ALTERNATIVE EARTHEN FINAL COVERS FOR LANDFILLS – THE MIDWEST EXPERIENCE

Anastasia J. Welch, PE[1], Michael S. Kukuk, PG[2], Nathan A. Hamm, PE[3], and Susan L. McCart, PE, PG[4]

ABSTRACT: Using the first three Evapotranspiration (ET) Landfill Covers permitted in Kansas, this paper examines design considerations, lysimeters, pilot test pads, and economic considerations of alternative landfill covers compared to traditional prescriptive covers.

Municipal solid waste (MSW) landfills as well as hazardous waste landfills are successfully deploying alternative earthen final cover systems. The soil-based ET cover concept exploits the water storage capacity of fine-textured soils and the transpiration processes of vegetation. ET covers represent new and exciting thinking in solid waste management and the evolution of the landfill system and have been the subject of much research and debate over the past several years. This paper uses real-world facilities' experiences to understand engineering issues, along with real-world information to illustrate potential savings for typical facilities.

Soil-based covers provide several benefits over prescriptive low-permeability covers, some of which will be discussed in this paper. Each of the three ET covers discussed in this paper were conceived, designed, modeled, approved, and constructed in 2003 and 2004. The undertaking at each landfill facility included full-scale projects (7 to 75 acres) with two pan-type lysimeters for monitoring on each landfill. Three years of data are presented for each facility. To date, the pan lysimeters continue to be monitored and infiltration results compared with predicted estimates.

Lysimeter results have been generally encouraging, and two of the three covers appear to be performing better than their prescriptive cover equivalents. Although the third cover is not performing as modeled, interesting insights and lessons have been gained from the monitoring results.

Although this paper could focus on how successful the ET cover projects have been in Kansas, we have chosen not to concentrate on this as the success of Kansas ET covers has already been published by Aquaterra. Instead, this paper discusses the lessons learned from the construction processes and the performance monitoring results we have collected over a 3-year period. The intention of focus on the unexpected is to

[1]Project Manager, Aquaterra Environmental Solutions, Inc., 7311 W 130th Street, Overland Park, KS 66213 USA, awelch@aquaterra-env.com
[2]Principal, Aquaterra Environmental Solutions, Inc., 7311 W 130th Street, Overland Park, KS 66213 USA, mkukuk@aquaterra-env.com
[3]Project Manager, Aquaterra Environmental Solutions, Inc., 7311 W 130th Street, Overland Park, KS 66213 USA, nhamm@aquaterra-env.com
[4]Project Manager, Aquaterra Environmental Solutions, Inc., 7311 W 130th Street, Overland Park, KS 66213 USA, smccart@aquaterra-env.com

provide information that may assist others in making better decisions regarding the use and monitoring of ET covers in the future.

This paper also provides technical as well as economic comparisons between the three cover designs, including the significant savings each landfill has achieved and additional savings that may be realized as facilities implement alternative covers earlier in the life of the landfill.

INTRODUCTION

ET cover design is based on the concept that fine-textured soils can retain or store water until such time as the transpiration processes of vegetation can utilize the moisture. These covers store infiltrating precipitation, allowing minimal drainage during winter months (when vegetation is dormant) and during rainy seasons (when precipitation is high). During the growing season, plant transpiration removes stored water from the soil cap, thus freeing up storage capacity for future precipitation.

While the purpose of a landfill cover is to slow percolation of water into the waste mass, traditional prescriptive cover designs focus on compacted soil materials and synthetic components. In contrast, alternative soil-based cover systems rely on site-specific soil characteristics and natural plant processes to maintain a favorable water balance.

Soil-based covers offer several benefits over prescriptive low permeability covers:

- Reduced construction cost, due to simpler construction;
- Enhanced potential to decrease levels of methane oxidation/greenhouse gas emissions via soil microorganisms and oxidation;
- Fewer problems associated with long term integrity of compacted clay, including landfill settlement and desiccation related to soil plasticity and compaction;
- Reduced landfill gas-to-groundwater effects by eliminating flexible membrane liners (FML); and
- Reduced closure and post-closure costs.

Focusing on the results of one lysimeter (or monitoring apparatus) at each landfill, this paper describes design, construction, analysis of three-years of data, and economic analysis of alternative covers at three facilities:

- Coffey County Sanitary Landfill (CCSL) in southeastern Kansas
- Barton County Sanitary Landfill (BCSL) in central Kansas
- Johnson County Landfill (JCL) in northeastern Kansas

Climate and soil conditions and construction methods varied among the sites, however the basic design [for each site] called for two lysimeters at each site: one lysimeter installed on the slope, the second on the flatter crown of the landfill. Table 1 shows the specific locations of each lysimeter at each site.

	CCSL	**BCSL**	**JCL**
Total Acreage	38	83	243
Acreage Closed w/ Alternative Cover	7	22	75
Average Rainfall	35.5 in	25.6 in	38 in
Soil Types	Silty clay and topsoil	Silty clay and topsoil	Shale and clay
Profile (bottom to top)	3.5 ft silty clay 0.5 ft Topsoil	4.0 ft silty clay 1.0 ft topsoil	4.5 ft shale 1.0 ft clay
Placement Range (percent of standard Proctor)	85- 95%	80-90%	85-95%
Vegetation	Native prairie grasses	Native prairie grasses	Native prairie grasses
Lysimeter Locations	South slope East slope	West slope South top	West slope East top

Table 1. Design and Construction Details of Three Alternative Covers

ET covers save landfill owners/operators thousands of dollars per acre of landfill closed when closure activities commence. In addition, significant savings can be realized during the operating life of the landfill if the facility uses a bond for its financial assurance instrument and if a lower bond cost can be negotiated, given the reduced upcoming closure costs. The sooner the regulatory agency approves the ET cover, the sooner the owner/operator begins to reduce costs.

LYSIMETERS

The Kansas Department of Health and Environment Bureau of Waste Management (KDHE-BWM) approved the ET cover designs for each site on the condition that the covers be monitored to determine actual drainage through the cover system. Using two pan-type lysimeters to monitor each cover would demonstrate the correlation between the results of the computer model and real-world performance.

Lysimeter Construction

Construction of the six lysimeters at the three facilities (CCSL, BCSL, and JCL) followed the same general process. Factors such as soil type, construction equipment available, weather, and location resulted in slight differences in construction. The lysimeter construction process included several stages: subgrade preparation; creating a “pan” using concrete curbing, PVC liners, and geocomposite drainage materials; placing the ET cover soil; and constructing lysimeter measuring system.

Component	**Stages**
Subgrade	• 18-inch thick base with density testing. • Elevation surveyed to maintain design grade.
Concrete Enclosures	• Enclosed 30- by 50-foot area (approx). • Sump at lower end of lysimeter located by surveyor; excavated using a track hoe.
PVC Liners	• PVC liner; inspected and repaired as necessary. • Sump outlet pipe installed through a PVC pipe boot.
Geocomposite Drainage Layer and Sump Construction	• Double-sided geocomposite drainage layer installed over the PVC liner. • Drainage rock placed in the sump area. • A 24-hour leak test performed.
Soil Cover Installation	• ET cover installed above lysimeter per design profiles and placement requirements. • Material placement and construction quality assurance (CQA) consistent with the rest of cover construction.
Lysimeter Measuring System	• Discharge piping that drains into a tipping bucket rain gauge with an electronic data logger. • Gauge measures water drained through the lysimeter pan outlet pipe, and the data logger records the number of tips.

Table 2. Lysimeter Construction Process

Performance Analysis Methods

As discussed above, each facility’s cover was equipped with two pan-type lysimeters (installed at the base of the cover, on top of a prepared subgrade). This allowed drainage through the constructed covers to be collected, measured, and compared to the performance standard used during the design activities. Based on the designed flux of 3 mm per year and a lysimeter pan area of 30 by 50 feet, the allowable drainage volume through each lysimeter was calculated to be approximately 110 gallons per year.

There are various ways to analyze the data; options typically consider volume of drainage recovered by the lysimeter, precipitation, and time. Analysis may also take into account the surface area of the lysimeter pan. The following charts and graphs show several different options for viewing data; one example is shown from each of the three facilities. (Note: The figures in this paper do not aim to present a comprehensive picture of all the data for each landfill; they are representative of the ways to analyze data from monitoring that is essential to understanding how a particular ET cover is performing.)

Coffey County: A Cyclical View of Volume Collected Compared to Precipitation

Figure 1 illustrates performance of the CCSL ET cover using data collected from its East Lysimeter over a three-year period. The total precipitation recorded in Coffey County during this period varied within historical normalcy. The peaks in precipitation and volume recovered (drainage through the cover) generally coincided in years one and two. In year three (2006), the volume recovered was significantly lower. The data not only supported the computer modeling, proving the cover design and installation, it also showed that the cover functioned even better than the model predicted. As seen on the graph below, the volume recovered by the lysimeter (the drainage) did not exceed 2 gallons. The allowable volume recoverable in a 30-foot by 50-foot lysimeter is approximately 110 gallons per year reflecting that this cover is performing exceptionally well.

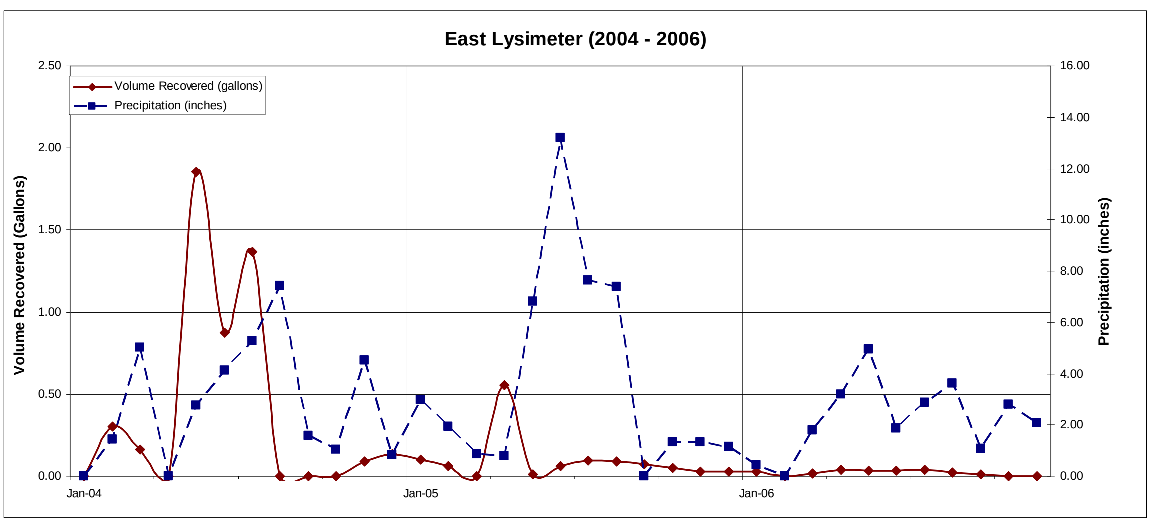

Figure 1. CCSL East Lysimeter
Volume Recovered Compared to Monthly Precipitation

Barton County: Month-to-Month Collection Data

Figures 2 and 3 illustrate ET cover performance and the relationship between monthly precipitation totals and drainage through the BCSL South Lysimeter. Data was collected over three years, although only two years of data are provided below. The figures show consistent performance across the seasons for each year of data.

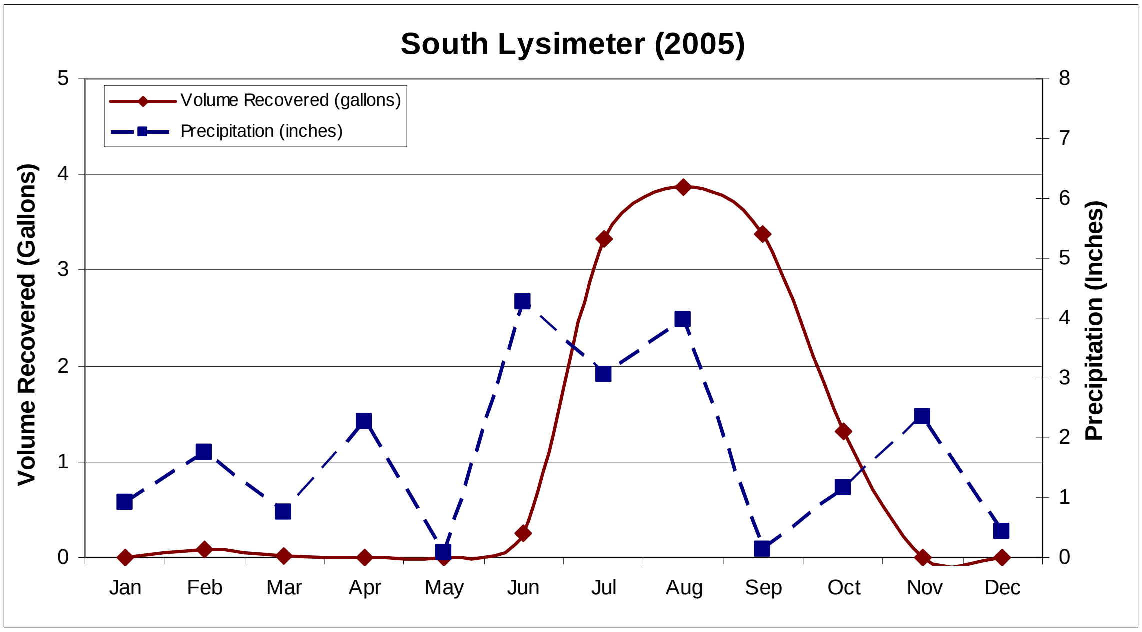

Figure 2. BCSL South Lysimeter - 2005
Volume Recovered Compared to Monthly Precipitation
Note: 110 gallons/year is the equivalency goal

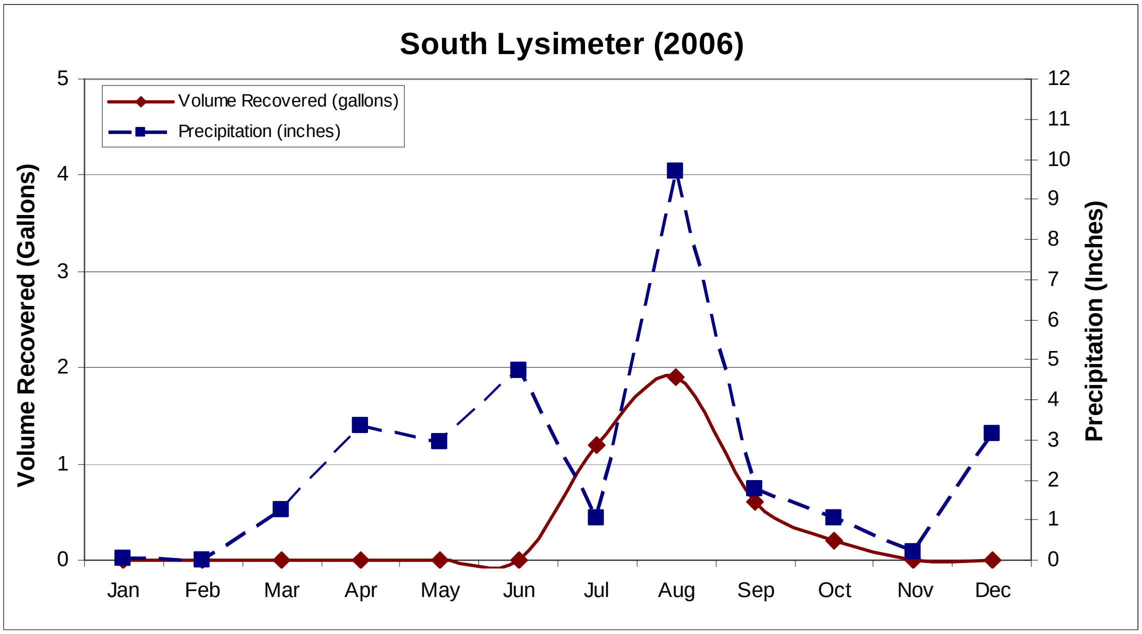

Figure 3. BCSL South Lysimeter - 2006
Volume Recovered Compared to Monthly Precipitation
Note: 110 gallons/year is the equivalency goal

The ET cover at the BCSL has performed better than expected or modeled. Based on an allowable infiltration rate of 3 mm/year (the equivalent of 110 gallons per year of collected or recovered water in the lysimeter), the ET cover at the BCSL has allowed only 1 percent (approximately) of the allowable drainage through the cap.

Johnson County: Total Potential Drainage

A third way to evaluate lysimeter data is to compare the recovered volume from the lysimeter to the total volume of precipitation that potentially could have drained through the cover. This analysis calculates gallons of precipitation over the lysimeter area and compares it to gallons of drainage through the lysimeter.

Figures 4 and 5 compare the volume of precipitation falling over the lysimeter pan surface area versus the volume of water recovered in the Top Lysimeter of the JCL. As shown, the volume recovered from the lysimeter did not change significantly as precipitation varied. The data does not support the design expectations for this ET cover. Additionally, there does not appear to be a clear correlation between precipitation and volume recovered in the lysimeter, as observed at the BCSL. However, the volume of water recovered in the Top Lysimeter showed a general declining trend from 2005 to 2006, which may indicated improved performance as the vegetation becomes established.

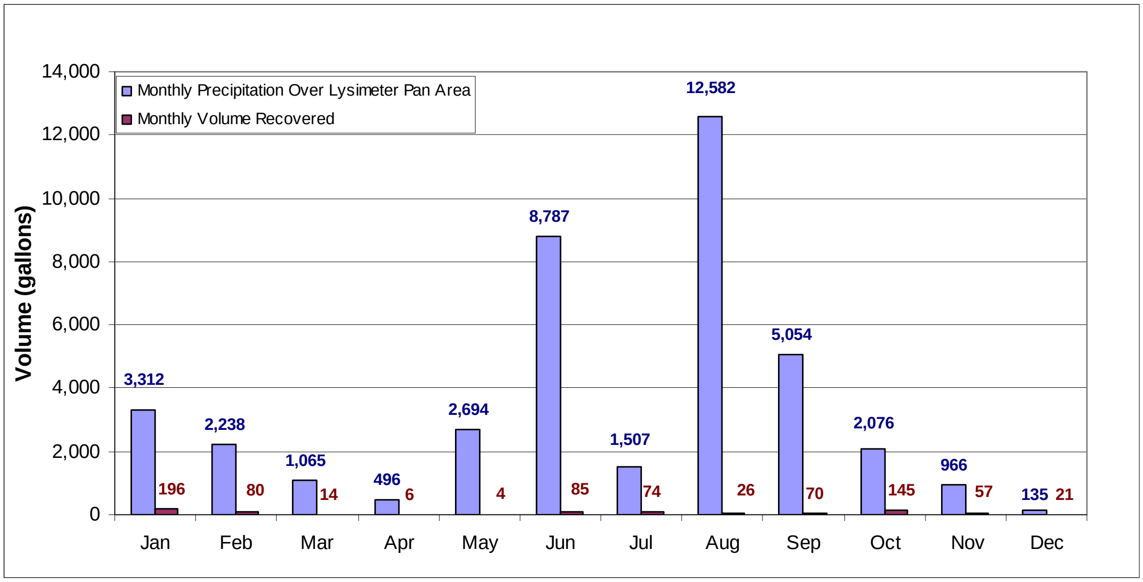

Figure 4. JCL Top Lysimeter – 2005
Volume of Precipitation Compared to Volume Recovered

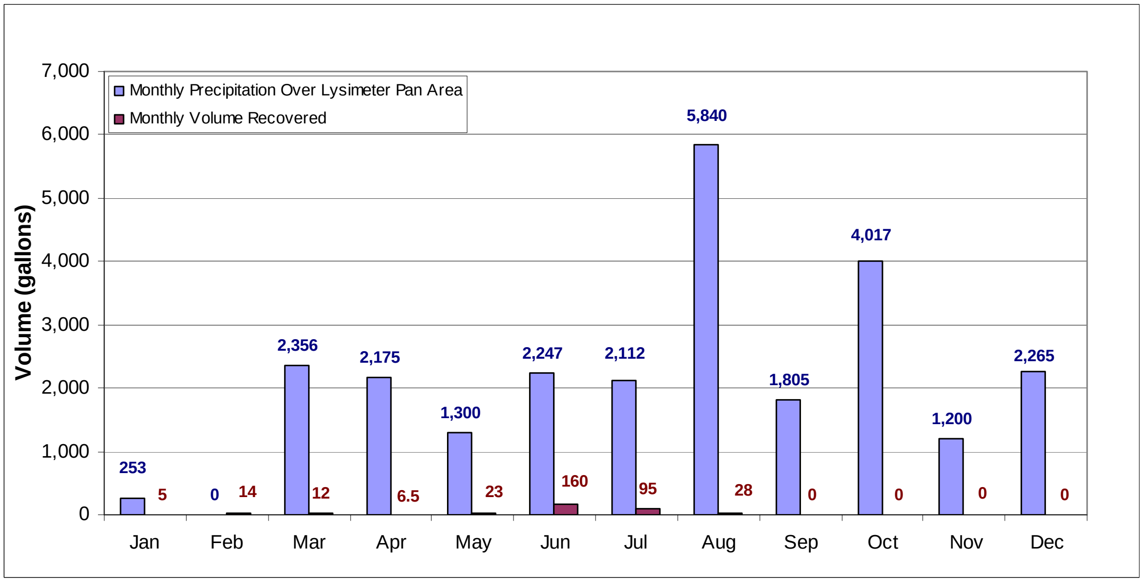

Figure 5. JCL Top Lysimeter – 2006
Volume of Precipitation Compared to Volume Recovered

Table 3 shows volume recovered as a percentage of volume precipitation for 2006.

Month	Volume Recovered (gallons)	Precipitation (gallons)	Percent Recovered
January 2006	5	253	2.0
February 2006	14	0	> 100
March 2006	12	2356	0.5
April 2006	6.5	2175	0.3
May 2006	23	1300	1.8
June 2006	160	2247	7.1
July 2006	95	2112	4.5
August 2006	28	5840	0.5
September 2006	0	1805	0
October 2006	0	4017	0
November 2006	0	1200	0
December 2006	0	2265	0
Total	**343.5**	**25570**	**1.3**

Table 3. Volume Recovered as Percentage of Volume Precipitation

Based on observations in the field and analysis of data, it is not believed that all of the drainage being collected by the lysimeter at JCL is true drainage through the cover caused by precipitation. Further evaluation by Aquaterra of the lysimeter and precipitation data has uncovered potential issues related to monitoring the lysimeters at the JCL. Since the drainage through the cover appears to be independent of the precipitation falling over the lysimeter area, it is possible there is another source of the drainage. For example, the non-precipitation liquid could be leachate occurring from a leachate seep or gas condensate that is oxidized as it vents through the cover. Liquids recovered from the collection system at JCL resembled leachate in both color and smell. A sample of drainage water was submitted to an analytical laboratory and was confirmed to contain volatile organic compounds, which are typically found in landfill leachate but not in precipitation.

Lessons Learned

Three years of data have demonstrated the effectiveness of the BCSL and CCSL ET covers. Real-world monitoring results have validated the design completed by computer modeling and the facilities have considered the project to be a success. However, in the instance where everything goes well, little can be learned for future applications. The on going monitoring at JCL has provided more insight into aspects of cover design and construction that will assist owners and operators in the future.

Data from the JCL has been valuable. It has uncovered potential operational and construction issues related to the monitoring system for JCL's ET covers and suggested further investigation and possible repairs and/or modifications to improve performance. All three landfill owners will likely continue to collect data from the lysimeters for several more years. This ongoing monitoring and data analysis is essential to assessing the functional performance of ET covers over time, identifying factors for effective design and construction and justifying installation of these alternative caps.

Experience with ET covers at the three Kansas facilities highlighted potential pitfalls to avoid during construction and operation of a landfill lysimeter.

1. Differential settlement of underlying waste could, over time, cause differential settlement of the lysimeter itself. Drainage lines could get disconnected (preventing any drainage), and the plastic liner could be damaged.
2. Leachate outbreaks could occur upslope of the lysimeter, then drain down into the pan. This leachate would be collected along with “real” drainage through the cover even though it originated from within the landfill.
3. As landfill gas migrates upward through the cover, the gas condenses as it cools. This condensate could enter the lysimeter pan and be measured as part of the drainage volume, even though it did not drain through the cover.
4. Daily activities on a landfill (e.g., haul trucks and equipment movements) may damage the lysimeter or data collection infrastructure.

PILOT TEST PADS

Consider this scenario: A landfill owner constructs a large area of alternative final cover to close part of the landfill, including a lysimeter to monitor the cover’s performance. However, the lysimeter does not show that the cover is performing as it should. What next? The governing agency could require the facility owner to remove the soil-based cover and replace it with a brand new prescriptive cover. We don’t anticipate for this to happen but it is a real possibility depending on the outlook of the state regulators.

Given this possibility and associated risks, the recommended approach is to construct a pilot test pad based on the selected alternative cover profile in a location that is not on top of an existing waste mass. This pilot test should be equipped with lysimeters and simulate construction of an identical lysimeter on the landfill under the designed cover. The pilot test can then be monitored for several years (or until the regulatory agency grants final approval) to determine real-world performance of the selected design prior to construction of a large area, thereby reducing the risk associated with an alternative cover.

Conducting a pilot test also provides the opportunity to develop a performance standard for the alternative cover. For these three Kansas facilities, the equivalency standard was set at 3 mm per year. However, regulation that allows an alternative design based on the concept of equivalency does not specify that a standard of 3 mm per year must be used; the design must only demonstrate equivalence to a prescriptive cover. Thus, the ideal situation would be to construct a test plot of the proposed ET cover alongside a test plot of a prescriptive cover. By monitoring both cover options, a real-time demonstration would more accurately forecast actual performance of the alternative cover compared to the prescriptive one.

Analyzing the data gathered at the JCL makes a strong case for construction of a pilot test plot prior to full-scale implementation of an alternative cover. The trials at the JCL can be summarized in several lessons for future ET monitoring.

- Ideally, a pilot or test area of the ET cover (located off of waste) with at least one lysimeter should be constructed prior to full-scale construction of the final cover. If construction of a test plot is not possible prior to full scale construction, it is still recommended to construct a lysimeter pilot test plot at a location not on waste.
- A test plot of the *prescriptive* cover should be constructed and monitored as well
- The pilot study would allow engineers to evaluate factors such as vegetation establishment and address issues such as desiccation cracking.
- The pilot also would provide an environment for testing that was separate from variables such as differential settlement or leachate outbreaks/gas condensate impacts on the drainage.

Given the time and financial investment in landfill covers, this is a compelling reason to build a pilot test pad and run tests before construction of the actual cover when at all possible.

ECONOMIC CONSIDERATIONS

As stated previously, alternative earthen final covers offer several benefits over prescriptive, composite final covers. In particular, alternative covers often are less costly. A standard, Subtitle D composite cover can cost from $70,000 to more than $120,000 per acre to construct. Variables such as access to and availability of suitable cover soils, approved cover profile, use of geosynthetic clay liners and local construction rates factor into the cost to construct a composite final cover. Selecting an alternative ET final cover reduces the importance of—or even eliminates—some of these factors, such as costs associated with purchase, installation, intensive construction quality assurance, and maintenance of geosynthetic materials. The construction costs of the alternative ET final covers described in this paper ranged from approximately $22,000 to $28,000 per acre.

It is difficult to make a direct comparison of the costs as there are significant differences in the three projects. Each is located in a slightly different climate; each approved cover profile is slightly different; each used different materials for cover construction. Additionally, the owner/operator of the JCL performs their own construction using their own personnel and equipment, which lowers their cost for construction. Likewise, Coffey County utilizes county personnel and equipment for their construction. Barton County solicited bids and contracted the cover construction work. Despite these differences, an overall savings estimate has been estimated for each site (Table 4). These figures reflect the cost savings for construction compared to estimated costs for constructing the prescriptive cover previously approved for each site.

Site (Total Acreage)	**Actual Savings Per Acre**	**Projected Total Site Savings**
Johnson County (315 acres)	$37,400	$11,780,000
Coffey County (34 acres)	$38,900	$1,323,000
Barton County (66 acres)	$37,800	$2,498,000

Table 4. Estimated Construction Cost Savings
ET Cover vs. Prescriptive Cover

As shown above, the projected savings from building alternative covers for the entire permitted waste disposal areas is significant. However, construction savings is a one-time cost savings; there are other costs to consider.

There often are differences in operational and capital funding mechanisms between public landfills and privately owned facilities. However structured, all facilities are required to provide financial assurance instruments (FAIs) to cover these costs in the event of the facility's early closure or the company's financial troubles. Given the time value of money, the closure savings will increase the sooner an alternative cover is approved by the permitting agency.

Some privately owned facilities use a bond as their form of FAI. The cost of securing a bond for the future closure of the facility presents an actual cost in dollars each and every year of operation of the facility. If the closure cost can be reduced via the approval of an alternative final cover, the annual cost for the closure bond also will decrease.

Table 5 presents bond and closure costs over 26 years for a typical 100-acre, privately owned landfill facility, assuming the FAI is a closure bond executed each year. As the facility constructs additional acreage, its closure costs increase and the cost of the bond increases. However, if an alternative final cover is approved for the facility, the landfill owner realizes a cost savings immediately. As additional acreage is constructed, the cost savings continues to increase. Table 5 reflects the total reduction in bond value as the landfill grows, constructs new cells, and closes areas.

Year	Year	Acerage Constructed	Acerage Closed	Reduction in Bond Requirement	Bond Cost Savings
2008	1	10	0	$ 380,500.00	$ 11,415.00
2009	2	10	0	$ 380,500.00	$ 11,415.00
2010	3	15	0	$ 570,750.00	$ 17,122.50
2011	4	15	0	$ 570,750.00	$ 17,122.50
2012	5	20	0	$ 761,000.00	$ 22,830.00
2013	6	20	0	$ 761,000.00	$ 22,830.00
2014	7	25	0	$ 951,250.00	$ 28,537.50
2015	8	25	0	$ 951,250.00	$ 28,537.50
2016	9	30	15	$ 570,750.00	$ 17,122.50
2017	10	30	15	$ 570,750.00	$ 17,122.50
2018	11	35	15	$ 761,000.00	$ 22,830.00
2019	12	35	15	$ 761,000.00	$ 22,830.00
2020	13	40	15	$ 951,250.00	$ 28,537.50
2021	14	40	25	$ 570,750.00	$ 17,122.50
2022	15	50	25	$ 951,250.00	$ 28,537.50
2023	16	50	25	$ 951,250.00	$ 28,537.50
2024	17	60	25	$ 1,331,750.00	$ 39,952.50
2025	18	60	25	$ 1,331,750.00	$ 39,952.50
2026	19	70	50	$ 761,000.00	$ 22,830.00
2027	20	70	50	$ 761,000.00	$ 22,830.00
2028	21	80	50	$ 1,141,500.00	$ 34,245.00
2029	22	80	50	$ 1,141,500.00	$ 34,245.00
2030	23	90	50	$ 1,522,000.00	$ 45,660.00
2031	24	90	50	$ 1,522,000.00	$ 45,660.00
2032	25	100	50	$ 1,902,500.00	$ 57,075.00
2033	26	100	50	$ 1,902,500.00	$ 57,075.00

Table 5. Total Reduction in Bond Value During Landfill Life Cycle
Hypothetical 100-acre Landfill

The cost to secure a closure bond is an actual cost to the company in today's dollars. Thus, the reduction in bond requirement value will reduce the cost to secure that bond, effectively saving the owner money—even before realizing the cost savings from actual construction of the cover. In the hypothetical example illustrated in Table 5, assuming a bond rate of 3 percent, the savings in bond costs over the life of the facility add up to just over $740,000. Converting the closure costs and bond savings costs into today's dollars adds up to a total true cost savings of more than $200,000. And this is entirely a cost savings above and beyond the one-time $38,050 per acre that can be saved during final cover construction activities.

The potential cost savings associated with alternative covers is enormous, especially when decisions are made early in the design and approval process.

CONCLUSIONS

Soil-based ET covers like the three Kansas facilities discussed herein exploit inherent characteristics of two components: the water storage capacity of fine-textured soils and the transpiration processes of vegetation. The design considerations for an ET cover design include site-specific soil characteristics, soil type and thickness specifications, soil placement criteria, and vegetation selection. The designed ET covers for BCSL and CCSL have been proven successes – monitored results in the field have supported the design completed in the office. But perhaps more informative are the lessons learned at the JCL, as these have provided insights that will allow better covers to be constructed in the future.

Constructing pan-type lysimeters to collect drainage provides a means to gather data and monitor cover performance over time. Analyzing three years of data provided valuable information. In the case of the CCSL and BCSL, the data demonstrated that these alternative covers effectively slow percolation of water into the waste mass and maintain favorable water balance. Lysimeter data did not support the design expectations for the JCL ET cover, although a non-drainage water source is thought to be the cause.

Experience with these projects also points to the value of constructing and monitoring pilot test pads prior to full-scale cover construction, and in a location off of the waste mass. Information that can be gained from pilot testing includes:

- Helps establish a performance standard, particularly when a prescriptive cover is tested along with the proposed alternative.
- Validates design and construction.
- Suggest improved design features and construction methods to implement the full-scale implementation.
- Identify and help resolve problems.
- Help maximize return on investment.

Alternative covers provide significant economic benefits, beginning with one-time, upfront costs of construction, and extending over the closure process for perhaps 20 years or more. For privately owned landfills, which are required to provide funding that would cover costs from early closure or financial troubles, closure savings increase the sooner the alternative cover is approved.

There is a clear link between test pads and optimal cover performance, regulatory agency approval, and economic benefits. The sooner the landfill owner constructs test pads with lysimeters and begins to collect data and monitor performance, the sooner the approval process can begin and the sooner the cost savings will be realized, from both construction and the bond mechanism.

In short, start the design/approval process for an alternative cover as soon as possible. It is a basic time-is-money consideration: It takes time to construct and monitor the pilot test pads, time to complete the agency approval process, and time to design and construct the full-scale cover. The sooner the entire process begins; the sooner costs savings can be realized.

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