EVAPOTRANSPIRATION FINAL COVERS:
THE KANSAS EXPERIENCE – FROM CONCEPT TO REALITY

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ABSTRACT
This paper depicts the evolution of the first three Alternative Earthen Evapotranspiration Landfill Covers permitted in Kansas. Each was conceived, designed, modeled, approved, and constructed in 2003 and 2004. These projects were all full-scale projects and not pilot tests. The largest landfill area closed with an alternative cover was 75 acres, and the smallest was seven acres. Two pan-type lysimeters were installed on each of the three covers for monitoring infiltration through the cover. Lysimeter results have been generally encouraging, and two of the three covers appear to be performing better than expected. This presentation provides technical as well as economic comparisons between the three cover designs, including the significant savings each landfill has achieved. Items discussed and compared include:

- Climate;
- Soil properties;
- Cover thickness and number of layers;
- Vegetation selection;
- Cover construction;
- Cover monitoring;
- Predicted infiltration rates versus actual; and
- Cost per acre to construct.

Actual cost data for construction of the ET covers compared to prescriptive Subtitle D covers is presented.

INTRODUCTION
Alternative Earthen Final Cover systems, such as evapotranspiration (ET) cover systems, are increasingly being designed, permitted, and constructed at waste disposal sites across the country. ET covers have been successfully deployed at both municipal solid waste (MSW) landfills as well as hazardous waste landfills. The ET cover concept exploits the water storage capacity of fine-textured soils, coupled with the transpiration capability of vegetation. These soil-based covers are designed to store infiltrating water, allowing minimal drainage during the winter months while vegetation is dormant or in the rainy season when precipitation is excessive. During the growing season, plant transpiration removes the infiltrated/stored water from the soil cap, which then provides additional storage capacity for future precipitation events.

Traditional, prescriptive cover designs that use low permeability materials (clay, geosynthetics, etc.) to slow percolation of water into the waste mass largely avoid addressing the issue of performance by focusing on laboratory measured values, such as the saturated hydraulic conductivity of the material to be used in the cover (Desert Research Institute website). Recent studies have shown that over time the hydraulic conductivity of compacted clay covers can increase by orders of magnitude due to freeze/thaw and other natural processes (Albright et al., 2006). Alternative soil-based cover systems, in contrast, rely on the water-holding capacity of soil and the transpiration capacity of plants to maintain a favorable water balance. In addition, ET covers are not as vulnerable as low permeability soil covers to desiccation cracking, and can be constructed as a more stable, non-layered monolithic cover on landfill side slopes.

Soil-based covers have several benefits over prescriptive (composite) low permeability covers including:

- Reduces construction cost due to simpler construction;
- Reduces operation and maintenance costs;
- Maintains integrity when landfill settlement occurs;
- Reduces problems associated with long term integrity of compacted clay;
- Enhances methane oxidation/greenhouse gas reduction potential via soil microorganisms;
- Improves slope stability;
- Reduces vulnerability to desiccation cracking by using low to medium plasticity soils and limiting the degree of compaction;
- Reduces landfill gas to groundwater effects due to elimination of flexible membrane liners (FML); and
- Creates a better wildlife habitat after closure.

The following paragraphs briefly describe design considerations for ET covers in Kansas. Afterward, site specific details, construction procedures, monitoring results, and costs of the three ET covers constructed in 2003 and 2004 are evaluated and compared.

ALTERNATIVE COVER MODELING

Kansas regulations specify closure requirements for solid waste facilities. Per the regulations, a landfill cover shall consist of a low permeability (composite) layer overlaid by a final protective vegetated layer. However, the regulations also allow the department an option to grant a variance from the regulations and stipulate conditions and time limitations, as necessary, to comply with the intent of all applicable state and federal laws.

For final landfill covers, it is understood that the intent of the regulations is, in part, to minimize percolation of surface water into the waste. Aquaterra performed computer modeling to demonstrate the equivalent performance of ET covers compared to prescriptive Subtitle D covers, in minimizing percolation through the cover. A percolation value (flux) of 3 millimeters (mm) per year was selected as the design criteria for equivalency to a prescriptive cover.

The computer model selected to perform the equivalency demonstration for all three sites was UNSAT-H Version 3.01: Unsaturated Soil Water and Heat Flow Model (UNSAT-H). UNSAT-H is a one-dimensional model that simulates run-off, infiltration, percolation, moisture redistribution, evaporation, and transpiration of water from soil by plants. The UNSAT-H model was selected because it is widely accepted by regulatory agencies and field verification in both arid and semi-arid climates has produced reasonable results. Literature reports UNSAT-H does a superior job of capturing the seasonal variations in overland flow, evapotranspiration, soil water storage, and percolation when compared to other models. The input parameters and variables for the model includes site specific soil properties, meteorological data, vegetation growth parameters, program control variables, and initial saturation conditions. These parameters were researched for each site described in this presentation and incorporated into the modeling performed for each site.

As requested by the Kansas Department of Health and Environment (KDHE) – Bureau of Waste Management (BWM), a variety of scenarios were modeled for each site to evaluate the performance of the proposed ET cover. The scenarios included, at a minimum:

- The historically wettest consecutive 30-year period on available records;
- The wettest year on record, repeated 30 times for a 30-year simulation;
- The consecutive 5-year period with the lowest potential evapotranspiration divided by precipitation (PET/P) ratio, repeated six times for a 30-year simulation; and
- The consecutive 3-year period with the lowest PET/P ratio, repeated five times for a 15-year simulation.

Additionally, for each scenario, multiple simulations were modeled, varying one or more of the following parameters, to evaluate and determine the most appropriate cover design specifications:

- Cover thickness;
- Initial soil saturation conditions;
- Soil moisture;
- Precipitation intensities;
- Depth of roots;
- Leaf area index;
- Percent bare cover area, including modifying the model to account for the vegetation establishment period; and
- Varied depths of differing hydraulic conductivities, to account for freeze-thaw effects within the maximum frost penetration interval.

Based on the results of the modeling, the ET cover profile was designed for each site, as described later in this presentation. The results varied from site to site, but generally indicated favorable results for the applicability of ET covers in these wet, humid climates. For all three sites, vegetation was a critical design parameter.

THE IMPORTANCE OF CHOOSING THE RIGHT VEGETATION

Given the increased popularity/demand for the permitting of ET covers and the importance of rooting depths for cover performance, it is necessary to discuss the subject of vegetation selection and its significance to the long term success of an ET cap. Many ET caps designed and/or constructed to date have used a mixture of both warm and cool season grasses in an attempt to maximize the duration of the available growing season. In most cases, this mixture should not be selected.

Warm season grasses (commonly referred to as native or prairie grasses) are generally deep-rooted (2 to 8-foot root depth) which provide a much better ET function, but have a shorter growing season. In contrast, cool season grasses (fescue, rye, brome, etc.) that have been commonly used on landfill covers develop minimal rooting depths (4 to 8 inches), but have a longer growing season than native grasses.

The problem with mixing warm and cool season grasses is that over time, the cool season grasses will out-compete warm season (native/prairie) grasses due to the fact that they:

- Emerge quicker in the spring; and
- Are moisture "hogs" and will steal needed moisture away from the native plants/seeds (Ohlenbusch, 2004).

In general, native (warm season) grass seeds germinate in soil above 55 degrees Fahrenheit (°F). In contrast, cool season grass seed can germinate when soil temperatures reach 45 to 50°F. The cool season seeds get a head start on the competition, but the subsequent plants do not root as deep nor handle drought or stress near as well as the warm season species.

In addition, cool season grasses tend to go dormant when most needed - during July and August. Over a five to ten-year period, an originally mixed cool and warm season vegetation stand will almost always convert over to mainly a cool season stand, leaving the site with predominately shallow root depths. In wetter, more humid climates, most water balance models will not pass the infiltration equivalency test, unless the rooting depth is greater than 1 foot.

Over time, native species have adapted the ability to survive unforgiving environments, such as an un-irrigated landfill cap in mid-summer. These plants have the capacity to change a soil's infiltration rate, water-holding capacity, carbon sequestration and turnover, and nutrient retention in order to improve their chances of survival (Dierks, 2007). The native species can withstand much harsher climatic environments such as those commonly found at closed landfill sites. The heterogeneity of native species and their attributes (varying heights, dead and dying stalks, plant litter, etc.) drives them to treat water as an essential resource. The native species have evolved to be actively engaged in water recycling. These plants continuously work to capture, store, and reuse precipitation. Restoring or emulating natural systems can provide a host of benefits to the landfill owner. There is a reason these systems have developed as they have – as they tend to take advantage of every opportunity for survival afforded to them.

A MORE NATURAL SOLUTION

ET covers offer a more natural approach to the final capping of waste facilities and is distinctly different from the approach employed with prescriptive covers. It is anticipated that an ET cover is more likely to be effective over the long-term as it more closely mimics the natural environment. An added benefit is that ET covers are often less costly than prescriptive covers.

ET covers are becoming the more common cap of choice in the arid and semi-arid regions of the United States. Many landfill owners with facilities in the more humid and wet climates are also interested in the viability of an ET design that can work in their climatic region. The following sections describe the performance of three ET covers constructed in Kansas, where the climate is wetter with increased humidity than in arid regions.

COFFEY COUNTY LANDFILL BURLINGTON, KANSAS

The Coffey County Sanitary Landfill (CCSL) is located just east of Burlington, Kansas in Coffey County. The CCSL is located on approximately 120 acres, of which a total of approximately 38 are permitted for waste disposal. The landfill is owned and operated by Coffey County. The current disposal area consists of 24 acres permitted under Subtitle D requirements. Seven acres of a pre-Subtitle D area was permitted for a Vertical Expansion in 1998. This Vertical Expansion was closed using an ET alternative final cover during the summer and fall of 2003. The following figure (Figure 1) illustrates the landfill property and approximate ET cover boundary.

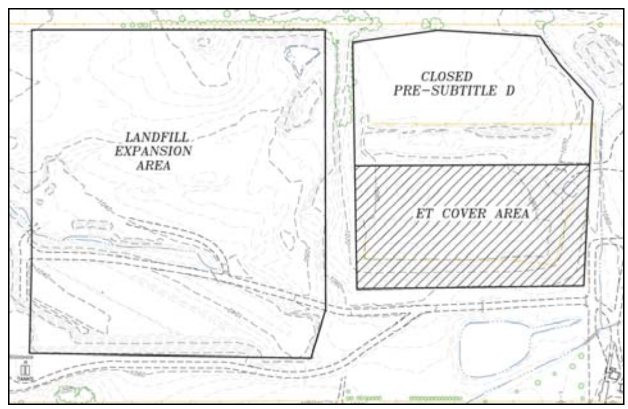


Figure 1 – Coffey County Sanitary Landfill

<u>Site and Final Cover Information</u>

Climate: The climate at the CCSL is classified as continental type. This climate type is characterized by a wide variation in daily and annual temperatures. The average daily temperature in the winter is approximately 32°F and the lowest temperature on record is -27°F (February 12, 1899). The average daily temperature in the summer is approximately 77°F and the highest temperature on record is 117°F (July 18 and August 14, 1936). The average annual precipitation in Coffey County is approximately 35.5 inches with 71 percent of this falling from April through September. The average annual snowfall is 17.5 inches. Since construction of the ET final cover at the CCSL, Coffey County received approximately 34 inches of precipitation in 2004, 45 inches in 2005, and 27 inches in 2006. The annual growing season is estimated to occur from April 15th through October 19th, with 186 frost-free days (Kansas State University Research and Extension Program).

Available Final Cover Soils: The soil material available for use as final cover at the CCSL consists of silty-clay and topsoil. The silty-clay had previously been used as intermediate cover on the Vertical Expansion. Additionally, undisturbed silty-clay was also available from the onsite borrow source (future disposal area). Based on soil property testing, the saturated hydraulic conductivity of the silty-clay material ranged from 3.1×10^{-6} to 2.6×10^{-7} centimeters per second (cm/sec), at approximately 85 percent of Standard Proctor. The average saturated hydraulic conductivity of the topsoil material was 4.0×10^{-6} cm/sec at approximately 85 percent of Standard Proctor.

Final Cover Design Soil Profile: Based on evaluation of numerous modeling scenarios of the estimated percolation through the cover, climate conditions, soil conditions, and selected vegetation, a 4.0-foot thick ET cover was designed for closure of the Vertical Expansion. The soil profile consists of 3.5 feet of loosely compacted silty-clay material (85 to 95 percent of Standard Proctor), overlain by 0.5 foot of topsoil, as illustrated in the figure below.

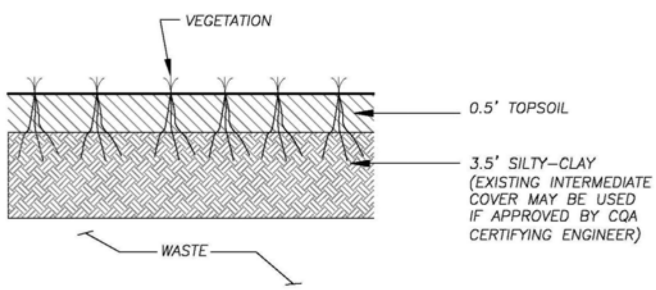


Figure 2 – CCSL Final Cover Profile

Vegetation: The selected vegetation for the ET cover included a variety of deep-rooted, native grasses, consisting of Big Bluestem, Little Bluestem, Indiangrass, Switchgrass, Sideoats Grama, Blue Grama, and Sand Dropseed. A local agronomist provided the specific recommended application rate.

Cover Construction

Intermediate Cover Evaluation: The intermediate cover material was evaluated to determine whether it was suitable for use as part of the final cover. The intermediate cover was evaluated for in-place soil density and thickness.

In-place soil density testing was performed at approximately 22 locations over the intermediate cover on the Vertical Expansion. All density results were above the lower acceptable limit of 85 percent of the maximum Standard Proctor dry density. The evaluation confirmed that in-place density of the soil used for intermediate cover was generally within established limits set forth in the Construction Quality Assurance (CQA) Plan.

The thickness of intermediate cover material placed over waste in the Vertical Expansion area varied from approximately 2 feet of cover on the top portion of the landfill to over 8 feet of cover on the side slopes. The thickness of the intermediate cover was verified by advancing a macro-core sampler to collect soil samples over an approximate 100-foot grid across the Vertical Expansion. A total of 55 locations were evaluated for cover thickness. The results of the thickness evaluation indicated that, if possible, existing in-place material should be used to the extent possible based on modeling results. Samples of the in-place intermediate cover were collected and modeled as part of the design effort.

Pre-Construction Soil Testing: Prior to constructing the remainder of the final cover, soil samples were collected from the in-place intermediate cover and proposed borrow areas for pre-construction laboratory testing. The purpose of the testing was to confirm that the selected materials had properties that were similar to the soils modeled during the alternative cover design, to historical data, and to provide a benchmark for comparison with the nuclear density in-place field test results.

Three in-place intermediate cover soil samples were submitted for the following tests:

- Unified Soil Classification (ASTM D2487)
- Atterberg Limits (ASTM D4318)
- Standard Proctor (ASTM D698)
- Particle Size Analysis (ASTM D422)

Soil Placement Activities: The silty-clay layer of the ET final cover was designed to be 3.5-feet thick. Based on the thickness evaluation, it was assumed a minimum of 0.5 feet of silty-clay intermediate cover was present on all areas of the Vertical Expansion; therefore, only 3 feet of material placement was actually required during construction. The intermediate cover material originally located on the Vertical Expansion had, in some locations, exceeded the placement density range specified by the CQA Plan. Therefore, prior to additional material placement, the in-place material was loosened using a ripper attachment on the back of a bulldozer. Once loosened, additional material was placed. Density testing of the material indicated densities in the lower 80 percent of Standard Proctor. These values fell below the placement criteria of 90 percent ± 5 percent. The KDHE-BWM was contacted and it was decided to allow placement at lower compactions since the likelihood of increased compaction with moisture addition from rainfall and additional equipment loads was possible.

The material was generally placed in 1-foot thick lifts since over-compaction was not a concern with this particular soil material. Upon completion of placing and spreading, each lift was tested with nuclear density methods to determine the in-place moisture and density. Tests were completed within 100-foot grids on a random pattern. The material was placed such that its moisture and density values fell within the target placement range.

The 0.5-foot thick topsoil layer was placed in the same manner as the silty-clay. The material was placed such that its moisture and density values fell within the target placement range.

Conformance Soil Testing: A total of five conformance samples were collected of the silty-clay material during construction. Two topsoil samples were also collected. This equated to an approximate rate of one sample per 5,000 cubic yards (cy) of soil used. Results generally indicated similarities between the material actually used for construction and the soil material modeled during design and permitting.

__Lysimeters__

Locations: The KDHE-BWM approved the ET cover design, provided two pan-type lysimeters were constructed to monitor drainage through the cover. In the case of CCSL, both lysimeters were located on side slopes; the Vertical Expansion and pre-Subtitle D areas have been converted to a construction and demolition (C&D) landfill area. If a lysimeter had been located on the top of the Vertical Expansion, it would have been covered with C&D waste and become inaccessible.

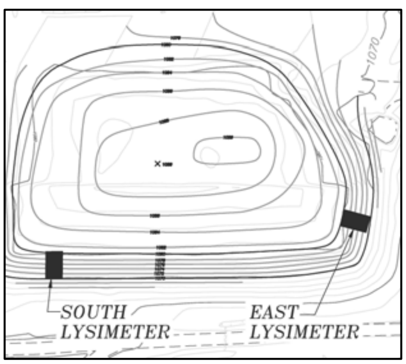


Figure 3 – CCSL Lysimeter Locations

One lysimeter was constructed on the south side slope; this lysimeter is referred to as the **South Lysimeter**. The second lysimeter was constructed on the east side slope to evaluate the effect of lower intensity sunlight and is referred to as the **East Lysimeter**. Furthermore, the East Lysimeter was planted with a test plot of hydrophilic trees to evaluate the variation in drainage through the cover with different types of vegetation.

Subgrade Construction: The design plans required an 18-inch thick compacted cohesive soil base below the lysimeter pans. The existing in-place intermediate cover in the two proposed lysimeter areas was in excess of 8 feet; therefore, a 4-foot excavation was made into the cover for lysimeter installation. Elevation surveys were performed to ensure the pan was sloped correctly and the silty-clay material above the base was placed as necessary. The subgrade for each lysimeter was tested for in-place density, which was found to be acceptable.

Concrete and Pan Construction: Concrete curbs were placed to enclose an approximate 30-foot by 50-foot area. The curbs were extended vertically 6 inches above the subgrade and were 12 inches wide. Soil material was sloped from the subgrade to the top of the curb. A surveyor located the sump pit which was then excavated using a track hoe. The sloped area and subgrade were then smooth rolled to provide a smooth surface for which to place poly-vinyl chloride (PVC) plastic liner.

PVC Liner Installation: After the subgrade, concrete curbs, and sump pit were constructed, a sheet of factory-welded PVC liner was deployed. The PVC panels were pre-fabricated to be approximately 40-feet wide by 60-feet long, so the material could overlap the curbs and fit inside the sump. Field welding for adjacent panels was not required, because the individual panels were welded together at the factory to the required dimensions. After deployment, the liner was observed for visual defects and holes. One small tear was noted in the northwest quadrant of the PVC deployed in the South Lysimeter. This tear was repaired by chemically welding a piece of PVC liner to the tear area.

A hole was cut in the PVC liner to install the outlet pipe in the sump, and a PVC pipe boot was glued over the pipe and hole. The PVC liner was swept following completion to minimize the presence of rocks, dust, or dirt on the PVC liner.

Drainage Layer Installation: A double-sided geocomposite drainage layer was installed over the PVC liner in three sections. The roll of composite was placed at the top of the lysimeter and held in place via a bar and two skid loaders. The composite material was then pulled from the roll and placed in the lysimeter with sufficient extra material to overlap the panels and the curbs. The 15-foot wide panels were placed at the sides first, then in the middle with a minimum of 2 foot of overlap between panels.

Drainage rock was placed in the sump area after geocomposite deployment was complete. Geotextile was then placed over the drainage rock to provide a separation barrier from the overlying ET cover soils.

Leak Tests: Leak tests were performed on the lysimeter sumps systems. For the South Lysimeter, a stand pipe was connected to the lysimeter discharge piping. The sump was then filled with water to a level that could be read on the stand pipe. Over the first 24 hours of the leak test on the South Lysimeter, a drop in water level of ½-inch was noted. It was determined by Aquaterra that this drop was due to a combination of absorption of water by the rock and evaporation.

For the second lysimeter leak test, a modified procedure was used. In the case of the East Lysimeter, the leak test was performed prior to placing the geocomposite in the lysimeter or rock in the sump. Again, a stand pipe was attached to the lysimeter discharge piping and the sump was filled with water to a level that could be read on the stand pipe. No evidence of leaking was observed from the leak test. Care was taken when placing the geocomposite and rock to not damage the lysimeter PVC liner.

Soil Layer Construction: After the lysimeter pans had been constructed and passed the leak tests, the soil cover was installed. Soil was spread in approximately 12-inch thick lifts over the lysimeter pans. The CQA technician observed soil placement with special attention paid during the first lift to avoid damaging the underlying geosynthetic components. The remaining lifts were placed in the same manner as the rest of the cover placed on the Vertical Expansion. Other CQA activities performed during soil installation included nuclear moisture and density testing and soil layer thickness observation and vegetation establishment.

Cover Drainage Measuring System Calibration: The cover drainage lysimeter measuring system includes the lysimeter discharge piping which drains into a RainWise Inc. (RainWise) Rainew tipping bucket rain gauge with an electronic data logger. This tipping bucket is situated on top of a 55-gallon drum; the drum, lysimeter discharge piping, and tipping bucket are all contained within a 48-inch corrugated metal pipe (CMP) with a locking lid for security. From the 55-gallon tank, discharge piping equipped with a valve exits the CMP at a minimum 2 percent slope where it daylights on the side of the slope.

The tipping bucket provides the ability to measure the amount of water from the lysimeter pan outlet pipe. After tripping the bucket, water drains out the bottom of the rain gauge and accumulates inside the 55-gallon drum. The electronic data logger records the number of tips of the bucket, which can be correlated to an approximate volume of drainage through the cover. If the tipping bucket malfunctions, the 55-gallon tank provides a means of estimating drainage.

Calibration tests were performed on the rain gauges after installation by pouring a known volume of water through the gauges at varying flow rates and recording the number of tips. The volume of water poured into the rain gauge was then divided by the number of tips to determine the volume of water per tip.

<u>Tree Test Plot</u>

In order to evaluate the effects of deep-rooted vegetation on the performance of the ET cover, the East Lysimeter was planted with a mix of hydrophilic trees as a test plot. A total of 35 trees were planted over an area approximately 40 feet by 60 feet to ensure complete coverage of the lysimeter. Three types of trees were planted, including 25 poplars, six cottonwoods, and four willows.

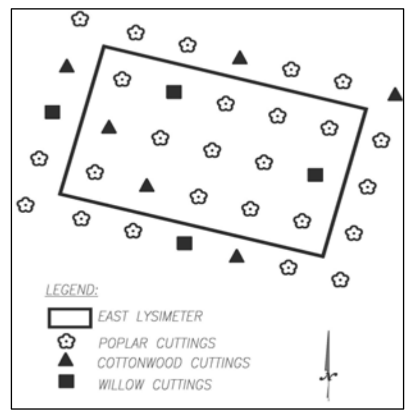


Figure 4 – CCSL East Lysimeter Tree Plot Layout

A post-hole digger was used to complete holes approximately 8 inches in diameter and 18 inches deep. Cuttings were placed in the holes to a depth such that two to three buds were above ground. The soil was then replaced in the hole and hand tamped to avoid settlement. A 3-foot by 3-foot weed blocking fabric mat was then placed around the cuttings in order to limit competition from the already planted native grasses. Over the first spring and summer following planting, the trees were watered on an intermittent basis. No special attention or maintenance has been performed.

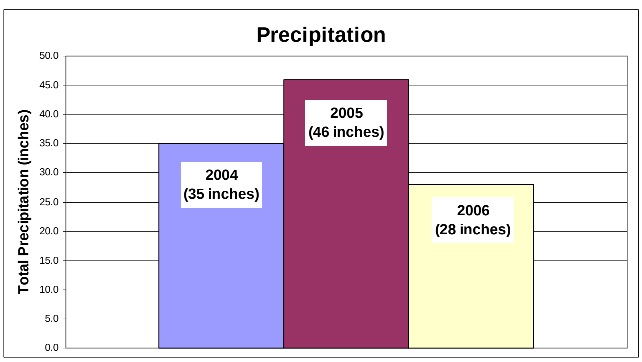
<u>Monitoring Results</u>

Initially, monitoring site visits were performed on a monthly basis. The frequency was dictated by the fact that it was unsure how much drainage would be passing through the lysimeter on a monthly basis. Each month, Aquaterra personnel visited the site and recorded the number of tips logged by each tipping bucket. During each visit, the exit valve for the 55-gallon drum was opened to allow collected water to drain from the drum. The Vertical Expansion was observed for vegetation deficiencies or problems, the trees in the East Lysimeter test plot were observed, and other general site observations were recorded.

Based on the designed flux of 3 mm per year and a lysimeter pan area of 30 feet by 50 feet, the drainage volume through each lysimeter was calculated to be approximately 110 gallons per year.

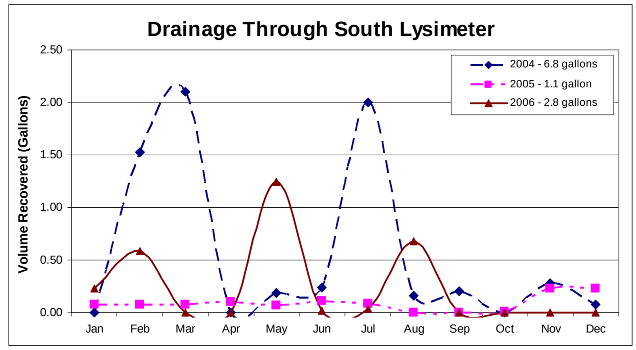
The ET cover has performed well over the past three years. Nurse crop vegetation (winter wheat) established quickly and prevented erosion from snow melt and spring rains. Native grass vegetation began to establish itself late in the first year after construction; vegetation was patchy as is typical with native grasses. Discussion of drainage through the cover as measured in each lysimeter is discussed below.

The total precipitation recorded in Coffey County over the past three years (since ET cover construction) has been variable but certainly within historical normalcy. The following graph shows the yearly precipitation experienced from 2004 through 2006 at Coffey County.



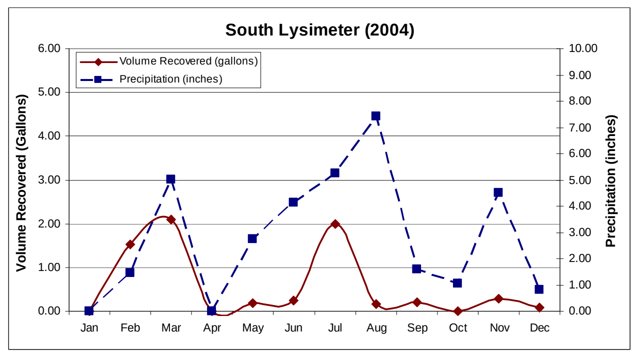
Graph 1 – Coffey County Precipitation

South Lysimeter: Readings taken from the South Lysimeter have indicated adequate performance of the ET cover. Volumes of water recovered through the lysimeters have varied over the past three years but have consistently been below the design limit of 110 gallons per year per lysimeter. During 2004 (February through December) a total of 2,910 tips were recorded which equates to a total of 6.8 gallons. Collected water for 2005 totaled 1.1 gallon, and in 2006 the total was 2.8 gallons. The following graph shows a comparison of drainage for each year:

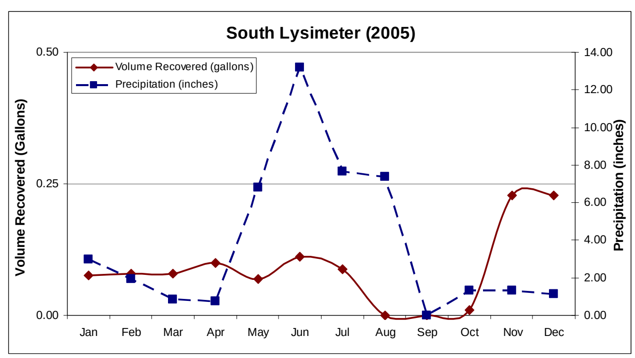


Graph 2 – CCSL South Lysimeter Recorded Drainage

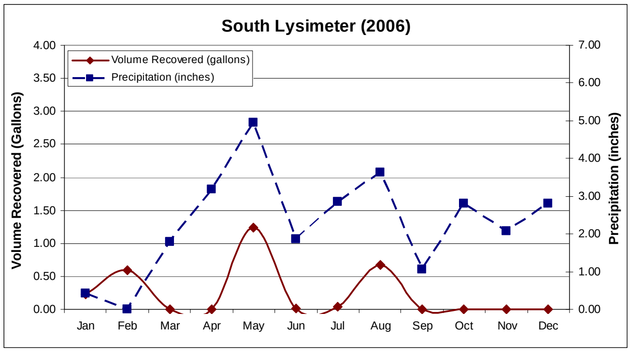
In general, it can be seen that drainage through the lysimeter tends to follow certain trends generally related to seasons. The following three graphs demonstrate the relationship between the timing of rainfall events to the drainage through the lysimeter.



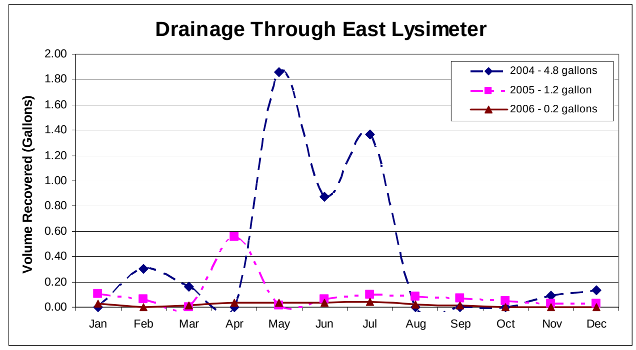
Graph 3 – CCSL South Lysimeter - 2004
Volume Recovered Compared to Monthly Precipitation



Graph 4 – CCSL South Lysimeter - 2005
Volume Recovered Compared to Monthly Precipitation



Graph 5 – CCSL South Lysimeter - 2006
Volume Recovered Compared to Monthly Precipitation



Graph 6 – CCSL East Lysimeter
Recorded Drainage

Modeling results during the ET cover design indicated a maximum of approximately 17 gallons of water would percolate through the cover. This was estimated for a year which followed several years of heavy precipitation. Based on measurements recorded in the South Lysimeter, the ET cover is functioning better than the model predicted.

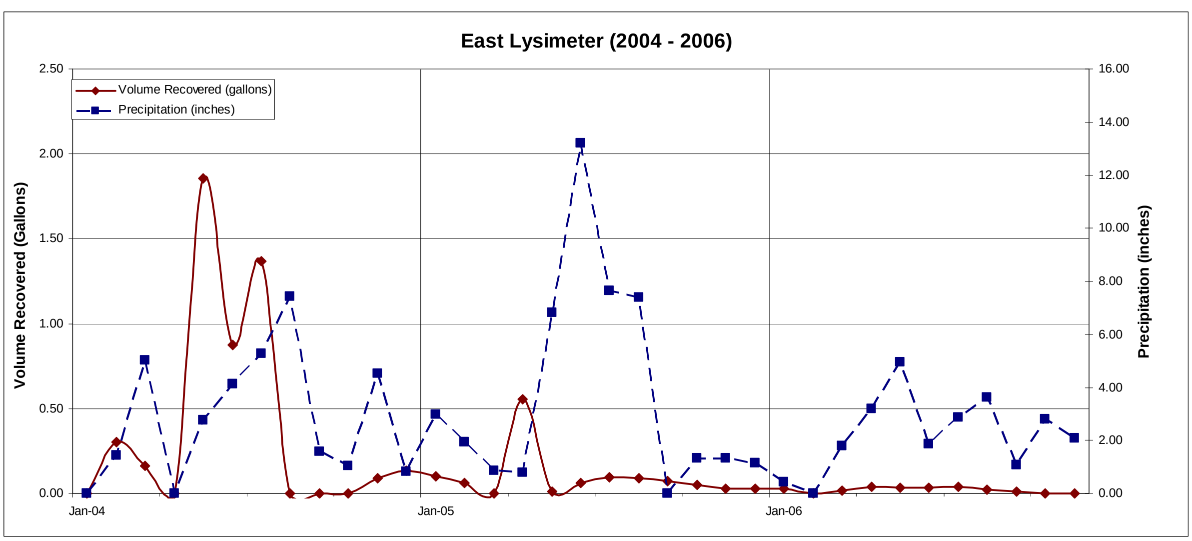
East Lysimeter: Readings taken from the East Lysimeter have also indicated adequate performance of the ET cover combined with the hydrophilic tree test plot. Volumes recovered through the lysimeters have generally been consistent and have been below the design limit of 110 gallons per year per lysimeter. The drainage for each year is shown on Graph 6.

Drainage through the cover did not agree with precipitation events as closely as results for the South Lysimeter. It is thought that the presence of the trees on the East Lysimeter have impacted the timing of drainage with respect to precipitation events. Although drainage through the East and South lysimeters was similar in 2004 and 2005, results were significantly different in 2006. The table below summarizes the differences between years and lysimeters:

Table 1 – CCSL
Yearly Comparison of Drainage Through Lysimeters

Year	South Lysimeter	East Lysimeter
2004	6.8 gallons	4.8 gallons
2005	1.1 gallons	1.2 gallons
2006	2.8 gallons	0.2 gallons

As with the South Lysimeter, the measured volume of water collected in the East Lsyimeter indicates the cover is functioning better than the model predicted. The following graph shows all three years of drainage data for the East Lysimeter, combined with the precipitation data for the three-year time period.



Graph 7 – CCSL East Lysimeter – Volume Recovered Compared to Monthly Precipitation

Tree Test Plot: The tree test plot has performed above expectations over the past three years. As of September 5, 2006, all 35 trees were still alive, although some of them appeared drought-stressed. Trees ranged in height from 5 to 12 feet tall. The willows had effectively established several runners, and two poplars had spawned new trees nearby. Based on the lysimeter drainage results from 2006, it appears the trees located on the East Lysimeter have increased evapotranspiration and decreased drainage through the cover system. Furthermore, it appears after three years, the tree roots may have developed to maturity, increasing the amount of water uptake by the trees.

Results of the lysimeter monitoring and tree test plot impacts on drainage will be discussed in the future with the KDHE-BWM to determine the appropriateness of planting deep-rooted vegetation on ET covers.

BARTON COUNTY SANITARY LANDFILL
GREAT BEND, KANSAS

The Barton County Sanitary Landfill (BCSL) is located in central Kansas, northeast of the City of Great Bend. Waste disposal is permitted on approximately 83 acres of the 380-acre tract of land owned by Barton County. Current disposal operations take place over 15.3 acres of an approximate 42-acre Subtitle D lateral expansion, located east of the original unlined 41-acre waste management unit (WMU). The northern 19 acres of the original WMU were closed in 2000 in accordance with pre-Subtitle D regulations. In 2003, an ET alternative final cover was constructed over the southern 22 acres of the original WMU, referred to as the "Vertical Expansion". The figure below illustrates the landfill property and approximate ET cover boundary.

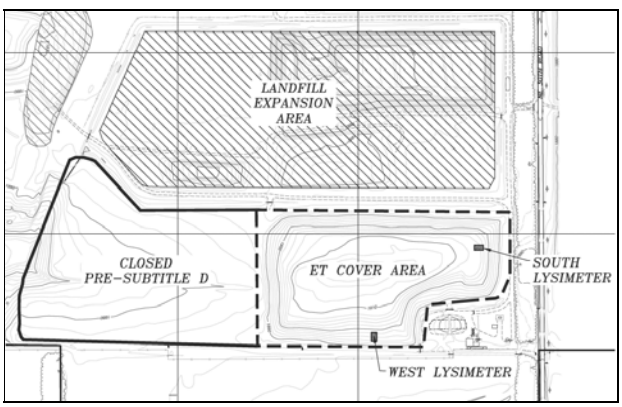


Figure 4 – Barton County Sanitary Landfill

<u>**Site and Final Cover Information**</u>

Climate: The climate at the BCSL is classified as continental type. This climate type is characterized by a wide variation in daily and annual temperatures. The average daily temperature in the winter is approximately 33.5°F, and the lowest temperature on record is -19°F (February 1, 1951). The average daily temperature in the summer is approximately 78.7°F, and the highest temperature on record is 111°F (July 11, 12, and 13, 1954). The average annual precipitation in Barton County is approximately 25.6 inches with 73 percent of this falling from April through September. The average annual snowfall is approximately 21.7 inches. The annual growing season is estimated to occur from April 13th through October 26th, with 196 frost-free days (United States Department of Agriculture, 1981). Since construction of the ET final cover at the BCSL, Barton County received 25.2 inches of precipitation in 2004, 21.2 inches in 2005, and 29.3 inches in 2006. (Kansas State University Research and Extension Program).

Available Final Cover Soils: The soil material available for use as final cover at the BCSL consists of silty-clay and topsoil. The silty-clay had previously been used as intermediate cover on the Vertical Expansion. The silty-clay was obtained from the borrow area (future waste disposal cell) from a soil horizon extending from approximately 6 to 40 feet below original ground surface. Based on soil property testing, the saturated hydraulic conductivity of the silty-clay material is 2.3 x 10^{-6} cm/sec, at approximately 85 percent of Standard Proctor. The saturated hydraulic conductivity of the topsoil material was 8.4 x 10^{-7} cm/sec, at approximately 85 percent of Standard Proctor.

Final Cover Design Soil Profile: Based on evaluation of numerous modeling scenarios of the estimated percolation through the cover, climate conditions, soil conditions, and selected vegetation, a 5-foot thick ET cover was designed for the BCSL. The soil profile consists of 4 feet of loosely compacted silty-clay material (80 to 90 percent of Standard Proctor), overlain by 1-foot of topsoil, as illustrated below.

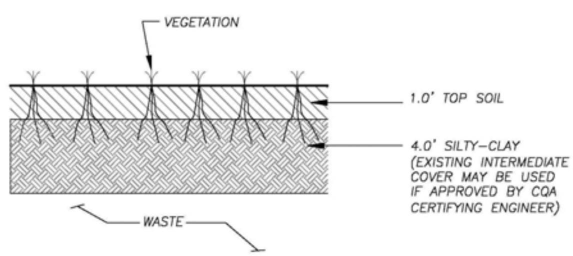


Figure 5 – BCSL Final Cover Profile

Vegetation: The selected vegetation for the ET cover included a variety of deep-rooted, native prairie grasses, consisting of Big Bluestem, Little Bluestem, Indiangrass, Switchgrass, Sideoats Grama, Blue Grama, Western Wheatgrass, Buffalo Grass, and Sand Dropseed. Application rates for the various grass species were developed by a local agronomist.

Cover Construction

Intermediate Cover Evaluation: The intermediate cover material was evaluated to determine whether it was suitable for use as part of the final cover. The intermediate cover was evaluated for thickness, in-place soil density, and composition.

The thickness of the intermediate cover was verified by advancing a 4-foot long macro-core sampler to collect soil samples over an approximate 100-foot grid across the Vertical Expansion. A total of 154 locations were evaluated for cover thickness. In many places, the existing intermediate cover exceeded 4 feet in thickness. The cover thickness evaluation determined that 11 of the 154 test locations had less than 1 foot of soil cover. Additional soil was placed in these areas to meet the 1-foot thick minimum intermediate cover requirements.

Following disking to remove the existing vegetation from the intermediate cover soils, the in-place soil density was measured over the same 100-foot grid using a nuclear density gauge. The soil density test results were all within the acceptable 85 ± 5% of the maximum Standard Proctor dry density range.

Twelve bulk soil samples were collected from the intermediate cover for laboratory analysis to compare properties with the soils utilized in the design and modeling. The samples were analyzed for Atterberg Limits, grain size analysis, and classified in accordance with the Unified Soil Classification system. The laboratory test results indicated the in-place intermediate cover soils matched up relatively well with the soils utilized during design.

The results of the intermediate cover thickness, in-place density, and characterization testing indicated the upper 12 inches of the existing intermediate cover could be utilized as a portion of the final cover.

Pre-Construction Soil Testing: Prior to cover construction, soil samples were collected from the proposed borrow areas for laboratory analysis. The purpose of the testing was to confirm that the selected materials had properties that were similar to the soils modeled during the design process and to provide a benchmark for comparison with the nuclear density gauge in-place field test results.

The soil samples were submitted for the following tests:

- Unified Soil Classification (ASTM D2487)
- Atterberg Limits (ASTM D4318)
- Standard Proctor (ASTM D698)
- Particle Size Analysis (ASTM D422)

Soil Placement Activities: The silty-clay layer of the ET final cover was designed to be 4 feet thick. Based on the intermediate cover evaluation, it was assumed a minimum of 1 foot of silty-clay intermediate cover was present on all areas of the Vertical Expansion; therefore only 3 feet of additional silty-clay soil was required during construction.

The additional 3 feet of silty-clay was installed in approximately 1-foot thick lifts. The soil was excavated from the borrow area and spread on the Vertical Expansion area using scrapers. After a 12-inch lift of soil was placed and spread, it was loosened by ripping with either a bulldozer or road grader fitted with a ripping attachment. Upon completion of placing, spreading, and loosening, each lift was tested with a nuclear density gauge to determine the in-place moisture and density. Tests were completed within 100-foot grids on a random pattern. The material was placed such that its moisture and density values fell within the target placement range.

The 1-foot thick topsoil layer was placed in the same manner as the silty-clay. The material was placed such that its moisture and density values fell within the target placement range. After placing the topsoil, 15 tons of cattle manure were spread over the cover and disked into the upper 6 inches. The manure was expected to increase the organic content of the soil, provide nutrients for the vegetation, and introduce additional bacteria to enhance nutrient cycling.

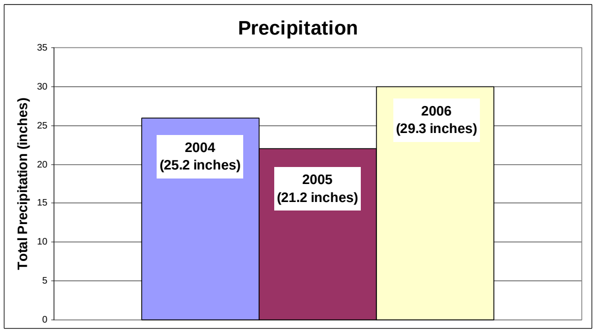
Conformance Soil Testing: No conformance samples were collected during construction.

Lysimeters

Two lysimeters were constructed at the BCSL to monitor drainage through the ET cover. One of the lysimeters was installed midslope on the west side of the Vertical Expansion (**West Lysimeter**), and one was installed on the flatter portion of the cover near the top on the south side (**South Lysimeter**). The lysimeters were designed and constructed similar to those at the CCSL. Drainage through the cover is continuously monitored using a RainWise tipping bucket rain gauge and data logger attached to the drainage pipe from each lysimeter. Backup verification readings are also taken when the data loggers are downloaded by reading the water level on the graduated lysimeter tank.

Monitoring Results

The total precipitation recorded in Great Bend over the past three years (since ET cover construction) has been variable but within historical normalcy. The graph below summarizes the yearly precipitation.

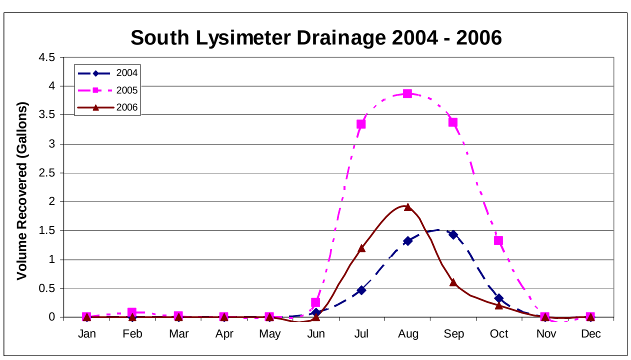


Graph 8 – Barton County Precipitation

West Lysimeter: Lysimeter monitoring began in January 2004. Since that time, there has been no drainage recorded in the West Lysimeter. Modeling results during the ET cover design indicated up to approximately 1.5 gallons of water would percolate through the cover annually. Based on the West Lysimeter monitoring results, the cover is exceeding design parameters.

South Lysimeter: Since January 2004, only a small amount of drainage has been recorded in the South Lysimeter. Based on the design flux of 3 mm per year and a lysimeter pan area of approximately 30 feet by 50 feet, the drainage volume through the South Lysimeter was calculated to be approximately 110 gallons per year.

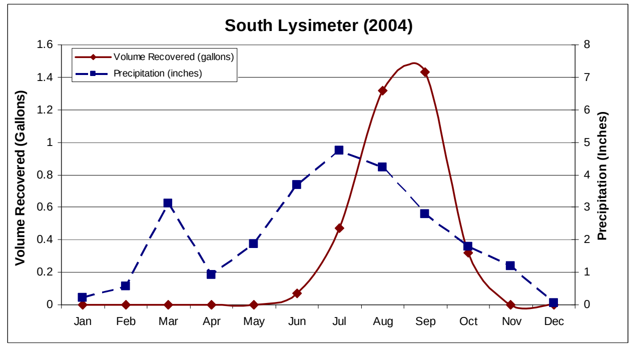
Infiltration recovered through the South Lysimeter has varied, but has consistently been well below the design limit of 110 gallons per year. Drainage for years 2004, 2005, and 2006 was approximately 3.6, 12.2, and 3.9 gallons, respectively. The following graph shows a comparison of monthly drainage for each year:



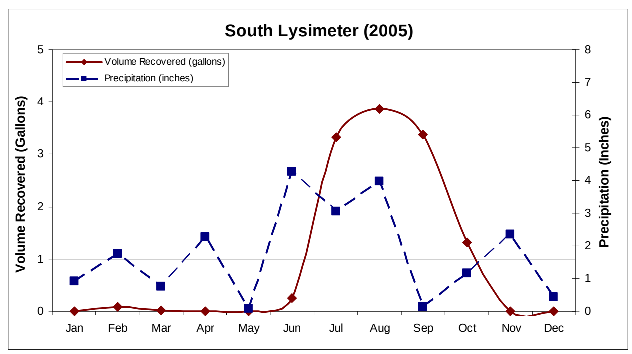
Graph 9 – BCSL South Lysimeter Recorded Drainage

Drainage through the South Lysimeter has consistently followed seasonal trends with no drainage during the winter, increasing drainage during the spring, peaking during the summer, and then declining during the fall.

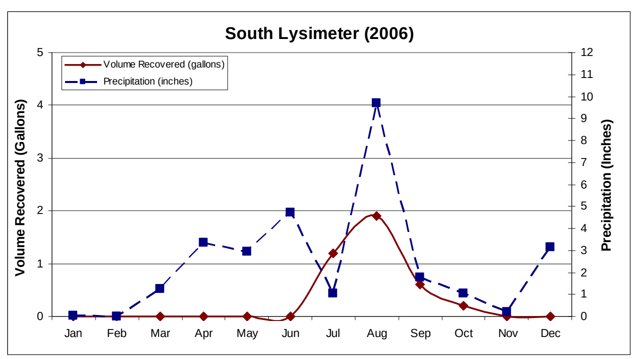
The following three graphs demonstrate the relationship between monthly precipitation totals and drainage through the lysimeter.



Graph 10 – BCSL South Lysimeter - 2004 Volume Recovered Compared to Monthly Precipitation



Graph 11 – BCSL South Lysimeter - 2005 Volume Recovered Compared to Monthly Precipitation



Graph 12 – BCSL South Lysimeter - 2006 Volume Recovered Compared to Monthly Precipitation

Although the volume of water recovered in the South Lysimeter is above the 1.5 gallons per year predicted by modeling, readings have indicated compliance with the design infiltration rate (3 mm/year).

JOHNSON COUNTY LANDFILL
SHAWNEE, KANSAS

The Johnson County Landfill (JCL) is located in Shawnee, Kansas, west of Interstate 435 and south of the Kansas River. The JCL currently occupies approximately 243 acres of a total 867-acre track of land owned by the owner/operator, Deffenbaugh Industries, Inc. (Deffenbaugh). The MSW disposal area designated as Phase III of the JCL occupies approximately 75 acres. An ET alternative final cover was constructed over Phase III during the fall of 2003. The cover was extended over the adjacent C&D waste disposal area (10 acres) during the summer of 2006.

Site and Final Cover Information

Climate: The climate at the JCL is classified as continental type. This climate type is characterized by a wide variation in daily and annual temperatures. The average daily temperature in the winter is approximately 32°F and the lowest temperature on record is -29°F (February 12, 1899). The average daily temperature in the summer is approximately 86°F and the highest temperature on record is 111°F (July 7, 1913). The average annual precipitation in Johnson County is approximately 38 inches with 71 percent of this falling from April through September. The average annual snowfall is 19 inches. Since construction of the ET final cover at the JCL, Johnson County received 40 inches of precipitation in 2004, 46 inches in 2005, and 29 inches in 2006. The annual growing season is estimated to occur from April 13th through October 26th, with 196 frost-free days (Kansas State University Research and Extension Program).

Available Final Cover Soils: The soil material available for use as final cover at the JCL consists of shale and clay. The shale material is described as highly weathered. Based on soil property testing, the saturated hydraulic conductivity of the shale material ranged from 6.9×10^{-5} to 3.4×10^{-7} cm/sec at approximately 85 percent of Standard Proctor. The clay material is a fat clay. The average saturated hydraulic conductivity of the clay material was 1.9×10^{-5} cm/sec at approximately 85 percent of Standard Proctor.

Final Cover Design Soil Profile: Based on evaluation of over 100 modeling scenarios of the estimated percolation through the cover, climate conditions, soil conditions, and selected vegetation, a 5.5-foot thick ET cover was designed for Phase III at the JCL. The soil profile consists of 4.5 feet of loosely compacted shale (85 to 95 percent of Standard Proctor) overlain by 1.0 foot of loose clay, as illustrated below.

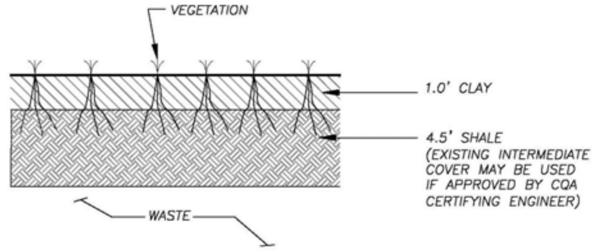


Figure 6 – JCL Final Cover Profile

Vegetation: The selected vegetation for the ET cover included a variety of deep-rooted, native grasses, consisting of Big Bluestem, Little Bluestem, Indiangrass, Switchgrass, Sideoats Grama, and Blue Grama. A local agronomist provided the specific recommended application rate.

Cover Construction

Intermediate Cover Evaluation: The intermediate cover material was evaluated to determine whether it was suitable for use as part of the final cover. The following intermediate cover material properties were evaluated:

- Material composition (soil characterization),
- In-place soil density, and
- Thickness.

Thirty-two samples of the intermediate cover material were collected from random locations of Phase III and submitted for geotechnical laboratory analysis, to evaluate continuity with the design soil parameters. In addition, in-place soil density testing was performed at approximately 60 locations. All density results were above the lower acceptable limit of 85 percent of the maximum Standard Proctor dry density.

Approximately 3 feet of shale material was placed over the waste in Phase III as intermediate cover. The thickness of the intermediate cover was verified by advancing an auger on an approximate 100-foot grid over the entire cover. A minimum of 3 feet of cover material was observed in 254 out of 256 boring locations.

The evaluation confirmed that the soil used for intermediate cover was similar to the soil modeled during the alternative cover design, and the in-place density was generally within established limits set forth in the CQA Plan. Therefore, the intermediate cover was acceptable for use as part of the final cover.

Pre-Construction Soil Testing: Prior to constructing the remainder of the final cover, soil samples were collected from proposed borrow areas for pre-construction laboratory testing. The purpose of the testing was to confirm that the borrow soils had properties similar to the soils modeled during the alternative cover design, similar to historical data, and to provide a benchmark for comparison with the nuclear density in-place field test results.

Seven soil samples were submitted for the following tests:

- Unified Soil Classification (ASTM D2487)
- Atterberg Limits (ASTM D4318)
- Standard Proctor (ASTM D698)
- Particle Size Analysis (ASTM D422)

Four of the samples were collected from proposed borrow material for the shale layer of the cover. The remaining three samples were collected from proposed borrow material for the clay layer of the cover.

Soil Placement Activities: The shale layer of the ET final cover was designed to be 4.5 feet thick. Although the existing intermediate cover was evaluated to be at least 3 feet thick, and therefore only 1.5 feet of shale material was required, for ease of construction, an additional 2 feet of shale material was placed over the intermediate cover to construct the 4.5-foot thick shale layer. The material was placed in one, 2-foot thick lift to minimize over-compaction by limiting the number of passes from the end dumps and dozer. Upon completion of placing and spreading the 2-foot shale layer, test pits were dug so that each 12-inch layer could be tested to document that the soil was placed such that its moisture and density values fell within the target placement range, as determined by pre-construction testing. All density values met the minimum density standard; however, occasionally density values fell above the maximum density range. Due to the potential for further increasing the compaction in these areas, they were not re-worked.

The 1-foot clay layer was placed in the same manner as the shale. With the exception of an occasionally high moisture result due to a rain event, the density and moisture tests fell within the target placement range.

Conformance Soil Testing: Based on the historical abundance of soil testing data at the site, additional conformance soil samples during the cover construction activities were not collected or tested. In place of the conformance soil testing, the CQA technician visually observed the soil to monitor consistency during construction. The visual observations and the relatively consistent nuclear density gauge readings indicated that soil properties remained relatively consistent throughout construction.

Lysimeters

Locations: The KDHE-BWM approved the ET cover design, provided two pan-type lysimeters were constructed to monitor drainage through the cover. One lysimeter was constructed in the northeast portion of the top of the cell, under the crown, and is referred to as the **Top Lysimeter.** The second lysimeter was constructed under the cover on the western side slope, straddling a storm water diversion terrace. This lysimeter is referred to as the **West Slope Lysimeter**. These locations were selected as two potentially worst-case conditions for cover infiltration.

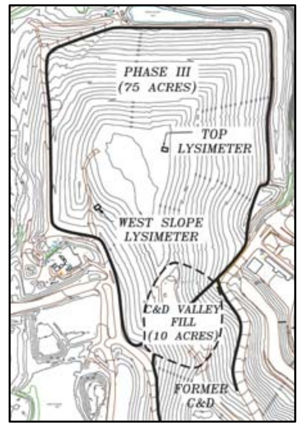


Figure 7
JCL Lysimeter Locations

Subgrade Construction: The design plans required an 18-inch thick compacted cohesive soil base below the lysimeter pans. A Geoprobe® and track-hoe bucket were used to verify a minimum of 18 inches of intermediate cover was present for the soil base. Elevation surveys were performed to ensure the pan was sloped correctly and additional shale material was placed as necessary. The Top Lysimeter subgrade was wheel-rolled and the West Slope Lysimeter was smooth-drum rolled to provide a smooth surface for PVC liner deployment.

Concrete and Pan Construction: Concrete curbs were placed to enclose an approximate 32-foot by 48-foot area for each lysimeter. Each curb was 8-feet long, 8 inches high, 6.5 inches wide at the top, 9 inches wide at the base, and weighed approximately 400 pounds. Two, 15-inch rebar stakes were used to secure each end of each curb into the subgrade. A surveyor located the sump pit, and field laborers excavated an area for the sump using shovels.

PVC Liner Installation: After the subgrade, concrete curbs, and sump pit were constructed, a sheet of factory-welded PVC liner was deployed over each lysimeter base. The PVC panels were pre-fabricated to be 42-feet wide by 60-feet long so the material could overlap the curbs and fit inside the sump. Field welding for adjacent panels was not required because the individual panels were welded together at the factory to the required dimensions. After deployment, the CQA technician observed the liner for visual defects and holes. No major defects or holes were found on either panel. A hole was cut in the PVC liner to install the outlet pipe in the sump and a PVC pipe boot was glued over the pipe and hole. The fitting edges were caulked with silicone to provide an additional factor of safety against leaking.

Leak Tests: Leak tests were performed on the lysimeter sumps and storage tank systems. The 55-gallon polyethylene tanks were leak tested by monitoring the water level in each tank when filled with water for a 24-hour period. No measurable drop in water level was recorded in either lysimeter tank.

The PVC liner within the lysimeter sumps was leak tested prior to installing the geocomposite drainage material and rock. The leak tests were performed by capping the end of the discharge piping from the sump, adding water to a level that was easily discernable on the sidewalls of the sump, and monitoring the water level for a 24-hour period. The Top Lysimeter sump leak test indicated a drop in the water level greater than ⅛-inch. The leak was determined to be around the pipe boot and outlet pipe fittings. The fittings were re-sealed with caulk and the liner was re-tested. The second leak test on the Top Lysimeter indicated the leak was repaired. Leaks were not observed during the leak test on the West Slope Lysimeter, and the water levels measured during the test did not indicate a drop greater than ⅛-inch. At the conclusion of each test, the water was released from the sumps and the underside of the PVC liner within the sumps was observed by the CQA technician. No evidence of leaking was observed from either lysimeter pan.

Geocomposite Drainage Layer Installation: A 6 ounce per square yard (oz/yd^2), double-sided geocomposite drainage layer was partially installed over the PVC liner prior to conducting the lysimeter pan leak tests, leaving the sump areas uncovered. The geocomposite placement was then completed following the leak testing activities. Adjacent panels of geocomposite were overlapped.

Drainage rock was placed in the sump area after geocomposite deployment was complete. The drainage rock was approximately 2-inch diameter clean gravel to reduce the potential for damage to the PVC liner and geocomposite drainage layer. The drainage rock was covered with 8 oz/yd^2 non-woven geotextile fabric to act as a filter between the rock and soil to reduce clogging.

Soil Layer Construction: After the lysimeter pans had been constructed and passed the leak tests, the soil cover was installed. Soil was spread in approximately 12 to 24-inch thick lifts over the lysimeter pans. The CQA technician observed soil placement with special attention paid during the first lift to avoid damaging the underlying geosynthetic components. The remaining lifts were placed at the same time as the placement of cover around the lysimeter, ensuring that the cover over the lysimeter was constructed in the same manner as the cover over the remainder of Phase III. Other CQA activities performed during soil installation included moisture and density testing and soil layer thickness observation.

Cover Drainage Measuring System Calibration: The cover drainage lysimeter measuring system is comprised of a graduated, conical bottom, 55-gallon polyethylene tank, enclosed in a metal vault with locking metal lid. The tank is graduated in gallons and can be used to approximate large quantities of water. Additionally, a dip stick is installed in the tank for water level observation. A RainWise tipping bucket rain gauge with an electronic data logger was mounted inside of the polyethylene tank to directly measure and electronically record water from the lysimeter pan outlet pipe. After tripping the bucket, water drains out the bottom of the rain gauge and accumulates inside the polyethylene tank. The electronic data logger records the number of tips, which can be correlated to an approximate volume of drainage through the cover. If the tipping bucket malfunctions, the graduated tank volume provides a backup reading.

Calibration tests were performed on the rain gauges after installation by pouring a known volume of water through the gauges at varying flow rates and recording the number of tips. The volume of water poured into the rain gauge was then divided by the number of tips to determine the volume of water per tip.

The landfill cover was designed to limit water percolation through the cover to less than 3 mm per year. Based on the dimensions of the lysimeter pans, the total volume of water corresponding to 3 mm of drainage is more than 100 gallons, which is additionally measured using the tank graduations.

Monitoring Results

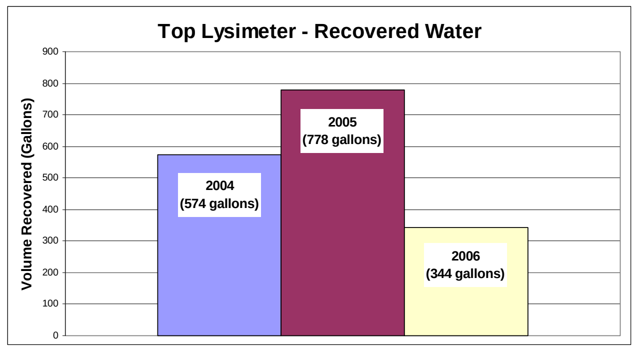
Initially, monthly monitoring site visits were performed to observe and record the volume of water in the lysimeter storage tanks. Within the first year, the data loggers malfunctioned and repairs were unsuccessfully attempted. Therefore, the majority of the monitoring data was observed by the graduated marks on the lysimeter tanks.

During each monitoring site visit, the pan area was observed for vegetation deficiencies or problems, the volume of water in the tanks (if any) was recorded, any accumulated water was drained from the tanks, and general observations were recorded. Repairs were made as needed and described in the following paragraphs. Quarterly monitoring reports were prepared and submitted to the owner/operator and the KDHE-BWM.

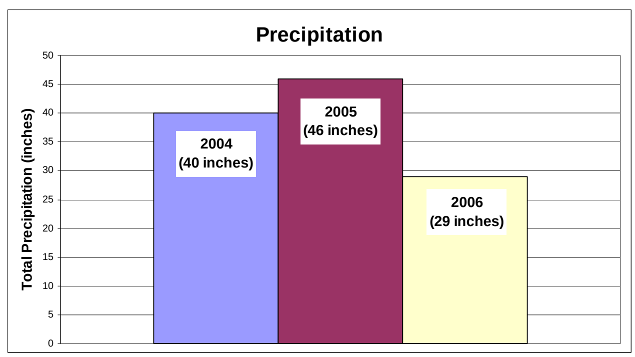
Top Lysimeter: Overall, monitoring results from the Top Lysimeter have been unfavorable. Many operational and maintenance problems have been encountered with the Top Lysimeter. These included the outlet valve freezing, breaking, and requiring replacement; the drain for the tipping bucket continually clogging and limiting flow; and corrosion to the data logger.

Monitoring began December 1, 2003. For the first six months, little to no water was recovered in the Top Lysimeter collection tank. From June through November 2004, 7 to 34 gallons of water were recovered in the lysimeter tank each month. A 6-inch landfill gas pipeline had been placed on top of the ground surface, parallel to the side slope, and immediately adjacent to the Top Lysimeter pan. The piping appeared to limit run-off and/or pond storm water directly over the lysimeter pan sump. Suspecting this may cause cover problems, the landfill gas piping was raised off of the ground surface during August 2004. However, following a heavy snowfall in November 2004, the monitoring technician found the Top Lysimeter collection tank was completely full of water and had overflowed into the lysimeter vault. Water continued to drain into the collection tank, averaging approximately 13 gallons per day, for the next several months. Due to the visual appearance of the water (odiferous, rust-colored), it was suspected that this water was not solely drainage through the cover, but included other water sources.

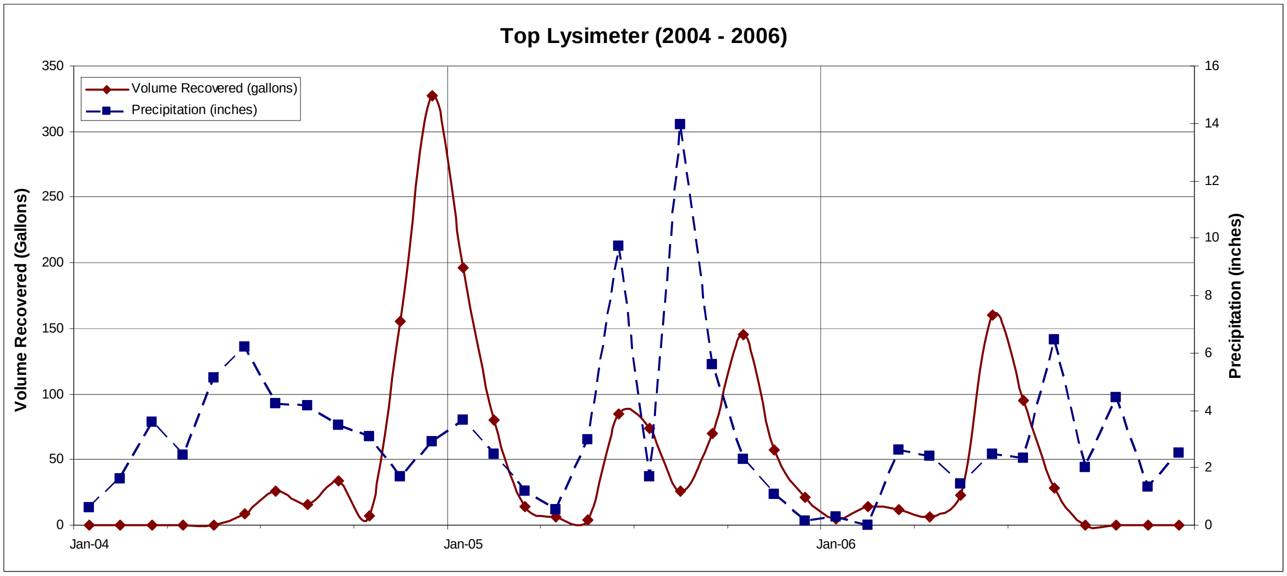
The following graphs illustrate the precipitation and volume of water recovered in the Top Lysimeter for 2004 through 2006. As shown and as expected, the recovered volume fluctuates with respect to the amount of precipitation.



Graph 13 – JCL Top Lysimeter Recovered Water



Graph 14 – Johnson County Precipitation 2004 - 2006



Graph 15 – JCL Top Lysimeter – Volume Recovered Compared to Monthly Precipitation

A significant volume of water has collected in the lysimeter tank each year (344 to 778 gallons). Based on visual observations and laboratory testing, the water was odiferous, rust-colored, and contained low levels of volatile organic compounds. These observations may indicate the water is not solely precipitation draining through the soil; rather it may be mixed with leachate or gas condensate.

As stated previously, a 6-inch landfill gas pipe line had been placed on top of the ground surface, parallel to the side slope, and immediately adjacent to the Top Lysimeter pan. The piping appeared to limit run-off and/or pond storm water directly over the lysimeter pan sump. Once significant volumes of water began collecting in the tank, concerns arose that the soil cover over the lysimeter may have become saturated and was failing to meet design specifications. Therefore, a Geoprobe® was used to collect soil samples of the cover material for moisture content analysis. Results indicated the average moisture content of the soil at a depth of 5 feet ranged from approximately 8 to 19 percent, well below the saturated moisture content of 36 percent. Therefore, the cover material did not appear to be saturated and the cap should function properly.

As illustrated by Graphs 13 through 15, the volume of water recovered in the Top Lysimeter shows a general declining trend from 2005 to 2006. Comparing the volume of water recovered to precipitation, 14.35 gallons per inch were recovered in 2004, 17.13 gallons per inch in 2005, and 16.38 gallons per inch in 2006. This slightly declining trend is likely primarily due to the lower precipitation in 2006, but may also represent cover improvement as the vegetation establishes. Observations during the past year indicate minor desiccation cracks were noted on the top of the lysimeter pan area during the early summer 2006. However the vegetation on the cap was noted to be significantly more verdant in August and September 2006.

Despite the slight improvement, significant water has been recovered in the Top Lysimeter collection tank. The cover was designed to limit infiltration to a flux less than 3 mm/year, which is equivalent to approximately 107 gallons per year by the Top Lysimeter. Due to increasing suspicions of inaccurate data collected by both lysimeters, hydraulic barrier trenches were constructed during January 2006 around each lysimeter to cut-off upslope infiltration of leachate, landfill gas condensate, or other source of water. The trenches were located approximately 5 feet outside each existing lysimeter pan, and extended approximately 5 feet below the lysimeter pan base. Geomembrane liner was placed in the trenches to serve as the hydraulic barrier. Approximately 2 feet of gravel was placed at the base of the trenches, to discharge moisture that may collect or build up outside the barrier into the underlying waste. Visual observations of the cover materials during trench construction once again confirmed the shale material was not saturated. By constructing the hydraulic barrier trenches, it was anticipated the data collected by the lysimeters would more accurately reflect the volume of precipitation perculating through the cover over the lysimeters. The slight improvement noted during 2006 may be the effects of the hydraulic barrier trench.

As shown by the data (Graph 15), there appears to be at least a one-month lag in recovering water from a particular precipitation event, and possibly up to a one-year lag in recovering water from a particular event, depending on the interpretation of the data. At this time, there is insufficient data to draw a conclusion regarding the lag time. Continued monitoring and comparison may confirm the pattern(s) shown thus far.

The volume of precipitation over the area of the Top Lysimeter was calculated and compared to the volume of water recovered in the lysimeter.

Table 2 – JCL Top Lysimeter

Year	Vol. Recovered (gallons)	Precip (gallons)	Percent Recovered
2004	574	35,328	1.6%
2005	778	40,915	1.9%
2006	344	25,570	1.3%

Although the volume of water recovered in the lysimeter tank is greater than the design limit (107 gallons) or modeled result, the volume is significantly low compared to the amount of precipitation falling on the cover. As the vegetation continues to establish, it is anticipated the recovered volume of water will decrease.

West Slope Lysimeter: Monitoring results from the West Slope Lysimeter have been less than desirable and have created more questions than answers. Many problems were encountered with the West Slope Lysimeter. It was anticipated that most precipitation would run off of the side slope and therefore very little to no moisture would percolate through the cover and be observed in the lysimeter tank. The following paragraphs summarize the monitoring results through July 2006, when the lysimeter was removed due to the construction of an access road for a future landfill cell on the property.

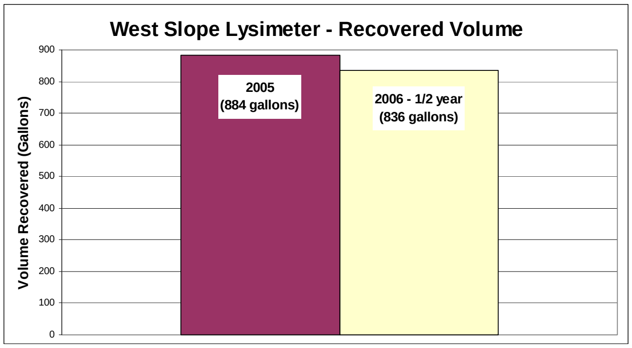
Monitoring began December 1, 2003. No water was observed in the West Slope Lysimeter collection tank from initial startup through December 20, 2004, as anticipated. However, water had periodically collected inside the lysimeter vault (outside the collection tank) and was removed using a sump pump on December 1, 2004 and again on December 20, 2004. At the time, it was suspected that surface water must have been leaking into the vault. The total volume of water removed was not recorded.

During the December 20, 2004 monitoring visit, the concrete jersey barrier located upslope of the lysimeter vault was discovered to have settled and sheared off the piping to the lysimeter vault. The jersey barrier was intended to reduce erosion and sediment from covering the lysimeter vault. As a result of the settling and pipe shearing, the piping from the lysimeter pan was no longer connected to the lysimeter vault. The jersey barrier was removed and the piping repaired on December 28 and 29, 2004. The jersey barrier was replaced with a section of lighter corrugated metal piping.

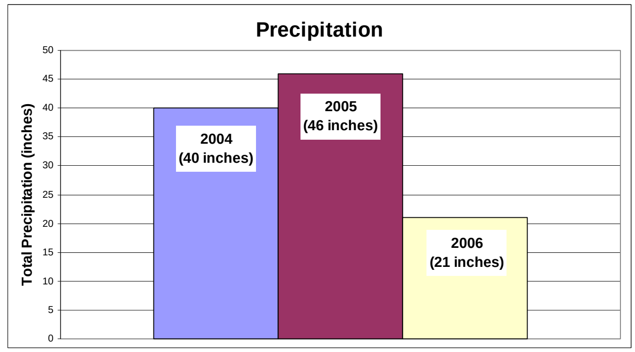
During the repair activities, the full piping length from the vault to the downslope edge of the lysimeter pan was uncovered and observed for cracks or damage. No cracks or damage were observed. However, the cover thickness over the downslope edge of the lysimeter pan was observed to be less than 5.5-foot thick. Therefore, following piping repair activities, additional materials were placed over this portion of the lysimeter pan and surrounding area. Subsequent surveyed elevations indicated the cover over the downslope edge of the lysimeter pan was greater than 5.5 feet thick following the addition of cover materials.

On July 6, 2006, the West Slope Lysimeter was removed to allow for the construction of an access road to a future landfill cell.

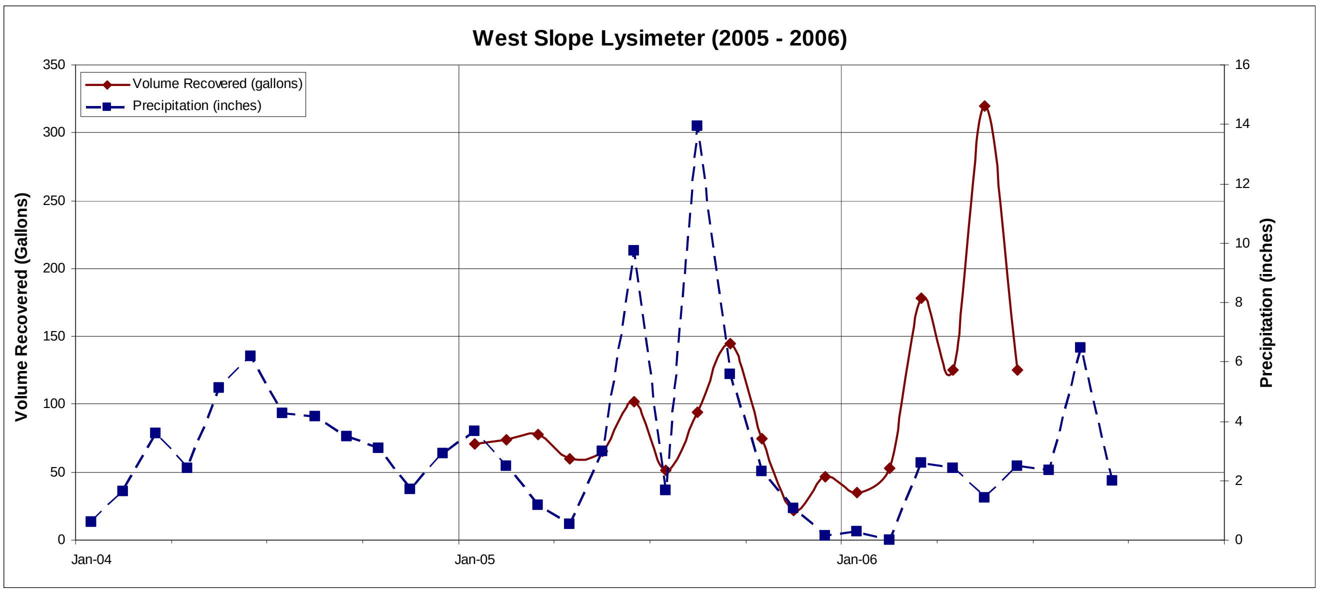
The following graphs illustrate the precipitation and volume of water recovered in the West Slope Lysimeter for 2005 through 2006. It should be noted that since it is unknown when the damage to the piping occurred in 2004, the 2004 water recovery data may not be reliable, and was not included.



Graph 16 – JCL West Slope Lysimeter Recovered Water



Graph 17 – Johnson County Precipitation (January 2004 – June 2006)



Graph 18 – JCL West Slope Lysimeter – Volume Recovered Compared to Monthly Precipitation

An evaluation of the data indicates that following the initial repair activities in December 2004, water began accumulating in the West Slope Lysimeter tank at an average rate of 15 to 20 gallons per week. Following heavy precipitation events, the weekly volume increased. The data is considered suspicious. It does not seem logical that a consistent volume of water (approximately 15 gallons of water per week) would infiltrate through the cover, particularly when there was little to no precipitation during the same time period. More data fluctuation would be expected, as was shown by data collected from the Top Lysimeter. Therefore, it is suspected that the volume of water collected in the lysimeter tank did not actually represent solely infiltration through the cover, as was intended. As observed in the Top Lysimeter, the collected water was observed as odiferous, rust-colored or black on occasion, and contained volatile organic compounds. Therefore, it was suspected to include more than precipitation infiltrating through the soil cover.

Some alternatives for the source of the water may be condensate from operation of the landfill gas collection system, or leachate seeping from waste located upslope of the lysimeter pan. During several monitoring events, the monitoring technician noted a landfill gas odor and at one time, could hear and feel landfill gas flowing out of the lysimeter piping when placing his hand in front of the pipe. The landfill gas collection system runs continuously, creating a continuous air flow in the subsurface; therefore, this may be a logical explanation for the consistent volume of water in the lysimeter pan.

The volume of precipitation over the area of the West Slope Lysimeter was calculated and compared to the volume of water recovered in the lysimeter. Please note the volumes indicated for 2006 are for January through June only (prior to removal of the lysimeter).

Table 3 – JCL West Slope Lysimeter

Year	Vol. Recovered (gallons)	Precip (gallons)	Percent Recovered
2004	0	34,571	0%
2006	884	40,039	2.2%
2006	836	17,701	4.7%

Following installation of the hydraulic barrier trench in January 2006, little to no change was observed in the volume of water recovered in the lysimeter vault. As stated previously, the West Slope Lysimeter was removed during July 2006.

At the JCL site, the use of pan-type lysimeters on the waste cell may not be appropriate. The waste column is over 250 feet high. This dynamic waste mass is settling, emitting gas, and producing leachate. Survey elevations one year following cover construction indicated the crown had settled an average of 5 feet. As shown by the two lysimeters installed on the Phase III cover, many maintenance and performance issues have been encountered, and the data is suspicious. It appears a better option for monitoring infiltration at the JCL would be to construct a lysimeter on site, yet not on top of the settling, gas-producing, and leachate-producing waste mass. In this manner, an evaluation of the percolation through the cover could be confidently made.

Although the monitoring results of the ET final cover at the JCL implies more infiltration has occurred than was intended by the design, it appears the monitoring results may not represent only drainage through the cover. The results of collected soil moisture monitoring data and observations during trench excavations do not indicate the soil is saturated. Additionally, water collected in the lysimeter tank visually does not appear to be infiltrating precipitation, but rather landfill related liquid (gas condensate or more likely leachate). Towards that end, the location and construction of future lysimeters should be carefully considered. As suggested, perhaps data from the lysimeters would be more reliable if they were located outside the waste cell boundaries and not on top of settling waste.

ECONOMIC COMPARISON

As stated previously, Alternative Earthen Final Covers have several benefits over prescriptive, composite final covers. Particularly, alternative covers are often less costly. A standard, Subtitle D composite cover can cost from $70,000 to over $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 construction rates factor into the cost of constructing a composite final cover. Selecting an alternative 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 associated with the three final covers described in this paper, 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 evaluated for each site, as shown below. The savings shown are the cost savings for construction, when compared to estimated costs for constructing the prescriptive cover previously approved for each site.

Table 4 – Estimated Cost Savings
ET Cover versus Prescriptive Cover

Site (Total Acreage)	Actual Savings Per Acre	Projected Total Site Savings
Johnson County (315 acres)	$37,408	$11,783,520
Coffey County (34 acres)	$38,925	$1,323,450
Barton County (66 acres)	$37,842	$2,497,572

As shown above, the projected savings by using an alternative cover for the entire permitted waste disposal areas is significant.

SUMMARY

To date, ET final covers have been built on five Kansas MSW landfills. This paper described the results of three of these landfills where Aquaterra completed the modeling, design, permit modification, construction oversight, and drainage monitoring. As discussed herein, the results of two of these three sites have been very encouraging both from a cost to construct and maintain standpoint as well as meeting or exceeding the more important infiltration requirements.

As the three case studies show, as long as the regulatory and design issues can be addressed in a quantifiable way, regulatory agencies are able to make an informed decision in permitting alternate covers. This will be important as future ET final cover designs for sites in more humid climates are submitted to state agencies for approval.

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