Long-term Water Balance Monitoring of Engineered Covers for Waste Containment

Robert C. Reedy[1] and Bridget R. Scanlon[2]

Abstract: The growing realization that remediation of many contaminated sites is technically infeasible has resulted in a shift in emphasis to containment as an alternative to remediation. Monitoring is required to demonstrate the effectiveness of engineered cover systems in minimizing infiltration into underlying waste. The purpose of this study is to evaluate a variety of monitoring technologies. Monitoring systems were installed in a resistive (GCL/asphalt) barrier at 1.3 m depth and a conductive (capillary) barrier at 2.0 m depth constructed near El Paso, Texas, in 1997. The site is heavily instrumented with both automated and manual monitoring systems designed to quantify the soil water balance and to monitor soil water potential energy. All of the water balance components are being monitored except evapotranspiration. Results indicate that electromagnetic induction (EM), once calibrated with neutron probe and temperature data, can reliably monitor water storage changes. The non-invasive nature of EM measurements could preclude the development of preferential pathways resulting from instrument installation. Neutron probe measurements of water storage are more reliable at this site than time domain reflectometry because of signal attenuation resulting from high conductivity soils. Heat dissipation sensors have proved more reliable than thermocouple psychrometers for measuring soil water potential. Results of this study provide valuable information on appropriate technologies for monitoring performance of engineered covers.

A more complete description of the site characteristics is presented in Scanlon et al (1997). The surface of the monitored area is 34 x 34 m divided equally into two rectangular areas for each barrier design. Each of the barrier designs is further subdivided into two 17 x 17 m plots resulting in a total four plots. The site was excavated to a depth of approximately 3.5 m and sequentially backfilled in nominal 0.15-m lifts with soil materials derived from local and off-site sources to construct the two barrier designs (Figure 1). A cylindrical silo 3.7 m in diameter and 6 m deep is located in the center of the installation and houses a computer and data logger network to automate the monitoring instruments, control systems, and data storage. The two designs are separated at the ground surface by a drainage ridgeline and in the subsurface by a vertically installed flexible membrane liner.

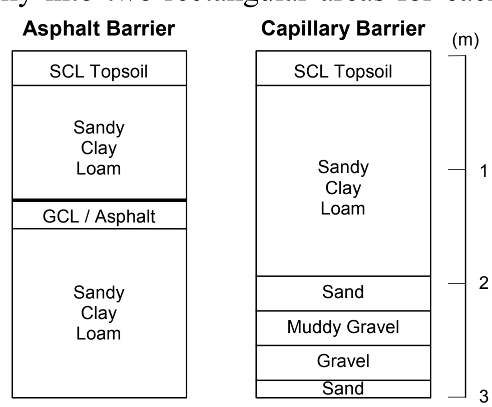

Figure 1: Barrier Designs

Monitoring of most systems began in October 1997. The monitored components of the water balance include precipitation, surface runoff, lateral drainage from the asphalt layer, deep drainage, and water content. Evapotranspiration (ET) is calculated as the residual of the

---

[1] Research Scientist Associate, Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78713-8924, Ph 512.471.7244, Fx 512.471.0140, bob.reedy@beg.utexas.edu
[2] Senior Research Scientist, Bureau of Economic Geology, The University of Texas at Austin, Austin, TX 78713-8924, Ph 512.471.8241, Fx 512.471.0140, bridget.scanlon@beg.utexas.edu

monitored components. Precipitation is monitored with heated and unheated tipping bucket rain gauges. Surface runoff is collected in lined drains located at the bases of each of the experimental pads and routed through pipes to four subsurface holding tanks. Lateral drainage from the asphalt layer (Figure 1) and deep drainage from four pan lysimeters located at the 3 m depth beneath each of the pads is routed to the silo for measurement. Water content above each barrier is monitored with a neutron probe at 10 locations in each of the barrier designs. Water content is also monitored with 48 horizontally- and 80 vertically oriented time domain reflectometery (TDR) probes installed in eight locations at depths above the barriers, with two profiles on each pad. Soil water potential energy is monitored using 56 heat dissipation sensors (HDS) installed above the barriers and 120 thermocouple psychrometers (TCP) installed above and below the barriers. Precipitation, air and soil temperature, relative humidity, wind speed and direction, barometric pressure, solar radiation, net radiation, and soil heat flux are monitored on site. Approximately 223 mm of irrigation was applied during August and September 1998 to establish vegetation. The 30-year average precipitation at the site is 305 mm and annual potential evapotranspiration has averaged 1573 mm during the course of this study.

Ground conductivity measurements using an EM38 (Geonics, Mississauga, Ontario) in the vertical and horizontal dipole modes were conducted concurrent with the neutron probe measurements to evaluate electromagnetic induction (EM) as a non-invasive technique for monitoring water content. Field measurements of apparent soil bulk conductivity (EC_a) were normalized to 25°C. The average normalized conductivity (EC_{25}) was linearly regressed on the average neutron probe water content for each survey date. Individual regression models were also generated for the EC_{25} data at each of the neutron probe access tube locations.

Results of the water balance monitoring for the last three months of 1997 and for the complete years 1998 through 2000 are presented in Table 1. Net infiltration was calculated as the sum of precipitation and irrigation minus runoff. The storage values shown are the results of the neutron probe surveys. The data indicate that both barrier designs have performed similarly. However, annual precipitation has averaged only 56% to 75% of the 30-year average (116% for 1998 including irrigation) with the result that neither barrier has been sufficiently stressed to induce drainage.

			Asphalt Barrier (0 to 1.1 m depth)				Capillary Barrier (0 to 1.8 m depth)			
Year	Precip	Irrigation	Infiltration	Drainage	ΔS	ET	Infiltration	Drainage	ΔS	ET
1997	78	0	58	0	20	38	55	0	18	36
1998	177	223	354	0	-10	364	357	0	1	355
1999	211	0	206	0	-55	261	206	0	-58	264
2000	187	0	172	0	16	156	174	0	15	160

Table 1. Water balance parameters (mm) for specified depth intervals of the two barrier designs.

TDR has been of limited use for monitoring water content at our site. Periods of higher water content and/or higher soil temperature increased the sandy clay loam subsoil (Figure 1) bulk conductivity to the point that TDR waveforms displayed little or no reflections. Probes installed in the topsoil were generally less affected. Water content values derived from analysis of the less attenuated waveforms were not in agreement with the neutron probe measurements despite calibration of the TDR probes using site soils. The TDR measurements also displayed seasonal changes in water content ranging from 0.05 to 0.10 m^3/m^3 at depths where no changes were indicated by the neutron probe measurements.

Electromagnetic induction has proved to be a rapid and accurate method for determining water storage at our site. The results of 30 surveys conducted at approximately monthly intervals between July 1998 and February 2001 on the capillary barrier design are shown in Figure 2. The figure compares the average water content of the 10 neutron probe access tubes in the capillary barrier over specified depth intervals with the water content predicted by the EM vertical and horizontal dipole mode linear regression models. The models predict water contents to within 0.007 m^3/m^3 of the measured averages. The GCL/asphalt barrier models had similar results. Using each of the individual location models to calibrate all of the remaining location data resulted in predicted water contents averaging within 0.015 m^3/m^3 of the measured average. These results demonstrate the usefulness of applying electromagnetic induction to obtain accurate measurements of water storage.

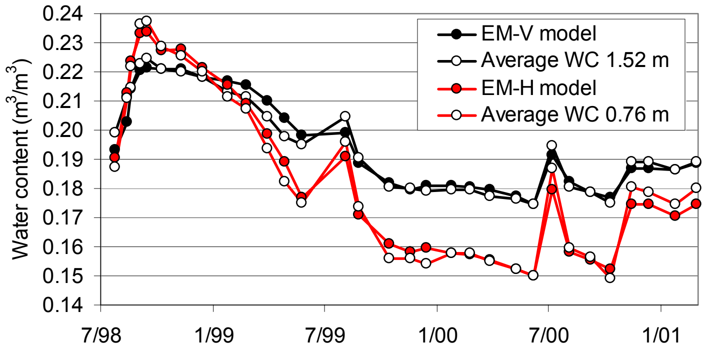

Figure 2. Monitored and predicted water content

Heat dissipation sensors have been more reliable than thermocouple psychrometers for monitoring soil water potential at our site. The HDS instruments displayed rapid and stable responses to changes in water content (Figure 3) and the data are in agreement with the neutron probe measurements. Duplicate HDS instruments generally displayed measurements within 10% of each other at potential values above -1.0 MPa. In contrast, most of the TCP data were not in agreement with the HDS or neutron probe data and duplicate TCP instruments rarely displayed similar responses. Heat dissipation sensors provide accurate measurements in the wet range (≥-0.5 MPa) and have the additional advantage of measuring a wider range of potential energy values (-0.01 to -1.0 MPa) compared to thermocouple psychrometers (-0.5 to -8 MPa). Heat dissipation sensors do respond to water potential changes below -1.0 MPa to very dry conditions (≤-10 MPa) though measurement sensitivity decreases with decreasing potential and potential energy gradients derived from data in this range should be interpreted with caution.

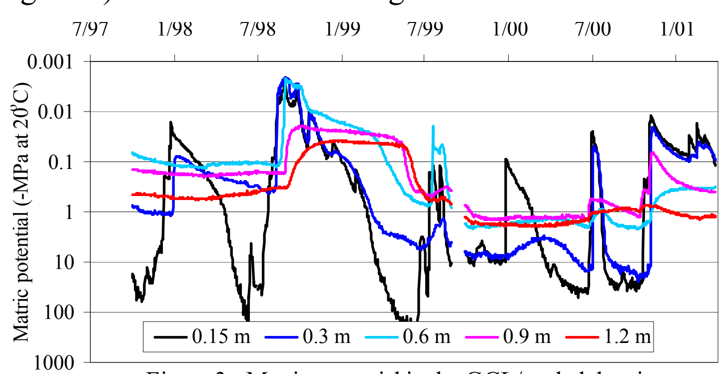

Figure 3. Matric potential in the GCL/asphalt barrier

Future work will include the installation of both a drip irrigation system to stress the capillary barrier to failure and advanced tensiometers to determine the water potential of the capillary barrier at failure. A chemical tracer will also be applied during irrigation to characterize the nature of infiltration into the capillary barrier.

References

Scanlon, B. R., Mullican, W. F., III, Reedy, R. C., and Angle, E. S., 1997. Prototype Engineered Barrier Designs for Low-Level Radioactive Waste Disposal in Texas, *in* Reynolds, T. D., and Morris, R. C., eds., Proceedings, Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions: Environmental Science and Research Foundation, p. 231-242.