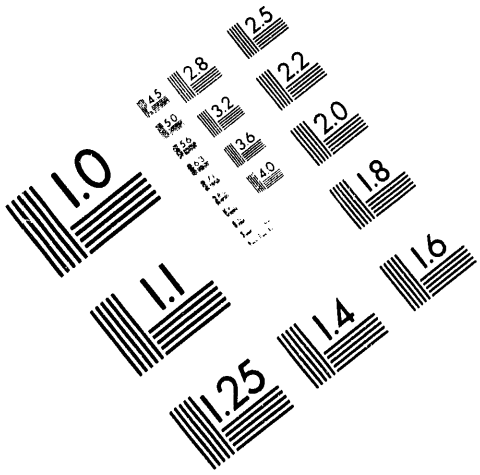


AIIM

Association for Information and Image Management

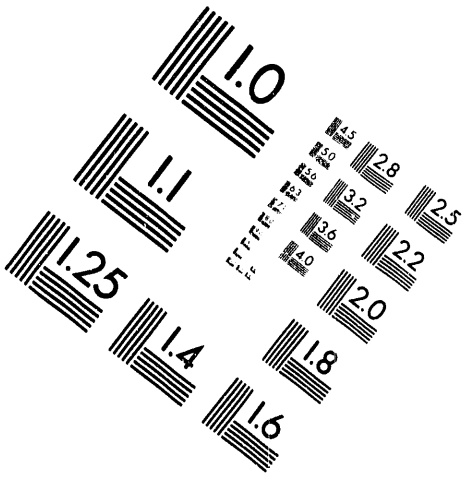
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

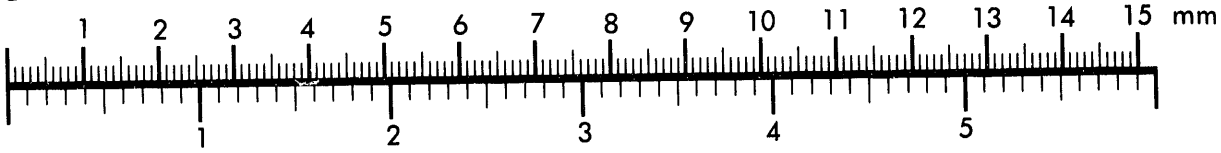
301/587-8202

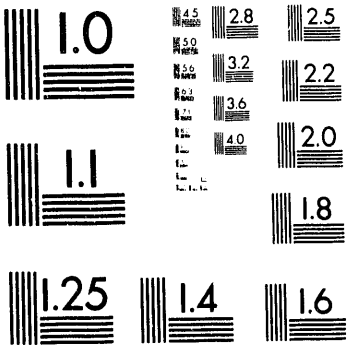
Centimeter

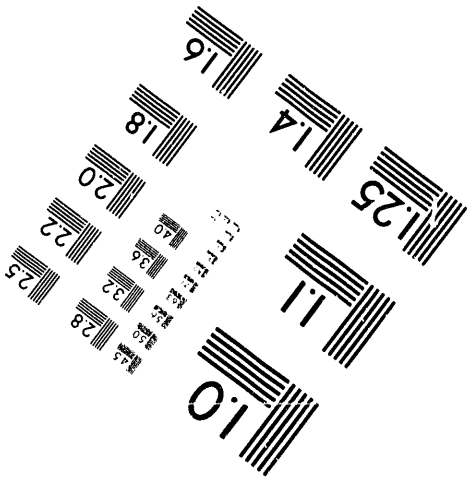
Inches

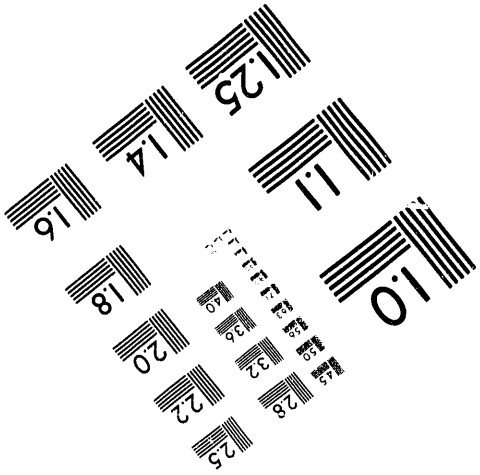
MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.











1 of 1

PNL-8675
UC-902

A COMPARISON OF SIMULATION MODELS FOR PREDICTING SOIL WATER DYNAMICS IN BARE AND VEGETATED LYSIMETERS

S. O. Link
R. N. Kickert
M. J. Fayer
G. W. Gee

June 1993

Prepared for
the U. S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Executive Summary

This report describes the results of simulation models used to predict soil water storage dynamics at the Field Lysimeter Test Facility (FLTF) weighing lysimeters. The objective of this research is to develop the capability to predict soil water storage dynamics with plants in support of water infiltration control studies for the Hanford Permanent Isolation Barrier Development Program. It is important to gain confidence in our ability to simulate soil water dynamics over long time periods to assess the barrier's ability to prevent drainage.

Two models were compared for their ability to simulate soil water storage dynamics with and without plants in weighing lysimeters, the soil water infiltration and movement (SWIM) and the simulation of production and utilization of rangelands (SPUR-91) models. These models adequately simulated soil water storage dynamics for the weighing lysimeters. The range of root mean square error values for the two models was 7.0 to 19.8. This compares well with the range reported by Fayer et al. (1992) for the bare soil data sets of 8.1 to 22.1. Future research will test the predictive capability of these models for longer term lysimeter data sets and for historical data sets collected in various plant community types.

Acknowledgments

This research was funded by the Office of Environmental Restoration and, in part, by the Office of Technology Development (via the Underground Storage Tank Integrated Demonstration) of the U.S. Department of Energy. The technical assistance of J. L. Downs, M. J. Harris, A. Phillips, J. L. Stroh, and M. D. Wessel is greatly appreciated.

Contents

Executive Summary iii

Acknowledgments v

1.0 Introduction 1.1

2.0 Methods 2.1

2.1 Soil Water Data 2.1

2.2 Simulation Models 2.1

2.2.1 SWIM 2.1

2.2.2 SPUR-91 ..... 2.3

2.3 Data Analysis 2.4

3.0 Results 3.1

3.1 SWIM 3.2

3.2 SPUR-91 ..... 3.5

4.0 Discussion 4.1

4.1 SWIM 4.1

4.2 SPUR-91 ..... 4.2

5.0 Future Work 5.1

6.0 References 6.1

Appendix A - SPUR-91 Model Parameters A.1

Figures

3.1 SWIM Model Predictions and Observed Soil Water Dynamics in the Vegetated-Ambient Precipitation Lysimeter (W1) 3.2

3.2 SWIM Model Predictions and Observed Soil Water Dynamics in the Bare-Ambient Precipitation Lysimeter (W2) 3.3

3.3 SWIM Model Predictions and Observed Soil Water Dynamics in the Vegetated-Irrigated Lysimeter (W3) 3.4

3.4 SWIM Model Predictions and Observed Soil Water Dynamics in the Bare-Irrigated Lysimeter (W4) 3.4

3.5 SPUR-91 Model Predictions and Observed Soil Water Dynamics in the Bare-Ambient Precipitation Lysimeter (W2) 3.5

3.6 SPUR-91 Model Predictions and Observed Soil Water Dynamics in the Bare-Irrigated Lysimeter (W4) 3.6

Tables

2.1. Parameter Values for Sagebrush in the Ambient Precipitation and Irrigated Lysimeters. 2.2

2.2. Parameter Values for Soils in the Four Lysimeters 2.2

3.1. Comparison of Root Mean Square Errors for the SPUR-91, SWIM, and UNSAT-H Models when Compared to the Field Lysimeter Test Facility Weighing Lysimeters 3.1

3.2. Linear Correlation Characteristics of the SWIM and SPUR-91 Models for the Field Lysimeter Test Facility Weighing Lysimeters 3.1

1.0 Introduction

The Pacific Northwest Laboratory (PNL) and Westinghouse Hanford Company (WHC) are working together to develop protective barriers for the near-surface disposal of hazardous waste at Hanford. The proposed barrier design consists of a layer of fine-textured soil overlying a series of layers grading from sand to basalt riprap (USDOE 1987). A multi-year research program is being conducted to assess the long-term performance of barrier configurations in restricting plants, animals, and water from contacting buried wastes (Wing 1989).

The permanent isolation barrier is being designed to prevent or minimize the infiltration of precipitation into the wastes. The design of the uppermost layer relies on plants to recycle precipitation back to the atmosphere. This upper layer is the first component of the barrier called on to prevent water from draining into the waste. To gain confidence in the barrier's ability to prevent precipitation from becoming drainage we have initiated efforts to predict how plants will affect water balance, including studies of evapotranspiration.

Evapotranspiration is the combined loss of water from the soil via soil evaporation and plant transpiration. Plants can extract a significant amount of water from the soil relative to water evaporated from the soil. For instance, observations on the Field Lysimeter Test Facility (FLTF) weighing lysimeters demonstrate that plants will reduce soil water storage to about 100 mm late in the summer compared with a value of about 200 mm for bare soil lysimeters. In addition, it has been demonstrated that plants still reduce soil water storage to about 100 mm even when irrigated. Deep-rooted sagebrush dominate the soil water extraction on the lysimeters. If we had planted the lysimeters with cheatgrass, a shallow-rooted annual, we would predict more soil water storage than for sagebrush, as Cline et al. (1977) have demonstrated.

In designing a permanent isolation barrier, it is important to develop our capability to predict how much water various plant species extract from the soil. We have chosen to develop a modeling capability that can predict soil water storage given changes in plant community structure caused by climate change, fire, and competition with invasive species, such as cheatgrass, which are very aggressive. It is possible for fire to kill sagebrush, allowing cheatgrass to gain a competitive advantage on the surface of the barrier, and climate change will likely change plant communities, which also could influence soil water storage.

We have initiated this task by comparing two existing models: the soil water infiltration and movement (SWIM) model, (Ross 1990a) allows us to examine up to 101 soil layers and four plant species, and the simulation of production and utilization of rangelands (SPUR-91) model (Carlson and Thurow 1991) allows examination of up to eight soil layers and seven plant species. We will determine the ability of these models to predict soil water extraction in the four FLTF weighing lysimeters, two of which are bare and two of which are planted, and will compare them with predictions of the UNSAT-H code (Fayer et al. 1992) for the bare lysimeters.

Section 2.0 of this report describes the data sets used to test these two simulation models. Model predictions and observed data are presented in Section 3.0 and discussed in Section 4.0. Section 5.0 describes future work.

2.0 Methods

The data sets used to test the models were acquired at the FLTF described in Gee et al. (1989). The lysimeters were filled with 15 cm of gravel at the bottom, 10 cm of sand, then 150 cm of silt loam near the surface. The lysimeters are 1.5 m on a side and 1.7 m deep.

2.1 Soil Water Data

Gee et al. (1989) provide a complete description of the lysimetry techniques used to collect soil water storage data. Soil water storage is the total amount of water in a lysimeter expressed as a depth of water (mm). The data sets used in our simulations were similar to those used by Fayer et al. (1992) with minor calibration changes. We used data from the two bare soil lysimeters (W2-ambient precipitation, W4-irrigated) to compare our simulation results with those of Fayer et al. (1992). Data from W1-ambient precipitation and W3-irrigated lysimeters were used to test our simulation results for soil water storage dynamics in the presence of plants. Driving abiotic variables used to compute soil water balance (precipitation input) and potential evapotranspiration (PET) were obtained from the Hanford Meteorological Station (HMS). Potential evapotranspiration was computed as in Fayer et al. (1992) for the SWIM model.

2.2 Simulation Models

We compared the ability of the SWIM and SPUR-91 models to simulate soil water storage for the weighing lysimeters. Simulations from these models were then compared with Fayer et al. (1992), who used the UNSAT-H code to predict soil water storage dynamics in the two bare lysimeters. The models are described in this subsection. The first day of observed and simulated data was November 4, 1987.

2.2.1 SWIM

The SWIM model simulates water infiltration and movement in soils. Water is added as precipitation (or irrigation) and removed by runoff, drainage, evaporation from the soil surface, and transpiration by plants. The model's parameters allow examination of up to 101 soil layers and four plant species. We used 33 soil layers and one plant species, sagebrush (*Artemisia tridentata*). This model assumes that conditions can be treated as horizontally uniform and that flow is described by Richards' equation. Details of the solution of Richards' (1931) equation in the SWIM model are described in Ross (1990b).

Plant parameters included minimum xylem water potential (Y_{min}), the depth at which root length density falls to 37% (d), maximum root length density at the surface (rld_{max}), the maximum fraction of potential evapotranspiration (PET_{max}) attributed to that plant species, and four parameters used to define a growth function. The growth function is a sigmoid curve given as shown in Equation (1)

$$f = 1/(1 + e^{(a - b * t)}) \qquad (1)$$

where t is time (days), and where a and b are parameters determined using the initial (t1) value of the fraction of the maximum fraction of PET (f1) and the final (t2) value of the fraction of the maximum fraction of PET (f2) as discussed in Ross (1990a). The parameter values used for vegetation are given in Table 2.1.

Table 2.1. Parameter Values for Sagebrush in the Ambient Precipitation and Irrigated Lysimeters

	Parameters							
Lysimeters	Y_{min}, m	d, cm	rld_{max}, cm/cm^3	PET_{max}	f1	t1 days	f2	t2 days
Ambient Precipitation	-700	30	5	0.18	0.3	0	0.9	200
Irrigated	-700	30	5	0.21	0.3	0	0.9	200

Runoff is assumed to be zero. Soil parameters for each depth include initial matric potential, water content at field capacity ($Ø_s$), minus the slope of a straight line approximating the water retention curve on a log-log plot (b), the air entry potential (Y_e), and the saturated hydraulic conductivity (K_s). The hydraulic conductivity (K) is computed as shown in Equation (2).

$$K = K_s * (Ø/Ø_s)^{(b * n)} \tag{2}$$

where Ø is soil water content, and n is 2 + 2/b. Parameter values are given in Table 2.2.

Table 2.2. Parameter Values for Soils in the Four Lysimeters

	Parameters				
Material	$Ø_s$	b, cm^3/cm^3	Y_e cm	K_s, cm	n, cm/h
Silt loam	0.496	2.964	-56.24	0.252	2.688
Sand	0.445	0.565	-13.78	24.63	5.61
Gravel	0.419	0.860	-0.203	78.75	2.422

The simulation time step is 1 day. We used the same assumptions in our simulations as Fayer et al. (1992) to modify PET, including the assumption that PET is zero during snow cover and reduced by 30% at other times. We optimized parameter values to minimize error for the bare-ambient precipitation lysimeter and then used these parameter values to predict soil water storage dynamics for the bare-irrigated lysimeter. The same soil parameters were used for the vegetated lysimeters. Parameters for the vegetated lysimeters were optimized in the same way except the proportion of PET attributed to plants in the irrigated lysimeter was optimized to account for increased growth associated with the additional water (Link et al. 1990).

2.2.2 SPUR-91

The second model we tested was SPUR (Wight and Skiles 1987; Hanson et al. 1988; and Hanson 1989). This major multi-disciplinary model was developed by the U.S. Department of Agriculture-Agricultural Research Service during the 1980's. The model was originally developed, at least the vegetation component, to use on shortgrass rangelands in northeastern Colorado, although the intent was to apply it to any kind of rangeland without significant forestation. So far, the SPUR model has only been tested in Texas rangelands. The initial results showed the model compared poorly to field conditions, especially for bare soil and soil water dynamics. Subsequently, extensive analysis was performed for much of the SPUR model code, errors corrected, several enhancements made, and a revised version called SPUR-91 was issued (Carlson and Thurow 1991). We used this revised version to field test lysimeters W2 and W4.

Four input parameter and data files are necessary to run the SPUR-91 model. Table A.1 provides the parameter values used for defining the time and space dimensions, site, and hydrology characteristics. The top ground surface area of the lysimeter was taken as the area of entire field. The maximum number of soil layers was eight. Rooting depth was set to 25 in., even though virtually no vegetation was defined for these simulations. The initial soil moisture fraction of field capacity was set at 0.70 (70%), rather than at 0.49, as was used with the SWIM model. All snow-related parameters shown in Table A.1 were taken by default from the sample data files for the Pawnee Site in northeastern Colorado (Wight and Skiles 1987) and from the suggested values found in Carlson and Thurow (1991). It is not known whether any of these snow-related parameters would be sufficiently different for snow conditions at the HMS.

In keeping with the starting day for the simulation, as shown in Table A.1, a weather file was set up with daily values for precipitation (cm), maximum air temperature (°C), minimum air temperature (°C), solar radiation (ly), and wind run (mi) for the HMS. These values were used as driving variables for the simulation.

The simulations were applied to bare soil conditions, but, because SPUR-91 expects a vegetation parameter file as input because it requires that at least one plant species be defined, a file was used for a dummy plant species as shown in Table A.2. The parameter values have no significance in this case because, as can be seen in Table A.2, initializing values for vegetation state variables were set to 0.0 except for a trivial 1.0 g/m^2 for live roots biomass. Also in Table A.2, several nonspecies-specific parameters can be seen whose values must be defined for the SPUR-91 model. Dead root biomass and litter biomass were set to zero, assuming this would represent the surface soil in the lysimeters. No data were available for soil inorganic nitrogen and soil organic matter biomass for the bare soil lysimeters at the HMS, so these values were assumed to be a minimal 0.1 and 1.0, g/m^2, respectively. Again, for bare soil simulations, we assumed this was not important to the processes being simulated.

We applied the SPUR-91 model without calibrating it. Parameter value settings were made as described above before simulating the dynamics. No attempt was made to optimize the fit of the SPUR-91 model as we did for the SWIM model and was done for the UNSAT-H code (Fayer et al. 1992). Calibration was done by modifying sensitive parameter values until model predictions accurately simulated observed values.

2.3 Data Analysis

Model predictions of soil water storage were compared with observed data to assess fit and error. The measure used to determine the model error is the root mean square error (RMSE) as used by Fayer et al. (1992). A small value of RMSE indicates that the model accounts for more variation than a model with larger RMSE values. We compared our model results directly with those of Fayer et al. (1992) using RMSE. The values of RMSE reported in Fayer et al. (1992) were multiplied by 10 for comparison with our RMSE values because our results are reported in units of millimeters while those in Fayer et al. (1992) were reported in centimeters. We used Equation (3) to determine root mean square error as follows:

$$RMSE = [(\sum_{i=1}^{n} e_i^2)/n]^{1/2} \tag{3}$$

where e is the difference between predicted and observed values, and n is the number of observations. Linear regression was used to assess the relationship between predicted and observed data. We used Equation (4) as follows:

$$\text{Predicted} = B0 + B1*\text{Observed}, \tag{4}$$

where B0 is the intercept, and B1 is the slope. A slope value of less than one indicates that the simulation underestimates the observed data. Finally, we used R^2 to assess the proportion of variation in the data explained by the linear regression.

3.0 Results

Model predictions and observed data are graphically presented for each lysimeter as a function of time (Figures 3.1 through 3.6). This presentation allows for a qualitative assessment of model fit. The model predictions were considered good if RMSE <20. RMSE values for the SWIM, SPUR-91, and UNSAT-H are also presented in Table 3.1.

Table 3.1. Comparison of Root Mean Square Errors for the SPUR-91, SWIM, and UNSAT-H Models when Compared to the Field Lysimeter Test Facility Weighing Lysimeters [W1 (vegetated, ambient precipitation), W2 (bare, ambient precipitation), W3 (vegetated, irrigated), and W4 (bare, irrigated)]

	Lysimeter			
Model	W1	W2	W3	W4
SPUR-91 (uncalibrated)		9.3		17.0
SWIM (calibrated)	15.6	7.0	19.8	12.0
UNSAT-H (uncalibrated)		14.7		22.1
UNSAT-H (calibrated)				8.1

Table 3.2 presents linear regression characteristics of the SWIM and SPUR-91 models.

Table 3.2. Linear Correlation Characteristics of the SWIM and SPUR-91 Models for the Field Lysimeter Test Facility Weighing Lysimeters [W1 (vegetated, ambient precipitation, W2 (bare, ambient precipitation), W3 (vegetated, irrigated), and W4 (bare, irrigated)]

	Lysimeter			
Model	W1	W2	W3	W4
SPUR-91				
B0		20.2		129.6
B1		0.89		0.64
R^2		0.91		0.77
SWIM				
B0	-12.7	40.3	4.30	56.0
B1	1.01	0.84	1.01	0.81
R^2	0.98	0.98	0.95	0.98

(a) Predicted = B0 + B1*Observed; R^2 is the proportion of variation in the data explained by the linear regression

3.1 SWIM

Figure 3.1 presents the simulation of the vegetated-ambient precipitation lysimeter (W1). The general effect of plants on soil water dynamics was effectively simulated. There was an underprediction in the spring during the rapid decline in soil water storage. There was an additional underprediction during the late summer until the end of the simulation. The magnitude of the underprediction is reflected in a relatively high RMSE value (Table 3.1). The relationship between predicted and observed was good in that there was a one-to-one relationship between the variables and a high R^2 value (Table 3.2).

The simulation of the bare-ambient precipitation lysimeter (W2) is presented in Figure 3.2. The general effect of these soils on soil water dynamics was effectively simulated. There was an underprediction in the winter, an overprediction in the summer, and a smaller underprediction at the end of the simulation. The magnitude of the underprediction is reflected in the lowest RMSE value for the SWIM simulations (Table 3.1). The relationship between predicted and observed was good in that there was a high R^2 value, but there was an underprediction as indicated by a slope of 0.84 (Table 3.2).

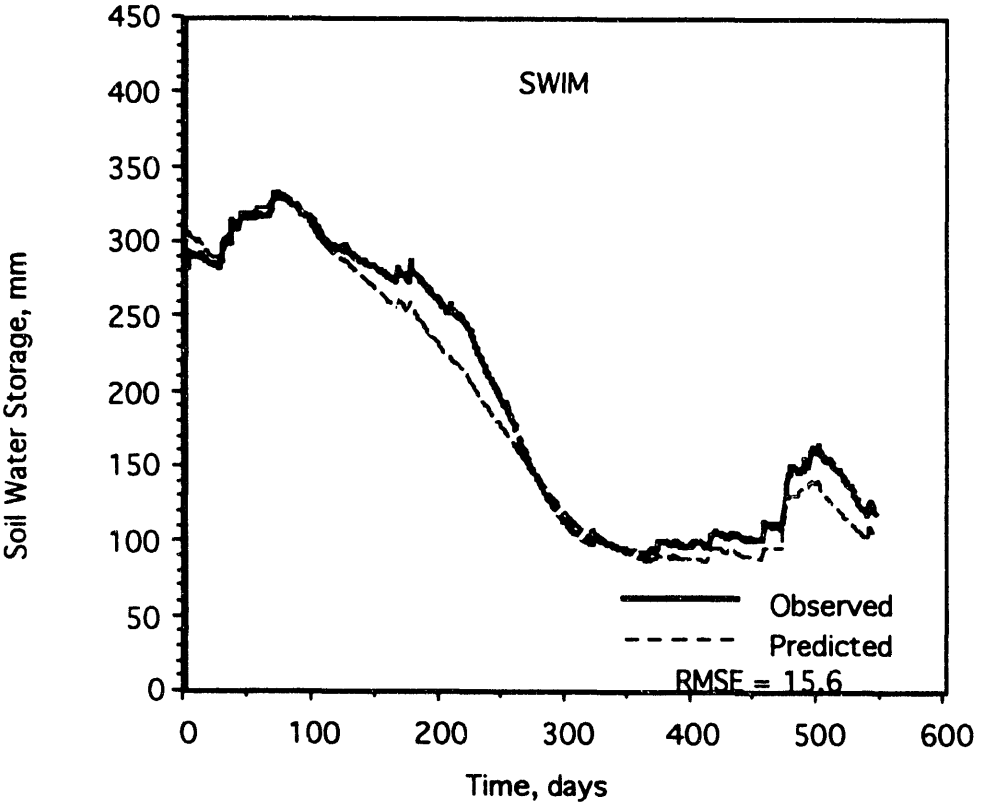


Figure 3.1. SWIM Model Predictions and Observed Soil Water Dynamics in the Vegetated-Ambient Precipitation Lysimeter (W1)

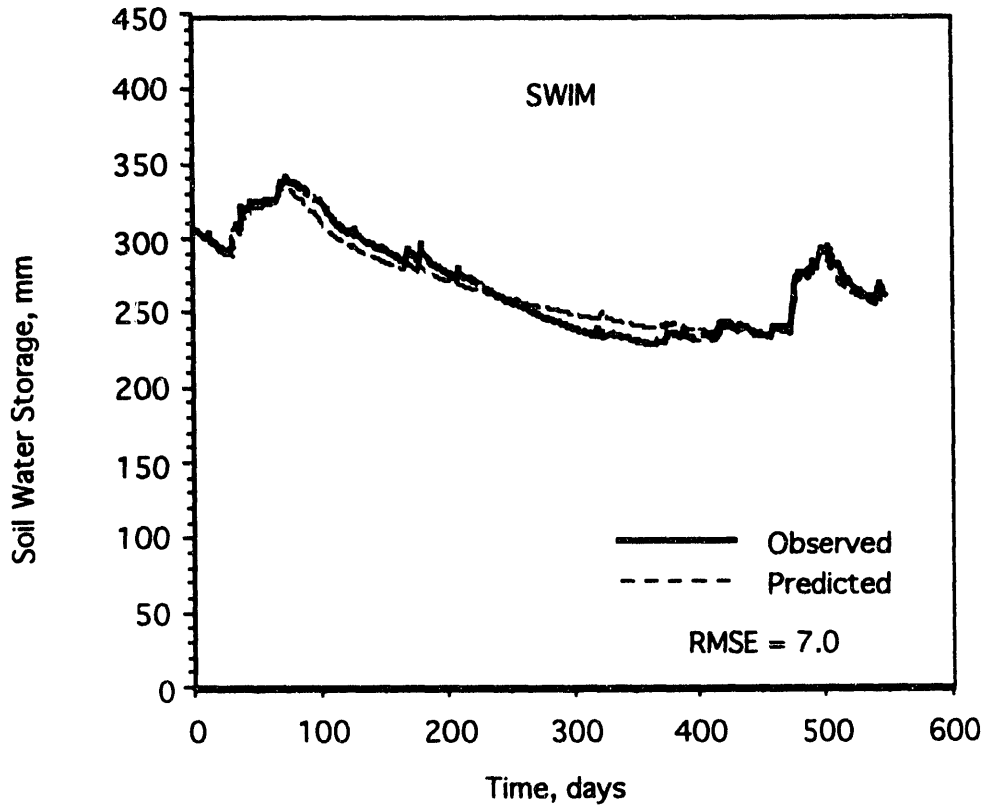


Figure 3.2. SWIM Model Predictions and Observed Soil Water Dynamics in the Bare-Ambient Precipitation Lysimeter (W2)

The simulation of the vegetated-irrigated lysimeter (W3) is presented in Figure 3.3. The general effect of plants on soil water dynamics was, again, effectively simulated. There was an overprediction in the winter and summer with a smaller underprediction near the end of the simulation. The magnitude of the underprediction is reflected in the highest RMSE value for the SWIM simulations (Table 3.1). The relationship between predicted and observed was good in that there was a one-to-one relationship between the variables and a high R^2 value (Table 3.2).

The simulation of the bare-irrigated lysimeter (W4) is presented in Figure 3.4. The general effect of these soils on soil water dynamics was effectively simulated using the same soil parameters as in the bare-ambient precipitation lysimeter. There was a small underprediction in the winter, an overprediction in the summer, and a larger underprediction at the end of the simulation. The magnitude of the underprediction is reflected in the relatively high RMSE value for the SWIM simulation compared with that of the W2 lysimeter (Table 3.1). The relationship between predicted and observed was good in that there was a high R^2 value, but there was an underprediction as indicated by a slope value of 0.81 (Table 3.2).

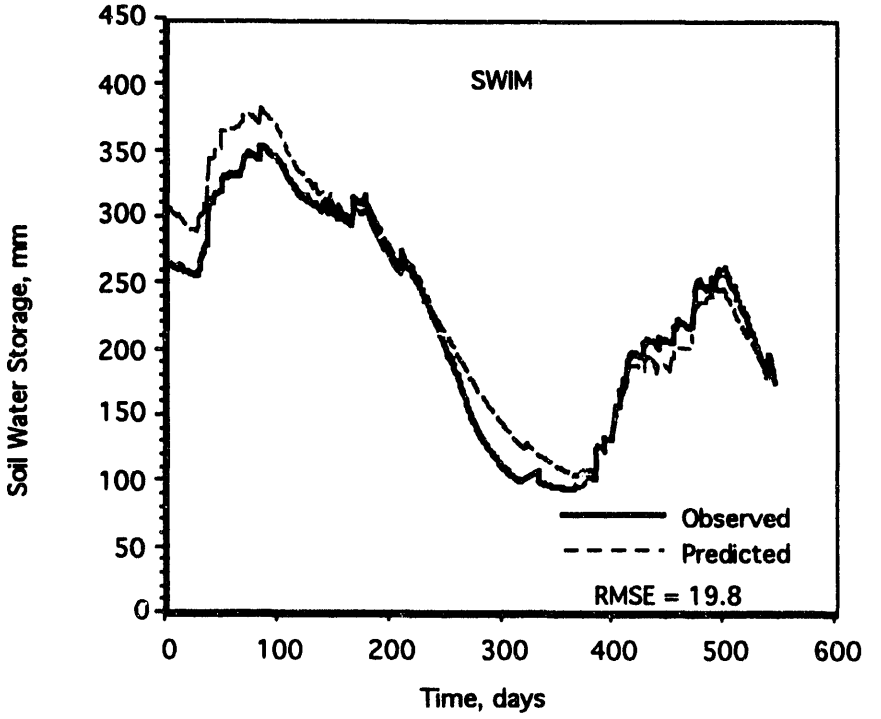


Figure 3.3. SWIM Model Predictions and Observed Soil Water Dynamics in the Vegetated-Irrigated Lysimeter (W3)

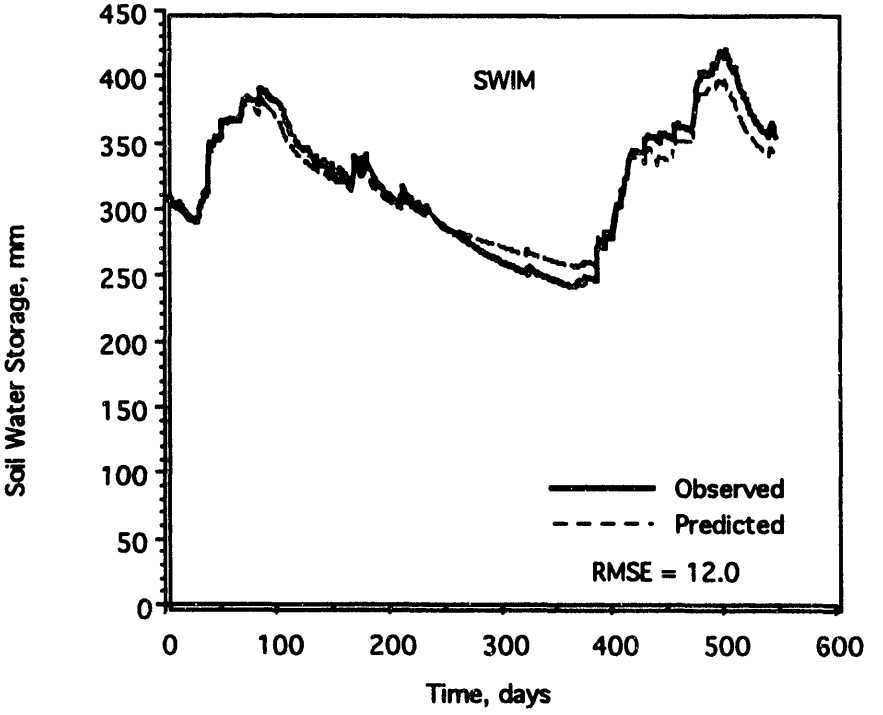


Figure 3.4. SWIM Model Predictions and Observed Soil Water Dynamics in the Bare-Irrigated Lysimeter (W4)

3.2 SPUR-91

For the entire period of the study for which data are available (527 days for the ambient precipitation lysimeter, and 533 days for the irrigated lysimeter), the mean observed soil water content in the soil profile for ambient precipitation conditions (W2) was 273.6 mm; the respective mean SPUR-91-simulated soil water content was 263.1 mm (-3.8 % underprediction). For the irrigated lysimeter (W4), the mean observed soil water content in the soil profile was 325.3 mm, and the respective mean SPUR-91-simulated soil water content was 337.0 mm (3.6 % overprediction), assuming that initial soil moisture content in each of the 8 soil layers on November 4, 1987, was 0.7 of field capacity. Daily temporal trends are equally revealing of model behavior of this version of SPUR-91 as these whole period mean values would indicate.

The time trace for the SPUR-91-simulated soil water storage for the W2 ambient precipitation lysimeter is shown in Figure 3.5 and in Figure 3.6 for the W4 irrigated lysimeter. Examination of Figure 3.5 shows that, for bare soil, ambient precipitation conditions, the simulated soil moisture content in the top 175 cm depth of soil on a daily basis, simulates very closely the observed total soil moisture content throughout the entire soil profile. The RMSE is 9.3 compared with a value of 14.7 for the UNSAT-H code (Table 3.1). The R^2 correlation coefficient between simulated and observed is 0.91. As can be seen from Figure 3.5, a consistent tendency exists toward a slight underprediction.

The time trace for simulated soil water content from SPUR-91 for the W4 irrigated lysimeter, as shown in Figure 3.6, is a little more deviant from the observed data, although it is still a good performance. The RMSE was 17.0 compared with a value of 22.1 for the UNSAT-H code (Table 3.1). The R^2 correlation coefficient between simulated and observed is 0.77. As can be seen from Figure 3.6, a tendency exists toward underprediction during the winter and overprediction during the summer. These comparisons can be seen in Table 3.2.

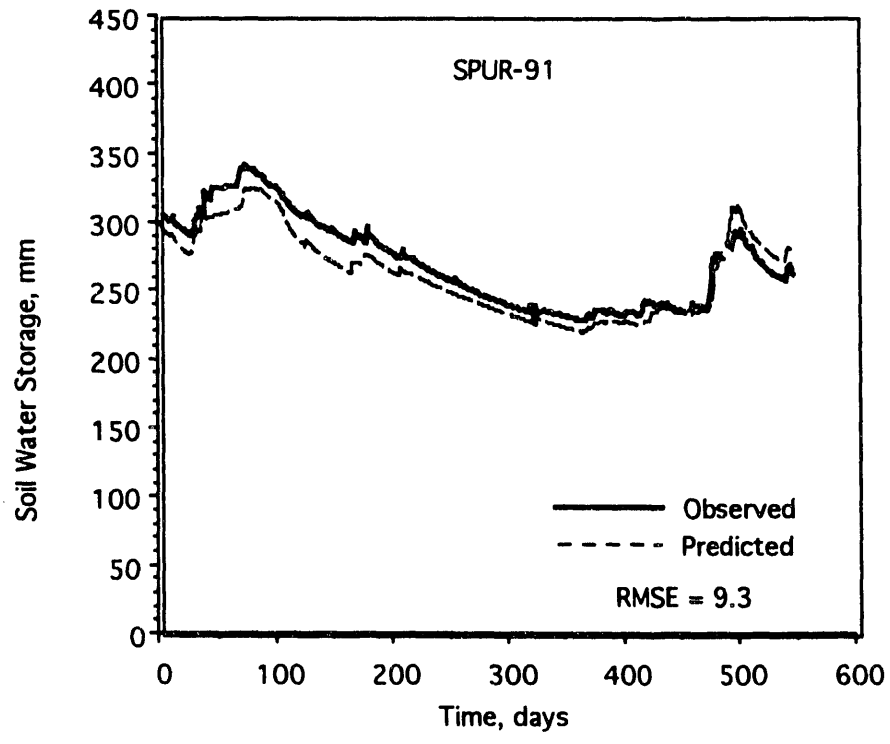


Figure 3.5. SPUR-91 Model Predictions and Observed Soil Water Dynamics in the Bare-Ambient Precipitation Lysimeter (W2)

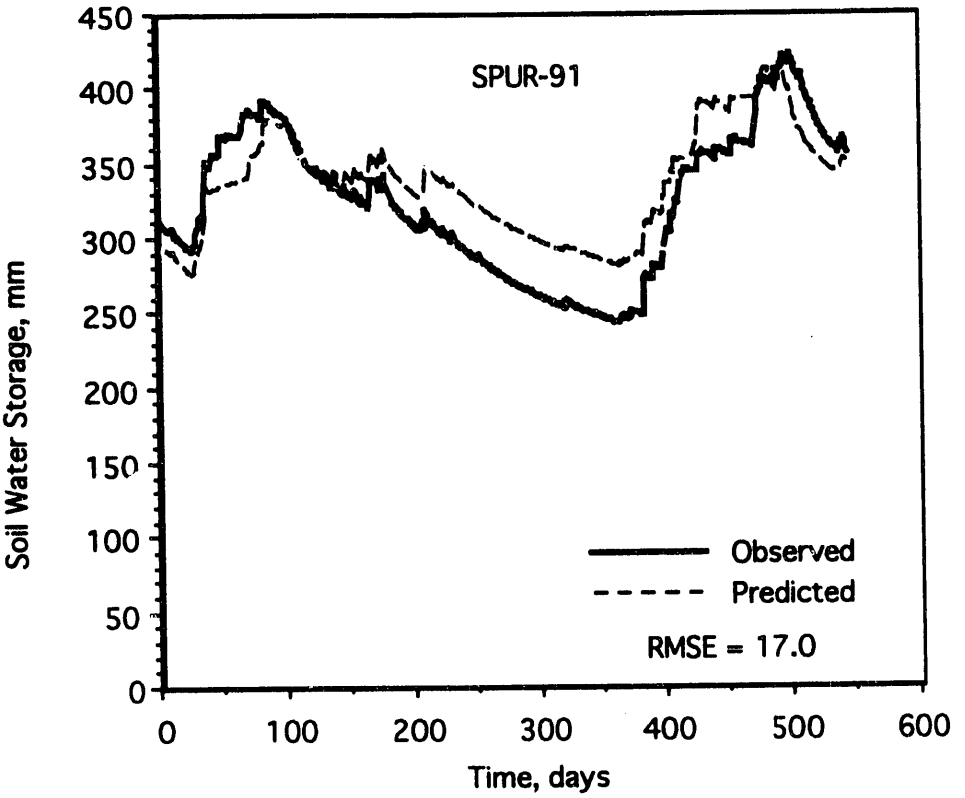


Figure 3.6. SPUR-91 Model Predictions and Observed Soil Water Dynamics in the Bare-Irrigated Lysimeter (W4)

4.0 Discussion

The purpose of this study was to compare existing models that include plants for the simulation of soil water dynamics. We chose to simulate soil water dynamics for four weighing lysimeter and compare our results to those of Fayer et al. (1992). We successfully simulated soil water storage dynamics in the bare soil lysimeters with the SWIM and SPUR-91 models, and we successfully simulated soil water storage dynamics in the vegetated lysimeters with the SWIM model. Vegetated lysimeters removed nearly twice the water that bare lysimeters did, and the SWIM model successfully simulated the water removal process by plants (transpiration).

4.1 SWIM

The SWIM model successfully simulated soil water storage dynamics in all four lysimeters. We started our simulation tests with the bare-ambient precipitation lysimeter case using soil parameters as in Fayer et al. (1992). Our initial simulation results did not adequately predict the observed data. As a consequence, we performed a simple sensitivity analysis by varying the soil parameters. We found that the SWIM model was most sensitive to changes in saturated hydraulic conductivity (K_s) and the b parameter. We varied these two parameters until a good fit was achieved. The value of K_s used was nearly 10 times smaller than the lower statistical bound for the K_s estimate reported in Fayer et al. (1992). This suggests that K_s is either highly correlated with other parameters in the SWIM model, allowing for significant bias in sensitive parameters while still achieving a good fit, or that the true value of K_s is poorly known. During these sensitivity tests we used a coarse time scale to speed up analyses. Input data were entered only every 10th day. After we settled on reasonable parameter estimates we decreased the time scale to single days, which significantly reduced RMSE. It is possible that a reduction of the time scale to hours would significantly improve model predictions.

To achieve good predictions we performed the calibrations described. Calibrating makes the model more empirical and less mechanistic in nature because parameter values are no longer within observed ranges based on experimental data. Our confidence in the chosen soil parameter values used for the bare-ambient lysimeter was increased after we found good predictions in the bare-irrigated lysimeter using the same soil parameter values. The same soil parameters were used in the vegetated lysimeters while we performed calibrations on the plant parameters to obtain good simulation results.

The SWIM model adequately predicted soil water storage dynamics in the vegetated lysimeters. The equations used to describe plant activity are simplistic in the SWIM model, yet we were able to achieve success with the simulation. The SWIM model was most sensitive to PET_{max}, which partitions PET between plant and soil. The more plant cover, the greater the PET_{max} value for the plant (Laundre 1990). Parameters for *A. tridentata* are poorly known for the purposes of the model. We used data in Rickard and Vaughan (1988) to estimate values for the parameters presented in Table 2.1. Root parameters are the most difficult to estimate, and thus, our estimates have to be considered with caution. The simplicity of the characterization of plants in the SWIM model makes the model easy to parameterize. To predict more complicated scenarios, such as a variety of species, each possessing differing phenologies, would require writing a computer shell to initiate the model with differing parameters for the various species. The SWIM model, as currently written for plants, is best used to simulate the effect that specific plant community types will have on soil water dynamics.

4.2. SPUR-91

The SPUR-91 model adequately simulated the bare ambient precipitation and the irrigated lysimeter soil water dynamics from November 4, 1987, through April 30, 1989. However, the major design objective for the SPUR-91 model, and its best performance, is to be expected with a vegetated soil, not a bare soil. The advantage of the SPUR-91 model is that it was designed for simulating rangeland vegetation dynamics. The SWIM and UNSAT-H models emphasize soil water dynamics. The results given here provide justification for applying and testing the SPUR-91 model for the vegetated lysimeters. Field test applications for the vegetated lysimeters will be the next step in evaluating the SPUR-91 model for application to the protective barrier designs.

5.0 Future Work

The objective of using hydrology models that include plant processes is to more realistically predict soil water dynamics over long time periods. Success with such model development will allow us to predict the probability that drainage can occur for varying climate and plant communities over hundreds of years for protective barrier designs. We plan to test these models for longer time periods with the lysimeters. If the predictions are good over longer time periods we will then test the predictive capability of the models for historical data sets gathered in differing plant communities. With success, we can then move on to predicting soil water storage with differing plant species, the consequences of climate change, and disturbance such as fire over hundreds of years.

6.0 References

Carlson, D. H., and T. L. Thurow. 1991. Workbook and User Guide. 1991 Update of the Simulation of Production and Utilization of Rangelands Model. Texas A&M University, College Station, Texas.

Cline, J. F., D. W. Uresk, and W. H. Rickard. 1977. "Comparison of Soil Water Used by a Sagebrush-Bunchgrass and a Cheatgrass Community." J. Range Manage. 30:199-201.

Fayer, M. J., M. L. Rockhold, and M. D. Campbell. 1992. "Hydrologic Modeling of Protective Barriers: Comparison of Field Data and Simulation Results." Soil Sci. Soc. Amer. J. 56:690-700.

Gee, G. W., R. R. Kirkham, J. L. Downs, and M. D. Campbell. 1989. The Field Lysimeter Test Facility (FLTF) at the Hanford Site: Installation and Initial Tests. PNL-6810, Pacific Northwest Laboratory, Richland, Washington.

Hanson, J. D., J. W. Skiles, and W. J. Parton. 1988. "A Multi-Species Model for Rangeland Plant Communities." Ecol. Model. 44:89-123.

Hanson, J. D. 1989. "A Systems Approach to Rangeland Modelling." pp. 695-700 In: Proceedings: Summer Computer Simulation Conference. The Society For Computer Simulation, San Diego, California.

Laundre, J. W. 1990. "Calibration and Sensitivity Testing of CREAMS and ERHYM-II Computer Models for use in a Cold Desert Environment." Arid Soils Res. and Rehab. 4:205-222.

Link, S. O., G. W. Gee, M. E. Thiede and P. A. Beedlow. 1990. "Response of a Shrub-Steppe Ecosystem to Fire: Soil Water and Vegetational Change." Arid Soils Res. and Rehab. 4:163-172.

Richards, L. A. 1931. "Capillary Conduction of Liquids in Porous Mediums." Physics 1:318-333.

Rickard, W. H., and B. E. Vaughan. 1988. "Plant Communities: Characteristics and Responses." In: Shrub-Steppe: Balance and Change in a Semi-arid Terrestrial Ecosystem (W.H. Rickard, L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau; Eds.), Elsevier, New York.

Ross, P. J. 1990a. SWIM - a Simulation Model for Soil Water Infiltration and Movement. CSIRO Division of Soils, Davies Laboratory, Townsville, Queensland, Australia.

Ross, P. J. 1990b. "Efficient Numerical Methods for Infiltration Using Richards' Equation." Water Res. Res. 26:279-290.

U.S. Department of Energy (USDOE) 1987. Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes. DOE/EIS-0113, U. S. Department of Energy, Washington, D. C.

Wing, N. R. 1989. Protective Barrier and Warning Marker System Development Plan. WHC-EP-0169, Westinghouse Hanford Company, Richland, Washington.

Wight, J. R., and J.W. Skiles 1987. SPUR - Simulation of Production and Utilization of Rangelands. Documentation and User Guide. ARS-63. United States Department of Agriculture, Agricultural Research Service, Washington, DC. 372 p.

Appendix A

SPUR-91 Model Parameters

Appendix A

SPUR-91 Model Parameters

Table A.1. SPUR-91 Model Simulation Control and Hydrology (Site, Soil, Snow) Parameters (partially modified from Wight and Skiles 1987; Carlson and Thurow 1991) for application to the Hanford Washington Barrier Program - FLTF Bare Soil Surface W2, W4 Lysimeters

Input Variable Definition	Used Value(s)	Units
Title of the simulation ....."Hanford, WA FLTF Bare Surface; SPUR91 Model"	text	
First year of the simulation (program adjusts for leap yr)	1987	NOD
Number of years to simulate	3	years
Number of sites on the simulated field	1	sites
Initial month simulation begins	11	month
Initial day simulation begins (must be first day of month)	305	Julian
Area of entire field (2.32 m^2)	0.00057	acres
Flag to convert temperature and precipitation input from metric to English units (English required by program)	1	NOD
Daily output report print flag	0	NOD
Monthly and yearly output report print flag	1	NOD
Additional soil and hydrology output print flag	3	NOD
Plant-component carbon-submodel output print flag	0	NOD
Plant-component nitrogen-submodel output print flag	0	NOD
Steer forage-harvest and growth output print flag	0	NOD
Wildlife forage-harvest output print flag	0	NOD
FORTRAN Format used in CLIMATE data file as weather input	(10X,5F10.3)	text
Coefficient for area-storm duration relation (1.9 - 5.6)	2	h/ac
Exponent for area-storm duration relation (0.1 - 0.6)	0.2	NOD
Coefficient for peak flow relation (2.7 - 6.1)	2.8	NOD
Site number (1 - 9)	1	
Number of soil layers for the site (2 - 8)	8	layers
USLE factor K (0.0 - 1.0)	0.5	
USLE C or cover factor (0.0 - 1.0)	0.45	
USLE P or practice factor (0.0 - 1.0)	1.0	
USLE slope factor (0.0 - 1.0)	0.01	
Area of site (0.00001 - 10,000.)	0.00057	acres
Condition I curve number (range: 0.0 - 100.)	55	NOD
Rooting depth (less than bottom soil layer depth) (<500.)	25	inches

Table A.1. (contd)

Input Variable Definition	Used Value(s)	Units
Bare soil evaporation parameter for ET (range: 0.0-0.26)	0.177	$in/d^{0.5}$
Aspect of the site (0.0 - 360.)	0.0	deg az
Slope of site (for solar radiation adjustment) (0.0 - 1.0)	0.0	ft/ft
Mulch (residue) cover factor (1.0 for initial bare soil.) (range: 1.0 - 0.0)	1.0	NOD
Crack factor for soil crack water flow (range: 0.0 - 1.0)	0.0	NOD
(relate soil "cracking" to animal burrowing ?)		
Initial soil moisture fraction of field capacity (0.0-1.0)	0.70	NOD
Porosity of each soil layer (must be > 1/3 bar WC) (0.0 - 1.0)		
0.496 0.496 0.496 0.496 0.496 0.496 0.445 0.419		inches/inch
1/3 bar volumetric soil water content by layer (0.0 - 1.0)		
0.26 0.26 0.26 0.26 0.26 0.26 0.015 0.007		inches/inch
15 bar volumetric soil water content by layer (0.0 - 1.0)		
0.08 0.08 0.08 0.08 0.08 0.08 0.010 0.005		inches/inch
Saturated soil hydraulic conductivity by layer (0.0 - 10.0)		
1.59 1.59 1.59 1.59 1.59 1.59 155.1 496.1		inches/h
Soil layer thicknesses by layer (top 2 must be 3.0 each) (0.0 - 10,000.)		
3.0 3.0 9.0 10.0 15.0 19.06 4.0 6.0		inches
Geographical latitude of the field (Hanford Met Station) (0.0 - 90.0)	46.57	degrees
Elevation of the field (Hanford Met Station) (0.0 - 10,000.)	733.	ft
Elevation of the temperature measurement station (Hanford Met Station)	733.	ft
Snow gage-catch correction factor (range 1.0 - 100.)	1.5	NOD
Maximum-melt factor for nonrain periods (> minimum) (range 0.0 - 5.0)	2.0	mm/day-°C
Minimum-melt factor for nonrain periods (>= 0.0) (typical range 0.0 - 2.0)	0.7	mm/day-°C
Wind-adjustment factor for rain-on-snow periods (0.03-0.19)	0.19	mm/mb-h
Maximum-accumulated-snow-water equivalent above which 100 % cover	300.	mm
Areal depletion curve type number (range 1 - 6)	3.	NOD
Maximum negative melt factor (0.0 - 5.0)	0.15	mm/°C
Weighting given to preceding period temperature to obtain current snowpack temperature (range 0.1 - 1.0)	0.5	NOD
Temperature for nonrain snowmelt (-5.0/+5.0)	0.0	°C
Temperature to differentiate rain from snow (lowlands: -5.0/+10.0)	0.0	°C
Liquid-water holding capacity of the (ripe) snowpack(range 0.0 - 1.0)	0.02	decimal
Constant daily melt rate at snowpack-ground interface(range 0.0 - 10.0)	0.3	mm
Initial snow-water equivalent on the field (0.0 - 10,000.)	0.0	mm

Table A.2. SPUR-91 Model Plant Parameters (Partially modified from Wight and Skiles 1987; Carlson and Thurow 1991) for Application to the Hanford Reservation for the Hanford, Protective Barrier Program - FLTF Lysimeter Bare Soil Surface. SPUR-91 requires at least one plant species, or group, be defined.

Input Parameter Definition	Dummy Species Value	Units
1. Theoretical maximum net photosynthetic rate (1 - 100)	15.0	mg dm^{-2} h^{-1}
2. Light-use efficiency coefficient (C3:1.5-5; C4:<1.0; 0. - 10.)	2.0	m^2 W^{-1}
3. Maximum temperature for pos. plant activity (C3:30-40; C4:45-60)	35.0	°C
4. Optimal temperature for pos. plant activity (C3:15-25; C4:30-45;0-50)	18.0	°C
5. Minimum temperature for pos. plant act. (C3:0-10; C4:15-30; -10/+10)	0.0	°C
6. Water potential at which photosynthetic activity is 0.5 x maximum (C3:5-12; C4:15-25; 0.0 -50.)	15.0	-bars
7. Drought tolerance coefficient (C3:3.0-4.84; C4:5.7-9.96; 0.0-25.)	5.7	NOD
8. Proportion of photosynthate translocated from shoots to roots after senescence begins (constant; 0.0 - 1.0)	0.7	NOD
9. Maximum root-to-shoot ratio (0.0 - 0.4 - 15.2 - 20.)	2.4	NOD
10. Wind-tolerance coefficient (standing dead) ((-1.0) - 0.0)	-0.00002	km^{-1}
11. Precipitation tolerance coefficient (standing dead) ((-1.0) - 0.0)	-0.00030	cm^{-1}
12. Proportion of phytomass susceptible to trampling (shrub:low;0.0-1.)	0.00050	NOD
13. Susceptibility of standing dead to trampling (shrub:low;-1.0 - 0.0)	-0.00100	ha an^{-1}
14. Susceptibility of green shoots to trampling (shrub:0.0;oth:-0.005) (-1.0 - 0.0)	-0.00000	ha an^{-1}
15. Proportion of green shoots susceptible to daily death (<.01; 0.0-1.0)	0.00050	NOD
16. Phytomass to leaf area index conversion factor (0.0-.015- .03-1.0)	0.030	m^2 g^{-1}
17. Proportion of photosynthate daily translocated to propagules after flower initiation (0.000 - 1.0 ?)	0.030	NOD
18. Proport. root phytomass daily translocated to shoots (constant;0-1)	0.005	NOD
19. Germination proportion (0.0 - 1.0 ?)	0.010	NOD
20. Maintenance-respiration coefficient (0. - 20. - 70. - 100.)	19.0	mg g^{-1} day^{-1}
21. Proport. additional shoot death after senescence (~.05; 0.0-1.0)	0.05	NOD
23. Seed-mortality proportion (daily) (constant; 0.0-1.0)	0.0100	NOD
24. Root-respiration proportion (daily; 0.0-1.0)	0.0015	NOD
25. Root-mortality proportion (daily) (often <=0.005; 0.0-1.0)	0.0005	NOD
26. Minimum percentage nitrogen for photosynthesis (0.0-1.0)	0.0100	NOD
27. Photosynthetic efficiency controlled by plant nitrogen (-200. - 0.0)	-128.0	NOD
28. Maximum-nitrogen-uptake coefficient (0.0 - 1.0)	0.002	g N g^{-1} day^{-1}
29. Nitrogen-use efficiency coefficient (0.0 - 0.21 - .30 - .42 - 1.0)	0.310	m^2 g^{-1}
Critical Parameters		
1. Maximum leaf area index of green shoots (0.0 - 25.0)	0.25	NOD
2. Temperature for frost kill (C4=-3; C3=-6; -20/+20	-4.0	°C
3. Temperature for root-to-shoot translocation (TRS) (-20/+50)	8.0	°C
4. Water potential for TRS (-50.0 - 0.0)	-8.0	bars
5. Water potential for seed germination (-50.0 - 0.0)	-1.0	bars

Table A.2. (contd)

Input Parameter Definition	Dummy Species Value	Units
6. Julian day that seed production begins (0-366)	180.0	
7. Julian day that senescence begins (0-366)	200.0	
8. Julian day that senescence ends (0-366)	288.0	
Number of plant species (1 - 7)	1	
Green shoot biomass (on first day) (0.0 - 10,000.)	0.0	$g\ m^{-2}$
Live roots biomass (on first day) (0.0 - 10,000.)	1.0	$g\ m^{-2}$
Propagules biomass (on first day) (0.0 - 10,000.)	0.0	$g\ m^{-2}$
Standing dead biomass (on first day) (0.0 - 10,000.)	0.0	$g\ m^{-2}$
Maximum rooting depth (soil layer #) at maturity by plant species (1 - 7)	4	layer #

Input Variable Definition	Used Value	Units
Nonspecies-Specific Site-Specific Parameters (i)		
Soil inorganic nitrogen (N) (0.0 - 1.0)	0.1	$g\ m^{-2}$
Dead root biomass	0.0	$g\ m^{-2}$
Litter biomass	0.0	$g\ m^{-2}$
Soil organic matter biomass (0 - 3000 ? gC/m^2) (Biomass = 2.5 * gC/m^2)	1.0	$g\ m^{-2}$
Nonspecies-Specific and NonSite-Specific Parameters (ii)		
Proportion of dead roots susceptible to decomposition	0.015	NOD
Proportion of litter susceptible to decomposition	0.07	NOD
Proportion of organic matter susceptible to decomposition	0.0035	NOD
Moisture tolerance of denitrification	-0.028	-bars
Water potential at which decomposition activity is 0.5 x maximum	5.0	-bars
Drought-tolerance coefficient for decomposition	2.2	NOD

Distribution

No. of Copies

OFFSITE

12 DOE/Office of Scientific and Technical Information

3 Botany Department
Arizona State University
Tempe, AZ 85287
ATTN: T. H. Nash III
J. Klopatek
D. Patten

Prof. Martyn Caldwell
Dept. of Range Management
Utah State University
Logan, UT 84322

Prof. Thomas L. Thurow
Dept. Rangeland Ecology and Management
Texas A&M University
College Station, TX 77843-2126

Dr. J. Ross Wight
USDA-ARS
NW Watershed Research Center
800 Park Blvd. Plaza IV, Ste. 105
Boise, ID 83712

3 Jacobs Engineering Group, Inc.
5301 Central Avenue NE
Suite 1700
Albuquerque, NM 87108
ATTN: M. Kyllo
F. Titus
T. Goering

3 Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, NM 87545
ATTN: T. E. Hakonson
J. W. Nylan
F. Barnes

No. of Copies

2 U. S. Ecology
P. O. Box 7246
9200 Shelbyville Rd
Suite 526
Louisville, KY 40207
ATTN: R. E. Sauer
D. Lane

2 U. S. Nuclear Regulatory Commission
Division of Engineering Safety
MS NL-005
Washington, DC 20555
ATTN: E. O'Donnell
T. J. Nicholson

2 Agronomy Department
Washington State University
Pullman, WA 99164
ATTN: A. J. Busacca
G. S. Campbell

4 Chem Nuclear Geotech
P.O. Box 14000
Grand Junction, CO 81502
ATTN: Jack Duray
John Elmer
Vince Ponc
W. J. Waugh

2 U. S. Department of Energy
785 DOE Place
Idaho Falls, ID 83402
ATTN: O. D. Markham
T. E. Reynolds

EG&G Idaho, Inc.
P. O. Box 1625
Idaho Falls, ID. 83415-3900
ATTN: K. M. Kostelnik

No. of Copies	
	C. Massimino U. S. Environmental Protection Agency 1200 Sixth Avenue Seattle, WA 98101
	Glen Suter II Oak Ridge National Laboratory PO Box 2008 Oak Ridge, TN 37831
	Peter J. Mehringer Anthropology Department Washington State University Pullman, WA 99164
	Jerry Olson U.S. Bureau of Mines Spokane Research Center East Montgomery Spokane, WA 99207
	Stan Smith Department of Bio. Science University of Nevada Las Vegas, NV 89154
2	Department of Health Radiation Protection Division Airdustrial Park Bldg. 5, M.S. LE-13 Olympia, WA 98504 ATTN: Al Conklin Alan Rainey
	J. Rensel High-Level Waste Management Washington State Department of Ecology Mail Stop Pu II Olympia, WA 98504
	R. K. Schulz University of California Department of Plant and Soil Biology Berkeley, CA 94720

No. of Copies	
	W. J. Brumley U.S. Department of Energy Savannah River Operations Office P.O. Box A Aiken, SC 29801
	F. T. Fong U.S. Department of Energy San Francisco Operations Office 1333 Broadway Oakland, CA 94612
	M. R. Jugan U.S. Department of Energy Oak Ridge Operations Office P.O. Box E Oak Ridge, TN 37830
	E. Maestas U.S. Department of Energy West Valley Project Office P.O. Box 191 West Valley, NY 14171
	C. S. Abrams Argonne National Laboratory P.O. Box 2528 Idaho Falls, ID 83401
3	Battelle Memorial Institute Project Management Division 505 King Avenue Columbus, OH 43201 ATTN: W. A. Carbeiner W. S. Madia Technical Library
	P. J. Wierenga Department of Soil and Water Science 429 Shantz Building University of Arizona Tucson, AZ 85721

No. of Copies	
	J. R. Berreth Westinghouse Idaho Nuclear Co. P.O. Box 4000 Idaho Falls, ID 83401
	A. T. Clark Division of Fuel Material Safety U.S. Nuclear Regulatory Commission Washington, D.C. 20555
	G. A. Dinwiddie U.S. Geological Survey 12201 Sunrise Valley Drive Reston, VA 22092
6	Westinghouse Savannah River Company Aiken, SC 29801 ATTN: R. G. Baxter M. D. Boersma J. G. Glasscock J. R. Knight M. J. Plodinec C.T. Randall
3	Low-Level Radioactive Waste Program U.S. Geological Survey Water Resources Division 12201 Sunrise Valley Drive Reston, VA 22092 ATTN: J. Fisher P. Stevens N. Trask
	L. Frank U.S. Department of Energy 625 Marion Street, N.E. Salem, OR 97310
	David E. Daniel Department of Civil Engineering University of Texas Austin, TX 78712
	Gregory N. Richardson Hazen and Sawyer 4011 W. Chase Blvd. Suite 500 Raleigh, NC 27607

No. of Copies	
	Lorne G. Everett Metcalf and Eddy Consultants, Inc. PO Box 24110 Santa Barbara, CA 93121
	Charles Reith Jacobs Engineering Weldon Springs Site St. Charles, MO 63301
	Geoff W. Spaulding Dames and Moore Suite 108 4220 S. Maryland Pkwy. Las Vegas, NV 89119
	W. A. Jury Department of Soils University of California at Riverside Riverside, CA 92502
	D. A. Knecht Westinghouse Idaho Nuclear Co. P.O. Box 4000 Idaho Falls, ID 83403
	S. Meyers U.S. Environmental Protection Agency Office of Radiation Programs (ANR-458) 401 M Street, S.W. Washington, D.C. 20460
3	Oak Ridge National Laboratory P.O. Box Y Oak Ridge, TN 37830 ATTN: J. O. Blomeke W. D. Burch R. T. Jubin
	L.D. Ramspott Lawrence Livermore National Laboratory University of California P.O. Box 808 Livermore, CA 94550

No. of Copies	
2	Sandia National Laboratories P.O. Box 5800 Albuquerque, NM 87185 ATTN: R. W. Lunch Technical Library
	R. Shaw Electric Power Research Institute 3412 Hillview Avenue Palo Alto, CA 94304
	M. J. Steindler Argonne National Laboratory 9700 South Cass Avenue Argonne, IL 60439
3	Desert Research Institute P.O. Box 60220 Reno, NV 89506 ATTN: J. T. Ball S. Tyler C. Fox
	E. P. Weeks U.S. Geological Survey Federal Center Mail Stop 413 Denver, CO 80225
5	Idaho National Engineering Laboratory P.O. Box 1625 Idaho Falls, ID 83415 ATTN: M. A. Knecht D. McElroy J. B. Sisson B. B. Russell Technical Library
	Department of Mechanical Engineering New Mexico State University Box 30001 La Cruces, NM 88003
2	New Mexico State University Agricultural Experiment Station Box 3BF Las Cruces, NM 88003 ATTN: R. G. Hills T. L. Jones

No. of Copies	
	I. Winograd U.S. Geological Survey MS 432 Reston, VA 22092
2	EBASCO Richland, WA 99352 ATTN: W. Rigsbee R. Treat
	A. A. Eiseewi Southern California Edison P.O. Box 800 Rosemead, CA 91770
2	Geology Department Washington State University Pullman, WA 99164 ATTN: K. Keller D. Gaylord
	L. J. Fritschen Forestry Department University of Washington Seattle, WA 98195
4	West Valley Nuclear Service Company P.O. Box 191 West Valley, NY 14171 ATTN: R. R. Borisch J. Buggy J. M. Pope R. A. Thomas
3	Washington State Department of Ecology MS-PU-11 Olympia, WA 98504-8711 ATTN: G. Anderson C. Cline R. B. Hibbard
2	Washington State Department of Ecology 7601 W. Clearwater # 102 Kennewick, WA 99336 ATTN: D. Teal N. Uziemblo

No. of
Copies

FOREIGN

P. Grimwood
Waste Management Unit
British Nuclear Fuels plc
Sellafield
Seascale, Cumbria CA201PG
ENGLAND

Graham M. Smith
Intera Information Technologies
Chiltern House
45 Station Road
Henley-on-Thames
Oxfordshire RG9 1AT
UNITED KINGDOM

ONSITE

12 DOE, Richland Operations Office

G. J. Bracken
J. J. Broderick
P. K. Clark
R. D. Freeburg
M. J. Furman
R. E. Gerton
J. D. Goodenough
A. C. Harris
J. M. Hennig
R. D. Izatt
J. P. Sands
D. E. Trader

5 EPA - Hanford Project Office

P. R. Beaver, B5-01
D. A. Faulk, B5-01
L. E. Gadbois, B5-01
P. S. Innis, B5-01
D. R. Sherwood, B5-01

53 Westinghouse Hanford Company

M. R. Adams
H. Babad
J. D. Berger
R. J. Bliss
L. C. Brown

No. of
Copies

J. W. Cammann
R. A. Carlson
C. J. Geier
R.L. Gilchrist
W. F. Heine
J. M. Henderson
G. W. Jackson
K. N. Jordan
C. J. Kemp
D. S. Landeen
R. E. Lerch
H. E. McGuire
D. R. Myers
D. J. Newland
K. L. Petersen
S. J. Phillips
R. C. Roos
M. R. Sackschewsky
J. L. Scott
J. C. Sonnichsen
D. R. Speer
J. A. Voogd
S. A. Weigman
G. W. Williamson
N. R. Wing (20)
D. D. Wodrich
R. D. Wojtasek
J.C. Womack
D. E. Wood

60 Pacific Northwest Laboratory

L. L. Cadwell
M. D. Campbell
J. L. Downs
M. J. Fayer (5)
M. G. Foley
H. D. Freeman
G. W. Gee (15)
B. G. Gilmore
R. W. Kickert (5)
C. T. Kincaid
R. R. Kirkham
G. V. Last
M. W. Ligotke
S. O. Link (10)
M. L. Rockhold
L. E. Rogers

No. of Copies	
	M. A. Simmons
	J. A. Stottlemyre
	M. E. Thiede
	J. M. Thomas
	W. H. Walters
	R. E. Wildung
	Publishing Coordination
	Technical Report Files (5)

No. of Copies	Routing
	R. M. Ecker
	M. J. Graham
	P. M. Irving
	R. L. Skaggs
	C. S. Sloane
	P. C. Hays (last)

DATE FILMED

8 / 16 / 93

END