A Method for Predicting CCR Landfill Leachate Generation Volume

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ABSTRACT

Coal Combustion Residual (CCR) landfill leachate is often treated at on-site CCR surface impoundments. Federal and state regulations are driving owners to close these impoundments, requiring more costly alternative leachate treatment methods. The volume of leachate generated influences the treatment cost; therefore, accurate leachate generation volume estimates are essential for developing a useful cost-benefit analysis to compare leachate treatment alternatives. The author developed a method to estimate leachate generation volume across the landfill life cycle. The author used this method to estimate leachate generation volume and compared to measured leachate generation volume at several landfill facilities in the southeastern United States.

BACKGROUND

The estimated volume of leachate generated over a CCR landfill life cycle can be estimated by establishing the following relationships:

2. Develop a relationship between landfill surface area and landfill volume.
3. Develop a relationship between landfill volume and waste mass.
4. Develop a relationship between waste mass and time (waste generation rate).

The leachate generation volume is calculated at a user-defined time step (i.e. monthly) and totalized to obtain a cumulative leachate generation volume. The four relationships were calculated for three landfills in the southeastern United States and compared to measured leachate generation volume for the three landfills.
METHOD FOR ESTIMATING LEACHATE GENERATION VOLUME

As previously described, leachate generation volume can be estimated by developing the following relationships:

2. Develop a relationship between landfill surface area and landfill volume.
3. Develop a relationship between landfill volume and waste mass.
4. Develop a relationship between waste mass and time (waste generation rate).

Each relationship is described in further detail as follows.

**Relationship 1: Develop an Equation-Based Relationship Between Leachate Generation and Landfill Height**

The leachate generation rate can be estimated for discrete elevations in the landfill life cycle by using a commercially available computer program such as the Hydrologic Evaluation of Landfill Performance (HELP) software. HELP software accounts for many factors including geographic region (rainfall), permeability of waste, and waste height. HELP calculates both estimated runoff from the active face of the landfill, and seepage through the waste mass. Runoff from the active face of the landfill cannot be discharged to the environment and should be treated as leachate.

HELP software can be used to evaluate runoff and seepage at discrete landfill heights such as newly open landfill conditions (waste height near 0), during landfill operations (waste height near the mid-point of landfill buildout conditions), just prior to landfill closure (waste height equal to buildout conditions), and after landfill closure. The output for each scenario is provided in terms of gallons per acre per day (gpad).

These discrete points can be plotted graphically where leachate generation rate (gpad) is shown on the y-axis and landfill height (feet) is shown on the x-axis. Best-fit curves can then be generated for percolation and runoff such that the estimated percolation and runoff generation rate can be calculated for a given landfill height.

The result of Relationship 1 are two equations; one equation calculates percolation rate (gpad) for a given waste height and the other equation calculates runoff generation (gpad) for a given waste height.

**Relationship 2: Develop a Relationship Between Landfill Surface Area and Landfill Volume**
The equations developed in Relationship 1 are unit generation rates (gpad) and need to be multiplied by a surface area (acres) to calculate a true generation rate (gallons/day). The percolation rate is multiplied by the landfill limit of waste which remains constant for a given landfill cell. The runoff rate is multiplied by the active face of the landfill. The active face of the landfill is equal to the limit of waste immediately after landfill construction and decreases in surface area during landfill operations.

The relationship between landfill surface area and landfill volume can be estimated by developing a stage-storage curve for the landfill. The stage-storage curve can be developed based on design data if available. Alternatively, the landfill can be assumed to approximate the volume of a pyramid with a square base. Geometric relationships between base area and landfill sideslope can be used to calculate the area of the active face and landfill volume for a given landfill height.

The pyramid method gets complicated when there is more than one cell or phase due to piggy-back effects. Also, the pyramid method is most applicable to landfills with a relatively flat base and relatively low volume below the limit of waste elevation.

The result of Relationship 2 is the landfill base area for use in calculating percolation volume and a relationship between active face area, landfill volume, and landfill height for use in calculating runoff volume.

**Relationship 3: Develop a Relationship Between Landfill Volume and Waste Mass**

The relationship between landfill volume and active face developed in Relationship 2 is useful; however, waste is often tracked in terms of mass instead of volume. The airspace utilization factor (AUF) can be used to convert between landfill volume and waste mass. The AUF is different than the unit weight of the waste because the AUF includes non-waste materials such as daily and interim cover as part of the volume.

The result of Relationship 3 is a mechanism to convert between tonnage of waste disposed and landfill volume.

**Relationship 4: Develop a Relationship Between Waste Mass and Time**

The relationship between waste mass and time is the waste generation rate.

**Using the Four Relationships to Estimate Leachate Generation Volume**

The four relationships can be used to estimate the leachate generation volume by using the following procedure for each user-defined time step:

1. Use Relationship 4 to define the waste generation (waste mass)
2. Use Relationship 3 to convert to volume by dividing waste mass by the AUF (waste volume)
3. Use Relationship 2 to determine the waste height based on the volume and use the waste height to calculate the area of the active face (active face area)
4. Use Relationship 1 to evaluate the quantity of runoff and percolation at that time step's landfill elevation (runoff volume, percolation volume)

The incremental volume of runoff and percolation can be totalized for each time step to estimate cumulative leachate generation.

COMPARISON OF ESTIMATED LEACHATE GENERATION VOLUME TO MEASURED LEACHATE GENERATION VOLUME

The four relationships were used to calculate leachate generation volume for three landfills in the southeastern United States. The calculated leachate generation volume was compared to measured leachate generation volume.

Site 1

Site 1 is a lined CCR landfill in the southeastern United States. Landfill Cell 1 has a footprint of 10.7 acres and began operations in the fourth quarter of 2009. Landfill Cell 2 has a footprint of 12.8 acres and began operations in the fourth quarter of 2011. HELP software was used to develop an equation-based relationship between percolation, runoff, and landfill height as shown in the following figure:
Geometric relationships were used to evaluate the height of the landfill for the tonnage of waste placed as shown in the following figure:

The cumulative leachate generation volume was then compared to the measured leachate generation volume as shown in the following figure:
The accuracy of the method can be quantified by dividing the estimated cumulative volume by the measured cumulative volume. A value of 1 indicates a perfect correlation (i.e. calculated leachate volume equals measured leachate volume). Values less than 1 indicate that the method underpredicts leachate volume, values greater than 1 indicate that the method overpredicts leachate volume. The method’s accuracy can be observed in the following figure:
The method overpredicted leachate generation by a factor of approximately 2 before converging on an overprediction of leachate volume by approximately 5 percent after 8 years.

**Site 2**

Site 2 is a lined CCR landfill in the southeastern United States. Landfill Cells 1 and 2 have respective footprints of 9.9 acres and 9.6 acres, and began operations in the first quarter of 2011.

HELP software was used to develop an equation-based relationship between percolation, runoff, and landfill height as shown in the following figure:
Geometric relationships were used to evaluate the height of the landfill for the tonnage of waste placed as shown in the following figure:

The cumulative leachate generation volume was then compared to the measured leachate generation volume as shown in the following figure:
The method's accuracy can be observed in the following figure:
The method overpredicted leachate generation by approximately 35 percent before converging on an underprediction of leachate volume by approximately 4 percent after 7 years.

**Site 3**

Site 3 is a lined CCR landfill in the southeastern United States. The landfill has one 31-acre phase and began operations in the fourth quarter of 2014. Site 3 is a zero liquid discharge facility.

HELP software was used to develop an equation-based relationship between percolation, runoff, and landfill height as shown in the following figure:

![Site 3 Percolation and Runoff from HELP Model Results](image)

Geometric relationships were used to evaluate the height of the landfill for the tonnage of waste placed as shown in the following figure:
The cumulative leachate generation volume was then compared to the measured leachate generation volume as shown in the following figure:

The method's accuracy can be observed in the following figure:
The method overpredicted leachate generation by a factor of approximately 2 before converging on an overprediction of leachate volume by approximately 2 percent after 3 years.

CONCLUSIONS

The method predicted cumulative leachate generation volume with an accuracy of plus or minus 5 percent at the end of the study period for the three sites and timeframes considered. The model for these three sites could be updated as additional information becomes available. The method should be applied to a larger population of sites to further evaluate its accuracy under a wider range of landfill locations, configurations, and life cycles.