ELECTRIC POWER RESEARCH INSTITUTE

Coal Combustion Residuals Leachate Management

Characterization of Leachate Quantity and Evaluation of Leachate Minimization and Management Methods

2015 TECHNICAL REPORT

Coal Combustion Residuals Leachate Management

Characterization of Leachate Quantity and Evaluation of Leachate Minimization and Management Methods

3002006283

Final Report, December 2015

EPRI Project Manager
B. Hensel

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

AECOM Technical Services

NOTE

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

AECOM Technical Services
564 White Pond Drive
Akron, OH 44320

Principal Investigators
M. Stepic
D. Orr
M. Rokoff
R. Hager
C. Backus
N. Golden
Y. Chen
G. Behrens
C. Hutson
K. Arambasick

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Coal Combustion Residuals Leachate Management: Characterization of Leachate Quantity and Evaluation of Leachate Minimization and Management Methods. EPRI, Palo Alto, CA: 2015. 3002006283.

ABSTRACT

Leachate management can be a major contributor to the operational cost of a landfill facility. Predicting the amount of leachate generated at a landfill is important both for the initial design of the landfill and for the design of associated facilities used to convey and manage leachate, such as leachate holding and treatment systems. The research described in this report involved the development of a tool to conservatively predict leachate quantity for a variety of climatic conditions encountered across the United States and for different stages in coal combustion residual (CCR) landfill operation. This model can be used for system-wide planning or to estimate leachate collection volume during planning phases of leachate management system designs such as leachate treatment or storage facilities.

This report also describes and qualitatively compares different methods for minimizing leachate generation. These include techniques to divert storm water from the CCR, thereby minimizing contact of precipitation with CCR, and operational techniques to reduce the volume of water added to CCR via precipitation, moisture conditioning, and dust control. The report also includes a discussion of standard approaches for leachate collection, conveyance, and disposal.

Keywords
Coal combustion residual (CCR)
Landfill design
Leachate management
Leachate minimization
Leachate quantity
Hydrologic Evaluation of Landfill Performance (HELP) Model

ACRONYMS AND ABBREVIATIONS

CCR	Coal Combustion Residual
EIA	Energy Information Administration
ELG	Effluent Limitation Guidelines
USEPA	U.S. Environmental Protection Agency
FGD	Flue Gas Desulfurization
HELP	Hydrologic Evaluation of Landfill Performance
IGWMC	Integrated GroundWater Modeling Center
LCS	Leachate Collection System
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
TSS	Total Suspended Solids
WWTP	Wastewater Treatment Plant

CONTENTS

1 INTRODUCTION AND BACKGROUND 1-1

2 CHARACTERIZATION OF LEACHATE QUANTITY 2-1

Introduction 2-1
Approach 2-1
Literature Review 2-1
Scenarios 2-3
Assumptions 2-4
Scenario Assumptions 2-4
Landfill Material Textures 2-4
Model Assumptions 2-5
Climate Zone Development 2-6
Example Prediction Calculation 2-8
Field Data Comparison 2-10
Case 1: Site A Landfill 1 2-10
Case 2: Site J Landfill 1 2-11
Case 3: Site D Landfill 1 2-12
Discussion 2-13

3 EVALUATION OF LEACHATE MINIMIZATION METHODS 3-1

Introduction 3-1
Description of Leachate Minimization Methods 3-1
Diversionary Techniques 3-1
Berms to Reduce Run-On and Run-Off 3-1
Perimeter and Interceptor Ditches/Channels 3-2
Rain Flaps 3-2
Infiltration Reduction Techniques 3-3
Regular Cover 3-3
Intermediate Cover 3-3

Final Cover 3-4
Operational Reduction Techniques 3-4
Minimization of Working Face 3-4
Managing Moisture Conditioning 3-4
CCR Placement and Landfill Grade 3-4
Qualitative Evaluation of Leachate Minimization Techniques 3-5
Overall Performance 3-9
Ease of Implementation 3-9
Schedule for Installation 3-9
Cost 3-9
Operation and Maintenance 3-9
Expansion and/or Closure Compatibility 3-10
Combining Leachate Minimization Techniques 3-10
Summary 3-10

***4* LEACHATE MANAGEMENT 4-1**
Introduction 4-1
Leachate Collection 4-1
Leachate Conveyance 4-3
Leachate Storage 4-3
Leachate Disposal 4-4
Off Site Disposal 4-4
Evaporation 4-4
Leachate Recirculation 4-4
Leachate Treatment 4-5

***5* REFERENCES 5-1**

***A* HELP MODEL INPUT VALUES A-1**

***B* CITIES WHERE DEFAULT CLIMATE DATA IN HELP WERE MODELED TO DEVELOP CLIMATE ZONES B-1**

***C* SIMPLIFIED MATRIX OF LEACHATE MINIMIZATION TECHNIQUES C-1**

LIST OF FIGURES

Figure 2-1 Leachate generation zone map 2-7
Figure 2-2 Leachate estimation for the example application 2-9
Figure 3-1 Soil berms to prevent precipitation run-on into a landfill 3-2
Figure 3-2 Rain flaps to prevent storm water run-on onto a working face 3-3
Figure 4-1 Schematic drawing showing components of a leachate collection system in plan view (top) and cross-section (bottom)—not to scale [17] 4-2
Figure 4-2 Sideslope riser pipe being installed in a leachate collection sump [17] 4-2

LIST OF TABLES

Table 2-1 Intermediate condition leachate generation ranges by zone 2-6
Table 2-2 Modeled peak daily leachate generation 2-7
Table 2-3 Modeled average annual leachate generation..2-8
Table 2-4 Estimated peak daily leachate generation for the example application 2-9
Table 2-5 Estimated annual average leachate generation for the example application.............2-9
Table 2-6 Anticipated average annual leachate generation for the Site A landfill 2-11
Table 2-7 Anticipated average annual leachate generation for the Site J landfill 2-12
Table 2-8 Anticipated average annual leachate generation for the Site D landfill 2-13
Table 3-1 Qualitative evaluation of diversionary techniques for minimizing leachate generation in CCR landfills 3-6
Table 3-2 Qualitative evaluation of infiltration reduction techniques for minimizing leachate generation in CCR landfills...3-7
Table 3-3 Qualitative evaluation of operational techniques for minimizing leachate generation in CCR landfills 3-8

1 INTRODUCTION AND BACKGROUND

Regulations for the management of coal combustion residuals (CCRs) and water discharges from steam electric generating units (effluent limitation guidelines [ELG]) were issued by the U.S. Environmental Protection Agency (USEPA) in 2015. These rules impact management requirements for CCR leachate and contact water. Effective management of landfill leachate will result in a more compliant and efficiently operated site, and is therefore an important part of landfill design.

The purpose of this research was to estimate typical leachate characteristics (quality and quantity) and develop a comprehensive resource that power companies can use to facilitate optimization of CCR leachate management.

Primary objectives were:

1. To characterize the quality of leachate at CCR landfill sites and the quantity of leachate generated by the facility;
2. To describe methods to minimize leachate treatment requirements by controlling the quantity and/or quality of leachate generated; and
3. To assess the practical implementations and general costs of leachate management alternatives.

The leachate quantity assessment was based on landfill modeling, which was compared to survey results to provide an indication of model uncertainty (Section 2). These data can be used as a leachate estimation tool during planning phases of landfill design. Leachate minimization (Section 3) and management (Section 4) methods were evaluated based on industry standard engineering practices. The leachate quality assessment is presented in EPRI report 3002007125 [1].

2
CHARACTERIZATION OF LEACHATE QUANTITY

Introduction

Predicting the amount of leachate generated at a landfill is important both for initial design of the landfill and for the design of associated facilities used to convey and manage leachate, such as leachate holding and treatment systems. For most landfills, a component of design and permitting is to develop a site-specific model to predict the quantity of leachate anticipated from the facility. The goal of the leachate quantity model presented here is to provide a preliminary range of anticipated values based on defined sets of conditions, or scenarios, for landfill cells at various stages of operation. In addition, a review of the available and selected mathematical models for leachate estimation is included.

The quantity of leachate generated varies by site, depending on features such as:

- Climate (rainfall, evaporation, and transpiration);
- Type of CCR;
- Leachate collection and liner system components;
- Landfill operations, including:
  a) Type of operational cover materials and frequency of application;
  b) Amount of area runoff diverted to storm water ditches;
  c) Compaction level of the CCR; and
  d) Type of final cover system installed upon closure.

Approach

Climate was anticipated to have a large effect on leachate generation at a CCR facility. To estimate leachate generation at CCR facilities through various climates, a model landfill with a common landfill liner system and cap system [2] was used. The model landfill was then evaluated in several regions throughout the United States. The model evaluated leachate generation at various stages of landfill operation to represent early, intermediate, and final stages of landfilling and thicknesses of CCR in the cell.

Literature Review

Over the years, several mathematical models have been developed to simulate the generation and transport of leachate in landfills. The Hydrologic Evaluation of Landfill Performance (HELP) model [3] is well known and widely used for landfill design. The HELP model is a quasi-two-dimensional hydrologic model that was developed to conduct water balance analyses of landfills, especially of cover systems. With minimal input, such as geographic location, hydrologic length, and the characteristics of the landfilled material, soil, and cover, the model will simulate daily, monthly, and annual runoff, evapotranspiration, percolation, and leachate generation [3]. According to standard HELP model results, leachate volumes decrease as waste height increases. Research shows that when the HELP model is used to estimate leachate for solid waste landfills, the model tends to underestimate the leachate volumes, with errors up to 80% [4][5]. On the other hand, several reports note that the HELP model overestimates leachate generation in CCR landfills [6][7], and the Desert Research Institute reports that the HELP model generally overpredicts leachate generation of landfill cover systems [8]. HELP version 3.07 was last revised in 1997; it is a DOS-program that can only run under Windows 95/NT/XP.

In 2012, Dr. Klaus Berger performed an extensive validation study based on climatic conditions in Germany [9]. An enhanced HELP version was developed based on the results of the validation study and further investigations. The current HELP version 3.95D is Windows-based, and includes corrections for some errors that version 3.07 had in vertical percolation, lateral drainage layers, frozen soil, actual evapotranspiration, vegetative growth and decay, and subsurface inflow [10].

MODUELO [11] is a simulation program for municipal solid waste landfills developed by the Environmental Engineering Group, University of Cantabria, Spain. It uses water balance analysis for estimating leachate generation. The program runs three main models, hydrological, biodegradation, and settlement, that can provide predicted leachate flows, organic composition of leachates, and gas generated in municipal waste landfills. The hydrologic model results can be compared to HELP model results to enhance solid waste landfill design [11][12].

EPIC (Environmental Policy Integrated Climate) is a one-dimensional model that was first developed in the early 1980s to evaluate the effects of wind and water erosion on plant management and growth. It is easy to use and can be used to estimate surface runoff, potential and actual evapotranspiration, percolation, and other hydrologic factors for landfill cover. However, it consistently underpredicted drainage compared with other software [8][13].

UNSAT-H (Unsaturated Soil Water and Heat Flow) is the latest version of the UNSAT model, originally developed in 1979. It was sponsored by the U.S. Department of Energy (DOE) to assess the water dynamics at arid locations. It simulates water flow, water vapor diffusion, and rational heat flow, and was able to closely predict measured drainage rates [8]. UNSAT-H has two primary limitations: 1) it was developed as a general vadose zone hydrology code and not specifically for landfill cover design, and 2) it is restricted to one-dimensional analysis and therefore cannot model lateral flow [8], although that is not a significant limitation for landfill simulation.

LEACHEM (Leaching Estimation and Chemistry Model) is similar to UNSAT-H and was developed for agricultural use. It is a one-dimensional model of water and solute movement, chemical reactions, and transformations in the unsaturated zone. Even though it is popular among consultants in some industries, there is not much information on its application to landfill covers [8].

The HYDRUS package is Microsoft Windows-based software with an interactive graphics-based interface [8][14][15] that uses the finite element methods to simulate water, heat, and solute movement in one-, two- or three-dimensional saturated subsurface media. Most software mentioned above is in the public domain. HYDRUS-1D is free to download, while HYDRUS-

2D/3D is commercially available from the Integrated GroundWater Modeling Center (IGWMC). While it can realistically simulate lateral subsurface flow for landfill cover design, there are still improvements that need to be made for this code to be a user-friendly option, for example, the ability to specify layer thickness as opposed to manual selection of nodes [8].

Each software program has its pros and cons. Many factors can affect the accuracy of modeling results. It is essential to understand the physical conditions of the landfill, as well as each model and its behavior, and to conduct a critical review of the simulation results. Proper use and interpretation of the simulation results based on experience is necessary [16] to develop predictions that are a reasonable approximation for real operations data.

The software programs listed above were evaluated for this application. HELP 3.07 was selected as the climate zone development model because of its long history and widespread usage. Of the software programs evaluated, HELP 3.07 is the most amenable for modeling multiple climate and site development conditions because it provides the user with as much assistance as possible in preparing data and has the flexibility to model a landfill under a variety of different conditions, including with geosynthetic cap systems. In testing by the Desert Research Institute, HELP 3.07 consistently provided higher leachate volume estimates than EPIC, UNSAT-H, and HYDRUS regardless of the condition tested [8], suggesting that it is a conservative choice for this research. HELP 3.95D was used for final predictions because it is the extension of HELP 3.07 with corrections.

Scenarios

There are many viable alternatives for liner and cover system designs in a CCR landfill. A typical case was selected for this application, but other alternatives are viable depending on site-specific conditions. Details are described below, and model input values are listed in Appendix A.

The modeled leachate collection system consisted of a geocomposite drainage layer with perforated leachate collection piping to direct leachate to the perimeter of the landfill for extraction. The leachate collection system was underlain by a composite liner system consisting of 60-mil HDPE over 2 feet of clay compacted to achieve a hydraulic conductivity of 1×10^{-7} cm/s. The slope of the landfill floor was modeled at 3%, with pipe spacing of 200 feet.

Six scenarios, representing different stages of landfill operations, were evaluated:

1. Initial Conditions: This scenario assumed that one 10-foot-thick lift of CCR had been placed. This scenario was meant to model the early stages of landfill operation. No intermediate soil covered the CCR, and a rain flap was assumed to minimize storm water contact with the CCR; thus, 0% of the landfill was assumed to allow runoff.
2. Intermediate Conditions (no runoff and no soil cover): This scenario assumed half of the permitted CCR height, or approximately 75 feet of materials, had been placed with the side slopes of the landfill at 3H:1V. It was meant to model the working progress of landfill, so there is no soil cover on the CCR. Therefore, 0% of the area was assumed to allow runoff and the vegetative condition is bare.
3. Intermediate Conditions: This scenario assumed half of the permitted CCR height, or approximately 75 feet of material, had been placed. The CCR was assumed to be covered with 12 inches of intermediate cover soils and was meant to model average landfill

operating conditions. Fair vegetative conditions were assumed, and 50% of the landfill was assumed to allow runoff. The side slopes of the landfill were modeled at 3H:1V and assumed to be covered with intermediate cover soils as the facility is developed.

4. Pre-Closure Conditions: This scenario assumed the full height of CCR, assumed to be 150 feet for this analysis, had been placed. The CCR was assumed to be covered with 12 inches of intermediate cover soils and the scenario was meant to model maximum loading conditions on the landfill prior to the installation of the final closure cap. Fair vegetative conditions were assumed, and 100% of the landfill was assumed to allow runoff to the facility's sediment basins.
5. After-Closure with Clay Cap System: This scenario included a 12-inch-thick vegetative cover soil capable of sustaining native vegetation and a 24-inch-thick compacted clay layer with hydraulic conductivity no greater than 10^{-7} cm/sec. Note that this cap system may not be allowable for a landfill with a geomembrane liner under state and federal laws but is presented here for illustrative purposes. In addition, this cap system may be utilized for unlined or clay lined facilities.
6. After-Closure with Geomembrane Cap System: This scenario consisted of the following layers, from top to bottom: a 24-inch-thick vegetative/protective cover soil capable of sustaining native vegetation; a double-sided geocomposite drainage layer; and a 20-mil linear low-density polyethylene (LLDPE) flexible membrane liner barrier layer that has a hydraulic conductivity much lower than 10^{-7} cm/sec.

Each scenario was simulated in the HELP model for a 100-year period. The model calculated peak daily results and average annual results over the 100-year simulation period.

Assumptions

The following assumptions were made in performing the HELP model analysis.

Scenario Assumptions

Results of the modeling can only be applied to facilities that meet these basic scenario assumptions:

- The landfill has a composite liner.
- The landfill has a leachate collection system.
- There is no lateral inflow of groundwater or surface water into the landfill.
- There are no seeps that discharge significant volumes of water from the landfill.
- Leachate is not diverted for recirculation prior to the flow meter.
- Application of water or leachate to the working surface is only as much as is needed for dust control.

Landfill Material Textures

It is anticipated that there will be differences between these assumptions and materials used at individual landfills. These differences can be considered when establishing the level of conservatism in the estimate or in the application of safety factors to the estimated volume. Specifically, if hydraulic conductivity values for the actual materials will be significantly higher than listed here, then the estimate may not be conservative and the application of a larger safety factor may be appropriate. Conversely, if hydraulic conductivity values for the actual materials will be lower than the modeled values, then the estimated leachate produced by this analysis may be considered conservative and a lower safety factor might be considered.

- The intermediate cover soil used in the initial, intermediate, and pre-closure conditions was modeled as HELP default texture 12 (Unified Soil Classification System Classification CL) with a default hydraulic conductivity of 4.2 x 10^{-5} cm/sec.
- The CCR was modeled as HELP default texture 30 (fly ash) with a default hydraulic conductivity of 5.0 x 10^{-5} cm/sec. This was deemed the most appropriate way to model the multiple CCR streams including fly ash, bottom ash, and FGD gypsum, as fly ash and gypsum have relatively similar grain size and hydraulic conductivity and make up the majority of the CCR produced by a typical power plant.
- The erosion protection/traffic filter layer used in the liner system of the landfill was modeled as HELP default texture 2 with a default hydraulic conductivity of 5.8 x 10^{-3} cm/sec.
- The geocomposite drainage layer used in the liner system of the landfill was modeled as HELP default texture 20 with a default hydraulic conductivity of 10.0 cm/sec.
- The 60-mil High Density Polyethylene (HDPE) geomembrane used as part of the landfill liner system was modeled as HELP default texture 35 with a default hydraulic conductivity of 2.0 x 10^{-13} cm/sec.
- The 2-foot-thick clay layer used as part of the landfill liner system was modeled as HELP default texture 17 (bentonite) with a modified hydraulic conductivity of 1.0 x 10^{-7} cm/sec.
- The 5-foot geological buffer layer below the landfill liner system was modeled as HELP default texture 16 with a modified hydraulic conductivity of 1.0 x 10^{-6} cm/sec.

Model Assumptions

These assumptions are for informational purposes, and have no bearing on application of model results.

- The initial water contents of all layers were manually set equal to the default HELP specified field capacity of the material, which represents the water content of the material after a prolonged period of gravity drainage. However, it should be noted that for the purpose of calculating hydraulic flow through the landfill system, the HELP model automatically assumes that all barrier layers (the compacted soil liner and/or geosynthetic clay liner) are saturated.
- The HELP model simulated temperature, precipitation, evapotranspiration, and solar radiation based on default data for the nearest climate stations.
- HELP model results are independent of the landfill area. A 1-acre area was considered for the analysis. Therefore, leachate generation results are presented as cubic feet per acre

per time period (annual or daily). Results were converted to gallons per acre per time period using the conversion factor below.

$$\frac{\text{ft}^3}{\text{time period}} \times \frac{7.48\text{ gallons}}{\text{ft}^3} \times \frac{\text{time period}}{\#\text{ of days}}$$

Climate Zone Development

Climate in the United States can vary significantly from state to state and even within a state. To minimize the complexity of the landfill leachate quantity model, the continental U.S. was divided into zones of similar climate. Results for various stages of landfill operation in each zone could then be extrapolated to evaluate the different scenarios and rapidly estimate leachate generation.

HELP 3.07 was used to divide the country into climate zones. Fifty-five U.S. cities in the HELP model default locations list were selected for testing (Appendix B). Weather data (including evapotranspiration, precipitation, temperature, and solar radiation) from the HELP model were used for the selected cities to determine the initial zones in the model. Initial modeling was conducted using the same landfill scenario for all zones, including liner system, CCR thickness, and cover soil type.

The intermediate condition (scenario 3) was modeled to evaluate the climate zones. The estimated leachate volumes were plotted on a map, and the map was used to divide the United States into eight zones as shown in Table 2-1 and Figure 2-1. Where possible, entire states were included within each zone unless significant variation was observed within the state. California, Idaho, and Oregon are not included in any zones because they do not have any substantial coal-fired power plants. In three cases involving six zones (zones 2 and 3, 4 and 5, 6 and 7) predicted annual leachate volume was similar, but separate zones were designated due to geographical differences. Table 2-1 shows the range of average annual leachate per acre in cubic feet under the intermediate condition at each proposed zone. Figure 2-1 shows the zones in colors on the map.

Table 2-1
Intermediate condition leachate generation ranges by zone

	Average Annual Leachate (Ft^3/Acre)	Average Annual Leachate (Gallons/Acre)
Zone 1	Below 10,000	Below 74,805
Zone 2	10,000–30,000 (North)	74,805–224,416 (North)
Zone 3	10,000–30,000 (South)	74,805–224,416 (South)
Zone 4	30,000–45,000 (North)	224,416–336,623 (North)
Zone 5	30,000–45,000 (South)	224,416–336,623 (South)
Zone 6	45,000–80,000 (North)	336,623–598,442 (North)
Zone 7	45,000–80,000 (South)	336,623–598,442 (South)
Zone 8	80,000 and up	598,442 and up

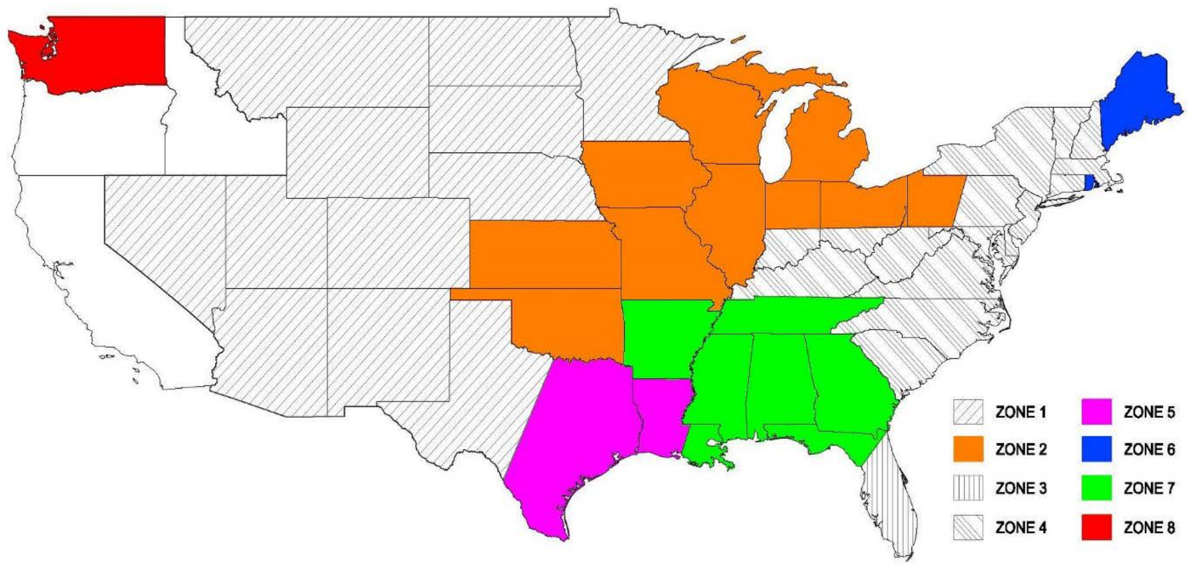


Figure 2-1
Leachate generation zone map

Prediction modeling was performed by simulating generated leachate volumes for all six scenarios in each of the eight climate zones using HELP 3.95D. This resulted in 48 simulations (6 scenarios × 8 climate zones). One representative city within each climate zone was used for generation of climatic variables. Peak daily and average annual leachate generation were compiled for each simulation. Table 2-2 summarizes the peak daily leachate generation estimate for each scenario in each climate zone.

Table 2-2
Modeled peak daily leachate generation

Zone	Representative City	Scenario					
		Initial Condition	Intermediate Condition Without Soil Cover	Intermediate Condition	Pre-Closure Condition	Cap System Clay	Cap System Geomembrane
Zone 1	Flagstaff, AZ	5,500	1,400	1,100	900	100	0
Zone 2	St. Louis, MO	8,700	1,900	1,800	1,500	200	0
Zone 3	Tampa, FL	12,800	1,800	1,800	1,200	100	0
Zone 4	Philadelphia, PA	7,900	3,300	2,900	2,400	200	0
Zone 5	Houston, TX	12,100	3,700	3,200	2,100	200	0
Zone 6	Providence, RI	16,300	4,400	3,800	3,100	300	0
Zone 7	New Orleans, LA	21,800	6,200	5,100	3,000	200	0
Zone 8	Olympia, WA	28,200	7,600	6,800	5,300	200	0

Model results are rounded to the nearest 100 gallons/acre/day
Modeled leachate volumes in gallons/acre/day

Table 2-3 summarizes the average annual leachate generation estimated for each scenario in each climate zone.

Table 2-3
Modeled average annual leachate generation

Zone	Representative City	Scenario					
		Initial Condition	Intermediate Condition Without Soil Cover	Intermediate Condition	Pre-Closure Condition	Cap System Clay	Cap System Geomembrane
Zone 1	Flagstaff, AZ	165,000	120,000	104,000	64,000	9,000	0
Zone 2	St. Louis, MO	294,000	191,000	178,000	124,000	11,000	0
Zone 3	Tampa, FL	447,000	175,000	181,000	93,000	8,000	0
Zone 4	Philadelphia, PA	451,000	360,000	330,000	248,000	13,000	0
Zone 5	Houston, TX	503,000	350,000	311,000	198,000	11,000	0
Zone 6	Providence, RI	615,000	542,000	472,000	356,000	14,000	0
Zone 7	New Orleans, LA	728,000	570,000	496,000	332,000	13,000	0
Zone 8	Olympia, WA	993,000	941,000	965,000	736,000	14,000	7

Model results are rounded to the nearest 1,000 gallons/acre/year.
Modeled leachate volumes in gallons/acre/year.

Example Prediction Calculation

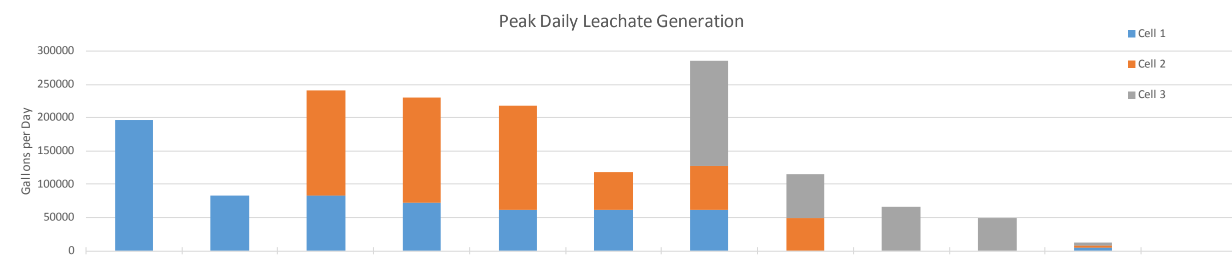
The Prediction Model was developed to rapidly estimate potential leachate generation at a CCR landfill. It can be used in initial planning of items such as leachate storage facility and treatment system sizing. The following is an example scenario illustrating the use of the Prediction Model.

A power company is converting to dry landfill operations. As part of the dry conversion and other plant upgrades, the project will include installing a wastewater treatment system to manage plant wastewater flows, scrubber wastewater, and leachate generated by the future landfill. The company needs to estimate anticipated peak and average yearly flows of leachate to the wastewater system to assure that it is adequately sized.

Information available at this stage of planning includes:

- The power station is hypothetically located in climate zone 4;
- The landfill is anticipated to cover 65 acres, constructed in 3 cells over the life of the facility;
- Cell 1, Cell 2, and Cell 3 will be 25 acres, 20 acres, and 20 acres, respectively; and
- Capping of Cell 1 will not begin until Cell 3 is in operation.

Figure 2-2 illustrates the daily leachate estimations (gallons per day) of several operation scenarios at the example landfill.



Cell 1	Initial	Intermediate w/o cover	Intermediate w/o cover	Intermediate w/ cover	Pre-closure	Pre-closure	Pre-closure	Geomembrane	Geomembrane	Geomembrane	Clay-Cap	Geomembrane
Cell 2			Initial	Initial	Initial	Intermediate w/ cover	Intermediate w/o cover	Pre-closure	Geomembrane	Geomembrane	Clay-Cap	Geomembrane
Cell 3							Initial	Intermediate w/o cover	Intermediate w/o cover	Pre-closure	Clay-Cap	Geomembrane

Figure 2-2
Leachate estimation for the example application

Table 2-4 illustrates the calculation of estimated peak daily leachate generation from the landfill for the combination of scenarios with highest leachate generation.

Table 2-4
Estimated peak daily leachate generation for the example application

Cell #	Condition	Size (Acres)	Anticipated Peak Daily Leachate Generation (Gal/Acre/Day)	Total Anticipated Peak Daily Leachate Generation (Gal/Day)
Cell 1	Pre-closure	25	2,400	60,000
Cell 2	Intermediate w/o soil cover	20	3,300	66,000
Cell 3	Initial	20	7,900	158,000
Total Anticipated Peak Leachate Generation (Gal/Day)				284,000

Table 2-5 illustrates the calculation of estimated average annual leachate generation for the example landfill during the peak period.

Table 2-5
Estimated annual average leachate generation for the example application

Cell #	Condition	Size (Acres)	Anticipated Average Annual Leachate Generation (Gal/Acre/Year)	Total Anticipated Average Annual Leachate Generation (Gal/Year)
Cell 1	Pre-Closure	25	248,000	6,200,000
Cell 2	Intermediate w/o soil cover	20	330,000	6,600,000
Cell 3	Initial	20	451,000	9,020,000
Total Anticipated Average Annual Leachate Generation (Gal/Year)				21,820,000

For the planning of the wastewater treatment system, the company can estimate that the average annual leachate generation that should be anticipated from the landfill is approximately 22 million gallons per year, and typical peak daily leachate generation is anticipated to be 280,000 gallons per day. Based on the literature review observation that HELP tends to overpredict the volume of leachate collected, and comparison to field data below, these values can be expected to be conservative as long as the planned landfill is consistent with the assumptions used in the modeling. An additional safety factor on top of this volume could be considered when selecting a storage volume to allow for flows that may be outside of the margin of error of this calculation or allow for large flows that may occur when the existing storage facilities are not empty at the beginning of the storm event.

Field Data Comparison

Model results were compared to field-measured leachate generation data collected during an industry survey. The survey asked for the location of the landfill, acreage of the landfill, cap and liner system components, thickness of emplaced CCR, and any available leachate quantity information. Data from landfills that had either no formal liner or no formal leachate collection system were not considered for this comparison. In addition, leachate data from landfills that only had a clay liner system without a geomembrane component were also excluded. These facilities were not considered because they did not meet the scenario assumptions used for the modeling.

Most landfills that had readily available leachate quantity data either monitored total leachate generated over a large period of time, such as per month or per year, or performed periodic flow rate tests. None of the data provided by survey responders had enough information to compare daily leachate peaks to predicted peak daily values from the Prediction Model, so the focus of this comparison was on average annual flow rates.

Case 1: Site A Landfill 1

Based on the survey replies, landfill characteristics for Site A are as follows:

- Landfill size – 244 acres
- Number of cells – 3
- Liner system – compacted clay/geomembrane
- Depth of each cell – each cell is approximately ½ full with respect to height
- Leachate generated – 2013 leachate generation for all 3 cells: 79,700,000 gallons

Based on the location and characteristics of the Site A landfill, the volume of leachate estimated by the Prediction Model is:

- Site A is located in Zone 4.
- All 3 cells most closely resemble the Intermediate Condition scenario but only Cell B has soil cover (to control dust).

Table 2-6 illustrates the calculation of the anticipated average annual leachate generation for the Site A landfill.

Table 2-6
Anticipated average annual leachate generation for the Site A landfill

Cell #	Condition	Size (Acre)	Anticipated Average Annual Leachate Generation (Gal/Acre/Year)	Total Anticipated Average Annual Leachate Generation (Gal/Year)
Cell A	Intermediate w/o soil cover	80	360,000	28,800,000
Cell B	Intermediate w/ soil cover	53	330,000	17,490,000
Cell C	Intermediate w/o soil cover	111	360,000	39,960,000
Total Anticipated Average Annual Leachate Generation (Gal/Year)				86,250,000

The Prediction Model estimate for leachate generation is about 86 million gallons/year. This estimate is approximately 8% higher than the measured value for leachate generated by the Site A landfill.

Case 2: Site J Landfill 1

Based on the survey replies, landfill characteristics for Site J are as follows:

- Landfill size – 38 acres
- Number of cells – 1
- Liner system – 4 feet of clay and composite
- Depth of each cell – approximately ½ full with respect to height except 18% of the fill area is capped
- Leachate generated – 2013 leachate generation: 4,437,000 gallons

Based on the location and characteristics of the Site J landfill, the volume of leachate estimated by the Prediction Model is:

- Site J is located in Zone 2.
- 18% of the total fill area is capped with geomembrane, and the rest closely resembles Intermediate Conditions without soil cover.

The resulting model-based leachate estimate is 5.9 million gallons per year (Table 2-7). Consistent with findings in the literature review that the HELP model tends to overpredict leachate volume, the model estimate is 33% higher than the volume measured in the field.

Table 2-7
Anticipated average annual leachate generation for the Site J landfill

Area	Condition	Size (Acres)	Anticipated Average Annual Leachate Generation (Gal/Acre/Year)	Total Anticipated Average Annual Leachate Generation (Gal/Year)
Uncapped area	Intermediate w/o soil cover	31	191,000	5,921,000
Capped area	Geomembrane cap system	7	0	0
Total Anticipated Average Annual Leachate Generation (Gal/Year)				5,921,000

Case 3: Site D Landfill 1

Based on the survey replies, Site D landfill characteristics are as follows:

- Landfill size – 17 acres
- Number of cells – 1
- Liner system – composite
- Depth of each cell – 0 to 125 feet
- Leachate generated – 2014 leachate generation: 3,400,000 gallons

Based on the location and characteristics of the Site D landfill, the volume of leachate estimated by the Prediction Model is:

- Site D is located in Zone 2.
- 13 acres are capped and 4 acres have CCR ranging from 0 to 125 feet without temporary soil cover.

The design height is 125 feet, and the current CCR heights on the landfill are between 0 and 125 feet, which makes the data comparison more difficult. To be conservative, half (2 acres) of the uncapped area was assumed to be similar to the Initial Condition and the remaining (2 acres) uncapped area was assigned the Intermediate Condition (Table 2-8).

Table 2-8
Anticipated average annual leachate generation for the Site D landfill

Area	Condition	Size (Acres)	Anticipated Average Annual Leachate Generation (Gal/Acre/Year)	Total Anticipated Average Annual Leachate Generation (Gal/Year)
Uncapped area	Initial	2	294,000	588,000
Uncapped area	Intermediate w/o soil cover	2	191,000	382,000
Capped area	Geomembrane cap system	13	0	0
Total Anticipated Average Annual Leachate Generation (Gal/Year)				970,000

The Prediction Model estimate for leachate generation is 970,000 gallons per year, which is approximately 71% lower than the measurement value reported for leachate generated by the Site D landfill. Because of this discrepancy, additional operations information was requested from Site D personnel. It was then determined that leachate recirculation is performed at this landfill, and leachate from another landfill is also measured using the same flow meter as the Site D landfill. These leachate management practices are not consistent with the Prediction Model assumptions, resulting in the underestimate.

Discussion

The purpose of this task was to develop a model for initial estimate of leachate quantities generated by CCR landfill operation. This Prediction Model tool can be used for system-wide planning or to estimate leachate collection volume during planning phases of leachate management system designs such as leachate treatment or storage facilities. It can also be used as a check for site-specific calculations, which should be of the same order of magnitude if site conditions are consistent with the assumptions used in the Prediction Model.

Due to the generalized nature of this model, it is not intended to replace site-specific calculations for final design of a landfill and/or leachate storage and treatment systems. As the design of the leachate treatment or leachate storage system progresses, experienced engineers will interpret site-specific calculations and conduct an analysis of the implications to the system being evaluated to determine if more or less leachate will be generated by the landfill than indicated by the calculation. The engineering analysis may also consider other potential sources of leachate generation, such as groundwater intrusion, a perimeter groundwater collection system, or increased leachate production because of storm water management practices.

3
EVALUATION OF LEACHATE MINIMIZATION METHODS

Introduction

Leachate management can be a major contributor to the operational cost of a landfill facility. However, leachate minimization techniques can be implemented to reduce operational costs associated with managing leachate. This review describes leachate minimization methods commonly used at CCR landfills, and qualitatively compares the methods based on factors such as effectiveness, ease of implementation, operation and maintenance, and relative cost.

Description of Leachate Minimization Methods

For purposes of this review, any water that comes into contact with CCR in a landfill is categorized as leachate. The primary source of added water at most landfills is precipitation. Additional water may be applied for moisture conditioning and dust control. When the primary source of water is precipitation, leachate minimization largely involves reducing the amount of precipitation, and precipitation run-on (including snowmelt in northern climates), that comes in contact with the CCR. Several methods to minimize exposure of the CCR to precipitation and run-on are reviewed below. Dust control and moisture conditioning are also discussed.

Diversionary Techniques

Berms to Reduce Run-On and Run-Off

Soil berms composed of structural fill may be constructed adjacent to landfill cells on the upstream side to prevent precipitation run-on from flowing into the active portion of the landfill and becoming leachate (Figure 3-1). The berms direct water away from the cells and into a collection area (pond or ditch) to be managed as storm water runoff rather than leachate.

Another common practice in landfill phasing and operations is to construct inter-cell berms to prevent leachate from running off an active cell to a constructed cell that has not yet received CCR, which could otherwise cause all water in the unused cell to be considered leachate. This simple measure also provides a visual guide for landfill operations to keep CCR within predetermined phasing or limits of CCR disposal.

Figure 3-1
Soil berms to prevent precipitation run-on into a landfill

Perimeter and Interceptor Ditches/Channels

Perimeter ditches can be constructed around the landfill to divert run-on water away from the active portions of the landfill. The perimeter ditch is designed to capture and route precipitation water from run-on areas to a collection area (pond or ditch) to be managed as runoff, rather than leachate. Interceptor ditches can also be installed around the perimeter of the individual cells to block any run-on that may flow into the cell and convey it to the perimeter ditch, which ultimately discharges to a storm water pond. These ditches have low base slopes to minimize erosion and increase capacity of the storm water collection system. Precipitation water may also be collected from lined portions of the landfill cell that have yet to receive CCR and directed to the storm water management system. In the storm water ponds, suspended soil particles are allowed to settle, and the water may be tested for leachate indicators. Once settling has occurred, it can then be discharged through a National Pollutant Discharge Elimination System (NPDES)-permitted outfall.

Rain Flaps

The rain flap method applies the principles of phasing operations to an individual cell. Rain flaps consist of a sacrificial geomembrane flap welded to the primary geomembrane the entire length of the cell, folded back toward the direction of the sump, and backfilled with aggregate, soil, or pipe for support. The rain flap is installed across the entire width and divides the cell (Figure 3-2). This provides an impermeable barrier though which precipitation water cannot infiltrate.

Figure 3-2
Rain flaps to prevent storm water run-on onto a working face

Run-off is typically directed toward one side of the cell that has not yet been filled with CCR. Since there has been no contact with the CCR, this water can be pumped out and managed with other storm water runoff, rather than being managed as leachate. Factors that can impact the effectiveness of rain flaps include cell size, cell geometry, and CCR generation (fill rate).

Infiltration Reduction Techniques

Regular Cover

Regular cover commonly consists of a soil that is placed periodically over the CCR. The soil material is spread in a minimum 6-inch lift across the CCR and compacted or tracked in with placement equipment. Alternative cover types include foam products, soil cement, organosilanes, and geosynthetic tarps or blankets. Some of the alternative cover types, especially geosynthetic products, can be water resistant and effective at reducing leachate volume. Simple techniques such as covering exposed CCR with plastic (battened down to protect against wind) can also be used to decrease storm water infiltration and water application for dust control while not actively placing CCR.

Intermediate Cover

Intermediate cover consists of 12 inches of soil material that can support vegetation or spray-applied soil cement. Once the CCR grades in a cell have reached an elevation above the perimeter containment berms, intermediate cover can be placed on the exterior side slopes to shed storm water. If the intermediate cover is placed effectively and healthy vegetative cover is established, it can reduce storm water infiltration into the side slopes of the CCR. Establishing vegetation on the intermediate cover material is important for preventing erosion, which would reduce the effectiveness of the cover, and promoting evapotranspiration. Intermediate cover can be used to minimize the exposed (working face) of the landfill, as noted below.

Final Cover

Final cover, commonly referred to as the landfill cap, is installed once a working area of the landfill has reached capacity or final grades, and CCR will no longer be placed in that area. Alternatives for final cover at CCR landfills are discussed in EPRI report 1023741 [17].

Final cover is placed to minimize infiltration of precipitation water into the closed areas of the landfill, which reduces leachate generation in these areas. Final cover can consist of a cohesive soil or clay layer, a geomembrane layer, or a combination of both, and a vegetative layer to minimize erosion of the final cover surface and promote evapotranspiration. Incorporating a drainage layer in the cap design can further reduce infiltration through the cap by improving the flow path for water to travel down the slope into perimeter ditches, thus allowing less time for infiltration into the cap soils. A soil-only cap can reduce storm water infiltration into the landfill and greatly reduce the amount of leachate generated once that area has been capped. However, modeling results presented in Section 2 illustrate how a combination soil and geomembrane cap can be more effective than a soil cap for reducing leachate generation in a capped area.

Operational Reduction Techniques

Minimization of Working Face

Typically, a landfill consists of multiple cells built in phases. Restricting operations to as small an area as possible (5 to 15 acres is typical) reduces the amount of CCR exposed to precipitation, which in turn reduces infiltration and leachate generation. The operational "working face" under this leachate management alternative is only as large as necessary to efficiently operate the facility.

Managing Moisture Conditioning

Moisture in excess of the CCR's retention capacity either evaporates or permeates down through the CCR and becomes leachate. Efforts to minimize the amount of moisture added to CCR prior to placement, while maintaining adequate moisture for workability, compaction, and dust control, can limit excess moisture that would otherwise become leachate. This technique requires knowledge of the moisture retention capacity curve for the CCR. If this information is available, then targeting moisture conditioning to bring moisture levels to the low end of the acceptable range for workability and compaction can reduce the amount of leachate generated.

CCR Placement and Landfill Grade

Placement of CCR can affect the landfill in many ways, including leachate management. Maintaining grades while placing CCR will facilitate shedding of water after the daily, intermediate, or final cover is placed. Conversely, a flat surface increases potential for surface ponding, which can increase the amount of surface water that infiltrates into the CCR mass and becomes leachate.

Related to all three of these operational reduction techniques is that fly ash and dry-FGD products may have a moisture deficit, even after moisture conditioning, when placed in a landfill [18]. As a result, the CCR will retain a certain volume of moisture added for dust control and by rainfall. This water is tightly held in the pore spaces between CCR particles by soil tension.

Using this soil physics concept, it may be possible for some facilities to manage placement of dry CCR such that moisture deficits are not eliminated, meaning that the water remains tightly held in the pore spaces of the CCR and does not percolate downward to the leachate collection system. In concept, this could be achieved by placement of successive lifts of dry CCR that has been moisture-conditioned to the low end of the optimal range, and graded to facilitate runoff, with each lift placed before there is enough moisture addition for dust control and via precipitation to overcome the moisture deficit of the underlying lift. Then, once the working area reaches final grade, immediate placement of a cap that allows negligible infiltration can create an environment where moisture deficits are not eliminated, such that soil tension forces do not enable downward moisture movement and it cannot flow to the leachate collection system. This concept is most applicable in arid to semi-arid climates, although it may be possible in some facilities in non-arid climates as well.

Qualitative Evaluation of Leachate Minimization Techniques

A qualitative evaluation of the leachate minimization methods reviewed above is presented in Tables 3-1, 3-2, and 3-3. The evaluation criteria are described following the tables. Note that the qualitative evaluations are generalized for typical CCR facilities based on the author's experience and engineering judgement, and site-specific circumstances may cause some methods to rate differently than indicated in the table.

Table 3-1
Qualitative evaluation of diversionary techniques for minimizing leachate generation in CCR landfills

Criterion	Diversionary Techniques		
	Soil Berms	Interceptor Ditches and Channels	Rain Flaps
Overall Performance			
- Effectiveness of Technique	AVERAGE	AVERAGE	GOOD
Ease of Implementation			
- Construction Requirements	AVERAGE	AVERAGE	MORE THAN AVG
- Material Availability	EXCELLENT	EXCELLENT	AVERAGE
- Technical Challenge	LOW	LOW	LESS THAN AVG
- Specialty Skills	FEWER	FEWER	LESS THAN AVG
Schedule for Installation			
- Duration of Installation	AVERAGE	AVERAGE	LESS THAN AVG
- Complexity of Installation	LOW	LOW	LESS THAN AVG
Costs (Capital and Operational)			
- Capital Costs	AVERAGE	AVERAGE	MORE THAN AVG
- Operational Costs	LOW	LOW	MORE THAN AVG
Operation and Maintenance			
- Repairs and Maintenance	HIGH	HIGH	LESS THAN AVG
- Effort to Repair/Maintain	AVERAGE	AVERAGE	MORE THAN AVG
Expansion and/or Closure Compatibility			
- Material Requirements	LOW	LOW	HIGH
- Impact on Expansion	LOW	LOW	NA
- Impact on Closure	LOW	LOW	NA

The ratings for each technique are qualitative and relative to all other techniques listed in Tables 3-1, 3-2, and 3-3. For example, rain flaps typically require *less than average* repairs and maintenance relative to all of the techniques listed in Tables 3-1, 3-2, and 3-3; however, when required those repairs typically require *more than average* effort.

NA indicates that the criterion is not applicable to that technique.

A simplified version of Tables 3-1, 3-2, and 3-3, with all techniques listed on a single page, is provided for cross-comparison in Appendix C.

Table 3-2
Qualitative evaluation of infiltration reduction techniques for minimizing leachate generation in CCR landfills

Criterion	**Infiltration Reduction Techniques**		
	Regular Cover	**Intermediate Cover**	**Final Cover**
Overall Performance			
- Effectiveness of Technique	EXCELLENT	GOOD	EXCELLENT
Ease of Implementation			
- Construction Requirements	NA	MORE THAN AVG	HIGH
- Material Availability	POOR	FAIR	POOR
- Technical Challenge	HIGH	AVERAGE	HIGH
- Specialty Skills	MORE	AVERAGE	MORE
Schedule for Installation			
- Duration of Installation	NA	MORE THAN AVG	LONG
- Complexity of Installation	NA	MORE THAN AVG	HIGH
Costs (Capital and Operational)			
- Capital Costs	NA	HIGH	HIGH
- Operational Costs	HIGH	HIGH	LOW
Operation and Maintenance			
- Repairs and Maintenance	MORE THAN AVG	MORE THAN AVG	LESS THAN AVG
- Effort to Repair/Maintain	HIGH	LESS THAN AVG	LESS THAN AVG
Expansion and/or Closure Compatibility			
- Material Requirements	LESS THAN AVG	LESS THAN AVG	HIGH
- Impact on Expansion	LOW	LESS THAN AVG	LESS THAN AVG
- Impact on Closure	NA	LOW	LOW

The ratings for each technique are qualitative and relative to all other techniques listed in Tables 3-1, 3-2, and 3-3. For example, the duration of installation for final cover is *long* relative to all of the techniques listed in Tables 3-1, 3-2, and 3-3.

NA indicates that the criterion is not applicable to that technique.

A simplified version of Tables 3-1, 3-2, and 3-3, with all techniques listed on a single page, is provided for cross-comparison in Appendix C.

Table 3-3
Qualitative evaluation of operational techniques for minimizing leachate generation in CCR landfills

Criterion	Operational Techniques		
	Working Face Minimization	**CCR Placement and Landfill Grade**	**Managing Moisture Conditioning**
Overall Performance			
- Effectiveness of Technique	EXCELLENT	AVERAGE	AVERAGE
Ease of Implementation			
- Construction Requirements	AVERAGE	NA	NA
- Material Availability	AVERAGE	NA	AVERAGE
- Technical Challenge	HIGH	AVERAGE	MORE THAN AVG
- Specialty Skills	MORE	AVERAGE	MORE THAN AVG
Schedule for Installation			
- Duration of Installation	LESS THAN AVG	NA	NA
- Complexity of Installation	MORE THAN AVG	NA	NA
Costs (Capital and Operational)			
- Capital Costs	LESS THAN AVG	NA	NA
- Operational Costs	LESS THAN AVG	AVERAGE	AVERAGE
Operation and Maintenance			
- Repairs and Maintenance	AVERAGE	NA	NA
- Effort to Repair/Maintain	AVERAGE	AVERAGE	AVERAGE
Expansion and/or Closure Compatibility			
- Material Requirements	HIGH	NA	NA
- Impact on Expansion	AVERAGE	NA	NA
- Impact on Closure	AVERAGE	NA	NA

The ratings for each technique are qualitative and relative to all other techniques listed in Tables 3-1, 3-2, and 3-3. For example, the technical challenge associated with working face minimization is *high* relative to all of the techniques listed in Tables 3-1, 3-2, and 3-3.

NA indicates that the criterion is not applicable to that technique.

A simplified version of Tables 3-1, 3-2, and 3-3, with all techniques listed on a single page, is provided for cross-comparison in Appendix C.

Overall Performance

The performance of a leachate minimization technique can depend on a number of factors. Each minimization technique reduces storm water infiltration in a slightly different manner. For example, interceptor ditches deter storm water from entering the general unit area, while rain flaps reduce the amount of storm water entering the working area of a particular cell where the CCR is currently being placed. While the technique for these two examples is similar (storm water diversion) their effects on leachate generation differ simply because of how and where they are diverting storm water.

Ease of Implementation

Construction requirements for each technique vary greatly. Some of the techniques listed have simple construction requirements (interceptor ditches), while others have complex construction requirements (final cover). Material availability is also a consideration. For example, regular use of soil cover requires significant soil stockpiles, while constructing interceptor ditches may require very little material and effort.

The technical ease of implementation for leachate minimization techniques is also a consideration. Some minimization techniques such as soil berms and interceptor ditches can be implemented without extensive engineering design. Other techniques, such as rain flaps and final cover, may require significant planning and detailed design. Minimization techniques also vary in terms of technical skill needed to implement them, and could potentially require specialists. For example, while interceptor ditches are fairly straightforward and can be constructed with little expertise and training, techniques such as final cover require working knowledge of cohesive soil properties and geosynthetics. Typically, specialty contractors are required for these types of installations.

Schedule for Installation

The duration required to install or implement the different techniques can vary considerably. Some of the techniques, such as rain flaps, can be installed as part of cell construction, while others need to be planned out as part of an overall management plan, such as working face minimization. Complexity of installation is also a factor worth considering, as discussed above in the ease of implementation section. Interceptor ditches can be implemented relatively quickly, while more complex techniques such as final cover require advance planning.

Cost

Costs for leachate minimization include both capital investments and operational expenses. Some techniques, such as final cover, have significant capital costs, while other techniques, such as regular soil cover, have high operational costs.

Operation and Maintenance

Once leachate minimization techniques have been implemented, they will require some form of operation and maintenance to maintain effectiveness. For example, erosion may occur in soil cover areas, requiring repairs. Planning for operational and maintenance issues that are unavoidable will allow these issues to be handled as they develop and prevent them from becoming larger issues that could become regulatory violations or require large construction efforts to fix.

Expansion and/or Closure Compatibility

Consideration of future activities for the landfill can facilitate efficient reuse of on-site materials, and can save significant costs of operating a CCR facility in the long run. Long-term closure planning can also be essential not only to reduce the exposed CCR at the facility but also to determine how feasible a specific minimization technique is when closure is taken into account. Also, if expansion of a facility is planned or being considered, this could have an impact on the feasibility of a leachate minimization implementation or installation technique.

Combining Leachate Minimization Techniques

The leachate minimization techniques described here can be used in conjunction with each other, either spatially or over time, to maximize their benefits. A spatial example might be a soil berm around a minimized working face to limit run-on and direct precipitation, respectively, combined with careful management of water added for moisture conditioning to limit water added with the CCR. A time example might be placement of intermediate cover over the cell where the previous spatial example was applied.

Combining minimization techniques from each of the categories (Diversionary, Infiltration Reduction, and Operational) can provide maximum protection from surface water run-on and infiltration directly impacting leachate generation, and potentially reduce water addition for dust control. The added benefits of implementing multiple techniques simultaneously from each of these categories can help overcome the potential deficiencies from using any single minimization technique.

Summary

The leachate minimization techniques discussed above can be implemented to reduce the volume of leachate generated, which in turn can reduce the operational costs associated with leachate management. This section describes and qualitatively evaluates leachate minimization methods in terms of application and benefit. The next section examines different types of leachate management systems, including storm water management, leachate collection, leachate conveyance, leachate storage, leachate disposal, and leachate treatment.

4
LEACHATE MANAGEMENT

Introduction

The leachate management system at a landfill facility typically includes components for:

- Collection
- Conveyance
- Storage
- Treatment and/or disposal

Each of these components are discussed below.

Leachate Collection

Leachate collection systems generally consist of a network of perforated pipes and a drainage layer consisting of highly permeable aggregate or a geocomposite that underlies the CCR and collects and directs leachate to the sump. A geocomposite is a synthetic geonet with a geotextile heat-bonded on one or both sides. In a typical design, the floors of landfill cells are graded to slope toward the sump (Figures 4-1 and 4-2), allowing leachate to flow to the sump by gravity drainage.

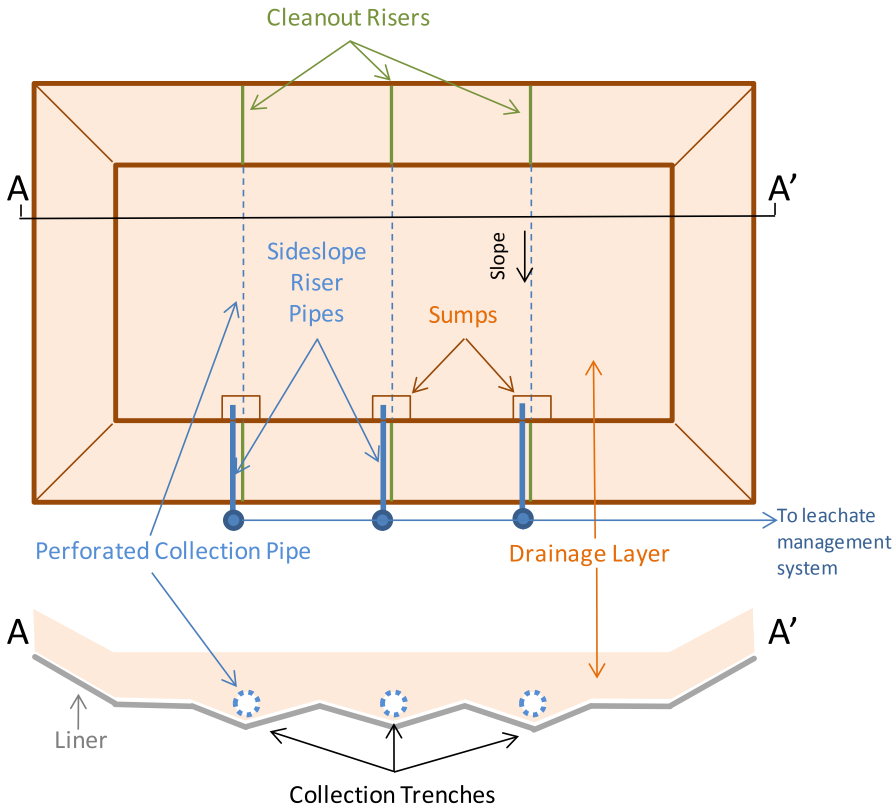


Figure 4-1
Schematic drawing showing components of a leachate collection system in plan view (top) and cross-section (bottom)—not to scale [17]

Figure 4-2
Sideslope riser pipe being installed in a leachate collection sump [17]

If the landfill designers determine that there is potential for obstruction of vertical leachate movement within the CCR, for example by horizontal layers of low-permeability intermediate cover soils, then chimney drains can be installed to facilitate vertical leachate percolation down to the leachate collection system. These drains are typically 24- to 36-inch perforated pipes set on end and filled with a drainage aggregate such as American Association of State Highway and Transportation Officials (AASHTO) #57 stone. These pipes sit directly above the horizontal collection pipes and are extended as the CCR elevations rise. Chimney drains can also be constructed of aggregate or bottom ash by dumping the aggregate in a pile in increments and placing CCR around the placed pile.

A “slope riser” pumping system with automated controls is commonly used to extract leachate from the collection sump. The pump is activated when the leachate reaches a set elevation in the sump. Leachate is then pumped up a riser pipe and into a force main that conveys the leachate.

Another method of evacuating the leachate from the sump is through a gravity drain system. The gravity drain system carries the leachate out of the cell through a penetration in the liner system to an exterior leachate extraction point. Leachate can then drain via gravity or be pumped to a leachate storage facility.

Leachate Conveyance

The leachate conveyance system starts at a pumping system or gravity drain. In the case of a pumping system, the leachate is pumped up a riser pipe from a submersible pump and into a force main. Estimation of leachate generation volume facilitates selection of a pump with appropriate capacity to maintain the permitted leachate level in the landfill, without excessive cycling, which can adversely affect the life of the pumps. Consideration of site-specific leachate management and minimization techniques also facilitates selection of proper pump size. If a gravity system is used to convey leachate from the landfill cell, gravity pipes can be installed, eliminating or reducing the need for pumps in the conveyance system. However, a gravity system is dependent on site topography, the configuration and geometry of the landfill, the depth of the leachate sump, and available space for a leachate storage area. If a gravity system is used, the penetration to drain the leachate requires careful design and construction in order to avoid leakage of leachate through the penetration to groundwater.

Leachate Storage

Leachate is stored using one of two types of systems: open or closed. Open systems consist of a leachate lagoon or series of lagoons. Lagoons are typically constructed below grade with a liner system to prevent leakage. The liner systems can be clay soil liners, geosynthetic liners, or a composite (combination of soil and geosynthetics). The liner systems are often equipped with an aggregate, concrete layer, or fabric form overlying the liner to protect it during maintenance activities. The advantage of using leachate lagoons is that they can be constructed at relatively low cost with respect to capacity. The main disadvantage to lagoons is that they are exposed to the elements, and any precipitation water that enters the lagoon mixes with leachate and therefore adds to the amount of leachate requiring management.

The closed leachate storage system uses tanks. Tanks are typically constructed above ground and can be glass-lined to reduce the potential for corrosion from the inside. The advantage of tanks over lagoons is that, because they are a closed system, they do not allow the intrusion of precipitation water. In addition, tanks typically take up less space than lagoons. The main disadvantage of storage tanks is that they are relatively expensive to build and may require complex foundation systems and secondary containment. Secondary containment can be achieved via a dual-walled tank (at significant expense) or an earthen berm that can hold leachate in the event of a spill or tank failure.

In either case of open or closed leachate storage systems, there is a finite amount of storage, and the leachate will eventually need to be treated and/or disposed of.

Leachate Disposal

Leachate disposal methods can vary greatly depending on several factors related to the landfill, including amount of leachate generated, quality of leachate, geographic location of the landfill, and proximity to CCR water treatment facilities. Disposal methods include off-site disposal, evaporation (depending on climate), and recirculation.

Off Site Disposal

If the facility is reasonably close to a wastewater treatment plant (WWTP) that can accept CCR leachate, the leachate may be conveyed to the WWTP for treatment and discharge. If conditions permit, a pump station may be installed to convey the leachate via force main and discharge directly into the WWTP sewer system. A number of variables can affect the feasibility of this option. Proximity is the primary factor. Other variables include leachate chemical characteristics, the ability of the WWTP to accept and treat the volume of leachate, and the feasibility of installing a force main that discharges into a sanitary sewer or conveys directly to the WWTP. In some cases, the power plant may already have an on-site WWTP that can treat or pretreat the leachate on site. This option has higher up-front capital costs, but may be more cost-effective than outside WWTP fees over the long run.

If a force main is not a feasible option, the leachate can be loaded into tanker trucks and hauled directly to a WWTP or other disposal facility that is licensed to accept leachate. This is generally a more expensive option than conveyance via the WWTP sewer system over the long term, and is still dependent on the receiving facility’s ability to accept and treat the leachate.

Evaporation

Depending on site conditions and climate, another option is to convey leachate to evaporation ponds where the volume of leachate can be reduced by evaporation. Evaporation ponds typically occupy a larger area than a leachate lagoon, and usually have some type of liner system. Evaporation will be greater in hot and dry climates than in cooler and/or humid climates.

Leachate Recirculation

A leachate management option that may be available, depending on state and local permitting requirements, is recirculation, which can reduce the volume of leachate requiring treatment and disposal. Two alternatives—there may be others—for use of recirculated leachate at CCR landfills are:

- Moisture conditioning: leachate can be considered in place of water to moisture-condition dry CCR to facilitate compaction to optimum density during placement. As previously noted, when fly ash and dry FGD residuals are collected from a power plant they have a moisture deficit. Leachate applied to these CCRs for moisture control will be tightly held in the pore spaces by soil tension forces, and will not be able to flow downward unless the placed fly ash is subject to sufficient precipitation to overcome the moisture deficit.

- Dust control: if leachate is used in place of water for dust control at CCR landfills, a percentage of that leachate will evaporate, thereby reducing leachate volume. Leachate that does not evaporate can further offset moisture deficits, if any, of the placed CCR. If the CCR does not have a moisture deficit, then the leachate that does not evaporate will either infiltrate through the CCR or run off the CCR surface to the leachate collection system. Either way, the recirculated leachate used for dust control does not increase the leachate volume collected from the landfill, it simply replaces another water source that would have been used for the same purpose and that would have had the same effect on leachate volume.

Leachate Treatment

Discussion regarding leachate treatment will often cover three specific leachate treatment types: biological, physical, and chemical treatment. CCR landfills do not produce leachate requiring biological treatment unless mixed with another waste stream, so physical and chemical treatment is more common, when a treatment is used. Chemical treatments may be used to control pH or the concentration of specific constituents, as described below, while physical treatments may be used to control total suspended solids (TSS). Constituents encountered in CCR leachate are inorganic, as discussed in depth in the 2006 EPRI report *Characterization of Field Leachates at Coal Combustion Product Management Sites* [19] and in the companion document to this [1].

Leachate is commonly conveyed to the nearest public or municipal WWTP to be treated and discharged. However, if public WWTPs impose limits on industrial water inflows, pretreatment may be required to bring the leachate to within the specified limits; otherwise a surcharge may be applied to compensate for the increased costs. In some cases, WWTPs may not have the capacity to treat trace elements found in CCR leachate. In these cases, on-site pretreatment facilities designed specifically for the facility’s normal leachate characteristics can be used for pretreatment as needed to reduce the concentrations of elements to acceptable levels.

Another alternative for leachate treatment at some facilities is passive treatment. This alternative utilizes wetlands engineered, constructed, and populated with plants to accomplish objectives such as reducing TSS, controlling pH, and/or uptake of specific constituents. Passive treatment is most amenable in climates that support year-round growth of vegetation that is able to achieve the design objectives. Alternative non-passive treatment can be considered for periods when vegetation is dormant. While natural wetlands can be used as a passive leachate treatment system, they are typically used only as a final treatment “polishing” measure because of their sensitivity to hydrologic and chemical loading. Engineered wetlands can be a more comprehensive leachate treatment system than natural wetlands because they can be designed to withstand heavy hydrologic or chemical load fluctuations. Again, these wetlands would be designed to target a specific facility’s leachate stream to maximize treatment effectiveness and wetland longevity.

5
REFERENCES

1. *Coal Combustion Residuals Leachate Management: Characterization of Leachate Quality*, EPRI, Palo Alto, CA: in preparation. 3002007125.
2. *"Disposal Site Economic Model for Coal Combustion Residuals Under Proposed Federal Non-Hazardous Waste Regulations,* EPRI, Palo Alto, CA: 2012. 1025378.
3. "The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3," Paul R. Schroeder, Tamsen S. Dozier, Paul A. Zappi, Bruce M. McEnroe, John W. Sjostrom, and R. Lee Peyton, Environmental Laboratory, U.S. Army Corps of Engineers.
4. "A new screening model for leachate production assessment at landfill sites," S. Pantini, I. Verginelli, and F. Lombardi, *International Journal of Environmental Science and Technology*, 2014, 11:1503-1516.
5. "An attempt to perform water balance in a Brazilian municipal solid waste landfill," Maria do Socorro Costa São Mateus, Sandro Lemos Machado, and Maria Cláudia Barbosa, *Waste Management* 32, 2012, 471-481.
6. "CCP Landfill Leachate Generation and Leachate Management," I. Kyle Baucom and Cedric H. Ruhl, 2013 World of Coal Ash (WOCA) Conference, April 22-25, 2013.
7. "Water Balance Modeling of Earthen Final Covers," Khire, Milind V. et al., *Journal of Geotechnical and Geoenvironmental Engineering*, August 1997.
8. "Alternative Cover Assessment Project Phase 1 Report," Albright, William H. et al., Desert Research Institute, October 2002.
9. "The Hydrologic Evaluation of Landfill Performance (HELP) Model, Engineering Documentation for HELP 3.95D: Enhancements beyond HELP 3.07," Klaus Berger, Institute of Soil Science, University of Hamburg, Germany, July 2012.
10. "Potential and Limitations of Applying HELP Model for Surface Covers," Klaus Berger, *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, July 2002, 192-203.
11. "MODUELO 2: A new version of an integrated simulation model for municipal solid waste landfills," *Environmental Modelling & Software*, 22, 2007, 59-72.
12. "Modelling for Environmental Assessment of Municipal Solid Waste Landfills (Part 1: Hydrology)," Lobo A., Herrero J., Montero O., Fantelli M., and Tejero I. (2002a), *Waste Management and Research*, 20(2), 198-210.
13. *Handbook of Advanced Industrial and Hazardous Wastes Treatment*, Lawrence K. Wang, Yung-Tse Hung, Nazih K. Shammas, CRC Press, 2009.

14. "Numerical Evaluation of Preferential Flow Through Evapotranspirative Landfill Covers," Thesis, Carolyn M. Hardt, Michigan State University. 2008.

15. "HYDRUS: Software for Flow and Transport Modeling in Variably Saturated Media," Yu, Ch., and Ch. Zheng, Software Spotlight, Ground Water, 48(6), 787-791, 2010.

16. "Validation of the Hydrologic Evaluation of Landfill Performance (HELP) Model for Simulating the Water Balance of Cover Systems," Klaus Berger, Environmental Geology 39 (11), October 2000, 1261-1274.

17. *State-of-the-Practice Liners and Caps for Coal Combustion Product Management Facilities*, EPRI, Palo Alto, CA: 2012. 1023741.

18. "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." J. Carlson and B. Hensel. Proceedings: 2007 World of Coal Ash, May 7-10, Northern Kentucky, USA, http://www.flyash.info/2007/120carlson.pdf.

19. *Characterization of Field Leachates at Coal Combustion Product Management Sites,* EPRI, Palo Alto, CA and U.S. Department of Energy, Pittsburg, PA: 2006. 1012578.

A
HELP MODEL INPUT VALUES

Layer Type 1: Vertical Percolation Layer		texture 2	texture 12	texture 16*	texture 17*	texture 30
HELP Description		Sand	Clay	Liner soil	Bentonite	Fly ash
Porosity	%	0.437	0.471	0.427	0.750	0.541
Field capacity	%	0.062	0.342	0.418	0.747	0.187
Wilting point	%	0.024	0.210	0.367	0.400	0.047
Hydraulic conductivity	cm/s	5.8E-03	4.2E-05	1.0E-06	1.0E-07	5.0E-05

* indicates the hydraulic conductivity is modified

Layer Type 2: Lateral Drainage Layer		texture 20
HELP Description		Drainage Net
Porosity	%	0.850
Field capacity	%	0.010
Wilting point	%	0.005
Hydraulic conductivity	cm/s	10.0
Maximum drainage length	ft	200
Drainage slope	%	2.0

Layer Type 3: Barrier Soil Layer		texture 29*
HELP Description		Clay
Porosity	%	0.451
Field capacity	%	0.419
Wilting point	%	0.332
Hydraulic conductivity	cm/s	1.0E-07

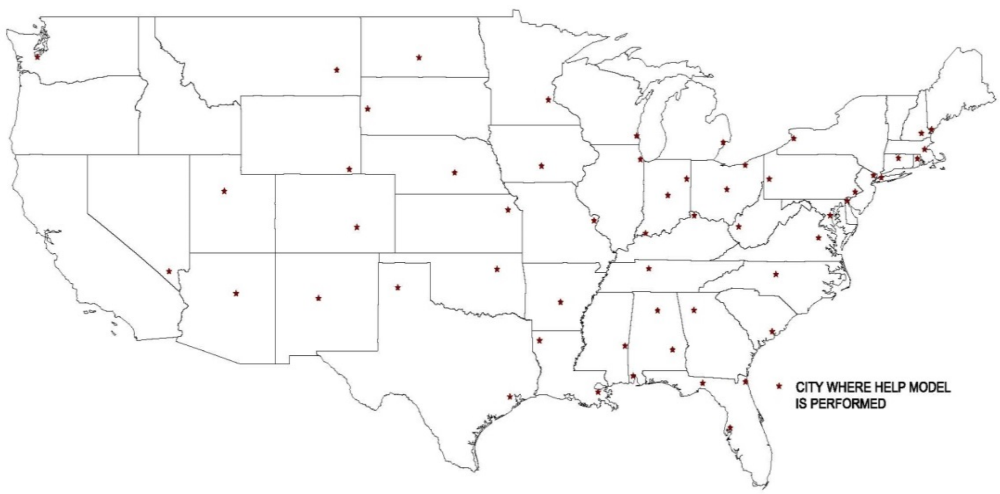
* indicates the hydraulic conductivity is modified

Layer Type 4: Geomembrane Liner		texture 35	texture 36
HELP Description		HDPE	LDPE
Hydraulic conductivity	cm/s	2.0E-13	4.0E-13
Placement quality		3-“good”	3-“good”
Installation defects/acre		4	4
Pinhole defects/acre		1	1

Parameter	Unit	Initial	Intermediate w/o Soil Cover	Intermediate	Pre-Closure	After: Clay Cap	After: Geomembrane
Soils – General							
Area	acres	1	1	1	1	1	1
% where runoff possible	%	0	0	50	100	100	100
Surface water/snow	inches	Calculated by HELP					
Soils – Runoff							
Slope	%	3	3	3	3	3	3
Length	ft	200	200	200	200	200	200
Vegetation		Bare	Bare	Fair	Fair	Fair	Fair
Vegetation Layer							
Thickness	inches	Not used	Not used	12	12	12	24
Layer Type				1	1	1	1
Texture				12	12	12	12
Cap Drainage Layer							
Thickness	inches	Not used	Not used	Not used	Not used	Not used	0.2
Layer Type							2
Texture							20
Cap Barrier Layer							
Thickness	inches	Not used	Not used	Not used	Not used	24	0.02
Layer Type						3	4
Texture						29	36
Protective							
Thickness	inches	Not used	Not used	Not used	Not used	12	12
Layer Type						1	1
Texture						12	12
CCR Layer							
Thickness	inches	120	900	900	1800	1800	1800
Layer Type		1	1	1	1	1	1
Texture		30	30	30	30	30	30
Leachate Protective Layer							
Thickness	inches	12	12	12	12	12	12
Layer Type		1	1	1	1	1	1
Texture		2	2	2	2	2	2
Leachate Collection Layer							
Thickness	inches	0.2	0.2	0.2	0.2	0.2	0.2
Layer Type		2	2	2	2	2	2
Texture		20	20	20	20	20	20
Geomembrane Liner							
Thickness	inches	0.06	0.06	0.06	0.06	0.06	0.06
Layer Type		4	4	4	4	4	4
Texture		35	35	35	35	35	35
Clay Liner							
Thickness	inches	24	24	24	24	24	24
Layer Type		1	1	1	1	1	1
Texture		17	17	17	17	17	17
Buffer layer							
Thickness	inches	60	60	60	60	60	60
Layer Type		1	1	1	1	1	1
Texture		16	16	16	16	16	16

B

CITIES WHERE DEFAULT CLIMATE DATA IN HELP WERE MODELED TO DEVELOP CLIMATE ZONES



Birmingham, AL	New Orleans, LA	Cleveland, OH
Mobile, AL	Shreveport, LA	Columbus, OH
Montgomery, AL	Boston, MA	Tulsa, OK
Little Rock, AR	Baltimore, MD	Philadelphia, PA
Flagstaff, AZ	Portland, ME	Pittsburgh, PA
Pueblo, CO	Detroit, MI	Providence, RI
Windsor Locks, CT	Minneapolis, MN	Charleston, SC
Wilmington, DE	St. Louis, MO	Rapid City, SD
Jacksonville, FL	Meridian, MS	Nashville, TN
Tallahassee, FL	Miles City, MT	Amarillo, TX
Tampa, FL	Greensboro, NC	Houston, TX
Atlanta, GA	Bismarck, ND	Salt Lake City, UT
Des Moines, IA	Grand Island, NE	Richmond, VA
Chicago, IL	Concord, NH	Olympia, WA
Evansville, IN	Newark, NJ	Milwaukee, WI
Fort Wayne, IN	Albuquerque, NM	Charleston, WV
Indianapolis, IN	Las Vegas, NV	Cheyenne, WY
Topeka, KS	Buffalo, NY	
Covington, KY	New York City, NY	

C

SIMPLIFIED MATRIX OF LEACHATE MINIMIZATION TECHNIQUES

Criterion	Diversionary Techniques			Infiltration Reduction Techniques			Operational Techniques		
	Soil Berms	Interceptor Ditches and Channels	Rain Flaps	Regular Cover	Intermediate Cover	Final Cover	Working Face Minimization	CCR Placement	Moisture Conditioning of CCR
Overall Performance									
- Effectiveness of Technique	AV	AV	GO	EX	GO	EX	EX	AV	AV
Ease of Implementation									
- Construction Requirements	AV	AV	MO	NA	MO	HI	AV	NA	NA
- Material Availability	EX	EX	AV	PO	FA	PO	AV	NA	AV
- Technical Challenge	LO	LO	LA	HI	AV	HI	HI	AV	MO
- Specialty Skills	FE	FE	LA	MO	AV	MO	MO	AV	MO
Schedule for Installation									
- Duration of Installation	AV	AV	LA	NA	MO	LG	LA	NA	NA
- Complexity of Installation	LO	LO	LA	NA	MO	HI	MO	NA	NA
Costs (Capital and Operational)									
- Capital Costs	AV	AV	MO	NA	HI	HI	LA	NA	NA
- Operational Costs	LO	LO	MO	HI	HI	LO	LA	AV	AV
Operation and Maintenance									
- Repairs and Maintenance	HI	HI	LA	MO	MO	LA	AV	NA	NA
- Effort to Repair/Maintain	AV	AV	MO	HI	LA	LA	AV	AV	AV
Expansion and/or Closure Compatibility									
- Material Requirements	LO	LO	HI	LA	LA	HI	HI	NA	NA
- Impact on Expansion	LO	LO	NA	LO	LA	LA	AV	NA	NA
- Impact on Closure	LO	LO	NA	NA	LO	LO	AV	NA	NA

Legend:

EX=EXCELLENT, LO=LOW FE=FEWER	AV=AVERAGE	PO=POOR HI=HIGH MO=MORE LG=LONG
GO=GOOD LA=LESS THAN AVERAGE	NA=NOT APPLICABLE	FA=FAIR MA=MORE THAN AVERAGE

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together...Shaping the Future of Electricity

Program:

Coal Combustion Products - Environmental Issues

3002006283

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com