Using the Moisture-Deficient Characteristics of Dry Scrubber Ash and an Arid Location to Develop a State-Approved Alternative Landfill Design:

The Sunflower Electric Power Corporation Holcomb Landfill, Holcomb Kansas

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ABSTRACT

Waste powder (fly ash and spent scrubber sorbent) derived from combustion of Powder River Basin coal and dry-scrubbed pollution controls is moisture deficient. When successive lifts of conditioned powder are placed in landfills located in arid regions, the result is a physically stable waste mass that will absorb moisture for decades before reaching field capacity and releasing leachate.

In preparation of a permit for a landfill expansion, Sunflower Electric used field characterization data and modeling to demonstrate that a design with no liner and an evapotranspirative cover would be protective of groundwater quality in an area with an arid climate. The evapotranspirative cover was designed while using USEPA's HELP software to evaluate cap performance. Mobilization of constituents of concern in groundwater was modeled using USEPA Industrial D Guidance IWEM software. Results from the IWEM modeling demonstrated the proposed design to be protective of the environment for arsenic, barium, chromium, and selenium—constituents that exceeded the MCL during synthetic (SPLP) leachate testing of fresh waste powder samples. Conclusions from this study were approved in 2006 by the Kansas Department of Health and Environment as part of capacity additions for the Holcomb Landfill. The processes, models, and approach could serve as a template for electric utilities located in arid climates desiring an environmentally protective demonstration for alternatives to conventional cover and liner designs.

INTRODUCTION

Sunflower Electric Power Corporation proposed to expand the Holcomb Common Facilities Industrial Landfill from 110 acres to 188 acres to accommodate coal combustion products (CCPs) from additional generating units proposed for the Holcomb Station. The existing landfill did not have a clay or synthetic liner, and had not caused detectable changes in groundwater quality after more than 20 years of operation. Based on this performance, Sunflower initiated an investigation to collect data to determine whether or not the expanded landfill could achieve similar performance. A successful demonstration would support permitting of an alternative landfill design that would be cost-effective and protective of groundwater resources.

The fuel source for the existing power plant is low sulfur, subbituminous coal from the Powder River Basin of Wyoming. The plant is equipped with a dry scrubber for SO_2 control. Twin particulate-control baghouses capture particulate emissions and spent sorbent from the dry scrubber. This waste powder (a CCP) is moisture-conditioned to improve handling and then truck-hauled to the landfill.

SETTING

A key element in the design is the environmental setting. The Holcomb Station is located in an area with a sub-humid to semi-arid climate, with average annual precipitation of about 19 in/yr (48 cm/yr). The site is underlain by as much as 400 feet (120 m) of unlithified deposits, primarily consisting of alluvial sand, gravel, silt, and clay. The upper 80 to 110 feet (24 to 33 m) of these deposits are unsaturated. Groundwater elevations have declined by approximately 25 feet (7.6 m) since monitoring began in 1985; however the overall westerly direction of groundwater flow has not changed over that period.

FIELD CHARACTERIZATION

Sample Collection and Analysis

Waste powder samples were collected both upstream and downstream of the plant moisture conditioning system. In-situ CCP core samples were collected by continuous-core technology from a closed cell. Core samples were collected from the top of the vegetative cover to just above the base of the closed cell. Drilling was performed using a rotosonic drill rig, and no water was introduced to the borehole during drilling. The core samples were collected using a 5-foot (1.5 m) split barrel unit with Lexan liners.

Following retrieval of each sample core, incisions were made in the ends of the tube so that no air volume or disturbed sample was included in the tube. The ends of the tube were then sealed with Parafilm™, plastic end caps, and cling-wrap tape. The cores were wrapped in bubble-wrap and other packing material for shipment to the laboratory. Laboratory tests are listed in Table 1.

Table 1. Laboratory Tests Performed on Solid Samples

Description	Method
Soil Moisture & Porosity	
Moisture Content	ASTM D2216
Dry Bulk Density	ASTM D4531
Total Porosity (calc.)	Klute (1986)[1]
Detailed Analyses	
Saturated Hydraulic Conductivity (constant head)	ASTM D2434
Moisture Characteristics	ASTM D6836/ASTM D2325/Klute (1986)[1]
Unsaturated Flow Parameters	van Genuchten (1980)[2]
Particle Size Analysis	ASTM D422
Particle Density	ASTM D854
Geotechnical Analysis	
Free Drainage Field Capacity	Laboratory-Specific
Moisture Used by Hydration	Laboratory-Specific
Saturated Hydraulic Conductivity	ASTM D5084
Porewater Analysis	
Not performed, insufficient water	

Field Characterization Results

The spray dryer ash is extremely dry as it comes out of the plant (< 2 percent moisture by weight; assuming an in-place bulk density of 1.2 g/cm^3, this equates to a volumetric moisture content of < 2.4 percent). The measured gravimetric moisture content of the moisture-conditioned ash was 21 percent (volumetric moisture content equals 25 percent, assuming an in-place dry bulk density of 1.2 g/cm^3). This difference was apparent during visual inspection of the contents in the sample buckets. The fresh CCP was powder, while the moisture-conditioned CCP had adsorbed moisture and formed small clumps (Figure 1).

Figure 1. Photos Showing Fresh (left) and Moisture Conditioned (right) Spray-Dryer Ash

Porosity values for the CCP ranged from 43 to nearly 60 percent, and averaged 52 percent (Figure 2). In order to remove the variability introduced by this porosity range, moisture content results are presented in terms of degree of saturation, defined as volumetric moisture content divided by porosity. The degree of saturation for the in-place CCP approached 100 percent in the upper 10 feet (3 m) of the closed cell and decreased to about 40 percent with increasing depth. The 40 percent saturation value was representative of the initial moisture of the as-placed, moisture-conditioned CCP, suggesting there has been little or no moisture migration below the surficial 10 feet (3 m) in the closed cell cores.

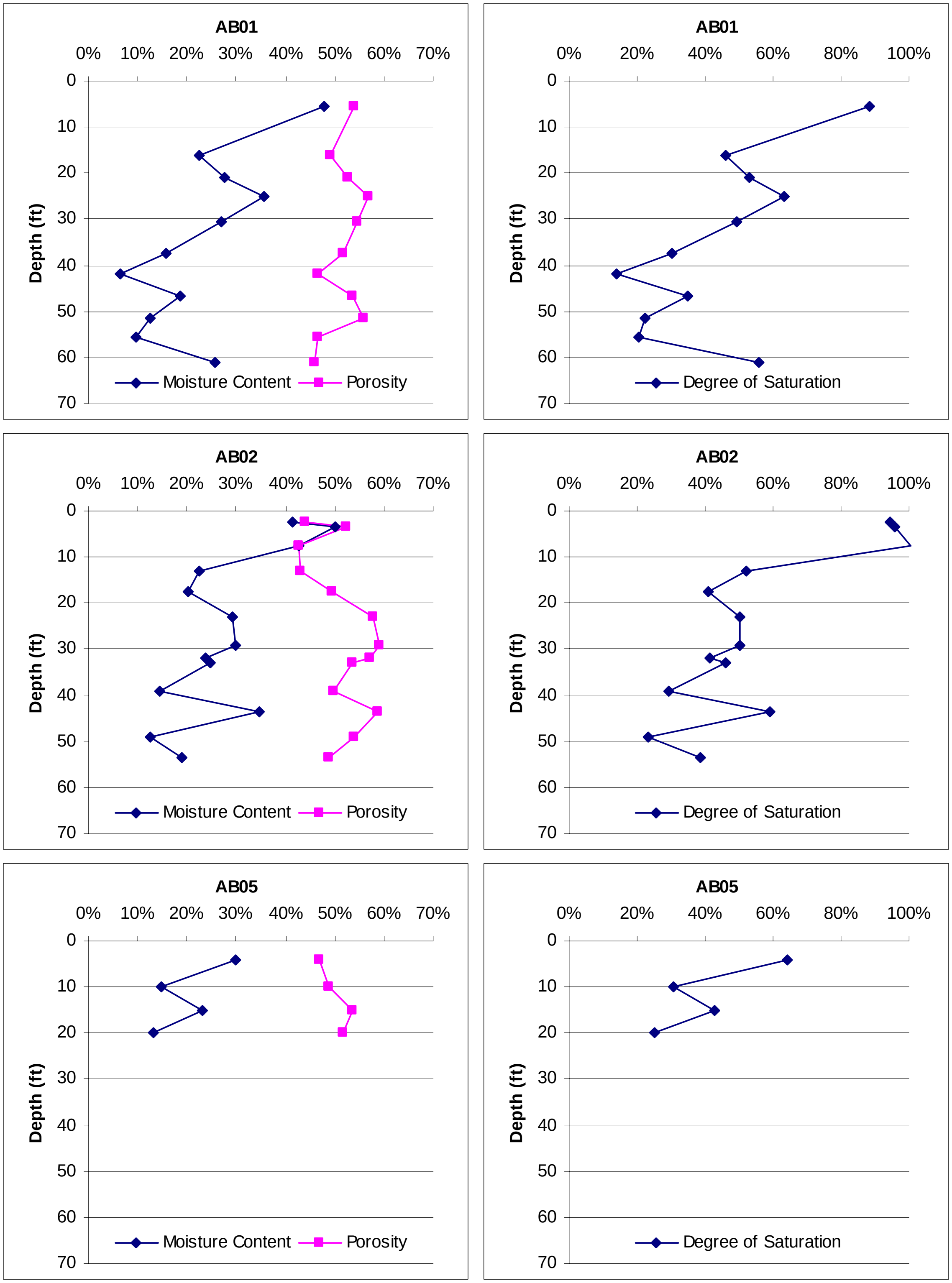

Figure 2. Moisture Content, Porosity, and Degree of Saturation in the Existing Landfill as a Function of Depth

The CCP samples were primarily composed of silt-sized particles, as is typical for fly ash, with 8 to 18 percent sand and 1 to 6 percent clay (Table 2). The base layer (bottom of core) samples were texturally similar to the CCP, although their particle density was slightly higher. The cap sample was texturally similar to the two native soil samples, with very high percentages of sand and particle density values of 2.65 g/cm^3.

Table 2. Particle Density and Size of Selected Field Samples

			Particle Size			
Sample	**Description**	**Particle Density (g/cm^3)**	**% Sand**	**% Silt**	**% Clay**	**USDA Class**
AB01 0.5-1	Cap	2.65	93%	6%	1%	Sand
AB01 10-10.5	Ash	2.28	11%	84%	5%	Silt Loam
AB03 26.5-27	Ash	2.15	10%	89%	1%	Sandy Loam
AB04 8.5-9	Ash	2.25	18%	76%	6%	Sandy Loam
AB04 18.5-19	Ash	2.33	8%	87%	5%	Silt Loam
MC02 1-2.5	Base Layer	2.41	5%	94%	1%	Silt Loam
MC03 1-2.5	Base Layer	2.40	11%	86%	3%	Silt Loam
SB01 0.5-1	Native Soil	2.65	89%	8%	3%	Sand
SB02 1.5-2	Native Soil	2.65	89%	8%	3%	Sand

The hydraulic conductivity values for three of the four CCP samples and both base layer samples were in the 10^{-5} cm/s range (Table 3). The geometric mean for these relatively consistent data, 3.6 x 10^{-5} cm/s, is similar to that previously reported for coal fly ash, 4.8 x 10^{-5} cm/s.[3] Sample AB01 10-10.5 had a relatively high hydraulic conductivity due to post-sampling disturbance that was found in the sample after the test, and . The cap sample and the two native soil samples yielded very consistent hydraulic conductivity results, in the 10^{-3} cm/s range.

Table 3. Unsaturated Soil Parameters and Saturated Hydraulic Conductivity for Selected Soil Samples

		van Genuchten coefficients				
Sample	**Description**	**α constant (cm^{-1})**	**N constant (---)**	**θ_r residual water (---)**	**θ_s porosity (---)**	**K_{sat} hydraulic conductivity (cm/s)**
AB01 0.5-1	Cap	0.1348	1.5003	0.0090	0.4045	2.7E-03
AB01 10-10.5	Ash	0.6335	1.0631	0.0000	0.3720	1.8E-03
AB01 26-28	Ash	ND^2	ND^2	ND^2	ND^2	1.7E-05
AB03 26.5-27	Ash	0.0152	1.1557	0.1372	0.4746	7.7E-05
AB04 8.5-9	Ash	0.0028	1.1575	0.0000	0.4945	6.5E-05
AB04 18.5-19	Ash	0.0316	1.0927	0.0000	0.3596	2.1E-05
MC02 1-2.5	Base Layer	0.0660	1.1835	0.0000	0.5906	2.6E-05
MC03 1-2.5	Base Layer	0.0047	1.6361	0.0532	0.5782	4.1E-05
SB01 0.5-1	Native Soil	0.1515	1.6749	0.0238	0.4095	3.1E-03
SB02 1.5-2	Native Soil	0.0549	2.3805	0.0327	0.4157	5.1E-03
Bulk^3	Native Soil	ND^2	ND^2	ND^2	ND^2	4.2E-03
Ash/Liner^1	Geometric Mean	0.0241	1.2451	0.0381	0.4995	3.5E-05
Cap/Native	Geometric Mean	0.1137	1.8519	0.0218	0.4099	3.6E-03

1. Excludes AB01 10-10.5 because of anamalous K_{sat} value
2. ND = not determined
3. This analysis was performed on a repacked sample.

Moisture retention was determined at seven tension points. One of these points (336 cm-H_20) corresponded to the field capacity for loamy to clay soils. The field capacity is the theoretical moisture-content at which free drainage can occur in unsaturated materials. The CCP samples retain a high percentage of their moisture at field capacity, suggesting that significant downward flow does not occur in this material unless it is nearly saturated. Furthermore, the field capacity values, which ranged from 26 to 45 percent (62 to 92 percent of total porosity), were considerably higher than the average in-situ moisture contents of the CCP core samples (21 percent; 42 percent of total porosity). These values clearly demonstrated the CCP has a considerable moisture deficit. Field capacity values for the Sunflower CCP were similar to those previously reported for coal fly ash samples (34 percent – wetting curve[3]).

Samples were also analyzed at a tension of 15,000 cm-water, the theoretical wilting point. This is the tension at which there is no water available for vegetative uptake, and is used by software such as HYDRUS and HELP when calculating moisture retention relationships.

Moisture retention curves were plotted for all samples (Figure 3). These curves show the relationship between tension and moisture retention (degree of saturation) in a solid sample. The slope of the line is an indication of the tension range over which drainage is most rapid (flat slope indicates rapid drainage). The moisture retention curves for the cap and native soil samples were typical of sand, having low field capacity. These curves suggested a material with rapid downward drainage and little moisture retention capacity. The curves for the CCP and base layer samples were typical of fine-grained, poorly-drained soils, such as silts and clays.

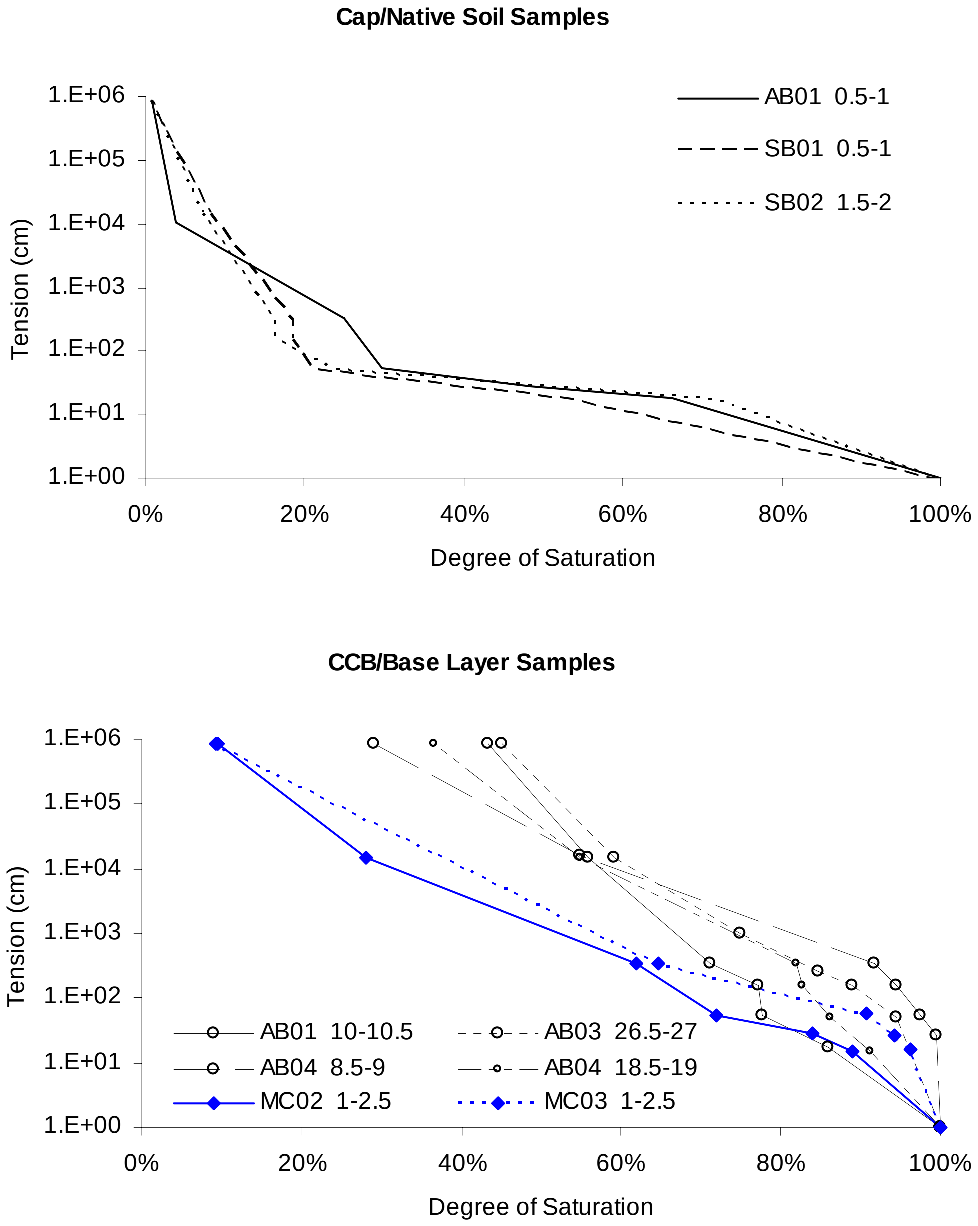

Figure 3. Moisture Retention Curves

The field capacity measurements discussed previously were determined using a standard method of applying tension to the samples. The CCP was also tested under gravity drainage conditions, termed free drainage field capacity. Free drainage field capacity results indicated that there will be no gravity drainage of moisture from the CCP until moisture capacity is at 99 percent of total porosity (Table 4).

Table 4. Free Drainage Field Capacity

Replicate	Porosity (%)	Volumetric Moisture Content (%)	Degree of Saturation (%)
A	43.00	42.65	99.2
B	41.12	40.75	99.1

In addition to this moisture deficit, the CCP hydrates when exposed to water. Hydration assessment of the CCP indicated a volume of water equal to at least 16 percent of total porosity may be consumed in the hydration reaction.

WASTE CHARACTERIZATION

High-volume CCPs and low-volume wastes were characterized for major and minor inorganic constituents, including most inorganic constituents regulated by the state (as listed in K.A.R. 28-29-104 Table 1).[1] Leachate was extracted using the SPLP procedure. Individual analyses were performed using appropriate SW-846 methods.

Results from SPLP testing are presented in Table 5. Leachate from the four low-volume basin sludge samples had lower concentrations than from fly ash and bottom ash samples, demonstrating the CCPs will dominate the leaching chemistry of the landfill. Three analytes had SPLP concentrations higher than state MCL values: barium, chromium, and selenium; all occurred in the fly ash and bottom ash leachate. In addition, the arsenic concentrations in the fly ash and bottom ash samples were higher than the Federal MCL of 0.01 mg/L. These four constituents were evaluated using a fate and transport model in order to determine the potential for an exceedance of the MCL in groundwater.

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[1] Two analytes, fluoride and nitrate, were not analyzed due to method incompatibilities; however, comparisons to utility-wide data for similar sites showed that these constituents do not typically occur in CCP leachate at concentrations greater than the MCL.

Table 5. Waste Characterization Analytical Results

SPLP	**unit**	**K.A.R. Table 1 MCL**	**Holcomb Fly Ash 11/10/2005**	**Holcomb Bottom Ash 11/10/2005**	**Basin B Comp. 11/10/2005**	**Basin A Comp. 11/10/2005**	**Basin D Comp. 11/10/2005**	**Basin X Comp. 11/10/2005**
Arsenic	mg/L	0.05	***0.016***	**0.014**	<0.010	<0.010	<0.010	<0.010
Barium	mg/L	1	***3.2***	**1.1**	0.26	0.77	0.68	0.10
Boron	mg/L		1.6	1.2	0.49	1.2	0.55	0.59
Cadmium	mg/L	0.005	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Chromium	mg/L	0.1	***0.16***	0.052	0.01	0.013	0.012	0.0073
Lead	mg/L	0.05	0.0078	<0.0050	0.0051	<0.0050	<0.0050	<0.0050
Lithium	mg/L		0.10	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury	mg/L	0.002	<0.00067	<0.00067	<0.00067	<0.00067	<0.00067	<0.00067
Molybdenum	mg/L		0.13	0.022	<0.020	<0.020	<0.020	<0.020
Selenium	mg/L	0.05	***0.067***	<0.015	<0.015	<0.015	<0.015	<0.015
Silver	mg/L	0.05	<0.0070	<0.0070	<0.0070	<0.0070	<0.0070	<0.0070
Strontium	mg/L		10.8	1.94	0.370	2.70	1.04	0.867
Vanadium	mg/L		0.11	0.19	<0.010	0.032	<0.010	0.048

[U-MJR 12/05, C-JAZ 12/05]

Table Notes:

1. A blank in the MCL column indicates no MCL for that constituent
2. Analyses for arsenic, barium, boron, cadmium, chromium, lead, molybdenum, selenium, silver, vanadium, and mercury were analyzed by Pace Analytical of Lenexa, Kansas.
3. Analyses for lithium and strontium were analyzed by Keystone Laboratories of Newton, Iowa.
4. K.A.R. or Federal MCL exceedances in bold, the highest MCL exceedance is italicized.
5. Basin X composite is a second sample from Basin A.

MODEL CHARACTERIZATION

The CCP is moisture deficient when placed in the landfill; however, the modeling did not take this into account, and assumed that water percolating through the cap would be released through the base of the landfill. After it is released from the landfill, leachate will migrate downward through the 80 to 110 feet of unsaturated deposits before reaching the water table. The modeling then assumed that groundwater would flow toward the property boundary.

Prediction of Leachate Percolation

USEPA’s HELP model was used to evaluate landfill cap designs. Climatic parameters were held constant for all simulations, and soil parameters representing different cap designs were based on geotechnical data determined from field-collected samples of the on-site materials proposed for the cap. HELP modeling supported an evaporative (ET) cap design, in which a fine-grained soil is used to retain moisture for evaporation and plant uptake.

The base case ET cap simulation yielded a percolation rate of 0.18 in/yr (0.46 cm/yr). Sensitivity testing yielded the following observations:

- Predicted percolation was less than 1 in/yr (2.5 cm/yr) for all tests where field capacity was greater than 0.15.

- The runoff curve for the base case assumed a non-compacted soil. A simulation where the runoff curve was based on a compacted soil resulted in a percolation rate of 0.09 in/yr (0.23 cm/yr).

- Increasing the ET cap thickness to 36 in (91 cm) had no significant effect (e.g., no decrease) on predicted percolation.

- Changes in wilting point and hydraulic conductivity had less effect on predicted percolation than changes in field capacity.

Sensitivity testing indicated field capacity was the most important factor contributing to cap performance for soils proposed for this ET cap.

Fate and Transport Modeling

Fate and transport modeling was performed using an approach consistent with USEPA's Industrial Guidance to Waste Management. A Tier 2 analysis using the Industrial Waste Evaluation Model (IWEM[4]) was performed for the four constituents (arsenic, barium, chromium, and selenium) with maximum concentration in SPLP leach samples of wastes managed in the landfill that exceeded K.A.R. 28-29-104 or Federal MCLs. IWEM takes site-specific input values for geology and infiltration and performs a Monte Carlo analysis where different values for attenuation parameters and hydrogeologic parameters that do not have site-specific values are varied 10,000 times. A facility is deemed protective of groundwater if 90 percent of the predicted maximum contaminant concentrations at the compliance boundary are lower than the MCL. The maximum concentrations are not constrained by time, meaning that the model does not select the maximum until calculated concentrations begin to decrease.

Site-specific input data used in IWEM included landfill dimensions (thickness, area, and distance to the compliance boundary); depth to groundwater; aquifer thickness, hydraulic conductivity, and gradient; infiltration and recharge; and pH and leachate concentrations. Sensitivity testing was performed on hydraulic conductivity, infiltration rate, aquifer thickness, hydraulic gradient, and distance to the compliance boundary. Input data were developed as follows:

- Landfill dimensions were based on design parameters for the proposed expansion.

- Depth to groundwater and aquifer thickness were based on site-specific data from geologic borings and monitoring wells.

- The hydraulic conductivity term was developed from an aquifer pump test performed two miles southwest of the site.

- Infiltration of leachate was based on HELP-predicted percolation rates.

- Recharge was an IWEM default, based on the geologic setting and climate.

- The pH value was the average for groundwater samples obtained from site monitoring wells.

- Leachate concentrations were based on the maximum concentration from SPLP leach tests of wastes managed in the landfill.

In all cases, the IWEM results were "protective of groundwater". For the base case, the 90th percentile concentrations were at least five orders of magnitude lower than the MCL of each parameter—such low concentrations would not be detectable in water samples. These fate and transport model results suggested that an exceedance of groundwater quality standards is extremely unlikely for the proposed landfill design.

CONCLUSIONS

The CCP managed in the Holcomb Power Plant landfill has a field capacity approaching total porosity and a significant moisture deficit. Because free drainage will only occur when field capacity is reached, water will not drain downward within the CCP until the CCP is nearly saturated. The CCP has sufficient capacity to retain all of the moisture that infiltrates during the active period of landfilling. The proposed ET cap will sufficiently limit leachate percolation from the landfill, once it does reach field capacity, such that an exceedance of current MCLs is not predicted to have a reasonable potential for occurring.

Given these findings, Sunflower concluded that there was no advantage to employing a liner design and that current operating practices will continue to be protective of the environment for the long term. Significant elements that assure performance of this site include the semi-arid climate, an ET cap, and the unique characteristics of the waste–all of which take advantage of this climate to limit flux into the CCP.

Sunflower Electric incorporated these findings into the landfill permit application, which called for a base layer of compacted CCP rather than a clay or synthetic liner, and an ET cap constructed from on-site alluvial soils. Based on the scientific studies described here, which supported this design, the State granted approval for this alternative landfill design.

A similar approach can be used at other CCP sites, following this recommended approach:

- Establish dialog with the appropriate contacts at the State responsible for landfill permitting. Maintain communication throughout the process, so regulators will understand the contents of the permit application before they review it.
- The site must be situated such that the base-grade of the landfill will be above the maximum annual water table elevation.
- Characterize CCP leachate using field samples, if possible, or appropriate laboratory leachate tests.

- If there is doubt that an alternative design will perform adequately, preliminary fate and transport modeling can be performed based on the leachate characterization and assumed or default climatic, soil, and aquifer parameters. Fate and transport modeling using the Industrial D Guidance Methodology is relatively inexpensive when compared to a field investigation. If the modeling indicates a low potential for a standard exceedance, proceed with the field investigation.
- Perform a field and laboratory investigation to characterize moisture retention properties for the CCP and cap materials. This investigation should be appropriate to the percolation model that will be used during cap design, and characterize aquifer properties if such data do not already exist.
- Perform the modeling. Where possible, utilize conservative assumptions for leachate properties, infiltration, and groundwater flow parameters. Conservative assumptions can be incorporated into the base case, or tested during sensitivity testing.
- Incorporate all field, laboratory, and modeling reports into the application, as appropriate.
- Be prepared to have experts on hand for face-to-face meetings with oversight agencies to review processes and address questions.

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