EVALUATION OF FINAL COVER PERFORMANCE: FIELD DATA FROM THE ALTERNATIVE COVER ASSESMENT PROGRAM (ACAP)

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ABSTRACT

Field tests of final covers are described that are being conducted as part of a five-year study referred to as the Alternative Cover Assessment Program (ACAP). Data are being collected from 24 final cover test sections located at eleven sites in seven states. Climates ranging from arid to humid/subtropical are represented. Percolation rates less than 1 mm/yr are currently being transmitted by all covers located in semi-arid or arid climates. The mean percolation rates for the covers in semi-arid climates are as follows: (i) conventional covers with composite barriers - 0.09 mm/yr; (ii) monolithic barriers - 0.16 mm/yr, and (iii) capillary barriers - 0.36 mm/yr. Percolation rates for the covers located in humid regions currently are higher than anticipated, and vary significantly from site-to-site for all cover types except conventional covers with composite barriers. For humid regions, the percolation rates range between 12.2 and 128 mm/yr for the alternative covers, between 3.1 and 315 mm/yr for the conventional covers with clay barriers, and between 1.0 and 7.1 mm/yr for the conventional covers with composite barriers. Tentative recommendations regarding equivalent percolation rates for conventional covers have been made based on the data. The recommended equivalent percolation rates for covers with composite barriers are 1 mm/yr for semi-arid and arid climates and 5 mm/yr for humid climates. These recommendations are based on the relatively short data record collected to date, and may change as more data are collected during the study. Recommendations for equivalent percolation rates for conventional covers with clay barriers have not yet been formulated due to insufficient data.

INTRODUCTION

Final covers are used to reduce the quantity of water that percolates into closed waste containment facilities and contaminated soils. Reducing the volume of percolating water reduces the rate of leachate generation and the risk of groundwater contamination. At most sites, regulations prescribe a final cover design based on resistive principles, i.e., layers having low saturated hydraulic conductivity (compacted clay barriers, geosynthetic clay liners, and/or geomembranes). These covers are referred to herein as “conventional” covers. Alternative cover designs are also permitted provided that the “alternative” cover is “equivalent” to the prescriptive cover. Equivalency generally requires that percolation from the alternative cover be less than or equal to percolation from the prescriptive cover.

Alternative covers based on water balance principles are currently being considered for closing many waste containment facilities, particularly in semi-arid and arid regions (*1-5*). These covers limit the amount of water entering the waste by exploiting the water storage capacity of finer textured soils and the water removal capability of vegetation. This natural approach to isolating waste is distinctly different from the approach employed by prescriptive covers, and is more likely to be effective over the long-term because it is congruent with nature. An additional benefit is that alternative covers typically are less costly than prescriptive covers (*1*).

Although alternative covers can be advantageous, field data describing their performance are limited and guidance for their design is lacking. In addition, little data exist regarding percolation rates for conventional covers, which complicates defining equivalency for alternative cover evaluations. The US Environmental Protection Agency’s (USEPA) Alternative Cover Assessment Program (ACAP) is being conducted in response to these shortcomings (*5*). A similar program, the Alternative Landfill Cover Demonstration, is being conducted by Sandia National Laboratories for waste containment facilities owned by the US Department of Energy (*3, 4*).

The objective of ACAP is to collect field performance data from a diverse network of alternative cover test facilities and to use the data to develop design tools and design guidance (*5*). ACAP has constructed 24 test sections simulating final covers at 11 different sites in the United States representing a wide range of climatic conditions. The field data are to be collected for five years. This paper describes the test sections that have been constructed, illustrates the type of hydrologic data being collected, and summarizes the percolation rates that have been recorded to date.

TEST SECTIONS

Cover Profiles

A summary of the cover profiles being tested is in Table I (semi-arid and arid sites) and Table II (humid sites). There are 14 “alternative” cover profiles and 10 “conventional” cover profiles being evaluated. When possible, alternative and conventional cover profiles are being tested side by side so that a direct comparison between the covers can be made. Side-by-side comparisons are being made at eight sites.

All of the alternative covers employ water balance methods to control the rate of percolation. In the water balance method, the water storage capacity of the cover soils is balanced by the capability of plants to extract soil water (*5*, *6*). Finer textured soil layers are designed to store infiltrating water with minimal drainage during periods of vegetative dormancy or excessive

Table I. Summary of Cover Profiles Being Evaluated by ACAP – Semi-Arid and Arid Sites.

Site	Climate	Annual Precip. (mm)	Cover Type	Profile Top to Bottom	Vegetation
Apple Valley, CA	Arid	138	Alternative Monolithic	910 mm Silty Sand 305 mm Silty Sand Interim Cover	Grasses
			Conventional Clay Barrier	305 mm Silty Sand 305 mm Clay 610 mm Silty Sand	
			Conventional Composite	305 mm silty sand 1.5 mm Geomembrane, GCL 610 mm Silty Sand Interim Cover	
Altamont, CA	Semi-Arid	340	Alternative Monolithic	1070 mm Crushed Claystone 300 mm Clay Interim Cover	Grasses
			Conventional Composite	305 mm Crushed Claystone Drainage Geocomposite 1.5 mm Geomembrane 305 mm Compacted Claystone 305 mm Interim Cover	
Sacramento, CA	Semi-Arid	440	Alternative Monolithic	150 mm Top Soil 920 mm Clayey Sand 460 mm Clayey Sand Interim Cover	Grasses & Shrubs
			Alternative Monolithic	150 mm Top Soil 2300 mm Clayey Sand 460 mm Clayey Sand Interim Cover	
Helena, MT	Semi-Arid	304	Alternative Monolithic	150 mm Top Soil 1200 mm Sandy Clay 300 mm Gravel 150 mm Sandy Clay Interim Cover	Grasses & Shrubs
Polson, MT	Semi-Arid	382	Alternative Capillary Barrier	150 mm Top Soil 460 mm Silt 600 mm Native Fine Sand 300 mm Gravel Interim Cover	Grasses & Shrubs
			Conventional Composite	150 mm Top Soil 460 mm Silty Sand Drainage Geocomposite 1.5 mm Geomembrane 460 mm Compacted Silt 460 mm Gravel Interim Cover	
Boardman, OR	Semi-Arid	220	Alternative Monolithic	1800 mm Sandy Silt 300 mm Sandy Silt Interim Cover	Grasses
			Alternative Monolithic	1500 mm Sandy Silt 300 mm Sandy Silt Interim Cover	
			Conventional Composite	900 mm Sandy Silt Drainage Geocomposite 1.5 mm Geomembrane, GCL 300 mm Sandy Silt Interim Cover	
Monticello, UT	Semi-Arid	384	Alternative Capillary Barrier	200 mm Silt-Gravel Mixture 900 mm Silty Sand 300 mm Gravel 300 mm Silty Sand 300 mm Sand	Grasses & Shrubs

Table II. Summary of Cover Profiles Being Evaluated by ACAP – Humid Sites

Site	Climate	Annual Precip. (mm)	Cover Type	Profile Top to Bottom	Vegetation
Monterey, CA	Humid	412	Alternative Monolithic	1220 mm Mixed Clayey Soil 300 mm Sand Interim Cover	Grasses
			Conventional Composite	300 mm Mixed Clayey Soil 1.5 mm Geomembrane 300 mm Compacted Clay 600 mm Sand Interim Cover	Grasses
Albany, GA	Humid	1280	Alternative Monolithic	600 mm Clay-Compost Mix 700 mm Clay 150 mm Clay Interim Cover	Grasses & Poplars
			Conventional Clay Barrier	150 mm Top Soil 450 mm Compacted Clay 150 mm Clay Interim Cover	Grasses
Cedar Rapids, IA	Humid	925	Alternative Monolithic	900 mm Clay-Compost Mix 300 mm Clay 300 mm Clay Interim Cover	Grasses & Poplars
			Conventional Clay Barrier	600 mm Top Soil 600 mm Compacted Clay 300 mm Clay Interim Cover	Grasses
			Conventional Composite	300 mm Top Soil Drainage Geocomposite 1 mm Geomembrane 450 mm Compacted Clay 300 mm Clay Interim Cover	Grasses
Omaha, NE	Humid	711	Alternative Capillary Barrier	150 mm Top Soil 450 mm Silty Clay 150 mm Clean Sand 300 mm Clay Interim Cover	Grasses
			Alternative Capillary Barrier	150 mm Top Soil 760 mm Silty Clay 150 mm Clean Sand 300 mm Clay Interim Cover	
			Conventional Composite	150 mm Top Soil 300 mm Clay 1 mm Geomembrane 460 mm Compacted Clay 300 mm Clay Interim Cover	

precipitation. In some cases, layers with contrasting particle size (i.e., coarse vs. fine soil) are used to create a capillary break that enhances the water storage capacity of the finer textured storage layer. Methods to select soils to achieve a target percolation rate are described in *Ref. 6*.

The alternative covers being tested by ACAP include ten monolithic barriers and four capillary barriers. Monolithic barriers are covers comprised primarily of a thick layer of finer textured soil; capillary barriers are covers that rely on a capillary break to enhance water storage (*1*).

Although great emphasis is placed on the soil in alternative covers, the vegetation plays an equally vital role because the plants remove the stored water and return it to the atmosphere. All available soil water should be removed by the end of the growing season so that the reservoir for soil water storage has sufficient capacity to store infiltration during the subsequent period of vegetative dormancy. Seven of the alternative covers in ACAP are vegetated with grasses, whereas five covers are vegetated with a combination of grasses and shrubs. Two of the alternative covers in humid sites are vegetated with a combination of grasses and hybrid poplar trees. Hybrid poplars are being used because of their ability to remove large quantities of water.

In contrast to alternative covers, conventional covers employ “resistive” principles where a barrier layer with high resistance to flow is used to limit percolation. The barrier layer may be a compacted clay layer or geosynthetic clay liner (GCL) with low saturated hydraulic conductivity, or a “composite” barrier consisting of a geomembrane (polymeric sheet 1-2 mm thick) underlain by a soil layer with low saturated hydraulic conductivity (compacted fine-grained soil or GCL). Seven of the conventional covers being tested in ACAP contain composite barriers, and two of these composite barriers employ a GCL as the soil component. The remaining three conventional covers use a compacted clay layer as the resistive barrier. The GCLs being used in ACAP are factory manufactured clay liners comprised of a thin layer of sodium bentonite clay (~3.5 kg air-dry bentonite/m^2) sandwiched between two geotextiles that are joined together by needle-punching. Four of the conventional covers (Altamont, CA, Boardman, OR, Cedar Rapids, IA, and Polson, MT) also include a drainage layer directly on top of the barrier layer.

Lysimeter

Percolation from final covers can be estimated indirectly or measured directly. Both approaches have advantages and disadvantages. A summary and critique of the methods is in *Ref. 7*. Indirect estimates of percolation generally are made by measuring water content, soil water potential, or both, and then computing the percolation rate using Darcy’s Law and the unsaturated hydraulic conductivity of the cover soil. Direct measurements are made by collecting the water that percolates from the base of the profile using a large pan called a “lysimeter.” Direct measurements made with lysimeters are generally at least one order of magnitude more precise than estimates made using water content and potential measurements (*7*).

When very low percolation rates (e.g., < 1 mm/yr) are to be measured, lysimetry provides the only viable option to accurately determine percolation rates (*7, 8*). Because percolation rates less than 1 mm/yr are anticipated for many of the ACAP sites, lysimeters were chosen as the primary method to assess cover performance. A large lysimeter (10 m x 20 m in areal extent) was incorporated in each test section to monitor the percolation rate. A schematic of the ACAP lysimeter is shown in Fig. 1.

The base and walls of the ACAP lysimeter are constructed with 1.5-mm-thick linear low density polyethylene (LLDPE) geomembrane. LLDPE is used because it is flexible and highly puncture resistant. The flexibility allows the geomembrane to readily conform to changes in grade and to be bent to form the transition between the floor and the vertical walls. Puncture resistance is also critical, because holes in the geomembrane preclude accurate measurements of percolation rate.

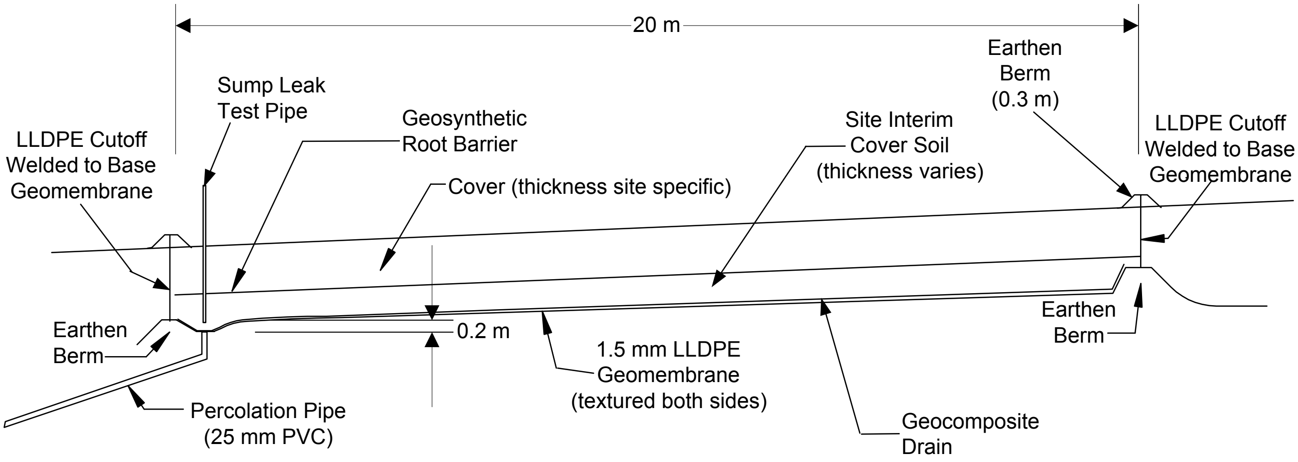

Fig. 1. Cross-section of ACAP lysimeter. LLDPE = linear low-density polyethylene and PVC = polyvinyl chloride.

ACAP lysimeters are constructed in the field from geomembrane panels 7 m wide and approximately 30 m long. Double-wedge fusion welds are used to join the geomembrane panels whenever possible, and for all seams in the base of the lysimeter. Extrusion welds are used when wedge welding is not possible. All welds are leak tested using air pressure or vacuum (ASTM D 5820 and D 5641). The sump area of the lysimeter is also filled with water and monitored for leakage (*9*).

Water emanating from the base of the cover is collected using a geocomposite drainage layer (geonet sandwiched between two non-woven geotextiles) placed on top of the geomembrane and extending across the floor of the lysimeter. Water collected in the drainage layer is directed to a sump that is plumbed to a metering system for measuring the flow rate. A geocomposite drainage layer is used rather than a granular drainage medium because the geonet rapidly transmits water to the sump with little storage. A no-storage sump design is used so that all water directed to the sump immediately flows into the metering system (*9*).

Flow Measurements

A pipe transmits percolation collected in the sump to a basin for metering. Rate of flow into the basin is measured using three independent devices: a tipping bucket, a pressure transducer, and a float switch. The tipping bucket measures the flow as it trickles in from the pipe, whereas the pressure transducer measures the stage in the basin over time. Both measurements provide a continuous record of flow into the basin. The float switch indicates when the basin is emptied (referred to as a “flush”), and thus provides a discrete measure of volume over a given period of time. The same volume of water (~ 90 L) is discharged from the basin during each flush.

The precision of the percolation measurements varies depending on the device being used. Percolation from the ACAP test sections can be measured with a precision of approximately 0.02 mm/yr with the tipping bucket or the pressure transducer, and approximately 0.4 mm/yr using the float switch (*7*).

Basins are also used to collect surface runoff and flow from drainage layers. Because these flows generally are larger than those from the lysimeter sump, and frequently exceed the capacity of conventional tipping buckets, they are only metered using a pressure transducer and a float switch (*7, 9*).

Meteorological and Geotechnical Data

Meteorological conditions are measured at each site using a weather station. Precipitation, wind speed, wind direction, air temperature, atmospheric relative humidity, and solar radiation are measured and recorded using a datalogger. A tipping bucket measures liquid (rain) and frozen (snow, sleet, or hail) precipitation. To minimize losses, frozen precipitation is melted using an ethylene glycol system rather than heat (*10*).

Profiles of soil water content are measured along the centerline of each test section by nests of sensors located at the quarter points (up slope, midpoint, and down slope). Profiles of soil water potential and soil temperature are measured at the midpoint nest. Water content is measured using a lower frequency (40 MHz) time-domain reflectometry technique (*11*). Thermocouples are used to measure soil temperature, and soil water potential is being measured using a thermal dissipation method (*12*).

Data Collection and Reduction

Data from all of the instruments are continuously collected and stored using a datalogger. A computer at the Desert Research Institute in Reno, Nevada regularly downloads the data from the dataloggers. The data are subjected to a series of quality control algorithms, and then are reduced and posted on a website (www.dri.edu/Projects/EPA).

EQUIVALENCY CRITERIA

ACAP is part of USEPA's Superfund Innovative Technology Evaluation (SITE) program. Each study sponsored by the SITE program includes a pass-fail criterion used to evaluate the technology. This pass-fail criterion was established for each field site in the context of "equivalency," as defined in Subtitle D of the Resource Conservation and Recovery Act (RCRA). In RCRA Subtitle D, an alternative cover is hydrologically equivalent to a prescribed conventional cover if the percolation rate for the alternative cover is less than or equal to the percolation rate for the prescribed cover (see *US Code of Federal Regulations*, Part 258.60, Subpart F).

A direct comparison of percolation rates is possible at those sites where side-by-side testing of alternative and conventional covers is being conducted. For sites without a side-by-side comparison, percolation rates were defined using data from the literature for conventional covers with composite barriers (*13*) and clay barriers (*14*). A summary of these criteria is in Table III.

Table III. Equivalent Percolation Rates.

Type of Barrier Layer in Conventional Cover	Equivalent Percolation Rate (mm/yr)	
	Humid Climate	Semi-Arid or Arid Climate
Compacted Clay Barrier	30	10
Composite Barrier	3	3

FIELD PERFORMANCE DATA

The field data from each test section are reduced into the fundamental water balance quantities: precipitation, runoff, soil water storage, interflow, and percolation. Evapotranspiration is not measured directly, but is computed as the residual of the water balance. Soil water storage is computed by integrating the water content measurements over the volume of the test section. This section provides examples of the data being collected, and summarizes the percolation data to date.

Humid Site – Albany, Georgia USA

Water balance data from the test sections in Albany, Georgia are shown in Fig. 2. The conventional cover is a resistive barrier design required by the Georgia Environmental Protection Agency. The conventional cover consists of 450 mm of compacted clay having hydraulic conductivity less than 10^{-7} cm/s overlain by 150 mm of top soil seeded with Bermuda grass. The alternative is a 1300-mm-thick monolithic barrier consisting of native clayey soils mixed with peanut-shell compost. The alternative cover, referred to as an "ECap" by its developers (Ecolotree Inc., N. Liberty, IA, USA, www.ecolotree.com), is vegetated with hybrid poplar trees (Imperial Carolina DN-34) with an understory of Bermuda and rye grasses. The trees were installed in rows 3 m apart with an in-row spacing of 1.2 m (*15*).

The water balance data shown in Fig. 2 are characteristic of covers in humid subtropical climates (*14*). Rainfall occurs regularly throughout year, with occasional periods of dryness. The regular rainfall results in frequent cyclic variations in soil water storage. The percolation record follows the precipitation record. Percolation occurred continuously at a fairly regular rate (Fig. 2) during the first half of the monitoring period. Near the middle of the monitoring period (Fall 2000), however, two important events occurred that had a dramatic effect on the percolation rate.

One event is a sustained period without precipitation that occurred between mid-September and December 2000. While a dry period of this duration is not unusual in semi-arid and arid climates, it is uncommon in humid climates. During this period both test sections dried, which is indicated by the nearly continuous drops in soil water storage from mid-September to mid-November (Figs. 2 a, b). The drop in storage was particularly large for the ECap (160 mm for ECap vs. 40 mm for the conventional cover), as the poplar trees extracted soil water for transpiration.

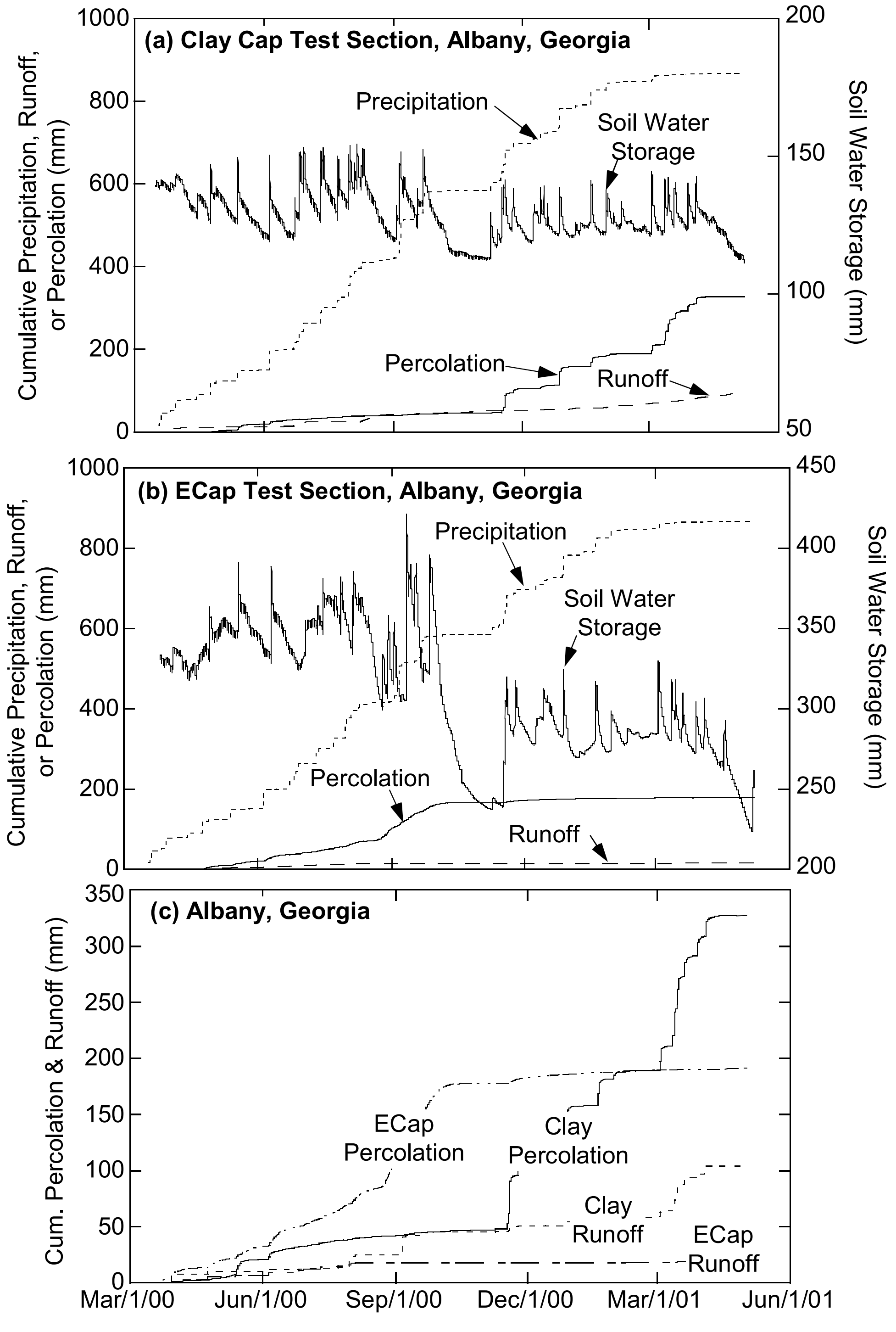

Fig. 2. Water Balance for ACAP Test Sections in Albany, Georgia: (a) Conventional Cover, (b) Alternative Cover, (c) Comparison of Percolation and Runoff.

Although less water was removed from the conventional cover than the ECap, the drying had a more severe impact on the hydrology of the conventional cover. Desiccation cracks formed in the clay barrier, and these cracks became preferential flow paths during subsequent precipitation periods, as is evinced by the step-like pattern in the percolation record after mid-November 2000. These steps mimic the precipitation record, which is indicative of preferential flow (Fig. 2a). Desiccation cracking did not occur to the same degree or have the same impact on the ECap. The soil used for the ECap was placed more loosely, and thus was not prone to the large-scale cracks associated with desiccation of dense and stiff compacted clays (*16, 17*).

The impact of desiccation on the percolation rate for the conventional cover is dramatic (Fig. 2c). Prior to the dry period the percolation rate was approximately 100 mm/yr. After the dry period, the percolation rate jumped to approximately 480 mm/yr.

The other event, which is more subtle but equally important, is establishment of the poplar trees on the ECap. The trees were planted in March 2000, but did not become established until August 2000. Transpiration by the established trees has maintained lower soil water storage in the ECap since the dry period in Fall 2000 (approximately 360 mm before September 2000, and approximately 290 mm after December 2000). As a result, the percolation rate has diminished substantially. Before establishment the percolation rate was 360 mm/yr; afterwards the percolation rate decreased to 14 mm/yr (Fig. 2c), a reduction of more than 25 fold. Additional reductions in the percolation rate are anticipated as the trees mature.

Other subtle, but important observations have been made regarding the hydrology of the alternative and conventional covers in Albany, GA. Runoff from the alternative cover is less than that from the conventional cover, which reflects the presence of the trees on the ECap as well as differences in the grass cover between the test sections (i.e., heavier grass cover results in more resistance to flow, and less runoff) (Fig. 2c). The grass cover on the ECap is hardy (leaf area index = 2.2), whereas the grass is poor on the conventional cap (leaf area index = 0.2). The hardiness of the grass cover is attributed to the organic compost mixed in with the cover soils used for the ECap, which suggests that organic amendments may be beneficial for establishing vegetation on covers. Also, soil water storage in the conventional cover has never returned to the pre-drying level, even though substantial rainfall has occurred since mid-November 2000. The soil water storage is lower because infiltrating water now passes directly through the cover via the desiccation cracks instead of being stored within the cover. Transpiration could also contribute to this effect, but probably is insignficant given that the grass on the conventional cover is poor.

Semi-Arid Sites: Sacramento, California and Polson, Montana, USA

Data from alternative covers at two sites (Sacramento, CA and Polson, MT) in semi-arid locations are shown in Fig. 3. These sites were selected as examples because they provide contrasting conditions. Sacramento is in a warm desert and rarely receives snow. Polson is in a cool desert, and thus has a more seasonal climate. Sub-freezing conditions occur during the winter in Polson, and snow cover accumulates. Different designs are also being tested at these sites. The covers in Sacramento are monolithic barriers (data from the barrier 1080 mm thick are

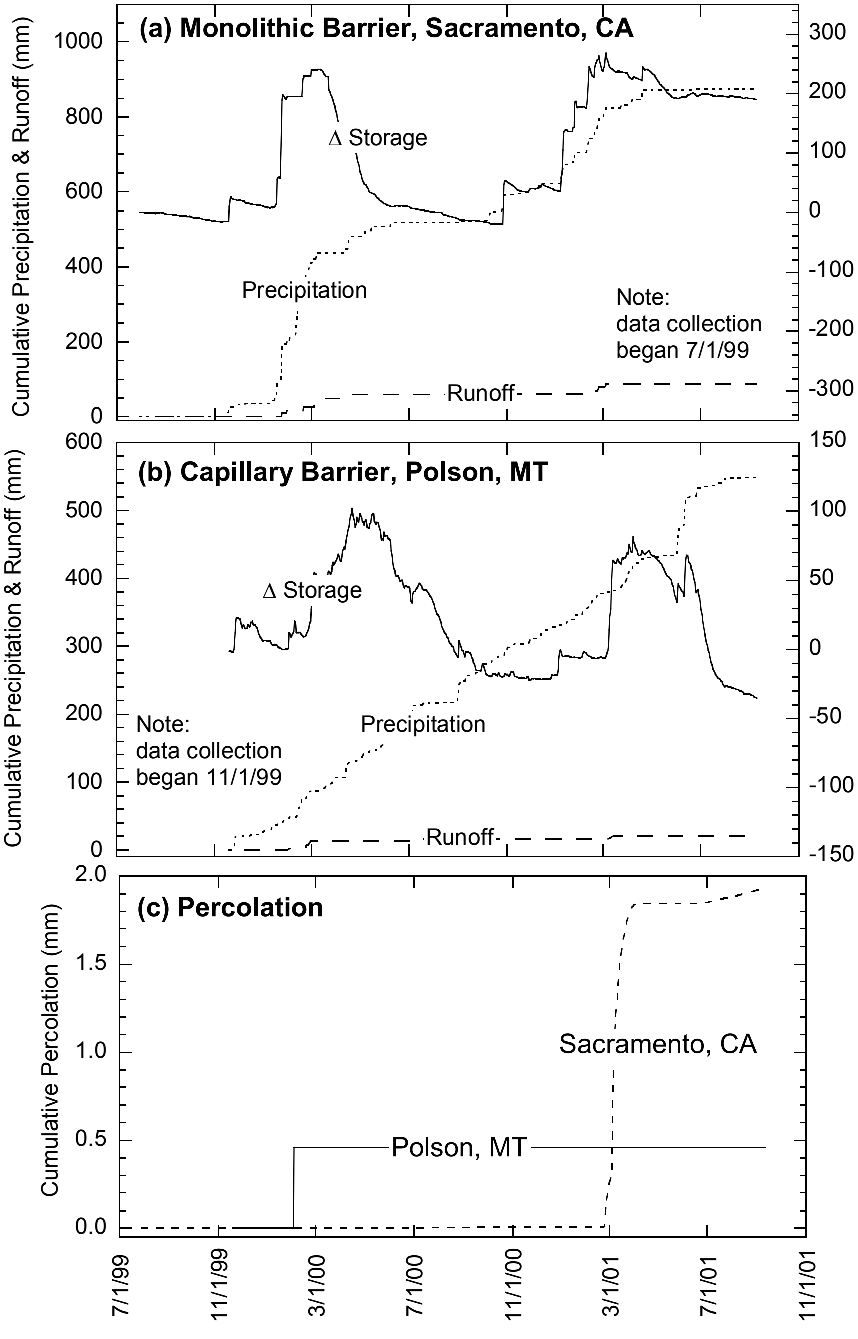

Fig. 3. Precipitation, Runoff, and Change in Storage for Alternative Cover Test Sections in Sacramento, CA (1080 mm Monolithic Barrier) (a) and Polson, MT (Capillary Barrier) (b). Graph in (c) Shows Percolation for Both Test Sections.

shown in Fig. 3), whereas a capillary barrier with a silt-over-sand configuration is being tested in Polson. Test sections at both sites are vegetated with a mixture of local grasses and shrubs (*15*). The soil water storage records in Figs. 3a and 3b are characteristic of covers in semi-arid areas (*2, 4, 18*). Soil water storage gradually accumulates during the winter months when precipitation generally occurs more frequently and less intensely, and the vegetation is dormant (*14, 19*). During the spring and summer, soil water is extracted until the wilting point is reached, providing an empty storage reservoir for the upcoming fall and winter. The peak in soil water storage occurs later in Polson (Fig. 3b) due to spring snow melts, and because the growing season begins later in Montana than central California. Also, the soil water storage diminishes more gradually in Polson. Montana generally has lower air temperature and receives less intense solar radiation than central California, which results in less potential transpiration and slower extraction of water (*19*).

The drop in soil water storage in Sacramento during Summer 2001 was much smaller than anticipated (Fig. 3a). The reason for this unexpected behavior has not yet been resolved, but it has been observed in both test sections at this site. Precipitation during Winter 2001 was less than that received in Winter 2000 (360 mm vs. 450 mm), but the precipitation occurred more gradually, which resulted in less runoff, more infiltration, and a higher peak in soil water storage for 2001. Because the soil water storage remained fairly large in Fall 2001, a smaller reservoir for soil water storage exists for Winter 2002, which may result in more percolation in Spring 2002. This unexpected behavior illustrates the importance of collecting long-term data regarding the hydrology of covers.

The percolation records shown in Fig. 3c are typical of percolation records for covers in semi-arid climates (*2, 14*). Percolation in semi-arid regions generally occurs within a very short period provided the cover is adequately thick. In semi-arid regions, exceedances of the storage capacity typically occur toward the end of winter and, as a result, only a short period exists before the growing season begins and the soil water storage is reduced below the storage capacity. During some winters no percolation may be transmitted provided the soil water storage does not exceed the storage capacity of the cover (*18*), as occurred in Sacramento during Winter 2000 and Polson in Winter 2001 (Fig. 3a).

An exception to the general behavior in the percolation records is the gradual increase in percolation occurring in Sacramento towards the end of the record (Fig. 3c). This increase in percolation rate is tied to the elevated soil water storage in Sacramento (Fig. 3a) at the end of the record, and is currently receiving additional study.

Percolation Summary

The percolation rates measured to date are summarized in Table IV (semi-arid sites) and Table V (humid sites). Data for the test sections in Apple Valley, CA are not included, since these test sections were constructed in October 2001, and thus their data record is very short. The percolation rates reported in Tables IV and V represent the mean rate for the monitoring period, and were computed by dividing the total percolation recorded to date by the duration of the monitoring period. Box plots depicting percolation rates for the four cover types being tested are shown in Fig. 4. The center lines in the box plots shown in Fig. 4 represent the mean percolation rate for a given cover type rather than the median.

Table IV. Summary of Percolation Rates: Semi-Arid Sites.

Site	Duration (days)	Total Precipitation (mm)	Cover Type	Percolation Rate (mm/yr)
Altamont, CA	306	219	Alternative Monolithic	0.00
			Conventional Composite	0.00
Sacramento, CA	775	874	Alternative (1080 mm) Monolithic	0.93
			Alternative (2450 mm) Monolithic	0.00
Helena, MT	693	357	Alternative Monolithic	0.00
Polson, MT	662	548	Alternative Capillary Barrier	0.25
			Conventional Composite	0.26
Boardman, OR	277	82.8	Alternative (1500 mm) Monolithic	0.00
			Alternative (1800 mm) Monolithic	0.00
			Conventional Composite	0.00
Monticello, UT	381	342	Alternative Capillary Barrier	0.46

Note: Apple Valley not included due to short data record (constructed in 10/01). Quantities based on data collected through 09/11/01

All of the covers in semi-arid locations are transmitting very small quantities of percolation (Fig. 4a). All of the percolation rates are less than 1 mm/yr, and meet the equivalency criteria stipulated in Table III. Seven of the test sections have transmitted no percolation. The mean percolation rate for the conventional covers with composite barriers is 0.09 mm/yr. For monolithic barriers, the mean percolation rate is 0.16 mm/yr and for capillary barriers it is 0.36 mm/yr. There is no box in Fig 4a for conventional covers with clay barriers due to insufficient data. Only one cover with a clay barrier has been constructed in a semi-arid or arid climate, and that cover is at the site in Apple Valley, CA.

Comparison of the box plots in Fig. 4a suggests that the alternative covers in semi-arid regions are performing comparably, and are transmitting percolation at a slightly higher rate than the conventional covers with composite barriers. Based on these data, an equivalency criterion of approximately 0.2 mm/yr seems reasonable for conventional composite covers in semi-arid or arid regions. Given that monitoring systems used for evaluating equivalency in industrial settings are less accurate and precise than those used in ACAP (*7*), a simple 1 mm/yr criterion is practical.

Less favorable results have been achieved in humid climates. Only one of the alternative covers (Cedar Rapids, IA) is meeting the equivalency criterion in Table III for clay barriers (<30 mm/yr). Additionally, only one of the conventional covers has a percolation rate less than those in Table III for humid climates. Thus, the equivalency criteria for humid climates may have been set too low.

Table V. Summary of Percolation Rates: Humid Sites.

Site	Duration (days)	Total Precipitation (mm)	Cover Type	Percolation Rate (mm/yr)
Monterey, CA	472	291	Alternative Monolithic	37.1
			Conventional Composite	7.06
Albany, GA	510	1254	Alternative Monolithic	128
			Conventional Clay Barrier	315
Cedar Rapids, IA	344	705	Alternative Monolithic	1.00
			Conventional Clay Barrier	3.10
			Conventional Composite	12.2
Omaha, NE	342	578	Alternative (600 mm) Capillary Barrier	100
			Alternative (910 mm) Capillary Barrier	60.0
			Conventional Composite	5.89

Note: Quantities based on data collected through 09/11/01

The percolation rates for alternative covers at humid sites vary between 12.2 and 128 mm/yr, and are much larger than anticipated. However, maturity of the vegetation needs to be considered when interpreting these data. None of the alternative covers has mature vegetation, and at two of the four sites (Cedar Rapids, IA and Omaha, NE) the vegetation was not established by the time the first large pulse of percolation was transmitted. Mature vegetation is critical for effective alternative covers in humid regions, because larger volumes of water need to be managed, snow cover can persist, and snow melt can result in relatively large infiltration events in the late winter and early spring.

As the vegetation matures, the percolation rates for the alternative covers will probably diminish. This effect is illustrated in Fig. 2c. After the trees at the site in Albany, GA became established, the percolation rate for the alternative cover diminished from 360 mm/yr to 14 mm/yr, which meets the equivalency criterion stipulated in Table III for conventional covers with clay barriers in humid locations.

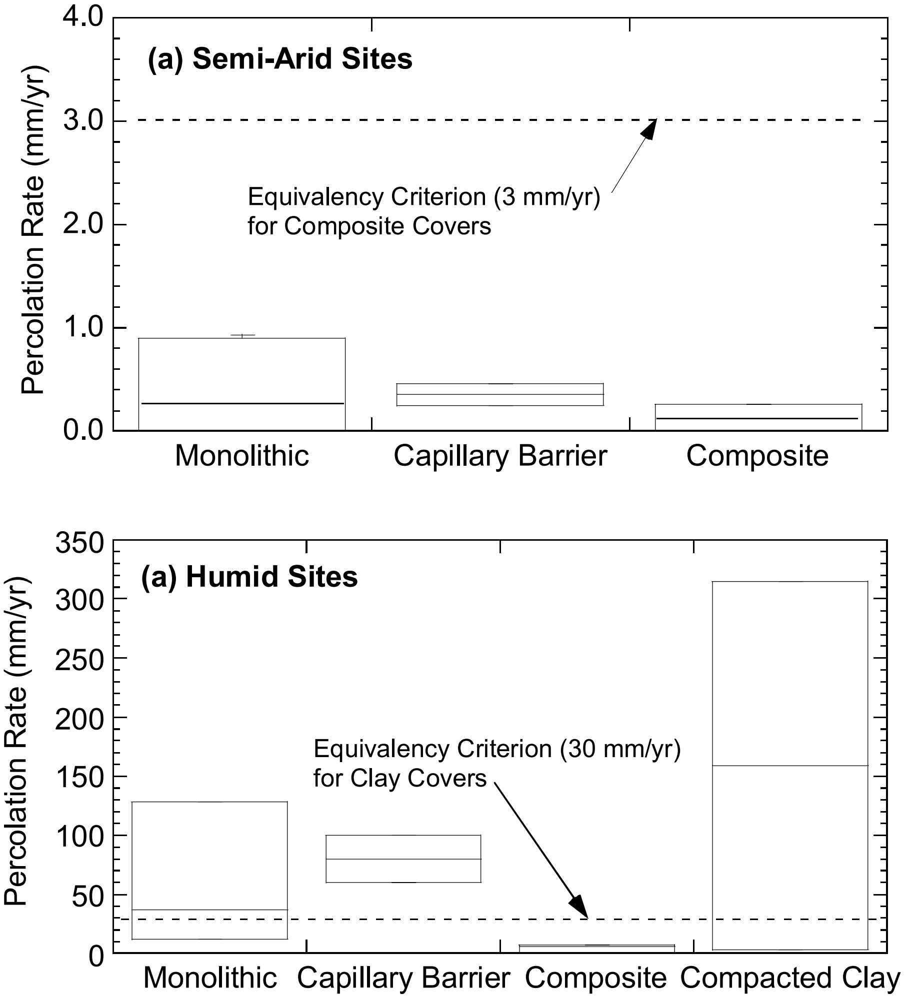

Fig. 4. Box Plots of Percolation Rates: (a) Semi-Arid Sites and (b) Humid Sites.

The percolation rates for the conventional covers at humid sites are also much higher than anticipated, and for the clay barriers the percolation rates vary widely. The mean percolation rate for the conventional covers with clay barriers varies between 3.1 mm/yr and 315 mm/yr. This broad range is probably due to the preferential flow occurring in the clay barrier at the site in Albany, GA as well as differences in the cover profiles. For covers with composite barriers, the mean percolation rate is 4.6 mm/yr, and the range is smaller (1.0 – 7.1 mm/yr). These data suggest that 5 mm/yr is a reasonable equivalency criterion for covers in humid climates with a composite barrier. A reasonable equivalency criterion for conventional covers in humid climates with clay barriers cannot yet be recommended given the wide range of percolation rates that has been measured.

These observations and recommendations need to be considered as tentative given that the data records are short and the vegetation at several sites is immature. As ACAP progresses, the data will be reviewed regularly and the recommendations will be revised as necessary.

SUMMARY

Covers being tested as part of the Alternative Cover Assessment Program (ACAP) have been described in this paper along with the water balance data collected to date. Data are being collected from 24 test sections at eleven sites. Diverse climates are represented, ranging from arid (Apple Valley, CA, average precipitation = 138 mm/yr) to humid subtropical (Albany, GA, average precipitation = 1280 mm/yr). Fourteen test sections are located in semi-arid or arid climates, and ten are located in humid climates.

Percolation rates less than 1 mm/yr are being transmitted by all of the covers located in semi-arid climates, and all have met the equivalency criteria. No percolation has been recorded for seven of these test sections. The mean percolation rate for the conventional covers with composite barriers is 0.09 mm/yr. For monolithic barriers, the mean percolation rate is 0.16 mm/yr, and for capillary barriers it is 0.36 mm/yr. No data are available for conventional covers with clay barriers due to insufficient data.

Percolation rates for the alternative and conventional covers located in humid regions are higher than anticipated. The percolation rates vary significantly from site-to-site for all covers except the conventional covers with composite barriers. Percolation rates for the alternative covers range between 12.2 and 128 mm/yr. For the conventional covers with clay barriers, the percolation rates range between 3.1 and 315 mm/yr. The conventional covers with composite barriers have percolation rates between 1.0 and 7.1 mm/yr, with a mean percolation rate of 4.6 mm/yr. The relatively high percolation rates for the alternative covers in humid regions are attributed to immature vegetation. Percolation rates for these covers are expected to diminish as the vegetation matures. At one site, the percolation rate dropped more than a factor of 25 as trees became established.

The data collected to date for conventional covers with composite barriers provide a basis for tentative recommendations regarding equivalent percolation rates. Insufficient data are available for recommending a reasonable equivalency criterion for covers with clay barriers. The recommended equivalent percolation rates for covers with composite barriers are 1 mm/yr for semi-arid and arid climates and 5 mm/yr for humid climates. These recommendations are based on the relatively short data record collected to date, and may change as more data are collected during the study.

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