Appendix C

Hydrodynamic Modeling of Leachate Recirculating Landfills

Philip T. McCreanor and Debra R. Reinhart

Civil and Environmental Engineering Department, University of Central Florida,
P.O. Box 162450, Orlando, Florida 32816-2450

Abstract

Leachate recirculation is an emerging technology for the enhanced stabilization of active landfills and in situ treatment of problematic landfills. A variety of researcher have documented the benefits of increasing landfill moisture content and liquid movement through the fill. However, little work has addressed the hydrodynamic characteristics of the recirculating landfill, specifically the effect of leachate flow rate and waste characteristics upon leachate routing. This paper presents the results of mathematical modeling of the horizontal infiltration trench and vertical infiltration well, two commonly employed leachate application methods. From transient modeling, it was found that the vertical well is inefficient at wetting the upper portion of thelandfill while the horizontal trench was less effective at wetting the lower portion of the fill, suggesting a combination of the two devices would be the most efficient means of recirculating leachate.

Keywords

Leachate, recirculation, hydrodynamics, modeling, infiltration trench, infiltration well, impact area.

Introduction

The contamination of groundwater by landfill leachates has been recognized by a variety of researchers (Reinhard, *et al*, 1984; Schultz and Kjeldsen, 1986; Sawney and Kozloski, 1984). Organic chemicals found in 58 municipal and industrial landfill leachates represented a broad range of chemicals with significant genotoxic potential (Brown and Donnelly, 1988). Some 22 percent of the sites placed on the US National Priority List for hazardous waste site cleanup are closed municipal landfills (Repa, 1988). Groundwater is the primary contaminant release route at these sites. Remediation at problematic landfill sites is generally accomplished using source containment (usually via capping) along with groundwater pump and treat systems. It is widely recognized, however, that without source removal, pump and treat techniques merely prevent plume migration and generally cannot provide complete, long-term site restoration.

Leachate recirculation, an innovative remediation technique, has been proposed at two problematic municipal landfill sites, including one superfund site (Harper, 1993; Harper, 1995). Leachate recirculation involves the return of moisture emanating from an active or closed site to the landfill. Recirculation provides a means of optimizing environmental conditions within the landfill to provide enhanced stabilization of landfill contents as well as treatment of moisture moving through the fill. Leachate recirculation has application both to active landfill sites, providing a means of leachate management and accelerated stabilization of waste; as well as to problematic sites, where plume containment, in situ groundwater treatment, and source reduction can be simultaneously accomplished. Leachate recirculation is discussed in more detail elsewhere (Pohland, 1995).

Implementation of leachate recirculation requires an understanding of the effect of leachate recirculation on microbially mediated processes and reactions and of the hydrodynamics of leachate flow within a landfill, including moisture distribution, effects on leachate collection systems, and optimum operating strategy. While full-scale data are slowly becoming available, a more thorough consideration of the many parameters impacting the technology necessitates use of a mathematical model.

This paper presents the results of transient, unsaturated flow modeling of two commonly employed leachate recirculation devices; the vertical leachate infiltration well and the horizontal infiltration trench. These methodologies were selected based on their widespread use and their compatibility with the final closure of the landfill. The horizontal infiltration trench is generally constructed as shown in Figure C-1. A perforated PVC pipe is surrounded by gravel or tire chips. In order to prevent the migration of the gravel or tire chips and to maintain the trench integrity, a geotextile or sand layer often bounds the trench. To inhibit the upward flow of leachate, a clay layer or prefabricated vertical infiltrator may top the trench.

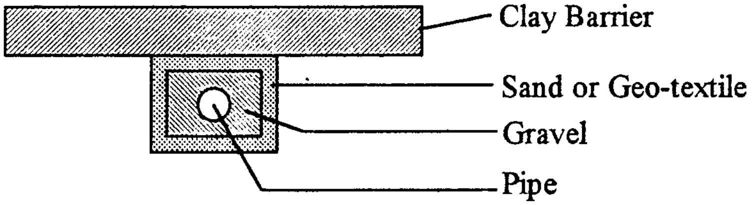


Figure C-1. Horizontal leachate infiltration trench.

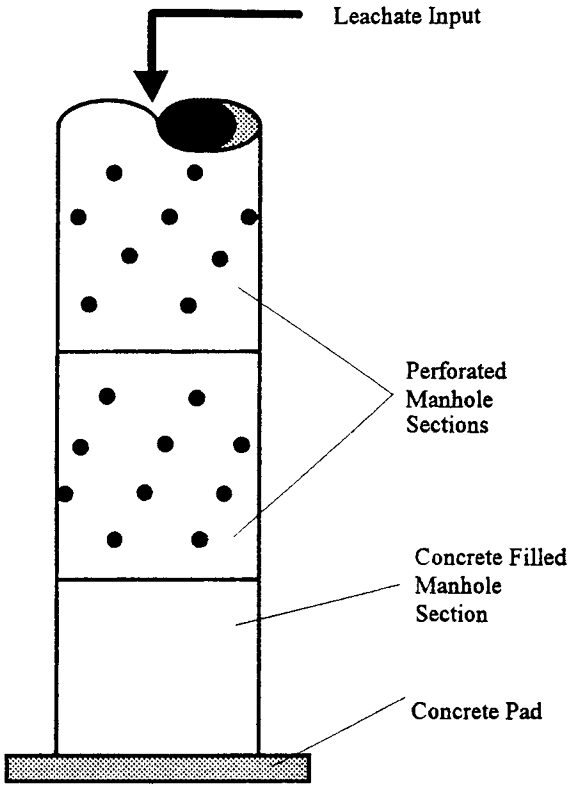


Figure C-2. Vertical leachate recirculation well.

The vertical infiltration well (Figure C-2) is composed of a series of gravel-filled perforated manhole sections which are stacked on top of a concrete-filled manhole section. The entire structure is placed on a concrete pad for stability. The vertical infiltration well is generally operated in a fill and drain manner. A single well is filled to capacity permitted to drain. Then the filling operation moves to the next well which is in turn filled to capacity, and so forth.

Methodology

A United States Geological Survey (USGS) model for Saturated and Unsaturated flow and TRAnsport, SUTRA (Voss, 1984, Voss, 1991), was used to model the recirculating landfill. SUTRA uses a two-dimensional hybrid finite element and integrated finite difference method to approximate the governing equations of flow and transport. SUTRA is capable of performing steady-state and non steady-state simulations. Modeling proceeded in two phases; steady-state modeling to perform an initial screening of SUTRA capabilities and to identify further data requirements, and transient modeling following extensive modifications to SUTRA.

The primary inputs to SUTRA are the physical characteristics of both the solid matrix and fluid, porosity, permeability, dispersivity, and the unsaturated flow characteristics. Porosity is input on a node-wise basis while permeability and dispersivity are input by element. The basis of the SUTRA simulation is a mesh of nodes in cartesian coordinates which are then connected to form quadrilateral elements. In addition, the impact of waste heterogeneity and gas production on fluid flow are under consideration. Output from the model provides degree of saturation (volume of water/volume of voids), fluid mass budgets, and depth of the head on the landfill liner as a function of the rate of leachate introduction and location of recirculation device(s).

The power equations (Equations C-1a and C-1b) proposed by Korfiatis, et al (1984) were used to model the unsaturated characteristics of the waste matrix. Korfiatis determined the saturated suction head to be 6 cm of water for municipal solid waste. The Brooks and Corey equations with appropriate parameters were used to model the sand and gravel components of the model (Lappala, et al, 1987).

$$k_r = \left(\frac{h}{h_S}\right)^{-2.75} \tag{C-1a}$$

$$\theta = \left(\frac{h}{h_S}\right)^{4} \tag{C-1b}$$

where:

k_r = relative hydraulic conductivity, unitless
θ = volumetric moisture content, wet basis, V/V
h_S = saturation suction pressure, $ML^{-1}T^{-2}$
h = suction pressure, $ML^{-1}T^{-2}$

During exploratory steady state modeling it was determined that SUTRA required several modifications in order to be capable of transient modeling of leachate recirculation. Programming changes included:

- adding a pressure-based variable removal boundary condition,
- adding unsaturated relationships more appropriate to modeling solid waste,
- reformatting output routines and files, and
- recompiling the code for use on UNIX systems.

These changes were directed at easing data analysis, enabling transient simulations of leachate recirculation components including the leachate collection system, and allowing the direct use of commonly accepted equations for unsaturated relationships in solid waste.

The modeling of the infiltration trench consisted of placing discrete fluid sources directly within the waste matrix (see Figure C-1). The gravel/tire chip and geo-textile materials commonly used within the trench were not modeled due to dimensionality constraints and to simplify the construction of the required input files. The recirculation rates modeled were 2.0, 4.0, 6.0, and

8.0 m^3/day/m of trench which bracket reported operating ranges of horizontal infiltration trenches (Miller, et al., 1993). Transient simulations of single and multiple horizontal injection lines have been conducted for a conductivity of 10^{-3} cm/s and a landfill depth of 15 m.

The modeling of the vertical infiltration well (see Figure C-2) consisted of using a radial coordinate system and placing a series of fluid sources vertically from a level of 2 m to 13 m, discharging directly into the waste. Simulation of recirculation rates of 0.20, 0.40, and 0.80 m^3/day at a hydraulic conductivity of 10^{-3} cm/s and a landfill depth of 15 m were conducted. It was also necessary to model the effect of increasing fluid pressure with depth within the well on discharge rate. This was accomplished by using "stepped" nodal fluxes as shown in Figure C-3.

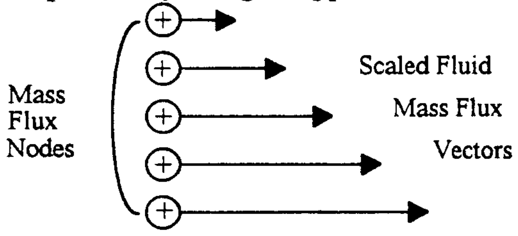


Figure C-3. Simplified example of flux nodes which simulate the vertical well.

The intent of the stepped approach shown in Figure C-3 was to simulate the effect of the variation of discharge velocities with depth along the well. First, an incremental flux unit was calculated as shown in Equation C-2.

$$q' = \frac{q}{\sum_{i=1}^{n} i} \qquad \text{(C-2)}$$

where:

q' = incremental flux unit, MT^{-1}
q = total flow to well, MT^{-1}
n = the number of nodes used to simulate the well flow
i = integer

Then the well discharge nodes were numbered from the top down beginning with one. The individual nodal discharges were calculated as in Equation C-3.

$$q_m = m \cdot q' \qquad \text{(C-3)}$$

where:

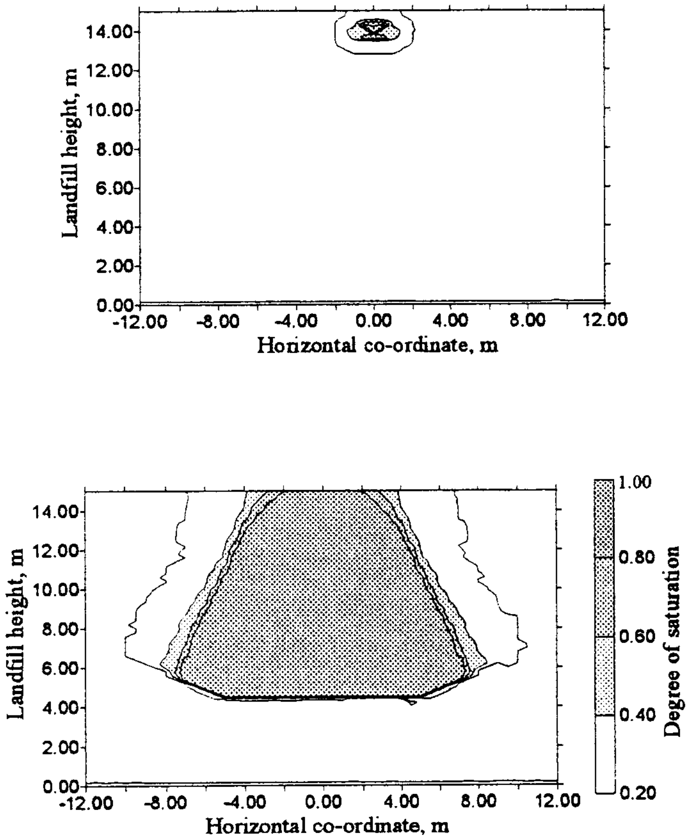
q_m = fluid flux at node 'm', MT^{-1}
q' = incremental flux unit, MT^{-1}
m = node number, unitless integer

For the case illustrated in Figure C-2, n is equal to 5 and then q' is equal to q/15, the uppermost node is numbered 1, the middle node is numbered 3 and the lowest node is number 5. The nodal fluxes are then:

$$q_1 = 1 \cdot q' = q/15,$$
$$q_3 = 3 \cdot q' = q/5, \text{ and}$$
$$q_5 = 5 \cdot q' = q/3.$$

Results

Degree of saturation iso-clines for the horizontal trench recirculating leachate at rates of 2.0 and 8.0 m^3/day/m of trench are depicted in Figures C-4a and C-4b respectively. Influence distance as a function of flow rate has been plotted in Figure C-5. The influence distance was defined as the lateral distance from the trench to which the saturation had been increased above the initial condition



(a) (b)

Figure C-4. Saturation profiles for horizontal trenches recirculating 2.0 and 8.0 m^3/day/m.

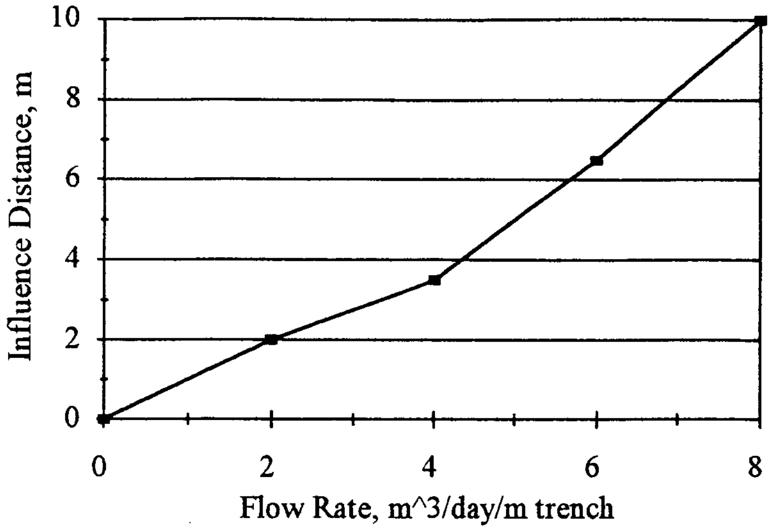
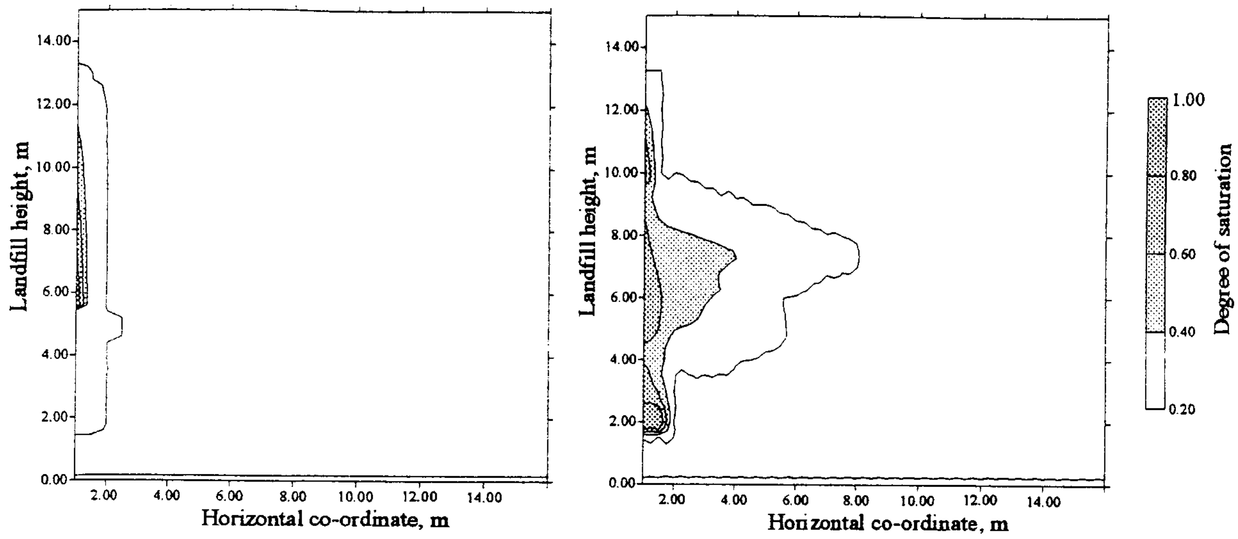


Figure C-5. Horizontal infiltration trench influence distance as a function of flow rate (single injection line results, transient conditions).

The degree of saturation iso-clines suggest that flow rates of 6.0 and 8.0 m^3/day/m trench result in the upward propagation of a saturated front and artesian conditions at the landfill surface. The influence distances in Figure C-5 should be used as guideline particularly when placing horizontal trenches near the landfill surface and boundaries. The influence distance may be doubled to determine trench spacing requirements.

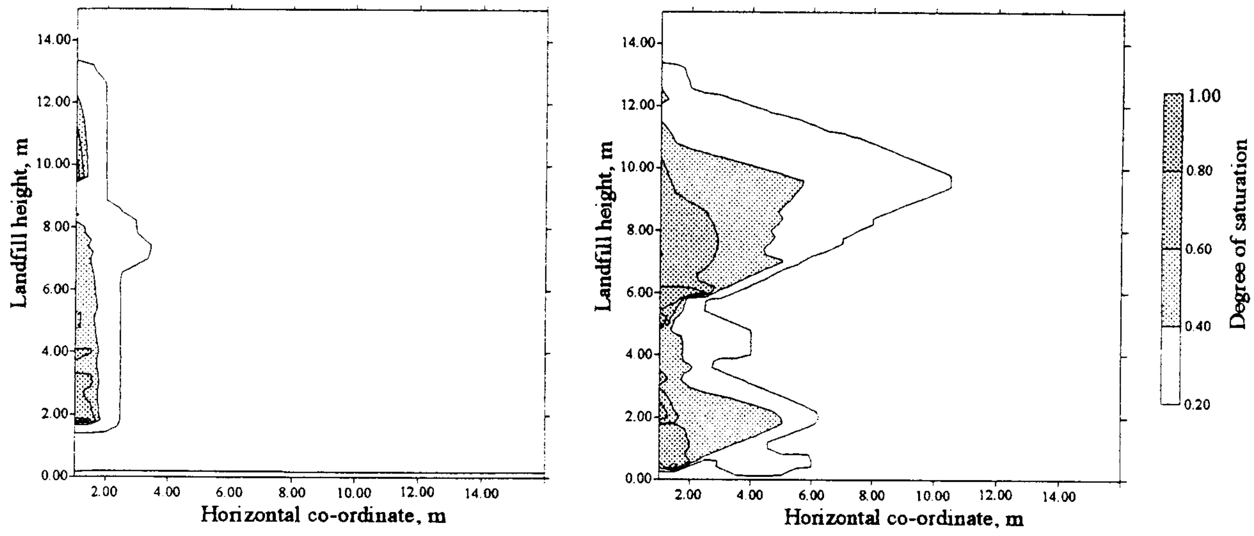
Two sets of simulations were conducted to assess the effect of trench spacing upon the degree of saturation profiles. The first set of simulations spaced the trenches at twice the influence distances noted in Figure C-5. In these simulations, a uniform wetting front developed approximately one meter beneath the injection level. In the second set of simulations, the trenches were spaced at 1 to 1.5 times the influence distances in Figure C-5. In these simulations, saturated conditions developed quickly above and below the injection level resulting in artesian conditions at the surface.

The vertical well was modeled at flow rates of 0.20, 0.40, and 0.80 m^3/day at a hydraulic conductivity of 10^{-3} cm/s for elapsed times of up to 44 days. The development of degree of saturation iso-clines for flow rates of 0.20 and 0.40 m^3/day are shown in Figures C-6 and C-7 respectively. It can be seen from Figures C-6 and C-7 that the leachate will initially show preferential flow along the well surface. Such flow may contribute to the localized subsidence around the wells at full-scale sites. Higher saturations (>0.6) will initially develop along the well surface and slowly begin to propagate laterally and vertically as leachate attempts to percolate downward more quickly than it can be conveyed by the waste matrix.



(a) (b)

Figure C-6. Saturation iso-clines at 22 days and 44 days, vertical well recirculating 0.20 m^3/day.



(a) (b)

Figure C-7. Saturation iso-clines at 22 days and 44 days, vertical well recirculating 0.40 m^3/day.

Summary and Conclusions

It must be recognized that the results presented herein are fairly idealized depiction of leachate recirculation operations. Leachate recirculation will be practiced on a periodic basis, waste is extremely heterogeneous, and waste characteristics change with time. However, this is the first attempt to model the routing of leachate through the waste using unsaturated conditions and provides important information for the design and operation of the leachate recirculating landfill.

The influence distances for both the trench and well are a direct function of the recirculation rate. The higher the recirculation rate, the greater the influence distance. However, increasing the recirculation rate may require injection under pressure and may result in leachate seeps, particularly in the case of the trench. The degree of saturation iso-clines for the horizontal trench suggest that insufficient spacing of trenches or over-pumping can result in vertical leachate seeps, and possibly artesian conditions. From these results, it is apparent that injection lines should be conservatively distanced from the landfill surface, boundaries, and each other. Figure C-5 can be used as a guideline when installing horizontal trenches.

The vertical well was inefficient at wetting the upper portion of the landfill while the horizontal trench was less effective at wetting the lower portion of the fill, except at high flow rates. A combined system would then deliver the most uniform wetting of the waste with the well impacting the lower portion and the trench impacting the upper portion.

References

Brown, K.W. and K.C. Donnelly (1988) "An Estimation of the Risk Associated with the Organic Constituents of Hazardous and Municipal Waste Landfill Leachates", Journal of Hazardous Wastes and Hazardous Materials, 5(1), 3.

Harper, S.R. (1995) "Design Elements Associated with leachate Recirculation at Existing, Unlined Landfills," Proceedings of the Seminar on Landfill Bioreactor Design and Operation Proceedings, Wilmington, DE, 45 - 64.

Harper, S.R. (August 2-5, 1993) "Design Elements Associated with Leachate Recirculation at New and Existing Landfills," presented at the SWANA's 31st Annual International Solid Waste Exposition, San Jose, California.

Korfiatis, G.P., et al. (1984) "Moisture Transport in a Solid Waste Column," J. of Env. Eng., 110(4), 780.

Lappala, E.G., et al. (1987), Documentation of Computer Program VS2D to Solve the Equations of Fluid Flow in Variably Saturated Porous Media, Water-Resources Investigations Report 83-4009, U.S. Geological Survey.

Miller, Lamar, et al. (1993) "Leachate Recycle and the Augmentation of Biological Decomposition at Municipal Solid Waste Landfills," presented at the FCSHWM First Annual Research Symposium, Orlando, Florida.

Pohland, F.D. (1995) "Landfill Bioreactors: Historical Perspective, Fundamental Principles, and New Horizons in Design and Operations," Proceedings of the Seminar on Landfill Bioreactor Design and Operation Proceedings, Wilmington, DE, 10 - 28.

Reinhard, M., *et al* (1984) "Occurrence and Distribution of Organic Chemicals in Two Landfill Leachate Plumes", Environmental Science and Technology, 18(2), 953.

Repa, E.W. (1988) "A Look at Superfund's' Municipal Landfills", Waste Age, 19(5), 86.

Sawney, B.L. and R.P. Kozloski (1984) "Organic Pollutants in Leachates from Landfill Sites", Journal of Environmental Quality, 13(3), 349.

Schultz, B. and P. Kjeldsen (1986) "Screening of Organic Matter in Leachate from Sanitary Landfills Using Gas Chromatography Combined with Mass Spectrometry", Water Research, 20(8), 965.

Voss, Clifford I. (1984), SUTRA, Saturated-Unsaturated Transport, A Finite-Element Simulation Model for Saturated-Unsaturated, Fluid-Density Dependent Ground-Water flow with Energy Transport or Chemically Reactive Single-Species Solute Transport, U.S. Geological Survey, national Center, Reston, Va.

Voss, Clifford I. (1991), SUTRA-SUTRA Plot - IGWMC - FOS 27 EXT, International Ground Water Modeling Center.