Evapotranspiration Landfill Cover Systems Fact Sheet

INTRODUCTION

Alternative final cover systems, such as evapotranspiration (ET) cover systems, are increasingly being considered for use at waste disposal sites, including municipal solid waste (MSW) and hazardous waste landfills when equivalent performance to conventional final cover systems can be demonstrated. Unlike conventional cover system designs that use materials with low hydraulic permeability (barrier layers) to minimize the downward migration of water from the cover to the waste (percolation), ET cover systems use water balance components to minimize percolation. These cover systems rely on the properties of soil to store water until it is either transpired through vegetation or evaporated from the soil surface. Compared to conventional cover systems, ET cover systems are expected to be less costly to construct. While ET cover systems are being proposed, tested, or have been installed at a number of waste disposal sites, field performance data and design guidance for these cover systems are limited (Benson and others 2002; Hauser, Weand, and Gill 2001).

This fact sheet provides a brief summary of ET cover systems, including general considerations in their design, performance, monitoring, cost, current status, limitations on their use, and project-specific examples. It is intended to provide basic information to site owners and operators, regulators, consulting engineers, and other interested parties about these potential design alternatives. An on-line database has been developed that provides more information about specific projects using ET covers, and is available at *http://cluin.org/products/altcovers*. Additional sources of information are also provided.

The information contained in this fact sheet was obtained from currently available technical literature and from discussions with site managers. It is not intended to serve as guidance for design or construction, nor indicate the appropriateness of using ET final cover systems at a particular site. The fact sheet does not address alternative materials (for example, geosynthetic clay liners) for use in final cover systems, or other alternative cover system designs, such as asphalt covers.

Online Database:
http://cluin.org/products/altcovers

BACKGROUND

Final cover systems are used at landfills and other types of waste disposal sites to control moisture and percolation, promote surface water runoff, minimize erosion, prevent direct exposure to the waste, control gas emissions and odors, prevent occurrence of disease vectors and other nuisances, and meet aesthetic and other end-use purposes. Final cover systems are intended to remain in place and maintain their functions for an extended period of time.

In addition, cover systems are also used in the remediation of hazardous waste sites. For example, cover systems may be applied to source areas contaminated at or near the ground surface or at abandoned dumps. In such cases, the cover system may be used alone or in conjunction with other technologies to contain the waste (for example, slurry walls and groundwater pump and treat systems).

The design of cover systems is site-specific and depends on the intended function of the final cover – components can range from a single-layer system to a complex multi-layer system. To

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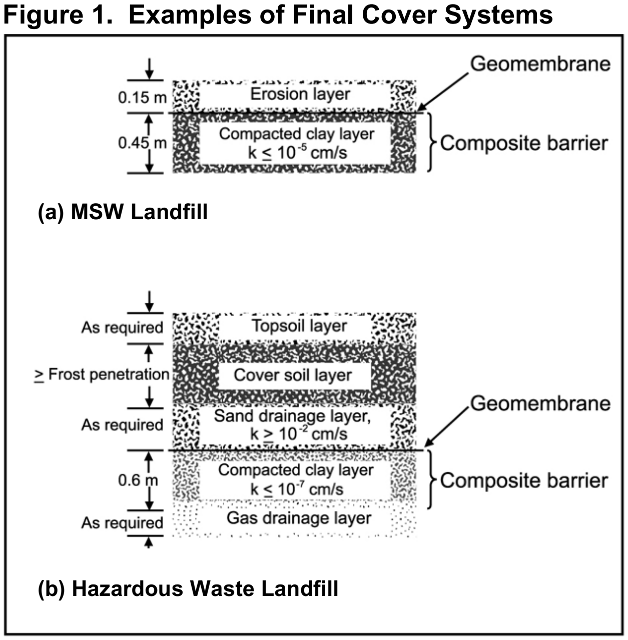
minimize percolation, conventional cover systems use low-permeability barrier layers. These barrier layers are often constructed of compacted clay, geomembranes, geosynthetic clay liners, or combinations of these materials.

Depending on the material type and construction method, the saturated hydraulic conductivities for these barrier layers are typically between 1×10^{-5} and 1×10^{-9} centimeters per second (cm/s). In addition, conventional cover systems generally include additional layers, such as surface layers to prevent erosion; protection layers to minimize freeze/thaw damage; internal drainage layers; and gas collection layers (Environmental Protection Agency [EPA] 1991; Hauser, Weand, and Gill 2001).

Regulations under the Resource Conservation and Recovery Act (RCRA) for the design and construction of final cover systems are based on using a barrier layer (conventional cover system). Under RCRA Subtitle D (40 CFR 258.60), the minimum design requirements for final cover systems at MSW landfills depend on the bottom liner system or the natural subsoils, if no liner system is present. The final cover system must have a permeability less than that of the bottom liner system (or natural subsoils) or less than 1×10^{-5} cm/s, whichever is less. This design requirement was established to minimize the "bathtub effect," which occurs when the landfill fills with liquid because the cover system is more permeable than the bottom liner system. This "bathtub effect" greatly increases the potential for generation of leachate. Figure 1 shows an example of a RCRA D cover at a MSW landfill with a 6-inch soil erosion layer, a geomembrane, and an 18-inch barrier layer of soil that is compacted to yield a hydraulic conductivity equal to or less than 1×10^{-5} cm/s (EPA 1992).

Figure 1. Examples of Final Cover Systems



For hazardous waste landfills, RCRA Subtitle C (40 CFR 264 and 265) provides certain performance criteria for final cover systems. While RCRA does not specify minimum design requirements, EPA has issued guidance for the minimum design of these final cover systems. Figure 1 shows an example of a RCRA C cover at a hazardous waste landfill (EPA 1989).

The design and construction requirements, as defined in the RCRA regulations, may also be applied under cleanup programs, such as Superfund or state cleanup programs, as part of a remedy for hazardous waste sites such as abandoned dumps. In these instances, the RCRA regulations for conventional covers usually are identified as applicable or relevant and appropriate requirements for the site.

Under RCRA, an alternative design, such as an ET cover, can be proposed in lieu of a RCRA design if it can be demonstrated that the alternative provides equivalent performance with respect to reduction in percolation and other criteria, such as erosion resistance and gas control.

DESCRIPTION

ET cover systems use one or more vegetated soil layers to retain water until it is either transpired through vegetation or evaporated from the soil surface. These cover systems rely on the water storage capacity of the soil layer, rather than low hydraulic conductivity materials, to minimize percolation. ET cover system designs are based on using the hydrological processes (water balance components) at a site, which include the water storage capacity of the soil, precipitation, surface runoff, evapotranspiration, and infiltration. The greater the storage capacity and evapotranspirative properties, the lower the potential for percolation through the cover system. ET cover system designs tend to emphasize the following (Dwyer 2003; Hakonson 1997; Hauser, Weand and Gill 2001):

- Fine-grained soils, such as silts and clayey silts, that have a relatively high water storage capacity
- Native vegetation to increase evapotranspiration
- Locally available soils to streamline construction and provide for cost savings

In addition to being called ET cover systems, these types of covers have also been referred to in the literature as water balance covers, alternative earthen final covers, vegetative landfill covers, soil-plant covers, and store-and-release covers.

Two general types of ET cover systems are monolithic barriers and capillary barriers. Monolithic covers, also referred to as monofill covers, use a single vegetated soil layer to retain water until it is either transpired through vegetation or evaporated from the soil surface. A conceptual design of a monolithic cover system is shown in Figure 2. Exhibit 1 provides an example of a full-scale monolithic cover at a MSW landfill.

Capillary barrier cover systems consist of a finer-grained soil layer (like that of a monolithic cover system) overlying a coarser-grained material layer, usually sand or gravel, as shown conceptually in Figure 3. The differences in the unsaturated hydraulic properties between the two layers minimize percolation into the coarser-grained (lower) layer under unsaturated conditions. The finer-grained layer of a capillary barrier cover system has the same function as the monolithic soil layer; that is, it stores water until it is removed from the soil by evaporation or transpiration mechanisms. The coarser-grained layer forms a capillary break at the interface of the two layers, which allows the finer-grained layer to retain more water than a monolithic cover system of equal thickness. Capillary forces hold the water in the finer-grained layer until the soil near the interface approaches saturation. If saturation of the finer-grained layer occurs, the water will move relatively quickly into and through the coarser-grained layer and to the waste below. Exhibit 2 provides an example of a capillary barrier field demonstration at a MSW landfill (Dwyer 2003, Stormont 1997).

Figure 2. Conceptual Design of a Monolithic ET Final Cover

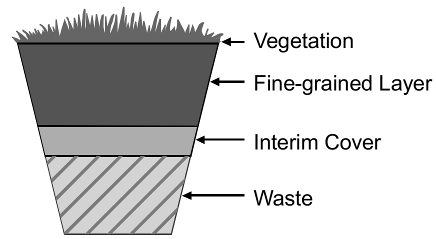
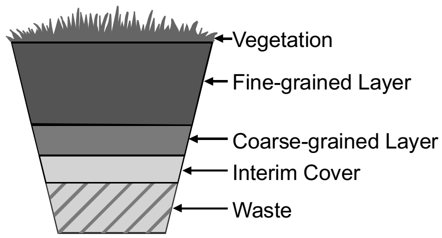


Exhibit 1. Monolithic ET Cover at Lopez Canyon Sanitary Landfill, Los Angeles, CA

Site type: Municipal solid waste landfill
Scale: Full-scale
Cover design: The ET cover was installed in 1999 and consists of a 3-foot silty sand/clayey sand layer, which overlies a 2-foot foundation layer. The cover soil was placed in 18-inch lifts and compacted to 95 percent with a permeability of less than $3x10^{-5}$ cm/s. Native vegetation was planted, including artemesia, salvia, lupines, sugar bush, poppy, and grasses.
Regulatory status: In 1998, Lopez Canyon Sanitary Landfill received conditional approval for an ET cover, which required a minimum of two years of field performance data to validate the model used for the design. An analysis was conducted and provided the basis for final regulatory approval of the ET cover. The cover was fully approved in October 2002 by the California Regional Water Quality Control Board - Los Angeles Region.
Performance data: Two moisture monitoring systems were installed, one at Disposal Area A and one at Disposal Area ABplus in May and November 1999, respectively. Each monitoring system has two stacks of time domain reflectometry probes that measure soil moisture at 24-inch intervals to a maximum depth of 78 inches, and a station for collecting weather data. Based on nearly 3 years of data, there is generally less than a 5 percent change in the relative volumetric moisture content at the bottom of the cover compared to nearly 90 percent change near the surface. This implies that most of the water infiltrating the cover is being removed via evapotranspiration and is not reaching the bottom of the cover.
Modeling: The numerical model UNSAT-H was used to predict the annual and cumulative percolation through the cover. The model was calibrated with 12 months of soil moisture content and weather data. Following calibration, UNSAT-H predicted a cumulative percolation of 50 cm for the ET cover and 95 cm for a conventional cover over a 10-year period. The model predicted an annual percolation of approximately 0 cm for both covers during the first year. During years 3 through 10 of the simulation, the model predicted less annual percolation for the ET cover than for the conventional cover.
Maintenance activities: During the first 18 months, irrigation was conducted to help establish the vegetation. Once or twice a year, brush is cleared to comply with Fire Department regulations. Prior to the rainy season, an inspection is conducted to check and clear debris basins and deck inlets. No mowing activities or fertilizer applications have been conducted or are planned.
Cost: Costs were estimated at $4.5 million, which includes soil importation, revegetation, quality control and assurance, construction management, and installation and operation of moisture monitoring systems.
Sources: City of Los Angeles 2003, Hadj-Hamou and Kavazanjian 2003.
More information available at http://cluin.org/products/altcovers

Figure 3. Conceptual Design of a Capillary Barrier ET Final Cover



In addition to being potentially less costly to construct, ET covers have the potential to provide equal or superior performance compared to conventional cover systems, especially in arid and semi-arid environments. In these environments, they may be less prone to deterioration from dessication, cracking, and freezing/thawing cycles. ET covers also may be able to minimize side slope instability, because they do not contain geomembrane layers, which can cause slippage (Weand and others 1999; Benson and others 2002; Dwyer, Stormont, and Anderson 1999).

Capillary barrier ET cover systems may also eliminate the need for a separate biointrusion and/or gas collection layer. The coarser-grained layer can act as a biointrusion layer to resist root penetration and animal intrusion, due to its particle size and low water content. The coarser-grained layer also can act as a gas collection layer, because the soil properties and location within the cover system are comparable to a typical gas collection layer in a conventional cover system (Dwyer 2003, Stormont 1997).

LIMITATIONS

ET cover systems are generally considered potentially applicable only in areas that have arid or semi-arid climates; their application is generally considered limited to the western United States. In addition, site-specific conditions, such as site location and landfill characteristics, may limit the use or effectiveness of ET cover systems. Local climatic conditions, such as amount, distribution, and form of precipitation, including amount of snow pack, can limit the effectiveness of an ET cover at a given site. For example, if a large amount of snow melted when vegetation was dormant, the cover may not have sufficient water storage capacity, and percolation might occur (EPA 2000a; Hauser, Weand, and Gill 2001).

Further, landfill characteristics, such as production of landfill gases, may limit the use of ET covers. The cover system may not adequately control gas emissions since typical ET cover designs do not have impermeable layers to restrict gas movement. If gas collection is required at the site, it may be necessary to modify the design of the cover to capture and vent the gas generated in the landfill. In addition, landfill gas may limit the effectiveness of an ET cover, because the gases may be toxic to the vegetation (Weand and others 1999; EPA 2000a).

Limited data are available to describe the performance of ET cover systems in terms of minimizing percolation, as well as the covers' ability to minimize erosion, resist biointrusion, and remain effective for an extended period of time. While the principles of ET covers and

Exhibit 2. Capillary Barrier ET Cover at Lake County Landfill, Polson, Montana

Site type: Municipal solid waste landfill
Scale: Field demonstration under Alternative Cover Assessment Program (ACAP)
Cover designs: The capillary barrier test section was installed in November 1999. From the surface downward, it is composed of 6 inches of topsoil, 18 inches of moderately compacted silt, and 24 inches of sandy gravel. The cover was seeded in March 2000 with a mixture of grasses, forbs, and shrubs, including bluegrass, wheatgrass, alfalfa, and prickly rose shrubs. A conventional composite cover test section was also constructed at the site.
Performance data: Percolation is being measured with a lysimeter connected to flow monitoring systems, soil moisture is being measured with water content reflectometers, and soil matric potential and soil temperature are being monitored with heat dissipation units. From November 1999 through July 2002, the capillary barrier cover system had a cumulative percolation of 0.5 mm. Total precipitation was 837 mm over the 32-month period. Additional field data are expected to be collected through 2005.
Modeling: Numerical modeling was conducted using HYDRUS 2-D, which simulated the wettest year on record over the simulation period of 10 years. The model predicted approximately 0.6 mm of percolation during the first year, and 0.1 mm per year for the remaining 9 years.
Sources: Bolen and others 2001, Benson and others 2002.
More information available at http://cluin.org/products/altcovers

their corresponding soil properties have been understood for many years, their application as final cover systems for landfills has emerged only within the past 10 years. Limited performance data are available on which to base applicability or equivalency decisions (Dwyer 2003; Dwyer, Stormont, and Anderson 1999; Hauser and Weand 1998).

Numerical models are used to predict the performance and assist in the design of final cover systems. The availability of models used to conduct water balance analyses of ET cover systems is currently limited, and the results can be inconsistent. For example, models such as Hydrologic Evaluation of Landfill Performance (HELP) and Unsaturated Water and Heat Flow (UNSAT-H) do not address all of the factors related to ET cover system performance. These models, for instance, do not consider percolation through preferential pathways; may underestimate or overestimate percolation; and have different levels of detail regarding weather, soil, and vegetation. In addition, HELP does not account for physical processes, such as matric potential, that generally govern unsaturated flow in ET covers. Further information about numerical models is provided under the Performance and Monitoring section of this fact sheet (Dwyer 2003; Weand and others 1999; Khire, Benson, and Bosscher 1997).

GENERAL CONSIDERATIONS

The design of ET cover systems is based on providing sufficient water storage capacity and evapotranspiration to control moisture and water percolation into the underlying waste. The following considerations generally are involved in the design of ET covers.

Climate – The total amount of precipitation over a year, as well as its form and distribution, determines the total amount of water storage capacity needed for the cover system. The cover may need to accommodate a spring snowmelt event that causes the amount of water at the cover to be relatively high for a short period of time or conditions during cool winter weather with persistent, light precipitation. Storage capacity is particularly important if the event occurs when local vegetation is dormant, yielding less evapotranspiration. Other factors related to climate that are important to cover design are temperature, atmospheric pressure, and relative humidity (Benson 2001; EPA 2000a; Hauser, Weand, and Gill 2001).

Soil type – Finer-grained materials, such as silts and clayey silts, are typically used for monolithic ET cover systems and the top layer of a capillary barrier ET cover system because they contain finer particles and provide a greater storage capacity than sandy soils. Sandy soils are typically used for the bottom layer of the capillary barrier cover system to provide a contrast in unsaturated hydraulic properties between the two layers. Many ET covers are constructed of soils that include clay loam, silty loam, silty sand, clays, and sandy loam.

The storage capacity of the soil varies among different types of soil, and depends on the quantity of fine particles and the bulk density of the soil. Compaction impacts bulk density, which in turn affects the storage capacity of the soil and the growth of roots. One key aspect of construction is minimizing the amount of compaction during placement. Higher bulk densities may reduce the storage capacity of the soil and inhibit growth of roots (Chadwick and others 1999; Hauser, Weand, and Gill 2001).

Soil thickness – The thickness of the soil layer(s) depends on the required storage capacity, which is determined by the water balance at the site. The soil layers need to accommodate extreme water conditions, such as snowmelts and summer thunderstorms, or periods of time during which ET rates are low and plants are dormant. Monolithic ET covers have been constructed with soil layers ranging from 2 feet to 10 feet. Capillary barrier ET covers have been constructed with finer-grained layers ranging from 1.5 feet to 5 feet, and coarser-grained layers ranging from 0.5 foot to 2 feet.

Vegetation types – Vegetation for the cover system is used to promote transpiration and minimize erosion by stabilizing the surface of the cover. Grasses (wheatgrass and clover), shrubs (rabbitbrush and sagebrush), and trees (willow and hybrid poplar) have been used on ET covers. A mixture of native plants consisting of warm- and cool-season species usually is planted, because native vegetation is more tolerant than imported vegetation to regional conditions, such as extreme weather and disease. The combination of warm- and cool-season species provides water uptake throughout the entire growing season, which enhances transpiration. In addition, native vegetation is usually planted, because these species are less likely to disturb the natural ecosystem (Dwyer, Stormont, and Anderson 1999; EPA 2000a).

Soil and organic properties – Nutrient and salinity levels affect the ability of the soil to support vegetation. The soil layers need to be capable of providing nutrients to promote vegetation growth and maintain the vegetation system. Low nutrient or high salinity levels can be detrimental to vegetation growth, and if present, supplemental nutrients may need to be added to promote vegetation growth. For example, at Fort Carson, Colorado, biosolids were added to a monolithic ET cover to increase organic matter and provide a slow release of nitrogen to enhance vegetation growth. In addition, topsoil promotes growth of vegetation and reduces erosion. For ET covers, the topsoil layer is generally a minimum of six inches thick (McGuire, England, and Andraski 2001).

Control layer types – Control layers, such as those used to minimize animal intrusion, promote drainage, and control and collect landfill gas, are often included for conventional cover systems and may also be incorporated in ET cover system designs. For example, a proposed monolithic ET cover at Sandia National Laboratories in New Mexico will have a biointrusion fence with 1/4-inch squares between the topsoil layer and the native soil layer to prevent animals from creating preferential pathways, potentially resulting in percolation. The biointrusion layer, however, will not inhibit root growth to allow for transpiration. At another site, Monticello Uranium Mill Tailings Site in Utah, a capillary barrier ET design has a 12-inch soil/rock admixture as an animal intrusion layer located 44 inches below the surface, directly above the capillary barrier layer.

In addition, a capillary barrier cover demonstration at Sandia National Laboratories has a drainage layer located above the capillary break. A drainage layer consisting of an upper layer of sand and a lower layer of gravel is located directly below the topsoil layer. The sand serves as a filter to prevent topsoil from clogging the drainage layer, while the gravel allows for lateral drainage of water that has infiltrated through the topsoil (Bolen and others 2001, Dwyer 2003).

In more recent applications, several types of ET cover designs also have incorporated synthetic materials, such as geomembranes, which are used to enhance the function of minimizing water into the waste. For example, the Operating Industries Inc. Landfill in California has incorporated a soil layer with a geosynthetic clay liner in the design. The cover system for this site will reduce surface gas emissions, prevent oxygen intrusion and percolation, and provide for erosion control (EPA 2000b).

PERFORMANCE AND MONITORING

Protection of groundwater quality is a primary performance goal for all waste containment systems, including final cover systems. The potential adverse impact to groundwater quality results from the release of leachate generated in landfills or other waste disposal units such as surface impoundments. The rate of leachate generation (and potential impact on groundwater) can be minimized by keeping liquids out of a landfill or contaminated source area of a remediation site. As a result, the function of minimizing percolation becomes a key performance criterion for a final cover system (EPA 1991).

Monitoring the performance of ET cover systems has generally focused on evaluating the ability of these designs to minimize water drainage into the waste. Percolation performance typically is reported as a flux rate (inches or millimeters of water that have migrated downward through the base of the cover in a period of time, generally considered as 1 year). Percolation monitoring for ET cover systems is measured directly using monitoring systems such as lysimeters or estimated indirectly using soil moisture measurements and calculating a flux rate. A more detailed summary on the advantages and disadvantages of both approaches can be found in Benson and others 2001 (EPA 1991, Benson and others 2001).

Percolation monitoring can also be evaluated indirectly by using leachate collection and removal systems. For landfills underlain with these systems, the amount and composition of leachate generated can be used as an indicator of the performance of a cover system (the higher the percolation, the more leachate that will be generated) (EPA 1991).

Although the ability to minimize percolation is a performance criterion for final cover systems, limited data are available about percolation performance for final cover systems for both conventional and alternative designs. Most of the recent data on flux rates have been generated by two federal research programs, the Alternative Landfill Cover Demonstration (ALCD) and the Alternative Cover Assessment Program (ACAP); see Exhibits 3 and 4, respectively, for further information on these programs. From these programs, flux rate performance data are available for 14 sites with demonstration-scale ET cover systems (Dwyer 2003, Benson and others 2002).

In addition, previous studies have been conducted that monitored the performance of ET covers. Selected studies include the following: integrated test plot experiment in Los Alamos, NM, which monitored both types of ET covers from 1984 to 1987 (Nyhan, Hakonson, and Drennon 1990); Hill Air Force Base alternative cover study in Utah, which evaluated three different covers (RCRA Subtitle D, monolithic ET, and capillary barrier ET) over a 4-year period (Hakonson and others 1994); and Hanford field lysimeter test facility in Richland, WA, which monitored ET covers for 6 years (Gee and others 1993).

Additional demonstration projects of ET covers conducted in the 1980's and early 1990's are discussed in the ACAP Phase I Report, which is available at *http://www.acap.dri.edu*.

Exhibit 3. Alternative Landfill Cover Demonstration (ALCD)

The U.S. Department of Energy (DOE) has sponsored the ALCD, which is a large-scale field test of two conventional designs (RCRA Subtitle C and Subtitle D) and four alternative landfill covers (monolithic ET cover, capillary barrier ET cover, geosynthetic clay liner cover, and anisotropic [layered capillary barrier] ET cover). The test was conducted at Sandia National Laboratories, located on Kirtland Air Force Base in Albuquerque, New Mexico, with cover design information available at *http://www.sandia.gov/Subsurface/factshts/ert/alcd.pdf*. The ALCD has collected information on construction, cost, and performance that is needed to compare alternative cover designs with conventional covers. The RCRA covers were constructed in 1995, and the ET covers were constructed in 1996. All of the covers are 43 feet wide by 328 feet long and were seeded with native vegetation. The purpose of the project is to use the performance data to help demonstrate equivalency and refine numerical models to more accurately predict cover system performance (Dwyer 2003).

The ALCD has collected data on percolation using a lysimeter and soil moisture to monitor cover performance. Total precipitation (precip.) and percolation (perc.) volumes based on 5 years of data are provided below. The ET covers generally have less percolation than the Subtitle D cover for each year shown below. More information on the ALCD cover performance can be found in Dwyer 2003.

	1997 (May 1 - Dec 31)		1998		1999		2000		2001		2002 (Jan 1 - Jun 25)	
	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)
Monolithic ET	267.00	0.08	291.98	0.22	225.23	0.01	299.92	0.00	254.01	0.00	144.32	0.00
Capillary barrier ET	267.00	0.54	291.98	0.41	225.23	0.00	299.92	0.00	254.01	0.00	144.32	0.00
Anisotropic (layered capillary barrier) ET	267.00	0.05	291.98	0.07	225.23	0.14	299.92	0.00	254.01	0.00	144.32	0.00
Geosynthetic clay liner	267.00	0.51	291.98	0.19	225.23	2.15	299.92	0.00	254.01	0.02	144.32	0.00
Subtitle C	267.00	0.04	291.98	0.15	225.23	0.02	299.92	0.00	254.01	0.00	144.32	0.00
Subtitle D	267.00	3.56	291.98	2.48	225.23	1.56	299.92	0.00	254.01	0.00	144.32	0.74

Monitoring systems – Lysimeters are installed underneath a cover system, typically as geomembrane liners backfilled with a drainage layer and shaped to collect water percolation. Water collected in the lysimeter is directed toward a monitoring point and measured using a variety of devices (for example, tipping bucket, pressure tranducers). Lysimeters have been used in the ALCD and ACAP programs for collecting performance data for ET cover systems.

Soil moisture monitoring can be used to determine moisture content at discrete locations in cover systems and to evaluate changes over time in horizontal or vertical gradients. Soil moisture is measured using methods to determine relative humidity, soil matrix potential, and resistance. Table 1 presents examples of non-destructive techniques that have been used to assess soil moisture content of ET cover systems. A high soil moisture value indicates that the water content of the cover system is approaching its storage capacity, thereby increasing the potential for percolation. Soil moisture is especially important for capillary barrier ET cover systems; when the finer-grained layer becomes saturated, the capillary barrier can fail resulting in water percolating through the highly permeable layer to the waste below (Hakonson 1997).

Maintaining the effectiveness of the cover system for an extended period of time is another important performance criterion for ET covers as well as conventional covers. Short-term and long-term performance monitoring of a final cover system includes settlement effects, gas emissions, erosion or slope failure, and other factors.

Numerical models – While there are limitations to numerical models, as previously described, they have been used to predict cover performance and assist in the design of ET cover systems. Numerical models have been used to compare the expected performance of ET cover systems to conventional cover systems. By entering multiple parameters and evaluating the design of cover systems, designs can be modified until

Exhibit 4. Alternative Cover Assessment Program (ACAP)

EPA is conducting the ACAP to evaluate the performance of alternative landfill covers. ACAP began in 1998, and cover performance is currently being evaluated at 13 sites. The sites are located in eight states from California to Ohio, and include a variety of landfill types, such as MSW, construction and demolition waste, and hazardous waste landfills. At eight sites, conventional and ET covers are being tested side by side. At the remaining five sites, only ET covers are being tested.

The alternative covers typically were constructed with local soils and native vegetation. At two facilities, however, hybrid poplar trees were used as vegetation. At 11 sites, percolation performance is being evaluated by lysimeters. At the other two sites, performance is being evaluated indirectly by monitoring leachate production. Soil moisture is also being evaluated at all 13 sites. Below is an example of the field data for precipitation (precip.) and percolation (perc.) volumes at 3 of the sites. A summary of field cover performance for all 13 sites through July 2002 is provided in Albright and Benson 2002. More information about ACAP is available on the Desert Research Institute website at *http://www.acap.dri.edu/*.

Site	Cover Design	Start Date	Year 1		Year 2		Year 3	
			Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)
Altamont, CA (semi-arid)	Monolithic ET	11/00	225	negligible	300	1.5		
	Composite/ compacted clay	11/00	225	negligible	300	negligible		
Polson, MT (semi-arid)	Capillary barrier ET	11/99	300	0.05	300	0.05	250	0.45
	Composite/ compacted clay	11/99	300	0.5	300	0.5	250	0.5
Omaha, NE (humid)	Capillary barrier ET (thick)	10/00	600	55	200	negligible		
	Capillary barrier ET (thin)	10/00	600	100	200	negligible		
	Composite/ compacted clay	10/00	600	5	200	negligible		

Table 1. Examples of Non-Destructive Soil Moisture Monitoring Methods

Method	Description	Instrumentation
Tensiometer	Measures the matric potential of a given soil, which is converted to soil moisture content	Commonly consists of a porous ceramic cup connected to a pressure measuring device through a rigid plastic tube
Psychrometer	Measures relative humidity (soil moisture) within a soil	Generally consists of a thermocouple, a reference electrode, a heat sink, a porous ceramic bulb or wire mesh screen, and a recorder
Electrical resistance blocks	Measures resistance resulting from a gradient between the sensor and the soil; higher resistance indicates lower soil moisture	Consists of electrodes embedded in a gypsum, nylon, or fiberglass porous material
Neutron attenuation	Emits high-energy neutrons into the soil that collide with hydrogen atoms associated with soil water and counts the number of pulses, which is correlated to moisture content	Consists of a probe inserted into access boreholes with aluminum or polyvinyl chloride casing
Time domain reflectrometry	Sends pulses through a cable and observes the reflected waveform, which is correlated to soil moisture	Consists of a cable tester (or specifically designed commercial time domain reflectrometry unit), coaxial cable, and a stainless steel probe

specific performance results are achieved. The numerical model HELP is the most widely used water balance model for landfill cover design. UNSAT-H and HYDRUS-2D are two other numerical models that have been used frequently for the design of ET covers. HELP and UNSAT-H are in the public domain, while HYDRUS-2D is available from the International Ground Water Modeling Center in Golden, CO *http://typhoon.mines.edu* (Dwyer 2003; Khire, Benson, and Bosscher 1997).

Recent studies have compared available numerical models and found that cover design depends on site-specific factors, such as climate and cover type, and that no single model is adequate to accurately predict the performance of all ET covers. Several of the studies identified are: intercode comparisons for simulating water balance of surficial sediments in semi-arid regions, which compared results of seven numerical models for nonvegetated, engineered covers in semiarid regions; water balance measurements and computer simulations of landfill covers, which evaluated ALCD cover performance and predicted results from HELP and UNSAT-H; and field hydrology and model predictions for final covers in the ACAP, which compared performance results with those predicted by HELP and UNSAT-H (Scanlon and others 2002; Dwyer 2003; Roesler, Benson, and Albright 2002).

COST

Limited cost data are available for the construction and operation and maintenance (O&M) of ET cover systems. The available construction cost data indicate that these cover systems have the potential to be less expensive to construct than conventional cover systems. Factors affecting the cost of construction include availability of materials, ease of installation, and project scale. Locally available soils, which are usually less costly than imported clay soils, are typically used for ET cover systems. In addition, the use of local materials generally minimizes transportation costs (Dwyer 2003, EPA 2000a).

While the construction cost for an ET cover is expected to be less than that for a conventional cover, uncertainty exists about the costs for O&M after construction. Several factors affecting the O&M cost include frequency and level of maintenance (for example, irrigation and nutrient addition), and activities needed to address erosion and biointrusion. In addition, when comparing the costs for ET and conventional covers, it is important to consider the types of components for each cover and their intended function. For example, it would generally not be appropriate to compare the costs for a conventional cover with a gas collection layer to an ET cover with no such layer. Additional information about the costs for specific ET cover systems is provided in project profiles, discussed below under Technology Status.

TECHNOLOGY STATUS

A searchable on-line database has been developed with information about ET cover systems and is available at *http://cluin.org/products/altcovers*. As of September 2003, the database contained 56 projects with monolithic ET cover systems and 21 projects with capillary barrier ET cover systems; these systems have been proposed, tested, or installed at 64 sites located throughout the United States, generally from Georgia to Oregon. Some sites have multiple projects, and some projects have multiple covers and/or cover types.

The database provides project profiles that include site background information (for example, site type, climate, precipitation), project information (for example, purpose, scale, status), cover information (for example, design, vegetation, installation), performance and cost information, points of contact, and references. Table 2 provides a summary of key information from the database for 34 recent projects with monolithic ET or capillary barrier ET covers.

In addition to this on-line database, several ongoing federal and state initiated programs are demonstrating and assessing the performance of ET cover systems. The following programs provide performance data, reports, and other useful information to help evaluate the applicability of ET designs for final cover systems.

- Alternative Landfill Cover Demonstration – See Exhibit 3 for more information or *http://www.sandia.gov/Subsurface/factshts/ert/alcd.pdf*
- Alternative Cover Assessment Program – See Exhibit 4 for more information or *http://www.acap.dri.edu*
- Interstate Technology and Regulatory Council – Published a report called *Technology Overview Using Case Studies of Alternative Landfill Technologies and Associated Regulatory Topics*; March 2003. For further information, see *http://www.itrcweb.org*

Table 2. Selected Sites Using or Recently Demonstrating Evapotranspiration (ET) Covers

Site Name and Location	*Site Type*	*Status of Project*	*Date Installed*
Monolithic ET Covers - Full Scale Projects			
Barton County Landfill, Great Bend, KS	MSW landfill	Installation	NA
Coyote Canyon Landfill, Somis, CA	MSW landfill	Operational	April 1994
Duvall Custodial Landfill, Duvall, WA	MSW landfill	Operational	1999
Fort Carson, Colorado Springs, CO	MSW landfill	Operational	October 2000
Hastings Groundwater Contamination Superfund Site, Hastings, NE	MSW landfill	Design	NA
Horseshoe Bend Landfill, Lawrenceburg, TN	Industrial waste landfill	Operational	1998
Idaho National Engineering and Environmental Laboratory Superfund Site, Idaho Falls, ID	Radioactive waste site	Proposed	NA
Industrial Excess Landfill Superfund Site, OH	Industrial waste landfill	Proposed	NA
Johnson County Landfill, Shawnee, KS	MSW landfill	Installation	NA
Lakeside Reclamation Landfill, Beaverton, OR	Construction debris	Operational	1990
Lopez Canyon Sanitary Landfill, Los Angeles, CA	MSW landfill	Operational	1999
Marine Corps Logistics Base Superfund Site, GA	MSW and hazardous waste landfill	Proposed	NA
Municipal Waste Landfill at Kirtland Air Force Base, NM	MSW landfill	Operational	2002
Operating Industries Inc. Landfill Superfund Site, CA	MSW landfill	Operational	May 2000
Pantex Plant, Amarillo, TX	Construction debris	Operational	2000

Site Name and Location	*Site Type*	*Status of Project*	*Date Installed*
Capillary Barrier ET Covers - Full Scale Projects			
Gaffey Street Sanitary Landfill, Wilmington, CA	MSW landfill	Installation	NA
Hanford Superfund Site, Richland, WA*	Radioactive waste site	Operational	1994
McPherson County Landfill, McPherson, KS	MSW landfill	Operational	2002

Site Name and Location	*Site Type*	*Status of Project*	*Date Installed*
Monolithic ET Covers - Demonstration Projects			
Altamont Landfill, Livermore, CA (ACAP project)	Non-hazardous waste site	Operational	November 2000
Bluestem Landfill #2, Marion, IA (ACAP project)	MSW landfill	Operational	October 2000
Finley Buttes Regional Landfill, OR (ACAP project)	MSW landfill	Operational	November 2000
Green II Landfill, Logan, OH (ACAP project)	MSW and hazardous waste landfill	Operational	2000
Kiefer Landfill, Sloughhouse, CA (ACAP project)	Non-hazardous waste site	Operational	July 1999
Marine Corps Logistics Base, Albany, GA (ACAP project)	MSW and hazardous waste landfill	Operational	March 2000
Milliken Landfill, San Bernadino County, CA (ACAP project)	MSW landfill	Operational	1997
Monterey Peninsula Landfill, Marina, CA (ACAP project)	Non-hazardous waste site	Operational	May 2000
Rocky Mountain Arsenal Superfund Site, Denver, CO	Hazardous waste site	Complete	April 1998
Sandia National Laboratories, NM (ALCD project)	Non-hazardous waste site	Operational	1996

Site Name and Location	*Site Type*	*Status of Project*	*Date Installed*
Capillary Barrier ET Covers - Demonstration Projects			
Douglas County Landfill, Bennington, NE (ACAP project)	MSW landfill	Operational	August 2000
Hill Air Force Base, Ogden, UT	Hazardous waste landfill	Operational	1994
Lake County Landfill, Polson, MT (ACAP project)	MSW landfill	Operational	November 1999
Lewis and Clark County Landfill, MT (ACAP project)	Non-hazardous waste site	Operational	November 1999
Sandia National Laboratories, NM (ALCD project)	Non-hazardous waste site	Operational	1996
Uranium Mill Tailings Repository, UT (ACAP project)	Hazardous waste landfill	Operational	July 2000

Notes:
* Project conducted as Superfund treatability test study with cover constructed over an existing waste site
NA Not Applicable
ALCD Alternative Landfill Cover Demonstration; program supported by DOE
ACAP Alternative Cover Assessment Program; program supported by EPA

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Cincinnati, OH 45242-2419
Telephone: (513) 489-8190 or (800) 490-9198
Fax: (513) 489-8695

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