STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION

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In the Matter of:	)	
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PROPOSED AMENDMENT	)	**No. WQCC 12-01(R)**
TO 20.6.2 NMAC (Copper Rule)	)	
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	)	

EXHIBIT MUNK – 2

Fact Sheet on Evapotranspiration Cover Systems for Waste Containment

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INTRODUCTION

This fact sheet updates the Evapotranspiration Landfill Cover Systems Fact Sheet that was published in 2003. At that time evapotranspiration (ET) covers were more in a demonstration phase. Now they are increasingly being considered for use at waste disposal sites. These include municipal solid waste (MSW) landfills, hazardous waste (HW) landfills, and isolated arid waste sites when equivalent performance to conventional final cover systems can be demonstrated. Conventional cover system designs use barrier layers consisting of materials with low hydraulic conductivity (e.g., clay, geosynthetic clay liners, or geomembranes) to minimize the percolation of water from the cover to the waste. ET cover systems use water balance components to minimize percolation. These cover systems rely on

> The alternative covers database contains 222 project profiles. These project profiles include site background information, cover type and construction details, status (proposed, complete, under construction), cost information, and contacts. Sources of information include EPA and state websites, conference proceedings, studies, and individual contributions. Individuals wishing to have a cover they are familiar with listed can submit it online. The database is updated as new information becomes available.
>
> Appendix A of this document contains a list of ET sites by EPA region and state.
>
> http://cluin.org/products/altcovers

This fact sheet is intended solely to provide general information about evapotranspiration covers. It is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation with the United States. Use or mention of trade names does not constitute endorsement or recommendation for use.

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soil properties (e.g., soil texture and associated soil water storage capacity) to store water until it is either transpired through vegetation or evaporated from the soil surface.

The fact sheet provides a summary of ET technical issues, including design considerations, performance monitoring, cost, technology status, and potential limitations on use. It is intended to provide basic information to site owners and operators, regulators, consulting engineers, and other interested parties about these potential design alternatives. Appendix A updates the 2003 list of ET cover sites by adding over 130 new full scale examples. A separate on-line database provides more site specific information about these sites as well as other projects using ET covers.

Additional sources of information are also provided in the project specific references in the database.

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 actual design or construction, nor is it intended to suggest that ET final cover systems should be used at any particular site.[1] The fact sheet does not address alternative materials for use in final cover systems, or other alternative cover system designs, such as asphalt covers.

BACKGROUND

Final cover systems often are used at landfills; abandoned dumps; some hazardous, low-level, and mixed low-level waste sites with conducive environmental conditions; hazardous waste containment facilities; sites with surface contamination; and other types of waste disposal sites. There are a number of reasons for using them, including to control moisture and percolation, manage surface water runoff, minimize erosion, prevent direct exposure to 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 periods of many decades to hundreds of years. Cover systems may be used alone or, if warranted, in conjunction with other technologies (for example, slurry walls and groundwater pump and treat systems) to contain waste or leachate.

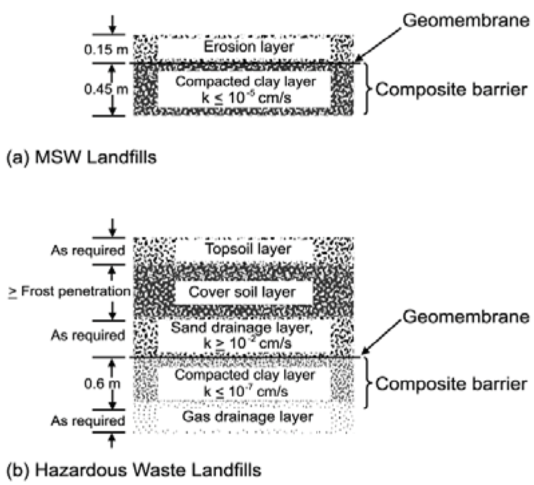
The design of cover systems is site specific and depends on the intended function of the final cover–cover designs can range from a single layer of soil to a complex multi-layer system that includes synthetic materials. To minimize percolation, conventional cover systems typically use low-conductivity 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 $1x10^{-5}$ and $1x10^{-9}$ centimeters per second (cm/s). In addition, conventional cover systems generally include shallow-rooted plants and 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 2001b).

The design, construction, and maintenance of cover systems may be subject to statutory and regulatory requirements under various federal and state programs; some of these requirements also may come into play in cleanup programs. For example, with regard to municipal solid waste facilities, regulations under the Resource Conservation and Recovery Act (RCRA) for the design and construction of final cover systems are based on using a low-conductivity barrier layer (conventional cover system). Under RCRA Subtitle D (40 CFR 258.60), the minimum design requirements for final cover systems at municipal solid waste landfills (MSWLF) 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 or equal to that of the bottom liner system (or natural subsoils) or a permeability no greater than $1x10^{-5}$ 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.

[1] For example, EPA's Superfund remedy selection decisions are made on a site-specific basis. Thus, final cover systems are evaluated in a manner consistent with the overall framework established for remedy selection under CERCLA, the National Oil and Hazardous Substances Pollution Contingency Plan, and associated Superfund program guidance.

Until March 2004, the equivalent reduction language provided the statutory underpinning for proposing an alternative cover at an MSWLF. On March 22, 2004, 40 CFR 258 was amended to allow for research, development, and demonstration permits (40 CFR 258.4). These permits are issued for three years with up to three renewals (12 years total). The regulation states, “The director of an approved state may issue a research, development, and demonstration permit for a new MSWLF unit, existing MSWLF unit, or lateral expansion, for which the owner or operator proposes to utilize innovative and new methods which vary from the final cover criteria of §258.60(a)(1), (a)(2) and (b)(1), provided the MSWLF unit owner/operator demonstrates that the infiltration of liquid through the alternative cover system will not cause contamination of groundwater or surface water, or cause leachate depth on the liner to exceed 30 cm.”

Figure 1 shows the minimum recommended requirements for a typical conventional Subtitle D landfill which consist of a 6-inch soil erosion layer, a geomembrane (when the landfill has a geomembrane liner), and an 18-inch barrier layer of soil that is compacted to yield a saturated hydraulic conductivity equal to or less than $1x10^{-5}$ cm/s (EPA 1992).



Source EPA 1992a and 1989

Figure 1. *Examples Subtitle D and C Cover Design.*

As another example, for hazardous waste landfills, RCRA Subtitle C (40 CFR 264 and 265) provides certain design specifications for final cover systems. These include the same provision for Subtitle D that the cover system have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present. To help implement these regulatory requirements, EPA has issued guidance for the minimum design of these final cover systems. Figure 1 shows an example of a RCRA Subtitle C cover at a hazardous waste landfill (EPA 1989).

The design and construction requirements, as defined in the RCRA regulations, also may be applied under RCRA corrective action and other cleanup programs (e.g., Superfund or state cleanup programs). At Superfund remedial sites involving on-site disposal, the RCRA regulations for conventional covers usually are identified as applicable or relevant and appropriate requirements (ARARs) for the site.[2] 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.

Examples of sites that have proposed, approved, or installed ET covers and the regulatory program they are operating under are given in Appendix A. Details on these sites can be found in the alternative cover profiles database at http://cluin.org/products/altcovers.

DESCRIPTION

ET cover systems are designed to rely on the ability of a soil layer to store the precipitation until it is naturally evaporated or is transpired by the vegetative cover. In this respect they differ from more conventional cover designs in that they rely on obtaining an appropriate water storage capacity in the soil rather than an as-built engineered low hydraulic conductivity. 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 are, the lower the potential for percolation through the cover system.

[2] In addition to compliance with ARARs, CERCLA Section 121 requires that remedial actions ensure protectiveness of human health and the environment.

ET cover system designs tend to emphasize the following (Dwyer 2003; Hakonson 1997; Hauser, Weand and Gill 2001b):

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

Use of local soils allows the opportunity to utilize natural analogue data for speculating future performance.

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.

ET cover systems are constructed using a monolithic soil barrier. Monolithic covers, also referred

Exhibit 1. *Monolithic Cover at Lopez Canyon Sanitary Landfill*

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. In 2001, fifty 30-KW microturbines that use landfill gas as fuel were installed at the site. They provide sufficient electricity to power 1,500 homes.

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 AB+ 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: Initial 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

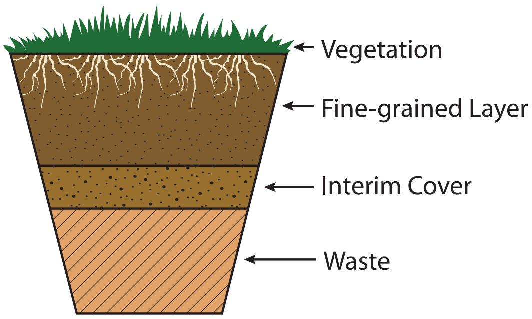


Figure 2. *Conceptual Design of a Monolithic ET Cover*

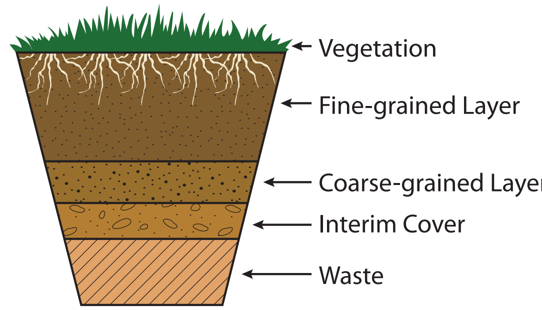


Figure 3. *Conceptual Design of a Capillary Barrier ET Cover*

to as monofill covers, use a single fine-grained soil layer to retain water and support the vegetative community (Albright et al. 2010 and Hauser 2009). Figure 2 shows an example of a monolithic ET cover. Exhibit 1 provides an example of a full-scale monolithic cover at a MSW landfill.

A monolithic cover design can be modified by adding a capillary break. This entails placing a coarser grained material, usually a sand or gravel, under the monolithic fine-grained soil, as shown conceptually in Figure 3. The differences in the unsaturated hydraulic properties (i.e., soil matric potential) between the two layers minimize percolation into the coarser grained (lower) layer under unsaturated conditions (Stormont 1997). The finer-grained layer 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 discontinuity in pore sizes between the coarser-grained and finer-grained layers forms a capillary break at the interface of the two layers. The break results in the wicking of water into unsaturated pore space in the finer grained soil, 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

Exhibit 2. *Capillary Barrier ET Cover at Rocky Mountain Arsenal Superfund Site*

Site type: Consolidation area covers

Scale: Full scale

Cover design: These RCRA Subtitle C equivalent ET covers have been constructed for former waste disposal basins and manufacturing process areas that were contaminated during pesticide production. The design consists of a minimum of 16 inches of crushed concrete placed as a biota barrier, followed by a capillary barrier layer of pea gravel that provides a capillary break. The surface soil layer consists of at least 4 feet of soil seeded with a mix of cool and warm season native vegetation.

Modeling: Construction parameters were developed using data from a four year RCRA equivalent demonstration study. The modeling was done using UNSAT-H.

Maintenance activities: Construction began in 2007 and finished in 2009. The covers are currently being monitored and maintained.

Performance: The ET cover performance is monitored using a number of pan lysimeters (30 feet x 50 feet) which have shown that the cover is performing as expected.

Cost: According to the responsible party, the total cost of constructing the ET covers was $69 million, and they cover approximately 450 acres.

Sources: Rocky Mountain Arsenal cleanup site: http://www.rma.army.mil/; and EPA Region 8 Superfund site: http://www.epa.gov/region8/superfund/co/rkymtnarsenal/index.html.

occurs, the water will move relatively quickly into and through the coarser-grained layer and to the waste below (Albright et al. 2010, Hauser 2009, and ITRC 2003). Exhibit 2 provides an example of a capillary barrier at a Rocky Mountain Arsenal hazardous waste site.

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 (generally accepted as areas having less than 10 and 20 inches of precipitation, respectively). In these environments, they may be less prone to deterioration from desiccation, 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 (Albright and Benson 2005, Benson et al. 2002; Dwyer et al. 1999).

LIMITATIONS

Although they have been approved in humid climates (e.g., Marine Corps Logistics Station Albany, GA and General Electric, Schenectady, NY), ET cover systems are generally considered more applicable in areas that have arid or semi-arid climates like those found in parts of the Great Plains and West (e.g., North and South Dakota, Montana, Idaho, eastern Washington and Oregon, Utah, Colorado, West Texas, New Mexico, Arizona, Nevada, and southern California). Albright and Benson (2005) in their examination of data generated in EPA's Alternative Cover Assessment Program (ACAP) found: "In humid locations with the abundant precipitation and typically lower potential evapotranspiration, the store-and-release mechanism used by ET covers does not provide sufficient hydraulic control to match the performance of *conventional composite covers*." (emphasis added) However, the ACAP field data did show that in humid locations properly designed ET covers can provide performance comparable to that of the *compacted clay covers* in those locations.

In addition, site specific conditions, such as site location (e.g., appropriate soil) and landfill characteristics, may limit the use or effectiveness of ET cover systems. Local climatic conditions (amount, seasonal distribution, and form of precipitation) also can limit the effectiveness of an ET cover at a given site. For example, snow often melts when vegetation is dormant, and without sufficient water storage capacity unacceptable percolation might occur (EPA 2000; Hauser, Weand, and Gill 2001b). However, if technically and financially feasible, this might be mitigated by thickening the ET layer.

Two federal research programs, the Department of Energy (DOE) sponsored Alternative Landfill Cover Demonstration (ALCD) and the ACAP, provide the best collection of data to describe the performance of ET cover systems in terms of minimizing percolation. Hauser (2009) also has some additional performance information; however, there are limited data on the ET covers' ability to minimize erosion, resist biointrusion, and retain long-term effectiveness. On the other hand, erosion, effectiveness of biobarriers, and maintenance of vegetative cover over extended periods of time are issues faced by all conventional covers, and those design aspects are similar to ET covers. While the principles of ET covers and their corresponding soil properties have been understood for many years, their application as final cover systems for landfills has emerged only since the mid-1990s. Regulators in southern California initially required any landfill operator who wanted to deploy an ET cover to set up a demonstration project to prove equivalency. The success of these demonstrations has led to the regulators allowing an ET cover if the landfill owner shows that soil, design, and climatic conditions are similar to those of a landfill facility with a permitted ET cover.

DESIGN 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 amount, form, and distribution of precipitation over a year, combined with factors that influence potential evapotranspiration, determine the total amount of water storage capacity needed for the cover system. This information can usually be found at nearby weather stations. 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 con-

Summary of Key Design Considerations

- Climate—amount, form and timing of precipitation determines storage capacity need
- Soil Type—finer grained soils are preferred for fertility and storage capacity
- Soil Thickness—combined with soil type determines storage capacity of cover
- Vegetation Types—must be appropriate for location with well developed root systems to promote transpiration and provide long-term performance
- Soil Fertility—to sustain vegetation when plants are used
- Control Layers—biobarriers, gas collection, and drainage layers are used as needed

ditions during cool winter weather with persistent, light precipitation. Storage capacity is particularly important if the event occurs when local vegetation is dormant, resulting in little or no transpiration. Other factors related to climate that are important to cover design are temperature, wind, and relative humidity (Benson 2001; EPA 2000; Hauser, Weand, and Gill 2001b).

Soil Type

Finer-grained materials, such as silts and clayey silts, are typically used for ET cover systems because they have a greater storage capacity than sandy soils. Sandy soils are typically used for the bottom layer of the ET 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, and sandy loam. The storage capacity of the soil varies among different soil types and requires laboratory analysis to quantify. One key aspect of construction is avoiding over-compaction (greater than 80-90%) during placement. Higher bulk densities from over-compaction may reduce the storage capacity of the soil and inhibit growth of roots (Chadwick et al. 1999; Hauser et al. 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 the design climate 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 feet to 2 feet.

In some arid to semiarid areas, when there is a lack of local precipitation data, the potential performance of an ET cover might be estimated by natural analog. This is done by trenching and examining the trench walls for a caliche layer. Caliche ($CaCO_3$) is a precipitation product and when shallow generally indicates the level of deepest recent percolation. Also, an accumulation of soluble ions such as chloride can indicate the depth of recent percolation.

Vegetation Types

Vegetation for the cover system is used to promote transpiration and minimize erosion by stabilizing the surface of the cover. It can also be used for aesthetics or to promote habitat. Grasses, shrubs, and trees have all been used on ET covers. A mixture of native plants generally is planted, though not always, because native vegetation usually is more tolerant than imported vegetation to regional conditions, such as extreme weather and disease. A combination of warm- and cool-season species should provide water uptake throughout the entire growing season, which enhances transpiration. In addition, native vegetation species are less likely to disturb the natural ecosystem (Dwyer et al. 1999; EPA 2000).

If deep rooting vegetation is considered for the cover, the designer should consider whether root penetration into the waste area will result in any transport of constituents into the above ground biomass. The presence of constituents such as heavy metals or radionuclides in leaf and stem tissue could present a hazard.

Finally, consideration needs to be given to how long the selected vegetation will take to establish itself and how this will affect the cover's performance.

Soil Fertility

When vegetation is a component of an ET cover system, the evaluation of the soil that is proposed for the cover (not the subgrade) should include a determination of whether the pH, cation exchange capacity, organic matter, and nitrogen, phosphorus, potassium, and micronutrient content are appropriate for the vegetation proposed for use on the cover (ITRC 2003b, Albright et al. 2010). Amendments, such as lime, biosolids, sawdust, or synthetic conditioners, can be worked into the soil to improve its suitability for planting and/or water storage capacity. These types of amendments, while adding to the cover construction cost, tend to be long-lived and should not need to be repeated. Fertilizers and amendments, such as manure, can be added at initial planting to help establish the cover; however, they are not long-lived and must be reapplied in nutrient-poor soils on a regular basis. The need for reapplication of fertilizers will present an ongoing cost to the project and should be carefully evaluated in selecting an ET cover over a conventional cover. While it is not necessary that borrow soils be obtained on-site or locally, the cost of transporting them any distance should be considered (e.g., it could be prohibitively expensive). For a more complete discussion, see Section 5.2 Preconstruction Cover Material Specifications of ITRC 2003b.

Control Layers

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 into ET cover system designs. For example, a capillary barrier ET cover for the mixed waste landfill at Sandia National Laboratories in New Mexico has a one-foot-thick crushed rock biobarrier located beneath the soil cover (about four feet bgs) to prevent animals from burrowing into the waste layer. Because of the difference in size between the soil and the rock, the rock layer also acts as a capillary break. At another site, Monticello Uranium Mill Tailings Site in Utah, an ET capillary barrier design has a cobble layer as an animal intrusion barrier located within the fine soil layer and above the 12-inch thick capillary barrier layer.

PERFORMANCE MONITORING

Protection of groundwater quality often is a primary performance goal for all waste containment systems, including final cover systems. The potential adverse impact to groundwater quality can result from the release of leachate generated in landfills or other closed in-place waste disposal units such as unlined 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 typically 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 pan lysimeters or estimated indirectly using soil moisture measurements and soil matric potential, thereby allowing the calculation of a flux rate. A more detailed summary on the advantages and disadvantages of both approaches can be found in Benson et al. (2001) and EPA (2004).

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 readily available data on flux rates have been generated by the ACAP and ALCD programs; see Appendix B for discussion and data presentation. From these programs, flux rate performance data are available for 14 sites with demonstration-scale ET cover systems (Dwyer 2003, Albright and Benson 2005).

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

Monitoring Systems

Direct measurement of water flowing through the bottom of a cover can be done using a pan lysimeter. The lysimeters are installed underneath the 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 transducers). Pan lysimeters were used in the ALCD and ACAP programs for collecting performance data for ET cover systems and are part of the design for the Rocky Mountain Arsenal cover systems. They are the monitoring system of choice for equivalency demonstrations. Details of the ACAP lysimeters are in Albright et al. (2004).

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 water properties are measured using a variety of methods and include methods for determining soil moisture (TDR, neutron attenuation, and resistivity), soil humidity (psychrometer), and soil matric potential (heat dissipation units or HDUs). 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). Monitoring instruments have various configurations, costs, and accuracies. The choice of which one to use would depend on the site data quality objective.

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. Some factors to consider in evaluating short-term and long-term performance monitoring of a final cover system include settlement effects, gas emissions, erosion or slope failure, and maintenance of vegetative cover. These factors can be monitored using a variety of methods including settlement gauges, erosion pins, TDR cables for subsidence, soil gas wells and associated sampling ports, and remote sensing (e.g., LIDAR).

Numerical Models

Models can be used to support the design of ET covers. Although models have strengths and weaknesses and none can accurately predict cover behavior in all environments, in their simplest application, a model can be used to test the assumptions made in the designer's conceptual model. A good example of this is where model simulation shows a cover thickness that is clearly too thin or shows diminishing returns in adding more soil beyond an optimum thickness to achieve water storage capacity. Simulations by several models to test the conceptual model and design can be very useful in identifying critical assumptions where a small change can result in large performance deviations. Identifying sensitive assumptions allows for more conservative design specifications or the application of greater quality control checks. If such a procedure is desirable, a model using Richards' equation (ITRC 2003b) is necessary to properly simulate the mechanisms important to cover function. At sites where ET engineered barriers are expected to last hundreds or thousands of years (e.g., DOE low-level radioactive burial grounds), the modeling should include extreme weather events and their resultant affects on engineered barrier design.

A number of models have been used for estimating water balances. Research reviewed for this fact sheet suggests that opinions differ among practitioners about how successful a given model will be in predicting cover performance. A model should only be selected after examining its strengths and weaknesses in simulating site-specific conditions. For example, if early snowmelt is a critical factor, how well does the model simulate it? For design purposes it might be prudent, though somewhat more expensive, to use two models, such as a water balance and a numerical model, to estimate cover performance (Khire et al. 1997). Table 2 in Chapter 3 of Albright et al. (2002) compares the processes and attributes of 10 models.

Table 1. Examples of Non-Destructive Soil Moisture Monitoring Methods		
Method	**Description**	**Instrumentation**
Capacitance sensor	Uses frequency domain induced polarization to measure the dielectric properties of the soil. The dielectric of dry soil is approximately 5, and the dielectric of water is approximately 80. When soil becomes moistened by water, its dielectric increases.	Consists of a probe connected to a coaxial cable and buried at appropriate depth
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
Gee lysimeter	Wicks water from soil around a collection container and measures the resulting water level in the container directly	Consists of a small collector body and a wick. The water level in the collector body is measured by an electronic water level gauge.
Thermal dissipation unit	Uses a heated ceramic block to determine soil moisture near the block. The rate of heat dissipation from the block is related to soil moisture—the quicker the dissipation the higher the soil moisture.	Consists of a small heater inside a porous block with a temperature sensor attached by cable to a surface meter
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
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
Suction lysimeter	Collects pore (unsaturated) water directly	Constructed of a porous ceramic bulb with a cylindrical reservoir to store water. A tube to the surface allows water to be drawn and measured.
Tensiometer	Measures the matric potential of a given soil, which is converted to soil moisture content	Commonly consists of a porous ceramic cup
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

The numerical model HELP is a widely used water balance model that is most appropriate for non-ET landfill cover design. UNSAT-H, VADOSE/W and HYDRUS-1D/2D/3D are examples of numerical models that have been used frequently for the design of ET covers. Some models are in the public domain, others require purchase. Hauser (2009) recommends using the water balance Erosion Productivity Impact Calculator (EPIC), which is in the public domain, for ET cover modeling. EPIC is a water balance model and does not use Richards equation.

COST

Despite the large number of projects installed to date, limited cost data are available for the construction and operation and maintenance 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, especially those requiring geomembranes. Factors affecting the cost of construction include soil layer thickness, availability of materials, placement methods, and project scale. Locally available soils are typically used for ET cover systems. In addition, the use of local materials generally minimizes transportation costs (Dwyer 2003, EPA 2000). Also, 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 some of the project profiles discussed under Technology Status.

TECHNOLOGY STATUS

EPA has developed and recently updated a searchable on-line database with information about ET cover systems, available at http://cluin.org/products/altcovers. As of February 2011, the database contained 167 projects with full scale monolithic ET cover systems and 5 projects with capillary barrier ET cover systems; these systems have been proposed, tested, or installed throughout the United States. Full scale applications have primarily been in the Great Plains and western states. Where data are available, the database provides project profiles that include site background information (such as site type, climate, hydrogeology), project information (such as purpose, scale, status), cover information (such as design, vegetation, installation), performance and cost information, points of contact, and references. Appendix A provides a summary of key information from the database for projects with monolithic ET or capillary barrier ET covers.

In addition to this on-line database, several federal and state programs have demonstrated and assessed 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 in Appendix B for more information or http://www.sandia.gov/Subsurface/factshts/ert/alcd.pdf.
- Alternative Cover Assessment Program: See Exhibit 4 in Appendix B for more information or http://www.dri.edu/acap-research.
- Interstate Technology and Regulatory Council published two reports on ET covers: *Technology Overview Using Case Studies of Alternative Landfill Technologies and Associated Regulatory Topics* and *Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers*. For further information, see http://www.itrcweb.org/guidancedocument.asp?TID=21.

In the initial stages of its program, California required any landfill that desired to employ an ET cover to conduct a demonstration project. The success of these demonstrations has led to the regulators allowing an ET cover if the landfill owner shows soil, design, and climatic conditions are similar to those of a landfill facility with a permitted ET cover. Texas has a similar program. Both of these states have seen a significant increase in the number of landfills using or proposing ET covers.

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This fact sheet is available for viewing or downloading from EPA's Hazardous Waste Cleanup Information (CLU-IN) web site at http://cluin.org.

GLOSSARY

Arid and semi arid climates. In 1953, Peveril Meigs divided desert regions on Earth into three categories according to the amount of precipitation they received. In this now widely accepted system, extremely arid lands have at least 12 consecutive months without rainfall, arid lands have less than 250 millimeters of annual rainfall, and semiarid lands have a mean annual precipitation of between 250 and 500 millimeters. Arid and extremely arid land are deserts, and semiarid grasslands generally are referred to as steppes. (USGS webpage http://pubs.usgs.gov/gip/deserts/what/)

Caliche. A subsurface carbonate horizon formed in a soil in an arid to semiarid region under conditions of low rainfall. The leaching of carbonates from the upper soil by precipitation combined with its limited downward percolation results in an accumulation of carbonates that form an often hard carbonate horizon and designate the deepest penetration of the precipitation.

Composite cover. A landfill cover that includes a synthetic layer such as a geomembrane.

Dump. An area where illegal waste disposal has occurred.

Evapotranspiration. The combination of water lost from the soil through direct evaporation and water lost to the atmosphere through plant transpiration.

Geosynthetic clay liner. A woven fabric that encases a clay material, generally a smectite clay, to provide a low permeability layer.

Hydraulic conductivity. In hydrology, a numeric coefficient describing the rate that water can move through a porous media. Usually expressed in cm/sec.

Infiltration. The movement of water from the soil surface into the soil.

Natural analog. A subsurface feature that occurs naturally that can be used to evaluate a similar engineered feature. In ET design the presence of a near surface caliche layer or chloride ion accumulation gives an indication of how deep precipitation is percolating in the subsurface.

Percolation. The movement of water through soil.

Permeability. The capacity of a porous media to transmit a fluid.

Richards equation. A numerical representation of unsaturated flow of a fluid through porous media.

Water balance. In the context of a landfill cover, the evaluation of the end fate of precipitation; that is, percent run-off, infiltration, evaporation, transpiration, and percolation.

Store and release. In the context of an ET cover, the cover soil will store precipitation (i.e., prevent its drainage into the underlying waste), until the water either evaporates or is transpired by the vegetative cover.

APPENDIX A

PROPOSED, APPROVED, AND INSTALLED SITES HAVING EVAPOTRANSPIRATION COVERS

This table is a list by region and state of sites that have proposed, approved, or installed ET covers. It also contains sites that had demonstration scale pilots, which may or may not have gone on to full scale. Proposed covers include sites where an ET cover has been proposed by the facility and approved by the governing agency (e.g., California) or has been proposed by the facility but approval is pending (e.g., Texas). In Texas the proposal is generally to amend an existing permit to add ET covers as an option. The state of Oklahoma provided a list of landfills that had approved and installed ET covers as did the states of Colorado and Montana. The state of Arizona provided electronic copies of the permits of facilities that had approved or installed ET covers. The California Regional Water Control Boards maintain electronic copies of their permits on their webpages as does the state of Utah. Sites were excluded from the list if the permit specifically called for a water infiltration barrier layer even though the permit referred to the cover as an ET cover. A legend and list of definitions is found at the end of the table.

Evapotranspiration Covers

Site	Program	Type of Site	Scale	Status	Type of Cover
Region 1					
Region 2					
New York					
GE Main Plant, Schenectady, NY	RCRA	HWS	F	Installed	M
State-Licensed Radioactive Waste Disposal Area, West Valley, NY	NRC	Rad	Demo	Complete	BE
Region 3					
Maryland					
Beltsville Agricultural Research Center (USDA), Beltsville, MD	NRC	Rad	Demo	Complete	BE
College Park Landfill, College Park, MD	CERCLA	MSW	Demo	Complete	M
College Park Landfill, College Park, MD	CERCLA	MSW	F	Proposed	M
Pennsylvania					
Welsh Road Landfill, Honeybrook, PA	CERCLA	MSW	F	Installed	M
Region 4					
Georgia					
Marine Logistics Base Albany Georgia	ACAP	MSW	Demo	Complete	M
Marine Logistics Base Albany Georgia	CERCLA	MSW	F	Installed	M
Region 5					
Illinois					
Sheffield City Landfill, Sheffield, IL	NRC	Rad	Demo	Complete	CB
Michigan					
Casting Sand Landfill, Detroit, MI	RCRA	IW	Demo	Complete	M
Wisconsin					
Omega Hills, Milwaukee, WI	RCRA	MSW	Demo	Complete	CB
Region 6					
New Mexico					
Cerro Colorado Landfill, Albuquerque, NM	RCRA	MSW	F	Proposed	M
Chemical Waste Landfill at Sandia National Laboratories, Albuquerque, NM	RCRA	HWS	F	Installed	M
Crouch Mesa Landfill, Farmington, NM	RCRA	MSW	F	Proposed	M
Kirtland Air Force Base, Albuquerque, NM	RCRA	HW	F	Installed	M

Site	Program	Type of Site	Scale	Status	Type of Cover
Los Alamos National Laboratory, Los Alamos, NM	DOE Research	Rad	Demo	Complete	CB
Mixed Waste Landfill at Sandia National Laboratories, Albuquerque, NM	RCRA	MW	F	Installed	M
Molycorp Tailings Facility, Questa, NM	CERCLA	HWS	F	Proposed	M
Red Rocks Regional Landfill, Thoreau, NM	RCRA	MSW	F	Proposed	M
Rio Rancho Landfill, Rio Rancho, NM	RCRA	MSW	F	Approved	M
Sandoval County Landfill, Bernalillo, NM	RCRA	MSW	F	Proposed	M
Sandia National Laboratories, Albuquerque, NM	RCRA	NHWS	Demo	Complete	M and CB
San Juan County Landfill, Aztec, NM	RCRA	MSW	F	Approved	M
Valencia Landfill, Los Lunas, NM	RCRA	MSW	F	Approved	M
Oklahoma					
Alderson Landfill, McAlester, OK	RCRA	MSW	F	Installed	M
American Environmental, Sand Springs, OK	RCRA	MSW	F	Installed	M
Broken Arrow Landfill, Broken Arrow, OK	RCRA	MSW	F	Installed	M
Canadian Valley Landfill, Shawnee, OK	RCRA	MSW	F	Installed	M
Center Point Landfill, Prague, OK	RCRA	MSW	F	Approved	M
City of Sallisaw, Sallisaw, OK	RCRA	MSW	F	Approved	M
East Oak Landfill, Oklahoma City, OK	RCRA	MSW	F	Approved	M
Muskogee Community Landfill, Muskogee, OK	RCRA	MSW	F	Approved	M
Newcastle Landfill, Newcastle, OK	RCRA	MSW	F	Installed	M
Oklahoma Landfill, Oklahoma City, OK	RCRA	MSW	F	Installed	M
Osage Landfill, Bartlesville, OK	RCRA	MSW	F	Design	M
Porter Landfill, Porter, OK	RCRA	MSW	F	Installed	M
Quarry Landfill, Tulsa, OK	RCRA	MSW	F	Installed	M
Red Carpet, Meno, OK	RCRA	MSW	F	Approved	M
Southeast OKC Landfill, Oklahoma City, OK	RCRA	MSW	F	Installed	M
Southern Plains, Ninnekah, OK	RCRA	MSW	F	Approved	M
Stillwater Landfill, Stillwater, OK	RCRA	MSW	F	Approved	M
Texas					
Caliche Canyon Landfill, Lubbock, TX	RCRA	MSW	F	Proposed	M
City of Corsicana Landfill, Corsicana, TX	RCRA	MSW	F	Proposed/ Pending	M
City of Fredericksburg Landfill, Fredericksburg, TX	RCRA	MSW	F	Proposed/ Pending	M
City of Kerrville, Kerrville, TX	RCRA	MSW	F	Proposed/ Pending	M
City of Lubbock Landfill, Lubbock, TX	RCRA	MSW	F	Installed	M
City of Snyder Landfill, Snyder, TX	RCRA	MSW	F	Proposed	M
City of Victoria Landfill, Victoria, TX	RCRA	MSW	F	Proposed/ Pending	M
DFW Recycling Disposal Facility, Lewisville, TX	RCRA	MSW	F	Proposed/ Pending	M

Site	Program	Type of Site	Scale	Status	Type of Cover
El Centro Landfill, Robstown, TX	RCRA	MSW	F	Proposed/ Pending	M
Golden Triangle Landfill, Beaumont, TX	RCRA	MSW	F	Proposed/ Pending	M
Itasca Landfill, Itasca, TX	RCRA	MSW	F	Proposed/ Pending	M
Mexia Landfill Mexia, TX	RCRA	MSW	F	Proposed// Pending	M
Pantex Plant (USDOE), Amarillo, TX	RCRA	CD	F	Installed	M
Pleasant Oaks Landfill, Mt. Pleasant, TX	RCRA	MSW	F	Proposed/ Pending	M
Rio Grande Valley Landfill, Donna, TX	RCRA	MSW	F	Proposed/ Pending	M
Sierra Blanca, Sierra Blanca, TX	Texas Low Level Rad	Rad	Demo	Complete	CB
Turkey Creek Landfill, Alvarado, TX	RCRA	MSW	F	Proposed/ Pending	M
Westside Landfill, Sledo, TX	RCRA	MSW	F	Installed	M
Region 7					
Iowa					
Bluestem Landfill Site No. 1, Cedar Rapids, IA	ACAP	MSW	Demo	Complete	M
Bluestem Landfill Site No. 2, Cedar Rapids, IA	ACAP	MSW	Demo	Complete	M
Grundy County Landfill, Grundy Center, IA	RCRA Cleanup	MSW	Demo	Complete	M
Kansas					
Barton County Landfill, Great Bend, KS	RCRA	MSW	F	Installed	M
Chanute Landfill, Chanute, KS	RCRA	MSW	F	Installed	M
Coffey County Landfill, Burlington, KS	RCRA	MSW	F	Installed	M
Holcomb Combustion Waste Landfill, Holcomb, KS	RCRA	IW Ash	F	Proposed	M
Johnson County Landfill, Shawnee, KS	RCRA	MSW	F	Installed	M
McPherson County Landfill, McPherson, KS	RCRA	MSW	F	Installed	M
Seward County Landfill, Liberal, KS	RCRA	MSW	F	Proposed	M
Missouri					
Electrical Power Plant, St. Louis, MO	RCRA	IW Ash	Demo	Complete	M
RCRA Solid Waste Unit at Former Wood Treating Plant, Kansas City, MO	RCRA	HWS	F	Installed	M
Nebraska					
Douglas County Recycling and Disposal Facility, Bennington, NE	ACAP	MSW	Demo	Complete	CB
Hastings Groundwater Contamination, Hastings, NE	CERCLA	MSW	F	Installed	M
Region 8					
Colorado					
Buffalo Ridge Landfill, Keenesburg, CO	RCRA	MSW	F	Approved	M
Clear Springs Ranch Ash Monofill, Fountain, CO	RCRA	IW	F	Approved	M
Colorado Springs Landfill, Colorado Springs, CO	RCRA	MSW	F	Installed	M

Site	Program	Type of Site	Scale	Status	Type of Cover
Conservation Services, Inc. Adams County, CO	RCRA	MSW	F	Installed	M
Custer County Landfill, Westcliffe, CO	RCRA	MSW	F	Installed	M
Denver Arapahoe Disposal Site, Arapahoe, CO	RCRA	MSW	F	Installed on closed cells	M
Fort Carson, Colorado Springs, CO	RCRA	MSW	F	Installed	M
Kit Carson County Landfill, Burlington, CO	RCRA	MSW	F	Proposed	M
Mesa County Landfill, Grand Junction, CO	RCRA	MSW	F	Installed	M
Midway Landfill, Fountain, CO	RCRA	MSW	F	Installed	M
North Weld Landfill, Ault, CO	RCRA	MSW	F	Installed	M
Rocky Mountain Arsenal (US Army), Denver, CO	DoD	HWS	Demo	Complete	M
Rocky Mountain Arsenal (US Army), Denver, CO	CERCLA	HWS	F	Installed	CB
Southside Landfill, Pueblo, CO	RCRA	MSW	F	Approved	M
West Garfield County Landfill, Rifle, CO	RCRA	MSW	F	Installed	M
Montana					
Allied Waste of Montana, Missoula, MT	RCRA	MSW	F	Installed	M
City of Billings, Billings, MT	RCRA	MSW	F	Installed	M
City of Bozeman, Bozeman, MT	RCRA	MSW	F	Installed	M
City of Butte Landfill, Butte, MT	RCRA	MSW (old fill)	F	Installed	M
City of Butte Landfill, Butte, MT	RCRA	MSW (new fill)	F	Approved	M
Harve Class II Landfill, Havre, MT	RCRA	MSW	F	Proposed	M
High Plains, Great Falls, MT	RCRA	MSW	F	Installed	M
Lake County Landfill, Polson, MT	ACAP	MSW	Demo	Complete	CB
Lake County Landfill Full Scale, Polson, MT	RCRA	MSW	F	Approved	CB
Lewis & Clark County Landfill, Helena, MT	ACAP	MSW	Demo	Complete	CB
Mr. "M" Landfill, Lewiston, MT	RCRA	MSW	F	Installed	M
Sanitation, Inc., Lewistown, MT	RCRA	MSW	F	Installed	M
Unified Disposal District, Havre, MT	RCRA	MSW	F	Proposed	M
Valley County Landfill, Glasgow, MT	RCRA	MSW	F	Proposed	M
Valley View, East Helena, MT	RCRA	MSW	F	Installed	M
North Dakota					
Grand Forks Municipal Solid Waste Landfill, Grand Forks, ND	RCRA	MSW	F	Approved	BE
Great River Energy - Coal Creek Station, Underwood, ND	RCRA	IW Ash	Demo	Installed	M
South Dakota					
Mitchell Landfill, Mitchell, SD	RCRA	MSW	F	Approved	M
Municipal Sanitary Landfill (Sioux Falls Regional Municipal Landfill), Hartford, SD	RCRA	MSW	F	Approved	M
Pierre Landfill, Pierre, SD	RCRA	MSW	F	Installed	M
Utah					

Site	Program	Type of Site	Scale	Status	Type of Cover
Bayview Landfill, 6 miles N. of Elberta, UT	RCRA	MSW	F	Installed	M
Chester Class II Landfill, 5 miles north of Ephraim, UT	RCRA	MSW	F	Installed	M
Emery County Class I Landfill, Castle Dale, UT	RCRA	MSW	F	Installation ongoing	M
Hill Air Force Base, Ogden, UT	DoD	Research	Demo	Complete	CB
Monticello Mill Tailings (USDOE), Monticello, UT	CERCLA	Rad	Demo	Complete	CB
Monticello Mill Tailings Repository, Monticello, UT	CERCLA	Rad	F	Installed	CB
Mountain View Landfill, Salt Lake City, UT	RCRA	CD Asbestos	F	Approved	M
Sanpete Sanitary Landfill Cooperative White Hills Class I Landfill, Sanpete County, UT	RCRA	MSW	F	Approved	M
Region 9					
Arizona					
Blue Hills Regional Landfill, St. Johns, AZ	RCRA	MSW	F	Proposed	M
Butterfield Station Facility, Mobile, AZ	RCRA	MSW	F	Approved	M
Cactus Landfill, Florence, AZ	RCRA	MSW	F	Approved	M
Calmat Avondale Reclamation Landfill, Avondale, AZ	RCRA	CD	F	Approved	M
City of Eloy, Eloy, AZ	RCRA	MSW	F	Approved	M
City of Glendale Municipal Landfill, Glendale, AZ	RCRA	MSW	F	Approved	M
Cochise County Western Regional Landfill Facility, Huachuca, AZ	RCRA	MSW	F	Approved	M
Copper Mountain Landfill, Wellton, AZ	RCRA	MSW	F	Approved	M
Gray Wolf Regional Landfill, Dewey, AZ	RCRA	MSW	F	Approved	M
Ironwood Non Municipal Landfill, Florence	RCRA	CD	F	Approved	M
Irvington Municipal Landfill, Tucson, AZ	RCRA	MSW/ CD	F	Installed	M
La Paz County Regional Landfill, Parker, AZ	RCRA	MSW	F	Approved	M
Lone Cactus Landfill, Phoenix, AZ	RCRA	CD	F	Approved	M
Los Reales Landfill, Tucson, AZ	RCRA	MSW	F	Approved	M
Northwest Regional Landfill, Surprise, AZ	RCRA	MSW	F	Approved	M
Painted Desert Landfill, Joseph City, AZ	RCRA	MSW	F	Approved	M
Silver Bar Mine Regional Landfill, Florence, AZ	RCRA	MSW	F	Approved	M
Southwest Regional Solid Waste Landfill, Buckeye, AZ	RCRA	MSW	F	Approved	M
Speedway Construction Debris Landfill, Tucson, AZ	RCRA	CD	F	Approved	M
California					
Allied Imperial Landfill, Imperial, CA	RCRA	MSW	F	Installed	M
Altamont Landfill & Resource Recovery Facility, Livermore, CA	ACAP	MSW	Demo	Complete	M
Altamont Landfill Closure, Livermore CA	RCRA	MSW	F	Conditionally Approved	M
Anza Sanitary Landfill, Anza, CA	RCRA	MSW	F	Installed	M
Apple Valley Landfill, Apple Valley, CA	ACAP	MSW	Demo	Complete	Varies
Apple Valley Landfill, Apple Valley, CA	RCRA	MSW	F	Installed	M
Azusa Landfill, Azusa, CA	RCRA	MSW	F	Proposed	M
Bakersfield Sanitary Landfill, Bakersfield, CA	RCRA	MSW	F	Installed	M

Site	Program	Type of Site	Scale	Status	Type of Cover
Benton Class III Landfill, Benton, CA	RCRA	MSW	F	Installed	M
Bishops Canyon Landfill, Los Angeles, CA	RCRA	MSW/ CD	F	Installed	M
Bradley Landfill, Los Angeles, CA	RCRA	MSW	F	Installed	M
Burbank Landfill No. 3, Burbank, CA	RCRA	MSW	F	Design	M
Buttonwillow Landfill, Kern County	RCRA	MSW	F	Approved	M
California Valley Landfill, California Valley, CA	RCRA	MSW	F	Installed	M
Camp Pendleton Marine Corps Base, San Diego County, CA	RCRA	MSW/ CAMU	F	Installed	M
Cedarville (East) Landfill, Cedarville, CA	RCRA	MSW	F	Installed	M
Chalfant Class III Landfill, Mono County, CA	RCRA	MSW	F	Installed	M
China Grade Sanitary Landfill, Bakersfield, CA	RCRA	MSW	F	Installed	M
Coachella Sanitary Landfill, Coachella, CA	RCRA	MSW	F	Installed	M
Eagleville Landfill, Modoc County, CA	RCRA	MSW	F	Installed	M
Edom Hill Sanitary Landfill, Riverside County, CA	RCRA	MSW	F	Installed	M
Edwards Air Force Base Operable Unit 7 Chemical Warfare Materiel, Lancaster, CA	CERCLA	HW/ MSW	F	Installed	M
El Toro Marine Corps Air Station, El Toro, CA	CERCLA	HW/ MSW	F	Installed	M
Forward Landfill, Manteca, CA	RCRA	MSW	F	Installed	M
Foxen Canyon Closed Class III Landfill, San Luis Obispo, CA	RCRA	MSW	F	Approved	M
Frank R. Bowerman Landfill, Irvine, CA	RCRA	MSW	F	Approved	M
Gaffey Street Sanitary Landfill, Wilmington, CA	RCRA	MSW	F	Installed	M
Hesperia Landfill, Hesperia, CA	RCRA	MSW	F	Installed	M
Hirschdale Landfill, Hirschdale, CA	RCRA	MSW	F	Installed	M
Holtville Sanitary Landfill, Holtville, CA	RCRA	MSW	F	Proposed	M
Jolon Road Closed Class III Landfill, King City, CA	RCRA	MSW	F	Installed	M
Kettleman Hills Facility, Kettleman City, CA	RCRA	HW/ MSW	F	Proposed	M
Kiefer Landfill, Sloughhouse, CA	ACAP	MSW	Demo	Complete	M
Kiefer Class III Municipal Landfill, Sloughhouse, CA	RCRA	MSW	F	Approved	M
Lake City Landfill, Lake City, CA	RCRA	MSW	F	Installed	M
Lamb Canyon Sanitary Landfill, Beaumont, CA	RCRA	MSW	F	Proposed	M
Lenwood-Hinkley Landfill, Lenwood, CA	RCRA	MSW	F	Installed	M
Lopez Canyon Sanitary Landfill, Los Angeles, CA	RCRA	MSW	F	Installed	M
Marine Corps Base Barstow, CA	CERCLA	HW/ MSW	F	Installed	M
Mead Valley Sanitary Landfill, Perris, CA	RCRA	MSW	F	Installed	M
Midway Solid Waste Disposal Site, San Luis Obispo County, CA	RCRA	IW	F	Installed	M
Milliken Landfill, Ontario, CA	RCRA	MSW	Demo	Complete	M
Milliken Landfill, Ontario, CA	RCRA	MSW	F	Installed	M
Monterey Peninsula Landfill, Marina, CA	ACAP	MSW	Demo	Complete	M

Site	Program	Type of Site	Scale	Status	Type of Cover
Needles Sanitary Landfill, Needles, CA	RCRA	MSW	F	Installed	M
Newberry Springs Sanitary Landfill, Newberry Springs, CA	RCRA	MSW	F	Installed	M
Norton Air Force Base (Landfill #2), San Bernardino, CA	CERCLA	MSW	F	Installed	M
Ocotillo Class III Municipal Solid Waste Management Facility, Ocotillo, CA	RCRA	MSW	F	Installed	M
Operating Industries Inc. Landfill, Monterey Park, CA	RCRA	HW/ MSW	F	Installed	M
Phelan Landfill, Phelan, CA	ACAP	MSW	Demo	Complete	M
Phelan Landfill Full Scale, Phelan, CA	RCRA	MSW	F	Approved	M
San Marcos Landfill, San Marcos, CA	RCRA	MSW	F	Installed	M
Spadra Landfill, Pomona, CA	RCRA	MSW	F	Installed	M
Twentynine Palms Sanitary Landfill	RCRA	MSW	F	Installed	M
U.S. Marine Corps Air and Ground Combat Center (MCAGCC) at Twentynine Palms, Twentynine Palms, CA	DoD	MSW	Demo	Complete	M
Yucaipa Landfill, Yucaipa, CA	RCRA	MSW	F	Installed	M
Hawaii					
Kaneohe Bay Marine Corps Base, Oahu, HI	DoD	MSW	Demo	Complete	BE
Nevada					
Nevada Test Site, NV (landfill U-3 ax/bl)	DOE Research	Rad	Demo	Complete	M
New Austin Landfill, Austin, NV	RCRA	MSW	F	Proposed	M
U.S. Ecology Nevada Site, Beatty, NV	RCRA	HW	F	Approved	M
Region 10					
Alaska					
Anchorage Pilot Study Site, Anchorage. AK	RCRA	MSW	Demo	Complete	M
City of Elim Landfill, Elim, AK	RCRA	MSW	F	Proposed	M
Elmendorf Air Force Base, Anchorage, AK	RCRA	MSW	F	Installed	M
Minchumina Landfill, Lake Minchumina, AK	RCRA	MSW	F	Proposed	M
Idaho					
Idaho National Engineering Laboratory, Idaho Falls, ID	CERCLA	HWS	F	Installed	CB
Oregon					
Finley Buttes Regional Landfill, Boardman, OR	ACAP	MSW	Demo	Complete	M
Washington					
Duvall Custodial Landfill	RCRA	MSW	F	Installed	M
Hanford 200-Area (USDOE), Richland, WA Prototype Barrier (BP-1)	CERCLA	Rad	Demo	Installed	CB
Nonradioactive Dangerous Waste Solid Waste Landfill (DOE Hanford)	CERCLA	HWS	F	Proposed	M

Definitions

Approved	A proposal to build an ET has been approved by the appropriate regulatory agency.
Complete	Associated with demonstrations and indicates the demonstration is complete.
Proposed	An ET design or proposal to construct an ET has been submitted to the appropriate regulatory agency
Installed	Construction complete.

Legend

ACAP	Alternative Cover Assessment Program
BE	Bioengineered
CAMU	Corrective Action Management Unit
CB	Capillary Break
CD	Construction Debris Landfill
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Demo	Demonstration Project
F	Full Scale
HW	RCRA Subtitle C Hazardous Waste Facility
HWS	Hazardous Waste Site—Generally concerned with cleanup activities
IW	Industrial Waste Such as Coal Ash
M	Monolithic
MSW	Municipal Solid Waste Site
MSW/CAMU	MSW being used in a RCRA cleanup to consolidate potentially hazardous wastes
NHWS	Non-Hazardous Waste Site
NRC	Nuclear Regulatory Commission
Rad	Radioactive Waste
RCRA	Resource Conservation and Recovery Act

APPENDIX B

DATA FROM TWO COMPARISON DEMONSTRATION PROJECTS

ALTERNATIVE LANDFILL COVER DEMONSTRATION (ALCD)

DOE sponsored the ALCD, 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. Cover design information is available at http://www.sandia.gov/Subsurface/factshts/ert/alcd.pdf.

The ALCD 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 were 43 feet wide by 328 feet long and were seeded with native vegetation. The purpose of the project was to use the performance data to help demonstrate equivalency and refine numerical models to more accurately predict cover system performance (Dwyer 2003).

The ALCD collected data on percolation using a pan 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

ALTERNATIVE COVER ASSESSMENT PROGRAM (ACAP)

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

The alternative covers typically were constructed with local soils and native vegetation. At two facilities, however, hybrid poplar trees were used as vegetation. Percolation performance was evaluated by pan lysimeters. Soil moisture also was evaluated at all sites. Below are the field data for precipitation and percolation volumes at 11 of the sites. A summary of field cover performance for all 13 sites through 2004 is provided in Albright and Benson (2005). More information about ACAP is available on the Desert Research Institute website at http://www.dri.edu/acap-research.

ACAP Water Balance Results					
Site Location	**Cover Design**	**Data Year (days)**	**Precipitation (mm)**	**Drainage**	
				mm	**As % of Precipitation**
Altamont CA	ET	7/1/01 - 6/30/02 (365)	287	1.5	0.52%
		7/1/02 - 6/30/03 (365)	425	2.5	0.59%
		7/1/03 -6/30/04 (365)	291	64.5	22.16%
		Annual Average		**22.8**	**7.76%**
	Membrane Composite	7/1/01 - 6/30/02 (365)	287	0.0	0.00%
		7/1/02 - 6/30/03 (365)	425	4.0	0.94%
		7/1/03 -6/30/04 (365)	291	0.2	0.07%
		Annual Average		**1.4**	**0.34%**
Apple Valley CA	ET	7/1/02 - 6/30/03 (365)	86	0.4	0.47%
		7/1/03 -6/30/04 (365)	106	0.0	0.00%
		Annual Average		**0.2**	**0.24%**
	Membrane Composite	7/1/02 - 6/30/03 (365)	86	0.0	0.00%
		7/1/03 -6/30/04 (365)	106	0.0	0.00%
		Annual Average		**0.0**	**0.00%**
	Compacted Clay	7/1/02 - 6/30/03 (365)	86	0.0	0.00%
		7/1/03 -6/30/04 (365)	106	0.2	0.19%
		Annual Average		**0.1**	**0.1%**
Cedar Rapids IA	ET	7/1/02 - 6/30/03 (365)	784	157.1	20.0%
		7/1/03 -6/30/04 (365)	1742	365.7	20.99%
		Annual Average		**261.4**	**20.5%**
	Compacted Clay	7/1/02 - 6/30/03 (365)	784	94	11.98%
		7/1/03 -6/30/04 (365)	1742	171	9.82%
		Annual Average		**132.5**	**10.9%**
	Membrane Composite	7/1/02 - 6/30/03 (365)	784	22.0	2.81%
		7/1/03 -6/30/04 (365)	1742	62.2	3.57%
		Annual Average		**42.1**	**3.19%**

ACAP Water Balance Results					
Site Location	**Cover Design**	**Data Year (days)**	**Precipitation (mm)**	**Drainage**	
				mm	**As % of Precipitation**
Omaha NB	Thin ET with Capillary Break	7/1/01 - 6/30/02 (365)	560	3.45	0.62%
		7/1/02 - 6/30/03 (365)	475	50.9	10.72%
		7/1/03 -6/30/04 (365)	511	68.5	13.41%
		Annual Average		**40.95**	**8.25%**
	Thick ET with Capillary Break	7/1/01 - 6/30/02 (365)	560	4.16	.74%
		7/1/02 - 6/30/03 (365)	475	28.7	6.04%
		7/1/03 -6/30/04 (365)	511	16.3	3.19%
		Annual Average		**16.4**	**3.32%**
	Membrane Composite	7/1/01 - 6/30/02 (365)	560	1.03	0.18%
		7/1/02 - 6/30/03 (365)	475	9.15	1.93%
		7/1/03 -6/30/04 (365)	511	10.9	2.13%
		Annual Average		**7.03**	**1.41%**
Boardman OR	ET Thin	7/1/01 - 6/30/02 (365)	164	0.0	0.00%
		7/1/02 - 6/30/03 (365)	185	0.0	0.00%
		7/1/03 -6/30/04 (365)	177	0.0	0.00%
		Annual Average		**0.0**	**0.00%**
	ET Thick	7/1/01 - 6/30/02 (365)	164	0.0	0.00%
		7/1/02 - 6/30/03 (365)	185	0.0	0.00%
		7/1/03 -6/30/04 (365)	177	0.0	0.00%
		Annual Average		**0.0**	**0.00%**
	Membrane Composite	7/1/01 - 6/30/02 (365)	164	0.0	0.00%
		7/1/02 - 6/30/03 (365)	185	0.0	0.00%
		7/1/03 -6/30/04 (365)	177	0.0	0.00%
		Annual Average		**0.0**	**0.00%**
Sacramento CA	ET Thin	7/1/00 - 6/30/01 (365)	379	1.4	0.37%
		7/1/01 - 6/30/02 (365)	456	96.2	21.10%
		7/1/02 - 6/30/03 (365)	426	3.9	0.92%
		7/1/03 -6/30/04 (365)	159	108.4	68.18%
		Annual Average		**52.48**	**22.64%**
	ET Thick	7/1/00 - 6/30/01 (365)	379	0.0	0.00%
		7/1/01 - 6/30/02 (365)	456	8.5	1.86%
		7/1/02 - 6/30/03 (365)	426	0.0	0.00%
		7/1/03 -6/30/04 (365)	159	0.6	0.38%
		Annual Average		**2.28**	**0.56%**

ACAP Water Balance Results					
Site Location	Cover Design	Data Year (days)	Precipitation (mm)	Drainage	
				mm	As % of Precipitation
Polson MT	ET with Capillary Break	7/1/00 - 6/30/01 (365)	358	0.18	0.05%
		7/1/01 - 6/30/02 (365)	308	0.39	0.13%
		7/1/02 - 6/30/03 (365)	326	0.19	0.06%
		7/1/03 -6/30/04 (365)	254	0.20	0.08%
		Annual Average		**0.24**	**0.08%**
	Membrane Composite	7/1/00 - 6/30/01 (365)	358	1.16	0.32%
		7/1/01 - 6/30/02 (365)	308	0.0	0.00%
		7/1/02 - 6/30/03 (365)	326	0.0	0.00%
		7/1/03 -6/30/04 (365)	254	0.5	0.20%
		Annual Average		**0.42**	**0.13%**
Helena MT	ET with Capillary Break	7/1/00 - 6/30/01 (365)	252	0.0	0.00%
		7/1/01 - 6/30/02 (365)	314	0.0	0.00%
		7/1/02 - 6/30/03 (365)	288	0.0	0.00%
		7/1/03 -6/30/04 (365)	103	0.0	0.00%
		Annual Average		**0.0**	**0.00%**
Albany GA	ET (Trees)	7/1/00 - 6/30/01 (365)	1079*	134	12.42%
		7/1/01 - 6/30/02 (365)	1039*	3.1	0.3%
		7/1/02 - 6/30/03 (365)	1457*	218.2	14.98%
		Annual Average		**118.4**	**9.23%**
	Compacted Clay	7/1/00 - 6/30/01 (365)	909	291.9	32.11%
		7/1/01 - 6/30/02 (365)	996	237.6	23.86%
		Annual Average		**264.8**	**27.98%**
Marina CA	ET with Capillary Break	7/1/00 - 6/30/01 (365)	492	44.7	9.09%
		7/1/01 - 6/30/02 (365)	401	64.2	16.01%
		7/1/02 - 6/24/03 (359)	467	51.1	10.94%
		Annual Average		**53.3**	**12.01%**
		7/1/00 - 6/30/01 (365)	492	9.0	1.82%
		7/1/01 - 6/30/02 (365)	401	25.0	6.23%
		7/1/02 - 6/24/03 (359)	467	36.0	7.71%
		Annual Average		**23.3**	**5.25%**
Monticello UT	ET with Capillary Break	8/12/00 - 6/30/01 (323)	393	0.0	0.00%
		7/1/01 - 6/30/02 (365)	213	0.0	0.00%
		7/1/02 - 6/30/03 (365)	342	0.0	0.00%
		7/1/03 -6/30/04 (365)	315	0.1	0.03%
		Annual Average		**0.03**	**0.008%**

*Precipitation values at Albany include irrigation of the ET cover test section.
Source: Albright and Benson 2005