CCP Landfill Leachate Generation and Leachate Management

I. Kyle Baucom, P.E.[1], Cedric H. Ruhl, P.E.[1]

[1]S&ME, Inc., 9751 Southern Pine Boulevard, Charlotte, NC 28273

KEYWORDS: coal combustion product, landfill, leachate, solid waste

INTRODUCTION

Many coal-fired power plants utilize inactive ash basins for leachate treatment. Should impending regulations require closing ash basins, alternative methods for leachate treatment must be implemented. The driving criteria for selecting a leachate treatment measure is likely to be cost, which in turn will likely be driven by estimated leachate generation rates. Therefore, an accurate estimation of leachate generation will be important to accurately compare leachate treatment alternatives.

A BRIEF HISTORY OF CCP MANAGEMENT

Coal combustion product (CCP) management for coal-fired power plants has evolved as our understanding of environmental impacts and regulatory requirements have evolved. Typically, power plants sluice CCPs, primarily bottom ash and fly ash, into a settling ponds or basin which provides detention time to allow ash particles to fall out of suspension prior to discharging the water. Many of the ash ponds and basins are (or were) unlined, which allows leakage through the bottoms of the ponds. This method of ash handling is known as wet ash handling.

Due to concerns about potential groundwater contamination, many coal-fired power plants have converted to dry ash handling, essentially de-activating the ash basins. With dry ash handling, the dry bottom ash and fly ash is typically moisture conditioned and temporarily stored in silos, and eventually hauled to a lined landfill. Coal-fired power plants typically have on-site landfills that are dedicated for CCPs. In many cases, leachate from the CCP landfills is then pumped or drained by gravity to the inactive ash basin.

Impending regulations may soon require coal-fired power plants to either modify existing ash basins by installing a liner system or to close ash basins outright. Closure of ash basins at a coal-fired power plant will require the implementation of an alternative method for treating CCP landfill leachate.

Several CCP landfill leachate treatment alternatives are available, two of which are the construction of an on-site wastewater treatment facility, and the construction of on-site leachate storage tanks for off-site treatment. The evaluation of leachate treatment options will be driven by costs, which in turn might be driven by estimated leachate generation rates. For instance, higher leachate generation rates might justify constructing an on-site wastewater treatment facility, lower leachate generation rates might justify constructing leachate storage tanks and off-site leachate treatment.

DESCRIPTION OF TWO ASH LANDFILLS

S&ME has participated in the siting, design, permitting, construction quality assurance, and landfill operations monitoring of several ash landfills in the southeastern United States. Participating in multiple phases of the landfill life cycle allows for continuity from siting and design concepts to landfill operations. Thus, concepts and principles from the landfill design phase, such as estimated leachate generation, can be compared to actual landfill performance during operations, such as measured leachate generation. Two ash landfill sites were considered with this study.

Ash Landfill Site 1

Ash Landfill Site 1 has a geosynthetic double liner system which includes leachate collection and leak detection layers. Site 1 has been in operations for approximately three years, during which time approximately 650,000 short tons (589,670 metric tons) of waste have been placed.

Leachate management at Site 1 includes a geocomposite drainage layer and leachate collection piping system along the landfill floor that conveys flow to a sump. Each cell has a dedicated sump and pump system, which conveys leachate to a common force main and ultimately to an ash basin.

Site 1 can be further divided into Cells 1 and 2. Cell 1 is approximately 10.8 acres (4.4 hectares) and has been in operations from December 2009 until August 2011, during which time approximately 25 to 40 feet (8 to 12 meters) of waste has been placed. Contact water management methods include an open sump area and placing bottom ash over drainage corridors.

Cell 2 consists of an active Subcell (2A) and an inactive Subcell (2B). Subcells 2A and 2B share a common sump and pump system; however, a geomembrane rain cover has been temporarily placed over Subcell 2B. Subcell 2A is approximately 7.6 acres (3.1 hectares) and has been in operations since July 2011, during which time approximately 3 to 20 feet (1 to 6 meters) of waste has been placed. Contact water management methods include chimney drains and placing bottom ash over drainage corridors. Chimney drains consist of a vertical, perforated pipe surrounded by an aggregate and/or geotextile filter system, and are intended to convey contact water from the active face at the surface of the landfill to the leachate collection system at the base of the landfill.

Ash Landfill Site 2

Ash Landfill Site 2 has a geosynthetic double liner system which includes leachate collection and leak detection layers. Site 2 and has been in operations for approximately 1.5 years, during which time approximately 370,000 short tons (335,660 metric tons) of waste have been placed.

Leachate management at Site 2 includes a geocomposite drainage layer and leachate collection piping system along the landfill floor that conveys flow to a sump. Each cell has a dedicated sump and pump system, which conveys leachate to a common force main and ultimately to an ash basin.

Site 2 can be further divided into Cells 1 and 2. Cell 1 is approximately 9.9 acres (4.0 hectares), Cell 2 is approximately 9.6 acres (3.9 hectares). Both cells have been in operations from July 2011 until March 2012, during which time approximately 10 to 15 feet (3 to 5 meters) of waste has been placed. Contact water management methods include chimney drains and placing bottom ash over drainage corridors.

The ash landfill site characteristics are summarized in the following table:

Table 1: Summary of Ash Landfill Sites

Site No.	Cell No.	Cell Area (acres)	Cell Area (hectares)	Operations Timeframe	Current Waste Height (feet)	Current Waste Height (meters)	Contact Water Management Methods
1	1	10.8	4.4	December 2009 - August 2011	~25-40	~8-12	open sump area bottom ash over drainage corridors
	2A	7.6	3.1	July 2011 - present	~3-20	~1-6	chimney drains bottom ash over drainage corridors
2	1	9.9	4.0	July 2011 - March 2012	~10-15	~3-5	chimney drains bottom ash over drainage corridors
	2	9.6	3.9	July 2011 - March 2012	~10-15	~3-5	chimney drains bottom ash over drainage corridors

ESTIMATED LEACHATE GENERATION

Leachate is typically defined as a liquid that has percolated through waste or drained from waste. Leachate by this definition includes an infiltration component and a runoff (contact water) component. Leakage through the liner was assumed to be negligible and also confirmed in the field via leak detection layers. A mass balance diagram for leachate generation is shown in the following figure:

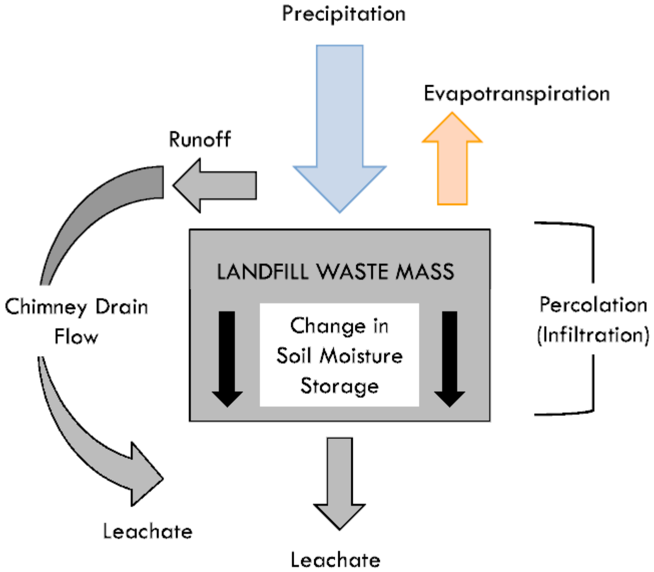


Figure 1: Leachate Generation Balance Diagram

The following equations can then be developed to describe leachate generation:

$Q_{in} = Q_{out}$+Storage (Equation 1)
Q_{in} = Precipitation (Equation 2)
Qout = Runoff+Infiltration+Evapotranspiration (Equation 3)
Precipitation = Runoff+Infiltration+Evapotranspiration+Storage (Equation 4)
Leachate Generation = Runoff+Infiltration (Equation 5)
Precipitation = Leachate Generation+Evapotranspiration+Storage (Equation 6)
Leachate Generation = Precipitation–Evapotranspiration–Storage (Equation 7)

Leachate generation modeling software packages, such as the Hydrologic Evaluation of Landfill Performance (HELP) model, can be used to estimate leachate generation. HELP modeling provides estimated values for runoff, infiltration, precipitation, evapotranspiration, and storage for a set of input parameters; therefore, leachate generation can be estimated from HELP modeling with Equation 5 or 7.

The estimated average rainfall for both sites from HELP modeling was approximately 3.5 inches (8.9 centimeters) per month, or approximately 42 inches (107 centimeters) per year. The estimated average rainfall can be converted into gallons per acre per day (gpad) or liters per hectare per day (lphd) as follows:

$$42\frac{inches}{year}\,x\,\frac{1\ \ year}{365\ \ days}\,x\,\frac{1\ \ foot}{12\ \ inches}\,x\,\frac{43{,}560\ \ ft^2}{1\ \ acre}\,x\,\frac{7.48\ \ gallons}{ft^3} = 3{,}124\ \ gpad$$

$$107\frac{cm}{year}\,x\,\frac{1\ \ year}{365\ \ days}\,x\,\frac{1\ \ m}{100\ \ cm}\,x\,\frac{10{,}000\ \ m^2}{1\ \ hectare}\,x\,\frac{1{,}000\ \ liters}{m^3} = 29{,}315\ \ lphd$$

The percent of rainfall that becomes leachate is the ratio of volume of leachate generated to rainfall generated over a given period of time. The average leachate generation and the percent of rainfall that becomes leachate from HELP modeling outputs are summarized in the following table:

Table 2: Estimated Leachate Generation from HELP Modeling

Condition	Average Leachate Generation {Site 1} (gpad)[1]	Average Leachate Generation {Site 1} (lphd)[2]	Average Leachate Generation {Site 2} (gpad)[1]	Average Leachate Generation {Site 2} (lphd)[2]	Percent of Rainfall that Becomes Leachate {Site 1}	Percent of Rainfall that Becomes Leachate {Site 2}
no waste	1,032	9,653	1,237	11,571	33.0%	39.6%
10 feet (3 meters) of waste	883	8,260	1,014	9,485	28.3%	32.5%
80 feet (24 meters) of waste	639	5,977	847	7,923	20.5%	27.1%

[1] gallons per acre per day
[2] liters per hectare per day

The estimated rainfall amounts were the same for Sites 1 and 2; however, HELP modeling results indicated higher estimated leachate generation and a corresponding lower rainfall to leachate ratio for Site 2. This may be attributed to additional HELP model site-specific input parameters, such as cell floor and active face slopes, slope lengths to drain leachate, soil conditions, etc. The predicted percent of rainfall that becomes leachate generally decreases with increasing waste height. Thus for a given time period, as the landfill waste height increases, less of the precipitation is converted to leachate.

The percentage of rainfall that becomes evapotranspiration, storage, and leakage from HELP modeling outputs are summarized in the following table:

Table 3: Estimated Evapotranspiration, Storage, and Leakage from HELP Modeling

Condition	Percent Evapotranspiration {Site 1}	Percent Evapotranspiration {Site 2}	Percent Storage {Site 1}	Percent Storage {Site 2}	Percent Leakage {Site 1}	Percent Leakage {Site 2}	Percent Leachate {Site 1}	Percent Leachate {Site 2}
no waste	65.81%	59.27%	0.12%	0.06%	1.31%	1.40%	32.76%	39.27%
10 feet (3 meters) of waste	69.28%	63.32%	0.75%	0.53%	1.93%	3.95%	28.05%	32.20%
80 feet (24 meters) of waste	67.23%	63.32%	10.61%	7.62%	1.86%	2.16%	20.29%	26.90%

According to HELP model results, leachate generation decreases with increasing waste height, and accounts for approximately 20 percent to 40 percent of rainfall. The amount of storage within the landfill mass increases with increasing waste height, and leakage rates are negligible. The majority of precipitation comes out of the landfill as evapotranspiration; the amount of evapotranspiration is approximately twice the amount of leachate generated.

COMPARISON OF ESTIMATED AND MEASURED LEACHATE GENERATION

Measured leachate generation rates were recorded from flow meter readings. The average cumulative measured leachate generation during operations is shown in the following table:

Table 4: Measured Leachate Generation					
Site No.	Cell No.	Current Waste Height (feet)	Current Waste Height (meters)	Measured Leachate Generation (gpad)	Measured Leachate Generation (lphd)
1	1	~25-40	~8-12	380	3,555
	2A	~3-20	~1-6	752	7,034
2	1	~10-15	~3-5	500	4,677
	2	~10-15	~3-5	429	4,013

The current landfill waste heights are generally between the waste heights of 10 feet and 80 feet (3 meters and 5 meters) assumed in the estimated leachate generation for HELP modeling. Estimated versus actual leachate generation rates are compared in the following tables:

Table 5A: Estimated Versus Measured Leachate Generation Rates - English Units					
Estimated or Measured	Condition	Leachate Generation {Site 1, Cell 1} (gpad)	Leachate Generation {Site 1, Subcell 2A} (gpad)	Leachate Generation {Site 2, Cell 1} (gpad)	Leachate Generation {Site 2, Cell 2} (gpad)
estimated	no waste	1,032	1,032	1,237	1,237
estimated	10 feet of waste	883	883	1,014	1,014
measured	~3-40 feet of waste	380	752	500	429
estimated	80 feet of waste	639	639	847	847

Table 5B: Estimated Versus Measured Leachate Generation Rates - SI Units					
Estimated or Measured	Condition	Leachate Generation {Site 1, Cell 1} (lphd)	Leachate Generation {Site 1, Subcell 2A} (lphd)	Leachate Generation {Site 2, Cell 1} (lphd)	Leachate Generation {Site 2, Cell 2} (lphd)
estimated	no waste	9,653	9,653	11,571	11,571
estimated	3 meters of waste	8,260	8,260	9,485	9,485
measured	~1-12 meters of waste	3,555	7,034	4,677	4,013
estimated	24 meters of waste	5,977	5,977	7,923	7,923

Based on waste height, the measured leachate generation rates should generally be consistent with the leachate generation modeling for 10 feet (3 meters) of waste. Estimated leachate generation overestimated actual leachate generation by a factor of approximately 2, except for Site 1 Subcell 2A.

Site 1 Subcell 2A overestimated actual leachate generation by a factor of approximately 1.2, and it appears to be an outlier relative to the other three cells. Subcell 2A shares a common sump with Subcell 2B. Subcell 2B was covered with a geomembrane rain cover during operations of Subcell 2A. It is possible that stormwater runoff from Subcell

2B entered the common sump, which would increase the amount of leachate generation measured for Subcell 2A.

Estimated versus measured leachate generation volumes are compared in the following tables:

Table 6A: Estimated Versus Measured Leachate Generation - English Units								
Site No.	**Cell No.**	**Cell Area (acres)**	**Measured Rainfall (gallons)**	**Estimated Rainfall (gallons)**	**Measured Leachate (gallons)**	**Estimated Leachate [assuming 10 ft waste] (gallons)**	**Measured Percent of Rainfall that Becomes Leachate**	**Estimated Percent of Rainfall that Becomes Leachate**
1	1	10.8	3.2E+07	3.6E+07	4.6E+06	1.0E+07	14.5%	28.3%
	2A	7.6	1.0E+07	1.1E+07	2.7E+06	3.2E+06	27.2%	28.3%
2	1	9.9	1.6E+07	1.4E+07	2.3E+06	4.6E+06	14.4%	32.5%
	2	9.6	1.5E+07	1.4E+07	1.9E+06	4.4E+06	12.4%	32.5%

Table 6B: Estimated Versus Measured Leachate Generation - SI Units								
Site No.	**Cell No.**	**Cell Area (hectares)**	**Measured Rainfall (liters)**	**Estimated Rainfall (liters)**	**Measured Leachate (liters)**	**Estimated Leachate [assuming 3 m waste] (liters)**	**Measured Percent of Rainfall that Becomes Leachate**	**Estimated Percent of Rainfall that Becomes Leachate**
1	1	4.4	1.2E+08	1.4E+08	1.8E+07	3.8E+07	14.5%	28.3%
	2A	3.1	3.8E+07	4.3E+07	1.0E+07	1.2E+07	27.2%	28.3%
2	1	4.0	5.9E+07	5.4E+07	8.6E+06	1.7E+07	14.4%	32.5%
	2	3.9	5.8E+07	5.2E+07	7.1E+06	1.7E+07	12.4%	32.5%

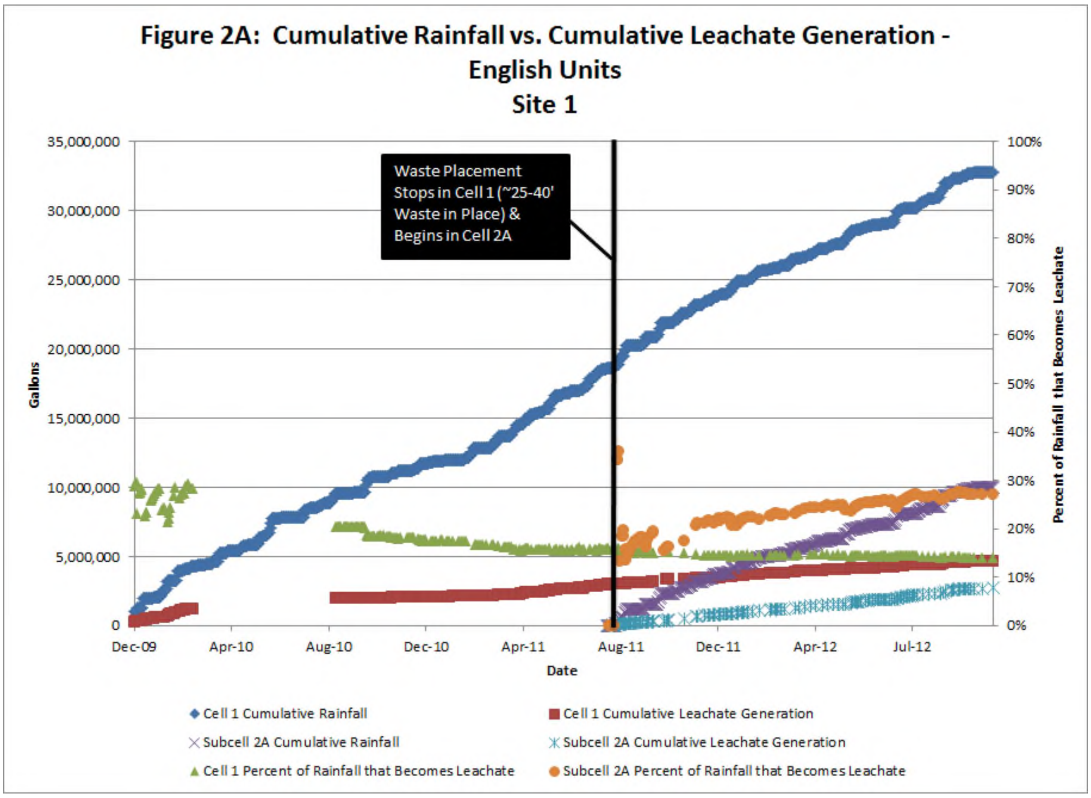
The data shown in Tables 6A and 6B is consistent with the data shown in Tables 5A and 5B; and indicates that leachate generation modeling overestimated leachate generation by a factor of approximately 2 in terms of cumulative rainfall versus cumulative leachate generation, except for Site 1 Subcell 2A.

The overestimation of leachate generation may be inherent in the HELP modeling software. The Desert Research Institute (DRI) performed a comparison of estimated leachate generation rates for four software packages (HELP, EPIC, UNSAT-H, and HYDRUS-2D). The DRI reported that, of the four leachate generation software packages tested, HELP modeling consistently predicted higher leachate generation than the other three software packages [1]. Sharma and Lewis report that HELP modeling underestimated evapotranspiration rates, and larger evaporative depths were suggested [2].

Additionally, Khire et. al. compared field measurements against percolation through soil final cover systems at sites in Georgia and Washington State as predicted by HELP and UNSAT-H modeling [3]. The results of this study indicated that HELP modeling generally overpredicted percolation, accurately predicted evapotranspiration at the Georgia site, and that leachate generation rates can be greatly affected by regional weather differences.

EFFECT OF PRECIPITATION ON LEACHATE GENERATION

Leachate generation is a function of precipitation, evapotranspiration, and storage, as shown in Equation 7. Of these three parameters, precipitation is the simplest to measure. Cumulative rainfall measured from on-site or nearby USGS rain gauges is compared to cumulative measured leachate generation rates for Sites 1 and 2 as shown in Figures 2 and 3, respectively.



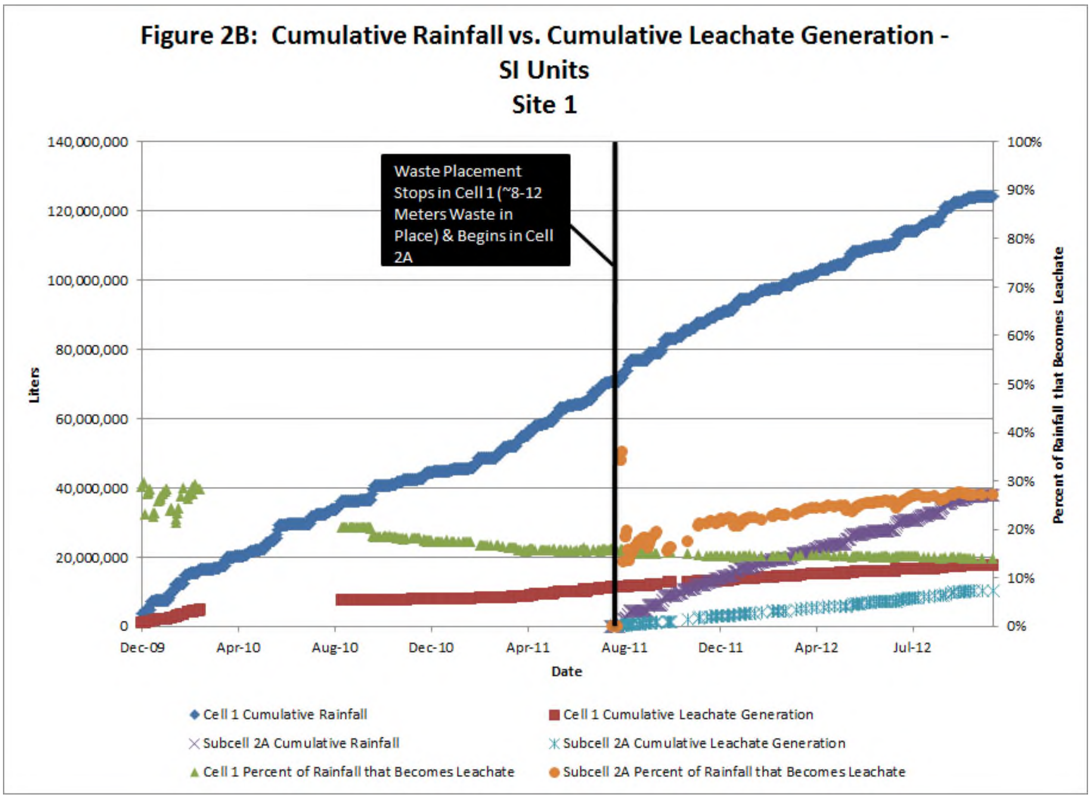


Figure 2B: Cumulative Rainfall vs. Cumulative Leachate Generation -
SI Units
Site 1
Waste Placement Stops in Cell 1 (~8-12 Meters Waste in Place) & Begins in Cell 2A
Liters
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
Percent of Rainfall that Becomes Leachate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Dec-09
Apr-10
Aug-10
Dec-10
Apr-11
Aug-11
Dec-11
Apr-12
Jul-12
Date
Cell 1 Cumulative Rainfall
Cell 1 Cumulative Leachate Generation
Subcell 2A Cumulative Rainfall
Subcell 2A Cumulative Leachate Generation
Cell 1 Percent of Rainfall that Becomes Leachate
Subcell 2A Percent of Rainfall that Becomes Leachate

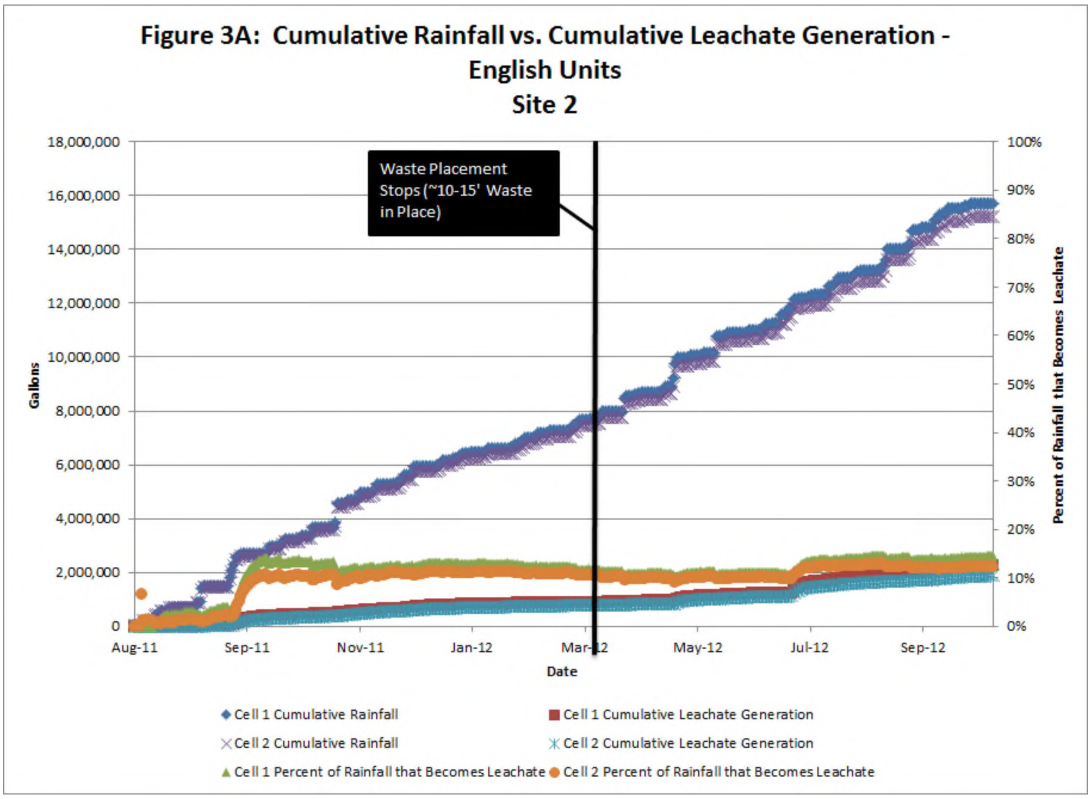
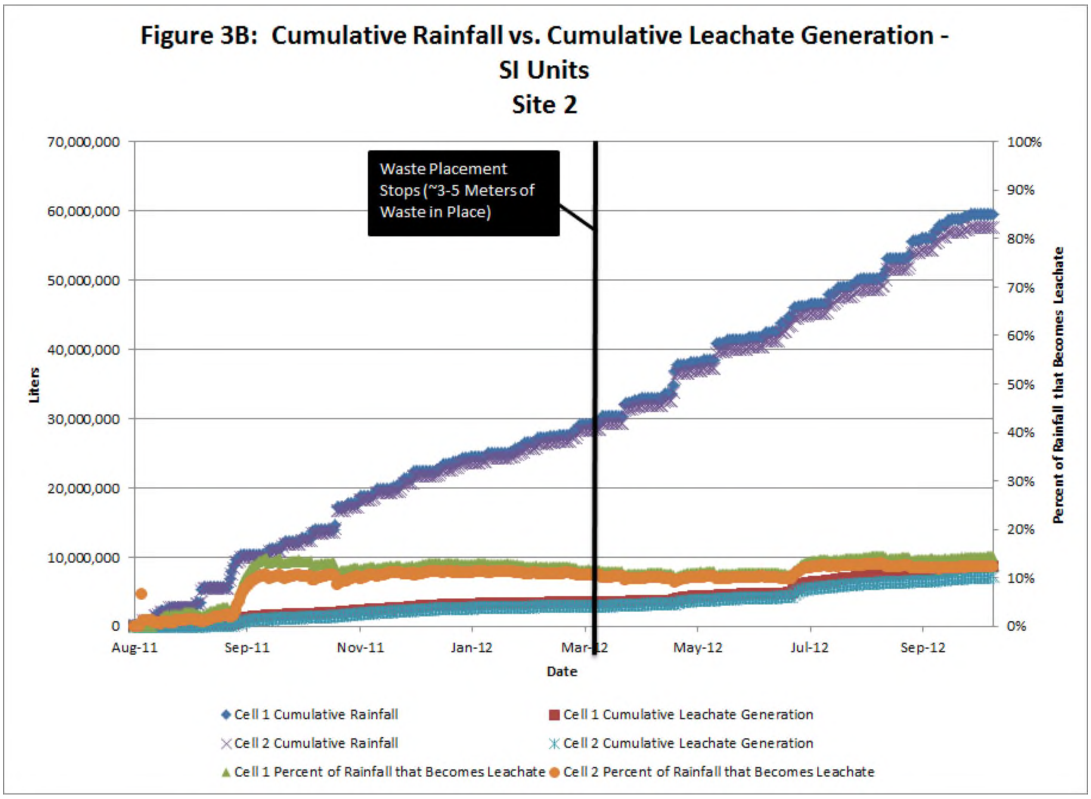


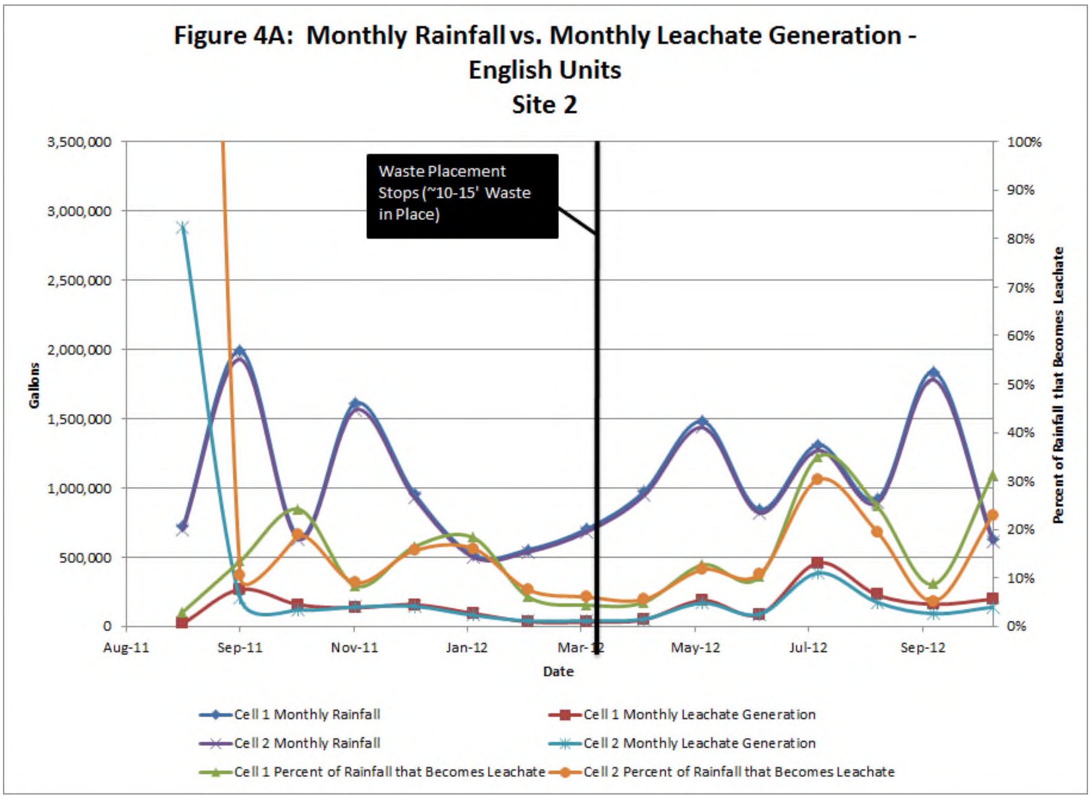
Figure 3A: Cumulative Rainfall vs. Cumulative Leachate Generation -
English Units
Site 2
Waste Placement Stops (~10-15' Waste in Place)
Gallons
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Percent of Rainfall that Becomes Leachate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Aug-11
Sep-11
Nov-11
Jan-12
Mar-12
May-12
Jul-12
Sep-12
Date
Cell 1 Cumulative Rainfall
Cell 1 Cumulative Leachate Generation
Cell 2 Cumulative Rainfall
Cell 2 Cumulative Leachate Generation
Cell 1 Percent of Rainfall that Becomes Leachate
Cell 2 Percent of Rainfall that Becomes Leachate

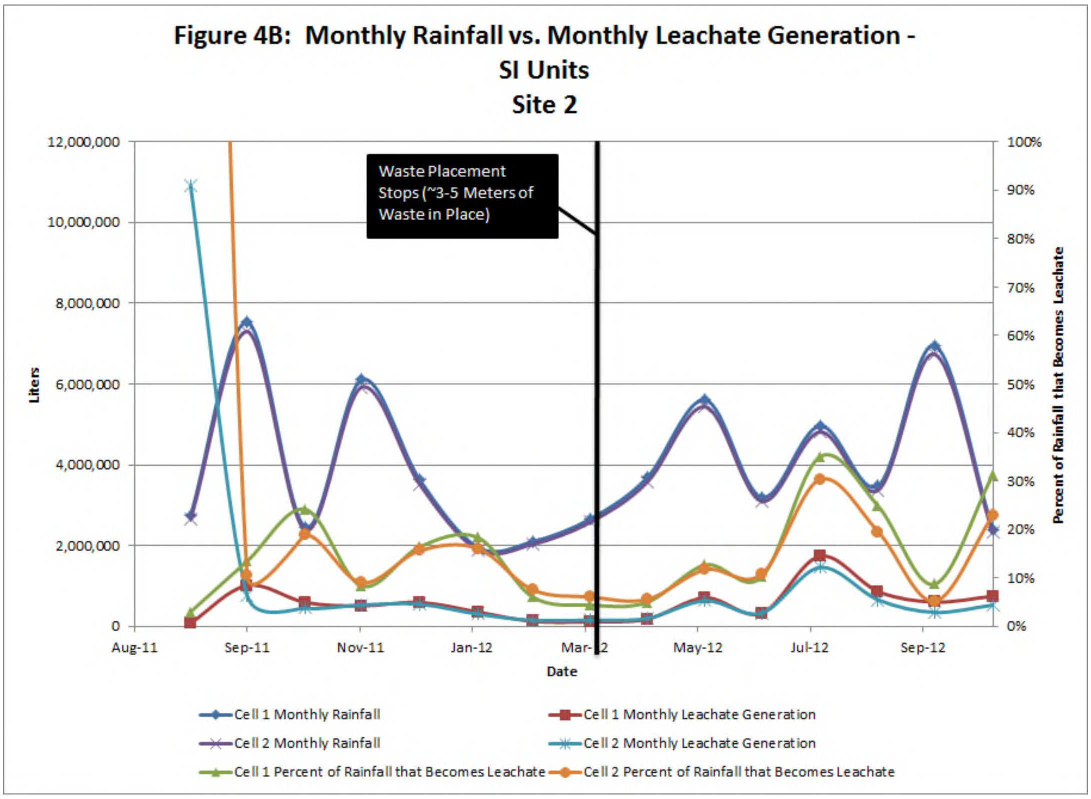


In these figures, cumulative rainfall and cumulative leachate generation are measured in terms of volume as shown on the primary, left y-axis, and the percent of rainfall that becomes leachate is measured as shown on the secondary, right y-axis.

The percent of rainfall that becomes leachate appears to converge on a value of approximately 13 percent for Site 1 Cell 1 and Site 2 Cells 1 and 2. The percent of rainfall that becomes leachate for Site 1 Subcell 2A appears to converge on approximately 27 percent; however, this phenomenon might be attributed to the open Subcell 2B adjacent to Subcell 2A, as previously described.

Drawing a comparison between cumulative rainfall to cumulative leachate generation may mask the influence of other factors. The relationship between monthly rainfall and monthly leachate generation rates for Site 2 are shown in the following figures:





The Cell 1 monthly rainfall, leachate generation, and percent of rainfall that becomes leachate is very similar to the corresponding Cell 2 relationships, as might be expected for two cells at the same site, similar in size and operations. While the cumulative percent of rainfall that becomes leachate appeared to converge on approximately 13 percent, the monthly percent of rainfall that becomes leachate ranged between approximately 5 percent to 35 percent. This indicates that leachate generation may be driven by seasonal fluctuations, changes in landfill operations, or other factors.

CONCLUSIONS

Estimated leachate generation rates were greater than measured leachate generation rates by a factor of approximately 2. The discrepancy might be explained by any combination of the inaccuracies in the measurement of rainfall and leachate generated, assumptions inherent in the HELP model, the nature of the ash waste material, the method of landfill operations, or the methods of leachate management.

Rainfall was measured from either on-site rain gauges or the nearest available USGS weather station. The amount of precipitation on the face of the landfill may be different than the amount of precipitation recorded at the on-site rain gauge or the nearest available USGS weather station. Additionally, there may be inaccuracies in the flowmeters which would cause an error in measuring leachate generation. Discrepancies due to measurement of precipitation and leachate generation are assumed to be relatively small due to the fact that HELP modeling predicted rainfall fairly accurately, and that the percentage of rainfall that becomes leachate was consistent among 3 of the 4 subcells evaluated.

Previous studies have noted that HELP modeling generally overpredicts leachate generation by percolation. For the purposes of this study, estimated leachate generation was assumed to consist of both percolation through the waste mass and runoff collected by chimney drains (infiltration and runoff). The current study indicated that precipitation was accurately estimated by HELP modeling, and Khire et. al. [3] found that HELP modeling accurately predicted evapotranspiration for a site in Georgia. Equation 7 is presented below for reference:

Leachate Generation = Precipitation–Evapotranspiration–Storage   (Equation 7)

HELP modeling is overestimating leachate generation. Assuming accurate HELP model estimates for precipitation and evapotranspiration, this would indicate that HELP is underestimating storage to satisfy Equation 7.

Accurate predictions of storage would depend on accurately predicting the relationship between fly ash and moisture content. Measurements of moisture content to depths of approximately 85 feet (26 meters) were taken at a dry ash handling facility in South Africa [4]. The moisture content was consistent with depth at approximately 25 percent.

Based on S&ME’s experience with ash landfills in southeastern United States, the optimum moisture content of fly ash is generally on the order of 25 to 30 percent. Assuming similar characteristics for the fly ash at the South African site, the moisture content with depth would be near optimum and thus not saturated, indicating that in general unsaturated flow conditions may prevail with depth.

Previous studies indicated that the HELP model accurately predicted evapotranspiration from a vegetated soil cover system for a site in Georgia. In our cases, fly ash is the surface component. One could hypothesize speculate that actual evapotranspiration from fly ash materials is much higher than predicted by the HELP model. This could be due to a higher degree of water retention and capillary action near the ground surface. Additional instrumentation of the upper layers of fly ash would be required to validate this hypothesis.

The method of landfill operations and leachate management may also be affecting the accuracy of HELP modeling. Three of the four subcells included with this study incorporated chimney drains to convey surface water runoff as contact water to the leachate collection system. Also, the subcells were active and inactive for various periods of time. The level of compaction of waste material could also be a factor.

It is recommended that the current facilities continue to be monitored to evaluate leachate generation rates, and that other facilities be added to the current study. Implementing an instrumentation and monitoring program may also help to identify correlations between precipitation, landfill operations, and leachate generation rates.

REFERENCES

[1] Albright, William H. et. al. Alternative Cover Assessment Project Phase 1 Report, Desert Research Institute, October 2002.

[2] Sharma, Hari D. and Sangeeta P. Lewis. Waste Containment Systems, Waste Stabilization, and Landfills, 1994.

[3] Khire, Milind V. et. al. Water Balance Modeling of Earthen Final Covers, Journal of Geotechnical and Geoenvironmental Engineering, August 1997.

[4] Nel, Jacobus M. et. al. Comparison Between the Geohydrological Properties of Wet and Dry Ash Disposal Sites, World of Coal Ash Conference, 2009.