Intercode Comparisons for Simulating Water Balance in an Engineered Cover

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Abstract: Numerical modeling is generally required to evaluate proposed cover designs for waste containment facilities and remediation sites and to estimate long-term performance of covers. A variety of codes are available to simulate the water balance of engineered covers; however, information on intercode comparisons is limited. The purpose of this study was to compare the characteristics and performance of different codes, including HELP, HYDRUS-1D, SHAW, SoilCover, SWIM, UNSATH, and VS2DT. The codes were used to simulate the water balance of a capillary barrier that is being monitored at a site near El Paso, Texas. Factors that differ among these codes include graphical user interfaces, user friendliness, dimensionality, upper and lower boundary conditions, hydraulic properties (Brooks and Corey, van Genuchten, other), and processes (liquid flow, vapor flow, hysteresis). Simulation results from all codes reasonably approximated the measured field water balance. The main difference among the various codes was in the partitioning of precipitation into evaporation and soil water storage. The intercode comparisons are being used to identify important attributes of codes to simulate infiltration into engineered covers. Such information can be used to make recommendations for modifications of existing codes and/or development of new codes.

The capillary barrier cover that was simulated is located near El Paso, Texas and was installed in the summer of 1997. The surface dimensions of the cover are 34 m x 17 m. The profile consists of 0.3 m of topsoil (sandy clay loam), underlain by 1.7 m of compacted native material (sandy clay loam), 0.3 m of sand, 0.3 m of muddy gravel, 0.3 m of gravel, and 0.15 m of sand at the base. The water balance equation is:

$$(P + Irr - R_0) - (ET + D) = \Delta S$$

where P is precipitation, Irr is irrigation, R_0 is runoff, ET is evapotranspiration, D is drainage, and ΔS is change in soil water storage. All components of the water balance equation are monitored with the exception of ET which is calculated. A lysimeter was installed at the base of the profile to collect drainage. Water content is monitored using time domain reflectometry and neutron probe logging. Simulations were conducted for the 1997 water year (October 1997 through September, 1998). The cover was not vegetated for this period. The surface was irrigated in August and September 1998 to establish vegetation.

The HELP code was originally developed for resistive barriers and uses a simplified approach to simulate routing of water in the subsurface. All other codes evaluated in this study are based on the Richards equation. Graphical user interfaces are available for HELP, HYDRUS-1D, SoilCover, UNSATH, and VS2DT.

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The soil profile (3 m) was divided into 6 layers representing the different materials. A total of 103 nodes was used to represent the profile with nodal spacing ranging from 0.2 cm at the soil surface, 2 cm at material interfaces, and a maximum of 15 cm within materials. Potential evapotranspiration was calculated using the Penman Monteith equation for HYDRUS-1D, UNSATH, and VS2DT and was calculated internally in the other codes. The lower boundary was specified as unit gradient in all codes. Initial conditions were based on field measurements of matric potential made with heat dissipation sensors. Water retention functions included van Genuchten (HYDRUS, SWIM, UNSATH, and VS2DT), Brooks and Corey (HELP), Campbell (SHAW), and code specific functions (SoilCover).

Table 1. Measured and simulated water balance for October 1997 through September 1998. d-daily, hr-hourly, and 15 min. precipitation events

	Precipitation Irrigation (cm)	Runoff (cm)	Evaporation (cm)	Storage change (cm)	Drainage (cm)
Measured	42.7	6.0	32.6	4.1	0.0
HELP	42.7 (d)	1.5	27.3	13.0	0.9
HYDRUS 1D	42.7 (d)	0.0	39.8	2.5	0.4
	42.7 (hr)	0.0	38.5	3.8	0.4
	42.7 (15 min)	0.8	37.7	3.8	0.4
SHAW	42.7 (d)	0.0	34.8	7.6	0.3
	42.7 (hr)	0.1	35.4	7.1	0.3
SoilCover	42.7 (d)	1.5	43.0	-1.8	0.0
SWIM	42.7 (d)	0.0	39.1	3.6	0.0
	42.7 (hr)	0.0	38.5	4.2	0.0
UNSATH	42.7 (d)	0.0	33.5	8.9	0.3
	42.7 (hr)	0.1	33.5	8.8	0.3
VS2DT	42.7 (d)	0.0	19.1	23.6	0.0
	42.7 (hr)	0.1	29.2	13.4	0.0
	42.7 (15 min)	0.9	29.3	12.5	0.0

A total of 6 cm of runoff was measured at the engineered barrier. Runoff occurred in October 1997 following an intense precipitation event (2 cm in 15 minutes) and in August and September 1998 when the cover was being irrigated to establish vegetation. Runoff was underpredicted by all codes. HELP and SoilCover predicted 1.5 cm of runoff whereas all other codes predicted zero runoff when using daily precipitation input. The effect of precipitation intensity on simulated runoff was tested by using daily, hourly, and 15 min precipitation input. Results showed little difference in simulated runoff between daily and hourly input and small increases in runoff (~ 1 cm) for 15 min input. Infiltration excess runoff is difficult to simulate at a site because of data required to represent actual precipitation intensity and uncertainties in hydraulic conductivity (which can vary over orders of magnitude). Underprediction of runoff results in more infiltration into the system which in turn affects the remaining terms in the water balance equation.

Annual evaporation simulated by SHAW and UNSATH is similar to that calculated from the monitored water balance (Table 1). HYDRUS-1D, SoilCover, and SWIM overpredicted evaporation whereas HELP and VS2DT underpredicted evaporation. HYDRUS-1D subtracts potential evaporation from precipitation to calculate a net precipitation, which then infiltrates the soil. This method overestimates evaporation as it assumes that all precipitation evaporates at the potential rate. The low evaporation rate simulated by VSD2T can be attributed to zero evaporation during precipitation; therefore, no evaporation is simulated for rain days when precipitation input is daily, which results in underestimation of evaporation for the year. Inputting precipitation on an hourly basis reduces the problem. The seasonal distribution in evaporation simulated by all codes is similar to that estimated from the monitored water balance.

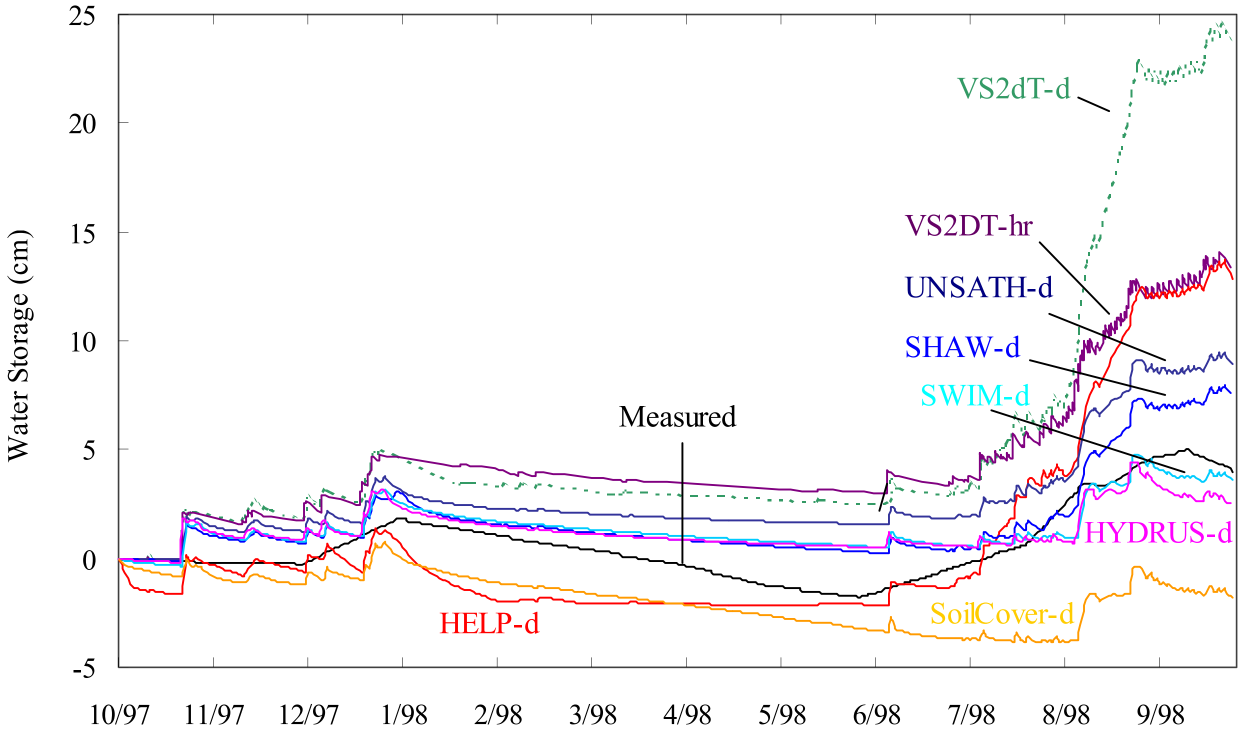

Figure 1. Measured and simulated soil water storage

Measured water storage increased by 4.1 cm for the year whereas simulated water storage either decreased (SoilCover) or increased by amounts ranging from 2.5 cm (HYDRUS-1D) to 23.6 cm (VS2DT) (Table 1). Simulated storage changes are inversely related to evaporation. HYDRUS-1D, SoilCover, and SWIM overestimated ET and underestimated water storage, whereas HELP and VS2DT underestimated ET and overestimated water storage. Other codes (SHAW and UNSATH) overestimated water storage because runoff was underestimated. The various codes generally underestimated storage decreases during the summer and overestimated storage increases in the fall during irrigation (Fig. 1).

No drainage was measured at the site. Small amounts of drainage, resulting from wet initial conditions in the cover, were predicted using most codes. This may be attributed to representation of the lower boundary as a unit gradient rather than a seepage face because most codes did not have a seepage face option. A seepage face is a more accurate representation of a drainage lysimeter than a unit gradient. When a seepage face was used instead of a unit gradient in HYDRUS-1D, simulated drainage was reduced to zero.

This study underscores the difficulties in simulating the water balance of engineered covers. Accurate simulation of runoff may be extremely difficult because of difficulties in representing actual precipitation intensities and inherent uncertainties in the hydraulic conductivity of surficial sediments. Inverse modeling based on monitoring data may be required to obtain realistic estimates of the hydraulic conductivity of surface sediments. Precipitation should be input at hourly or actual intensity if evapotranspiration is set to zero during precipitation to avoid underestimating ET. Accurate simulation of drainage in a lysimeter requires a seepage face lower boundary that is not included in many codes.