evapotranspiration (PET) for the 24-year period was generated using the CREAMS model (6). CREAMS requires inputs of daily solar radiation totals, monthly average air temperatures, and albedo. Solar radiation has been measured continuously at the Area 5 RWMS for over four years at a nearby micrometeorology station. PET has also been calculated using the Penman equation (7) with data from this station. CREAMS was used to generate 24-years of PET data using inputs of four years of solar radiation data from the Area 5 micrometeorology station, 24 years of monthly air temperature data from the NOAA database, and a value of 0.36 for albedo.

TESTING OF UNSAT-H

The accuracy of model prediction using UNSAT-H was tested by comparing simulations of soil water storage over a four-year period to soil water storage measured directly and accurately using a precision weighing lysimeter in Area 5. This type of model calibration with precision weighing lysimeters has been described in several studies including Fayer et al. (8).

Results of the comparisons between UNSAT-H and the bare-soil weighing lysimeter, and the vegetated weighing lysimeter are illustrated in Figure 1. Although there is some divergence from the lysimeter data, this divergence is never greater than 0.8 cm of total soil water storage per meter of soil for the bare-soil lysimeter, and never greater than 1.9 cm of total soil water storage per meter of soil for the vegetated lysimeter.

These results were obtained without adjusting parameters in the model. Such modeling studies usually include efforts to adjust certain hydraulic or plant parameters in order to calibrate the model to better match the lysimeter data. These model results indicate that UNSAT-H can adequately predict evaporation, evapotranspiration, drainage, and total soil water storage, even without calibrating the model.

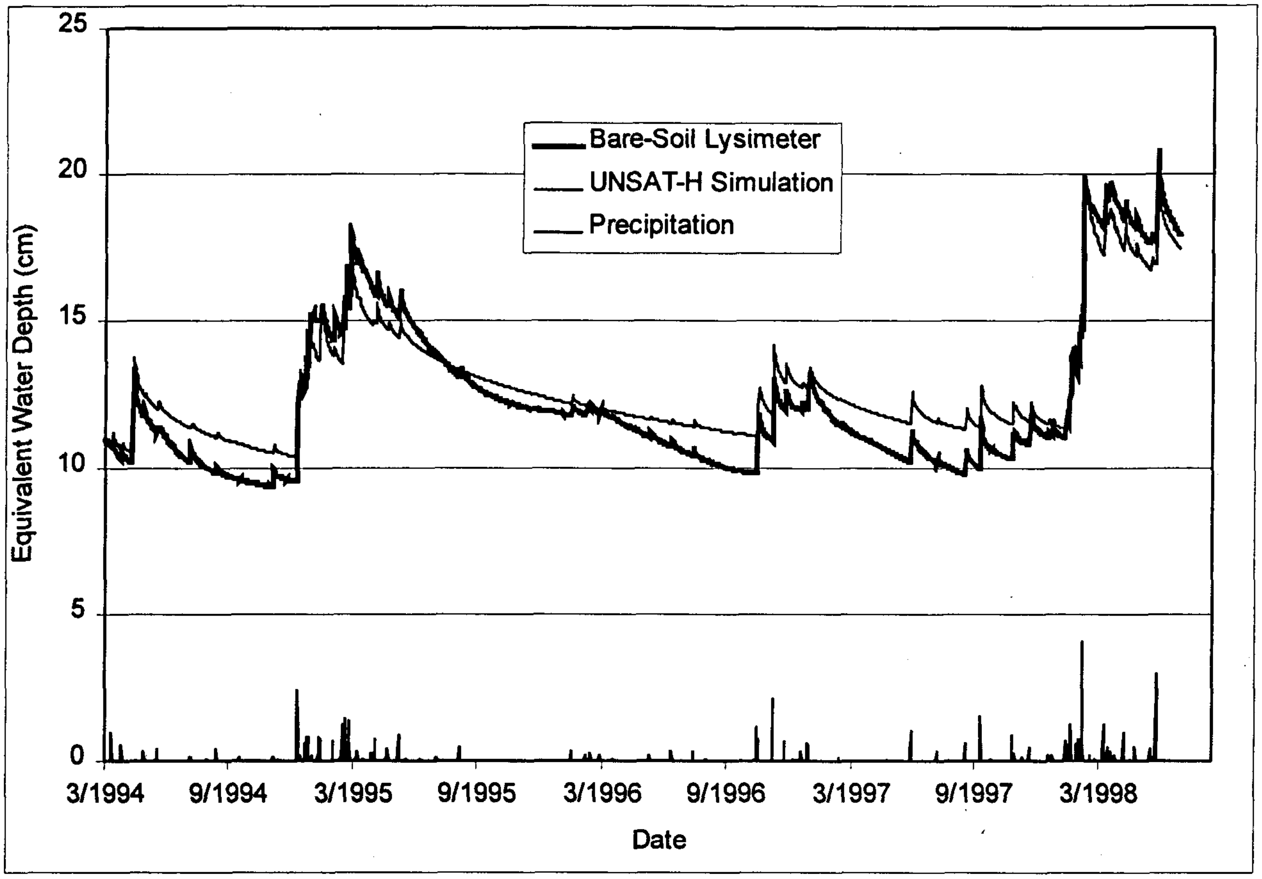

Figure 1a. UNSAT-H Simulation of Bare-Soil Water Storage: 1994-1998

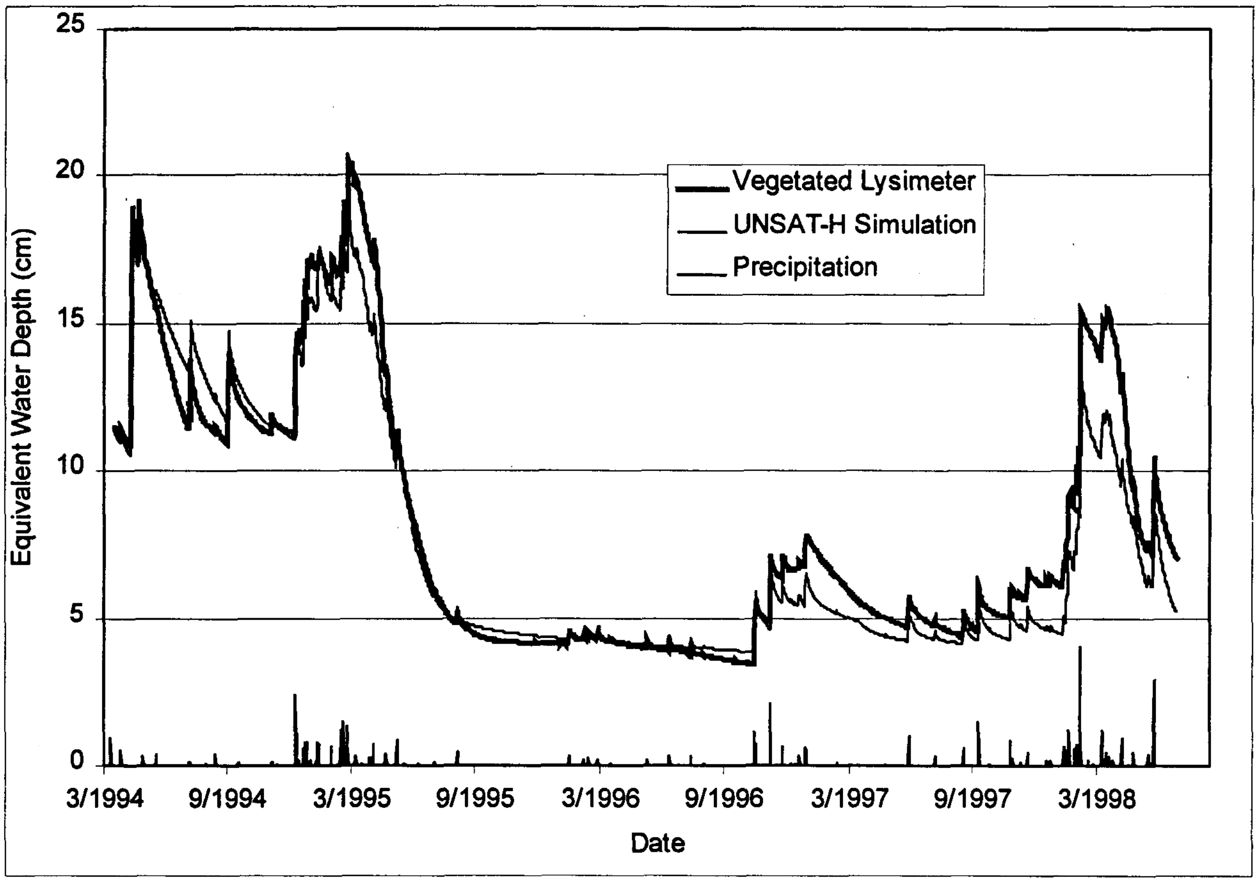

Figure 1b. UNSAT-H Simulation of Vegetated-Soil Water Storage: 1994-1998

SIMULATION RESULTS

Results of the UNSAT-H bare-soil simulations are illustrated in Figure 2 where total soil water storage in cm is shown for the 24-year period for the 2.44 m and 3.05 m thick bare covers. Total drainage through the bare-soil covers amounted to approximately 4.8 cm for the 2.44 m cover, and 1.8 cm for the 3.05 m cover. Drainage occurred after 12 years in the 2.44 m cover, and after 15 years in the 3.05 m cover. The covers effectively reduced infiltration to the waste zone to 1.6 and 0.6 percent of the total precipitation recorded for the 24-year period for the 2.44 m and 3.05 m bare covers, respectively.

Results of the HYDRUS-2D bare-soil simulations are illustrated in Figure 3a where soil water storage in cm is shown for the 24-year period for the 3.05 m thick bare cover. Total drainage through this cover was essentially zero.

Results of the UNSAT-H vegetated simulations are illustrated in Figure 3b where soil water storage in cm is shown for the 24-year period for a 3.05 m thick cover. Storage at the end of each year was always less than in the bare-soil case. Total drainage through this vegetated cover was zero. Total drainage for the modeled scenarios in which drainage occurred is illustrated in Figure 4.

CONCLUSIONS

The simulations show that all cover thicknesses modeled minimize the migration of liquids through the waste. Therefore, the potential for transport of radioactive constituents through the soil water pathway to the uppermost aquifer (at a depth of 235 m), should be judged to be negligible. In addition, the simulations show that: vegetation has a significant influence on soil water storage and effectively stops drainage; increasing bare-soil cover thickness delays drainage; increasing bare-soil cover thickness reduces drainage only slightly; and UNSAT-H and HYDRUS-2D yielded similar results.

The performance of instrumentation in the lysimeters and modeling of moisture profiles in the cover provided insight into instrument selection, instrument location, and monitoring frequency for the design of a cover monitoring system. This type of an evaluation strategy of cover performance and monitoring system design can be easily applied to other sites.

This modeling effort was based on current estimates of hydraulic and plant parameters to support a design recommendation. A sensitivity analysis of these parameters was not conducted. Future work could be performed to identify the sensitivity of these parameters and to incorporate estimates of uncertainty into the modeling results.

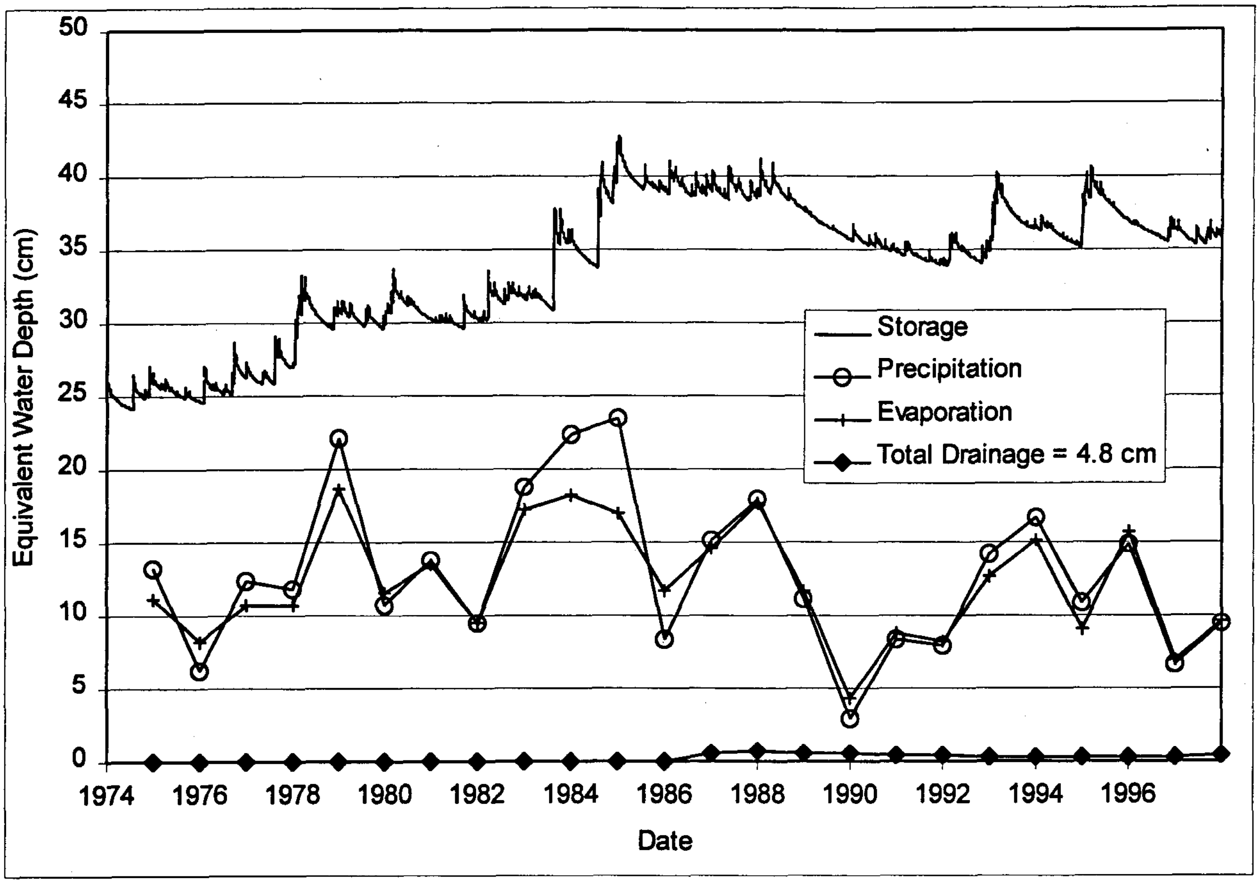

Figure 2a. UNSAT-H flow simulation of a 2.44 m (8 ft) thick bare-soil cover at Pit 3.

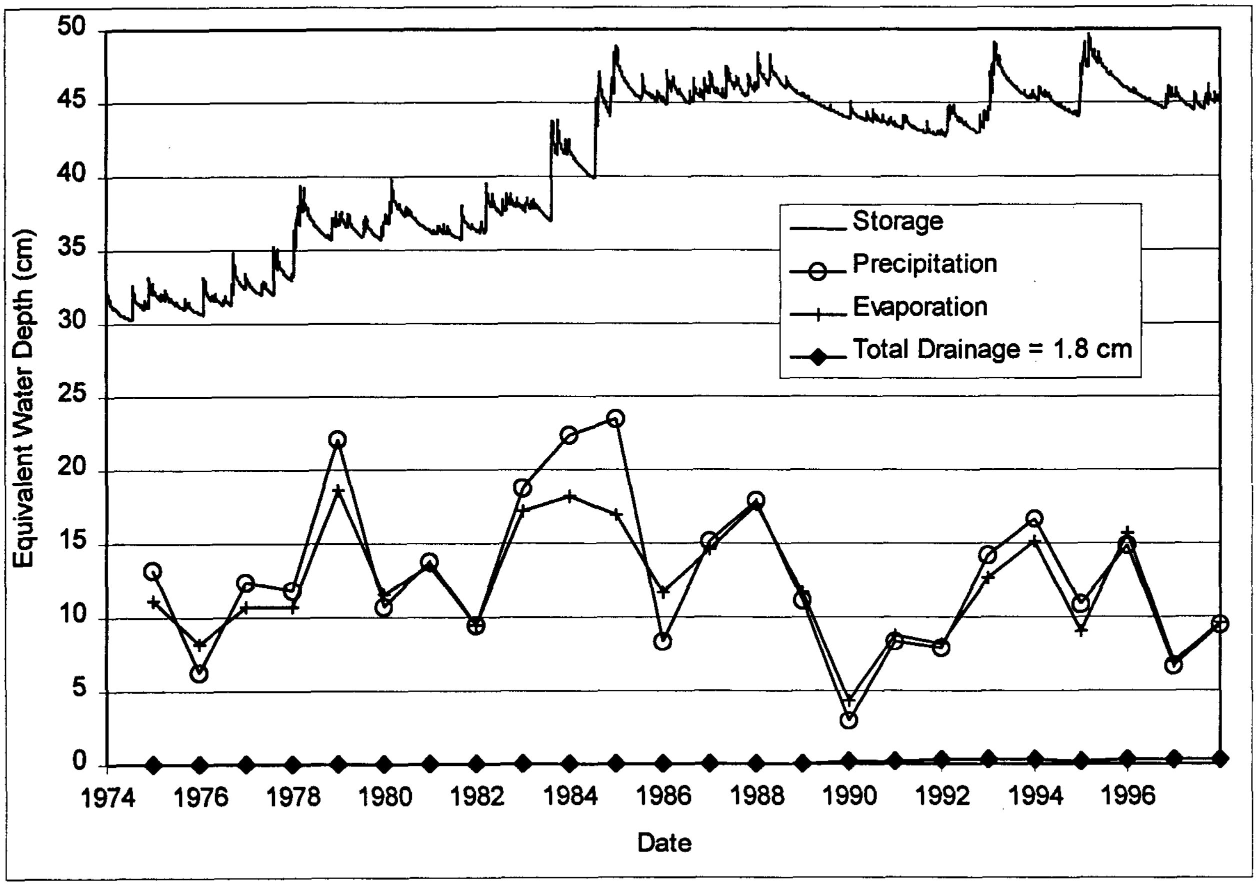

Figure 2b. UNSAT-H flow simulation of a 3.05 m (10 ft) thick bare-soil cover at Pit 3.

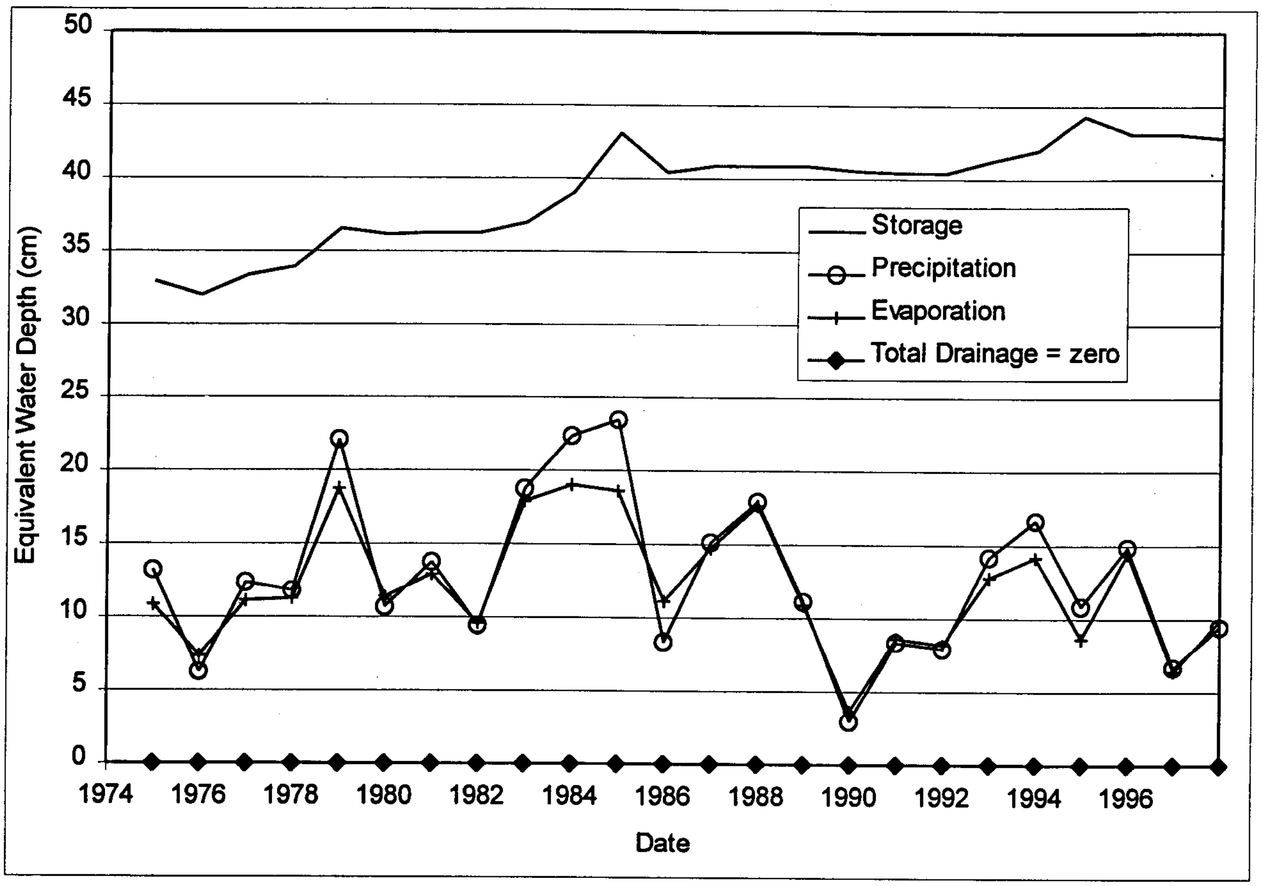

Figure 3a. HYDRUS flow simulation of a 3.05 m (10 ft) thick bare-soil cover at Pit 3.

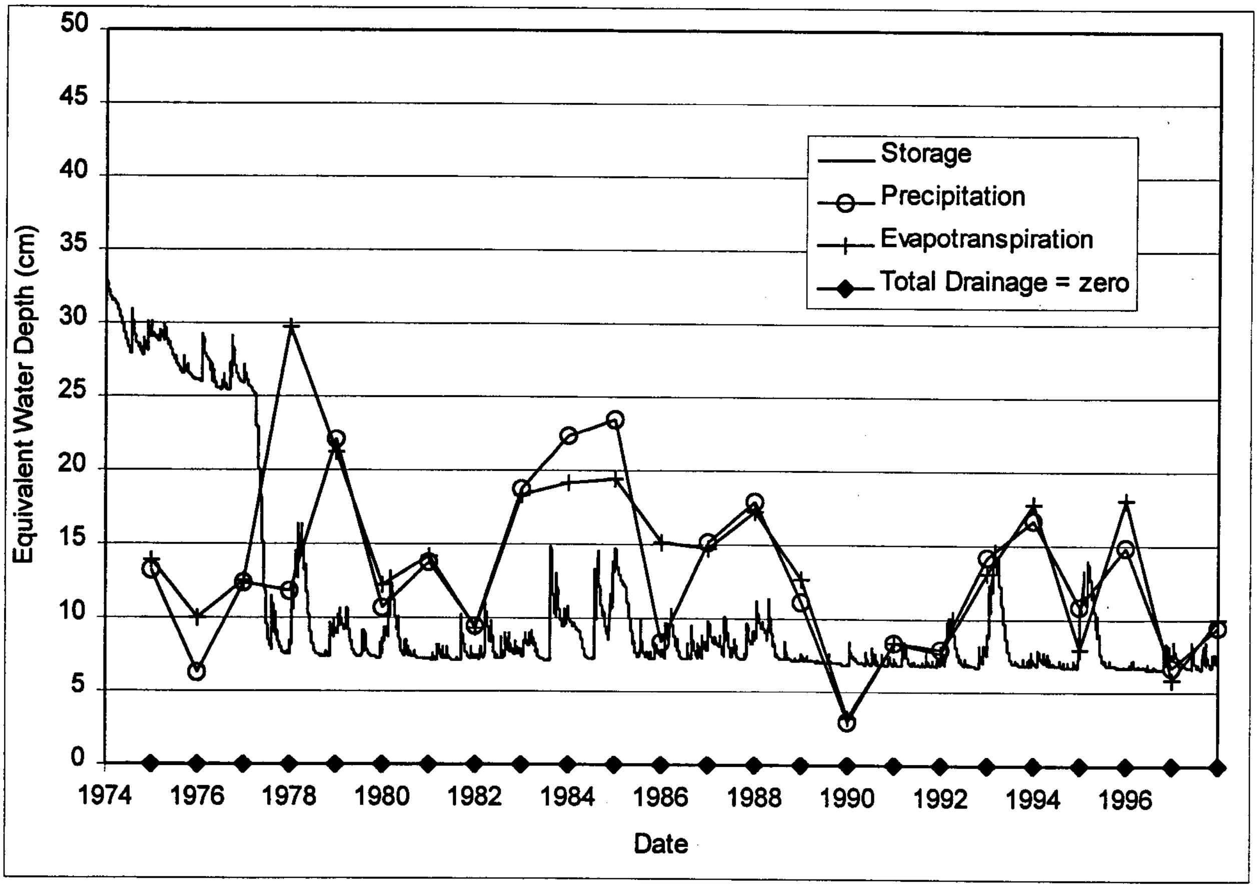

Figure 3b. UNSAT-H flow simulation of a 3.05 m (10 ft) thick vegetated cover at Pit 3.

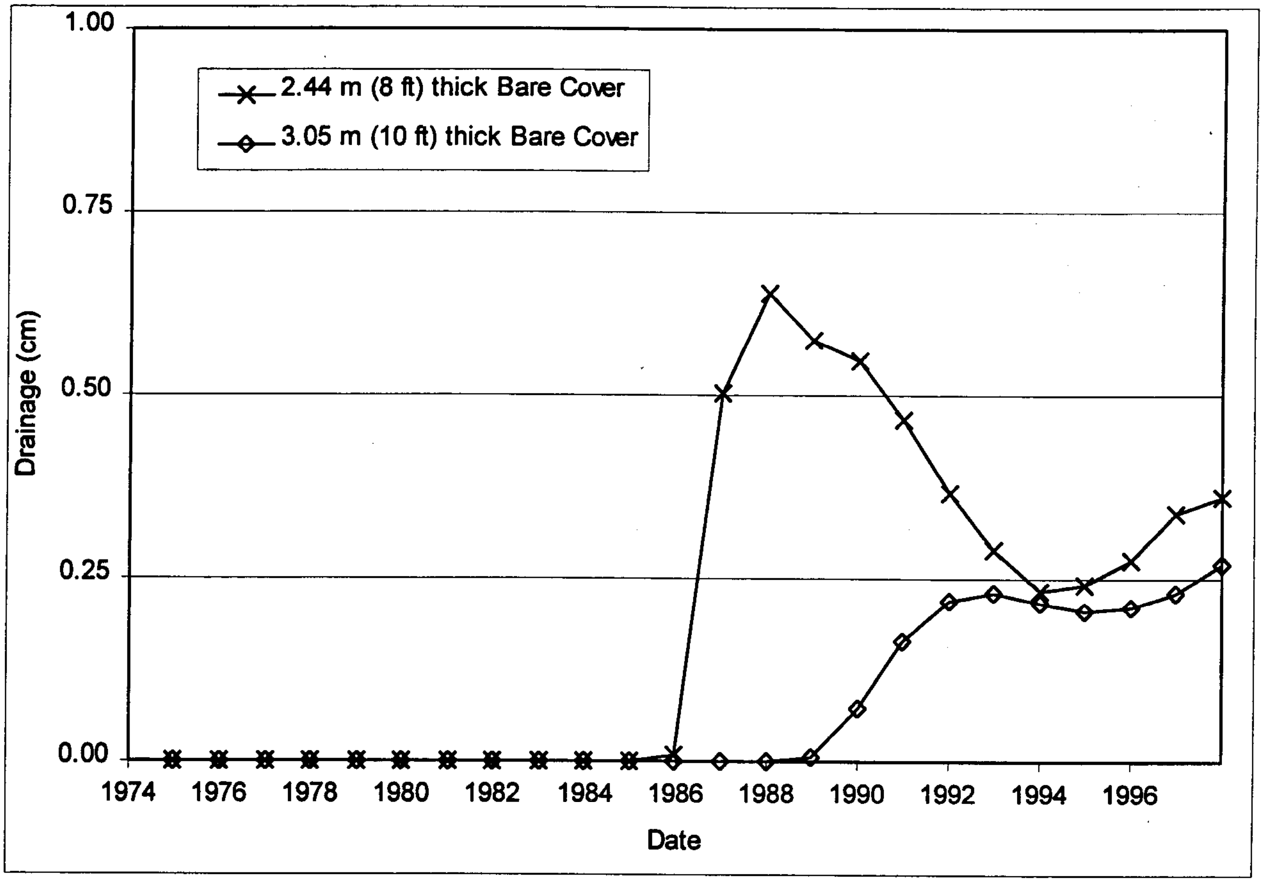

Figure 4. Drainage from UNSAT-H flow simulations of bare-soil covers at Pit 3.

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