# INVESTIGATING THE INTERIOR OF A LANDFILL CELL WITH LEACHATE INJECTION USING ELECTROMAGNETIC CONDUCTIVITY AND GROUND-PENETRATING RADAR SURVEYS

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## Abstract

Bioreactor landfills enhance waste degradation through recirculation of leachate inside the waste mass. In this study frequency-domain electromagnetic (EM) conductivity was measured along several profile lines before and after leachate injection at a leachate recirculation cell at the Veolia ES Orchard Hills Landfill, 15 km south of Rockford, Illinois. One profile line was located above and coincident with a leachate recirculation line (LRL). The other profiles were perpendicular to LRLs, which varied in depth from 5-15 m below the EM lines. Apparent conductivity increased along segments of the EM profile over the LRL during injection of 17.8 $m^3$ of leachate, when measured with a Geonics EM34 at 10 and 20 m vertical dipole separations. Leachate injection appears to be non-uniform along the LRL, with larger volumes entering the waste at the beginning, middle and ends. EM values during a second experiment, however, in which a smaller leachate volume was injected, showed no change. Ground-penetrating radar (GPR) profiles, made with 25 and 50 MHz antennas, showed diffractions at the position of the LRLs (between 5 and 10 m depth) and a very strong reflector (intermediate clay cover layer or pooled leachate) at about 8-9 m depth, whereas a 100 MHz GPR profile only showed the clay cap and top of waste at approximately 2.5 m depth.

## Introduction

This study was conducted over a municipal solid waste cell at the Veolia ES Orchard Hills Landfill, Ogle County, Illinois, approximately 15 km south of Rockford, Illinois. This cell was designed for leachate recirculation using horizontal LRLs which were installed as waste was emplaced. The LRLs consist of a 15 cm diameter perforated pipe surrounded by a trench, at least 0.6 m wide by 0.6 m thick, filled with aggregate. The leachate recirculation enhances waste degradation. Figure 1 shows the landfill cell. Leachate enters LRL28 and LRL29 along the east side of the line. The leachate is electrically conductive: a value of 768 mS/m was measured in the laboratory at room temperature during the geophysical experiments. During the first electrical resistivity tomography (ERT) surveys at this site the average waste resistivity was 10-50 ohm-m (conductivity 20-100 mS/m). Thus, both ERT and EM surveys have the potential to identify leachate accumulations in the subsurface, and assess the infiltration of leachate into the refuse. Figures 2 and 3 show profiles along which the ERT and EM data were obtained. EM surveys were made along the upstream, downstream and alongstream lines, as well as along additional lines crossing the LRLs. Surveys over the downstream line were discontinued after May, 2006, due to time limitations and the unlikely detection of leachate along this line since it was located west of the perforated interval of LRL29. Results of the ERT experiments are summarized in another publication (Grellier et al., 2007), so only results of the EM and GPR surveys are presented here.

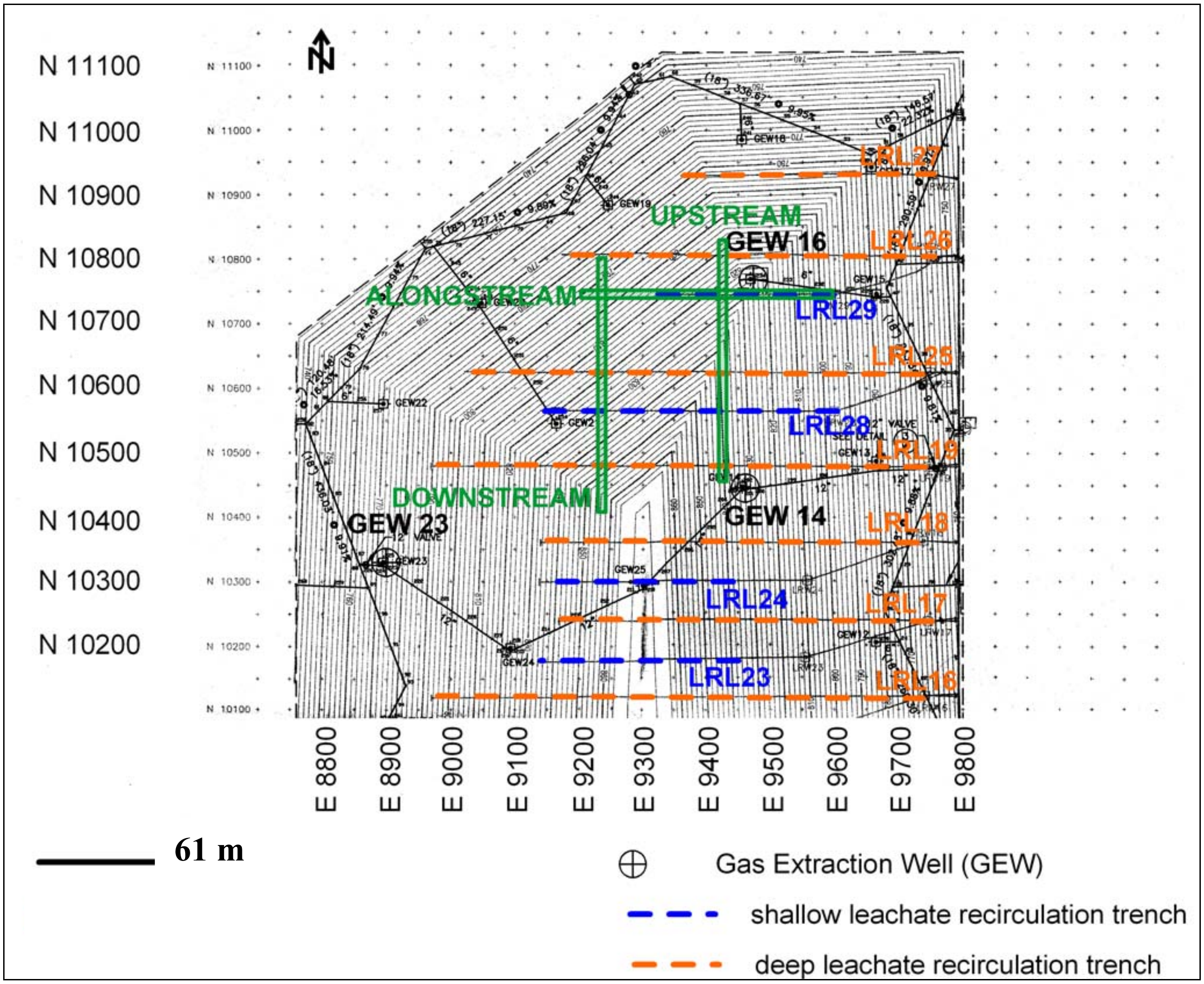


**Figure 1**: Map of the leachate recirculation cell at the Veolia ES Orchard Hills Landfill.

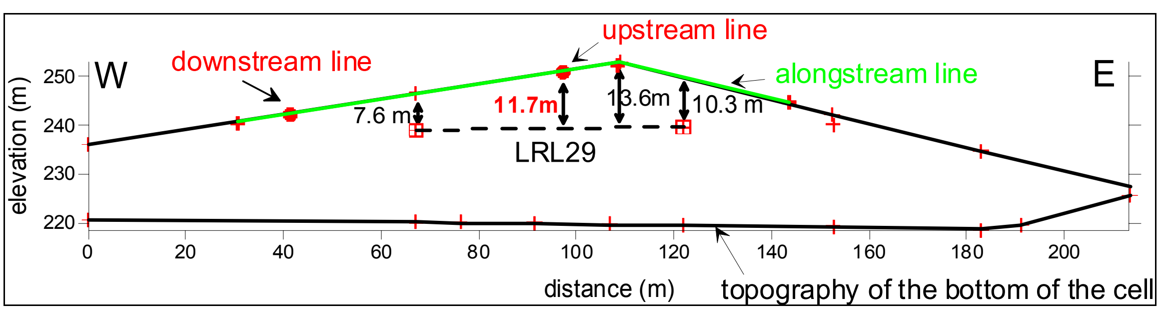


**Figure 2:** Cross-section showing perforated portion of LRL29 (dashed line), alongstream, upstream and downstream lines.

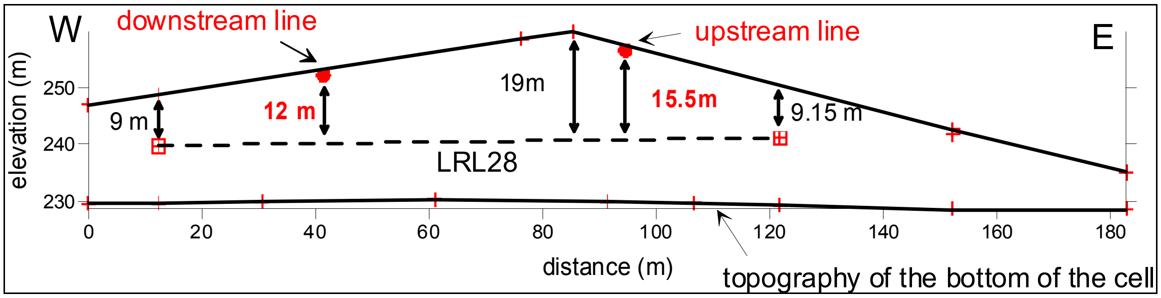


**Figure 3:** Cross-section showing perforated portion of LRL28 (dashed line), upstream and downstream lines.

## EM Surveys

Frequency-domain EM conductivity measurements were made along the upstream and alongstream lines, as well as some shorter crosslines, using the Geonics EM31 and EM34. The EM31 allows very rapid measurements to be made by one observer (one full line was acquired in about 20 min) but the maximum investigation depth was only about 2.8 m for the horizontal dipole (HD) and 5.7 m for the vertical diplole (VD) orientations (McNeill, 1980). The EM34 is a dual coil instrument requiring at least two operators. The EM34 has a maximum investigation depth of 7.5 to 30 m according the configuration and coil spacing (10 or 20 m respectively [McNeill, 1980]). One line was acquired in about 40 min.

Surveys with the EM31 failed to show any conductivity changes associated with leachate injection, probably due to the shallow response depth relative to the depth of the LRLs. Conductivities measured with the Geonics EM34, however, did show significant changes after leachate injection during one experiment in which 17.8 $m^3$ of leachate was injected over 6 hours. These results could not be replicated in earlier or later experiments, however, when smaller volumes of leachate were injected. Measurements before the beginning of the recirculation constitute the reference. Measurements were then repeated after recirculation (i.e. leachate injection) started. The EM34 HD orientation with a coil spacing of 10 m has a maximum penetration depth of 7.5 m, and should not see below the LRLs (except at the edges of LRL29), contrary to the VD orientation with a maximum investigation depth of 15 m. With a coil spacing of 20 m, both dipoles should see deep enough to map the LRLs and any leachate that accumulates adjacent to them.

The negative recorded conductivities have been removed from the data and a 3-point moving average applied to reduce the data noise. Negative conductivities are most likely caused by the presence of buried metal, producing a high induction number in the vicinity of the transmitter and receiver. Field observations suggest scatter in the data is primarily caused by coil misalignment along the sides of the landfill. This is particularly evident in the VD measurements, where coils were at different elevations, non-horizontal, and, in some cases, non-coplanar. Thus a 3-point moving average filter was used to reduce these variations, without over-smoothing the data. The 3-point moving average filter is essentially a "low-pass" filter that allows long-wavelength variations but removes short-wavelength variations.

### *Alongstream Line*

Approximately 17.8 $m^3$ of leachate was injected along LRL29 during an experiment on June 1-2, 2006. Apparent conductivity measurements were made both before and after leachate injection began (referred to as "ref" and "post," respectively, on the figures). Leachate injection along LRL29 appears to have little effect on the HD conductivity measurements, as shown in Figure 4. However, apparent conductivities obtained with the VD orientation change significantly after the start of leachate injection, as shown in Figures 5 and 6. For the 10 m coil spacing (with a maximum investigation depth of 15 m) a post-injection conductivity increase starts just at the beginning of the perforated interval and extends westward about 20 m. A zone of elevated conductivity is also present in the middle of the perforated interval. For the 20 m VD orientation (with a maximum investigation depth of 30 m) the conductivity increase also starts near the east end of the perforated interval. A second zone of post-injection increased apparent conductivity occurs near the west end of the perforated interval (Figure 6).

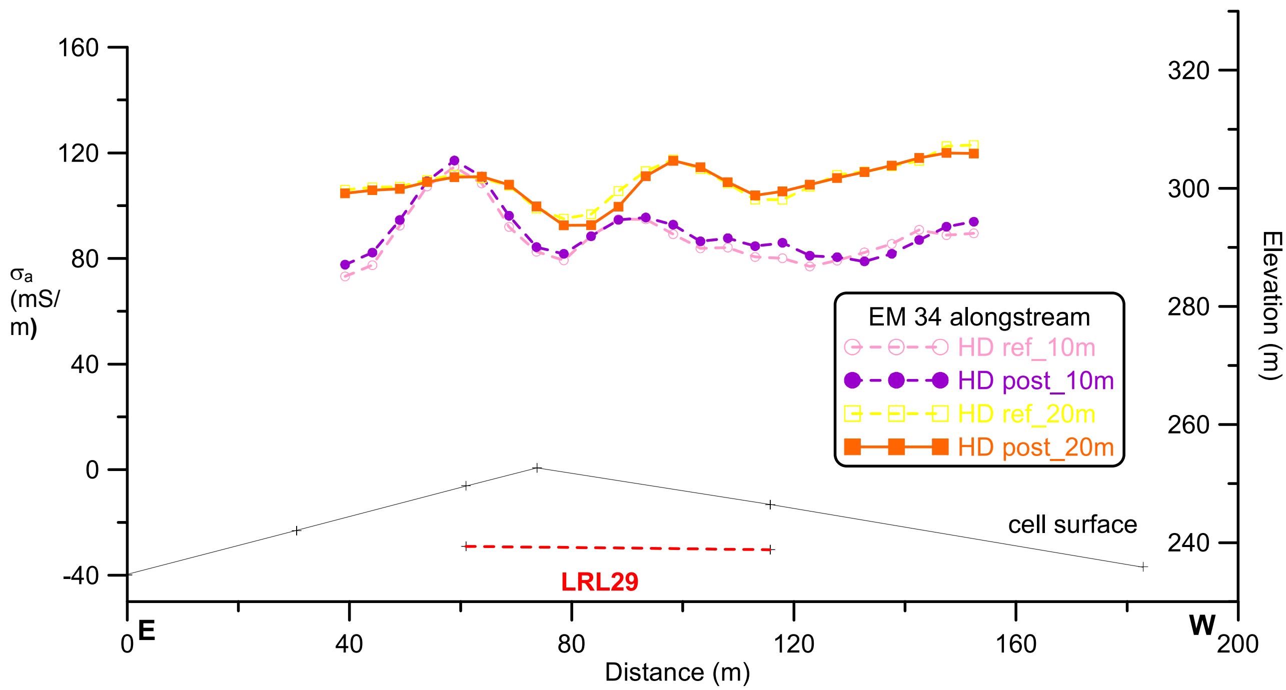


**Figure 4:** Apparent conductivity ($\sigma_a$) measured with the EM34 on the alongstream line, HD orientation, during recirculation on LRL29, smoothed with a 3-point moving average filter. The pre-injection measurements are denoted "ref" and the post-injection measurements "post." The LRL29 injection interval is shown as the dashed red line.

Assuming the conductivity changes are caused by leachate and not other factors, the apparent conductivity changes in the VD orientation at a 10 m dipole spacing suggest leachate at the east end and middle of the perforated interval is likely residing in the upper 15 m of waste. At the west end, it may be deeper since the conductivity increase is larger for the 20 m VD coil spacing.

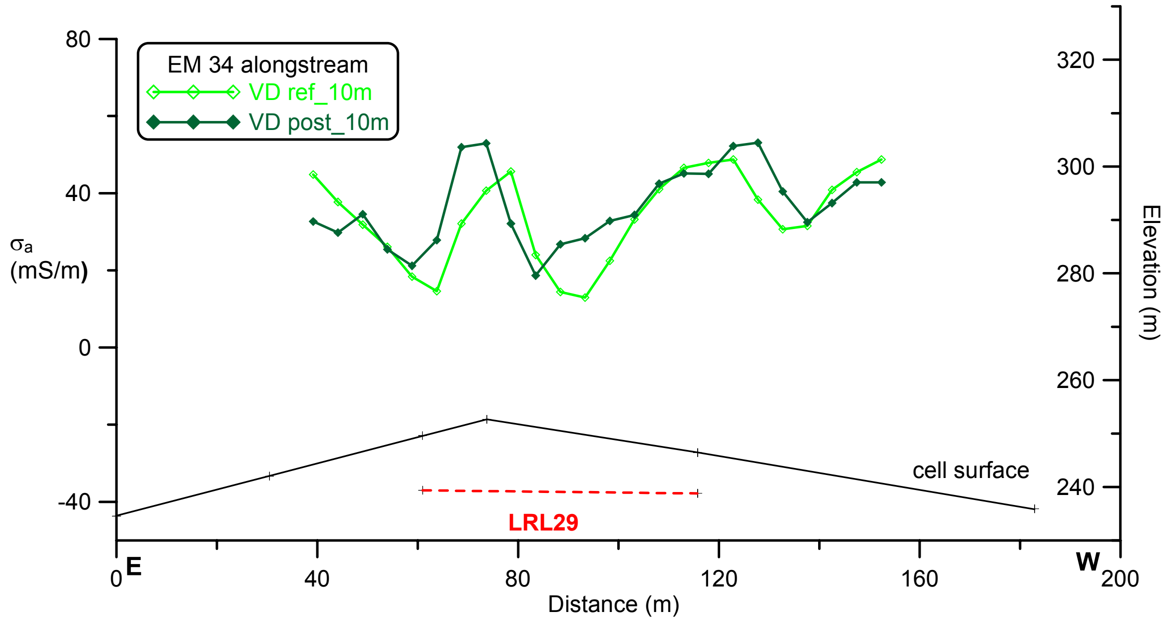


**Figure 5:** Apparent conductivity ($\sigma_a$) measured with the EM34 on the alongstream line, VD orientation, 10 m coil spacing, during recirculation on LRL29, after 3-point moving average filtering. The pre-injection measurements are denoted "ref" and the post-injection measurements "post." The LRL29 injection interval (perforated portion of the LRL) is shown as the dashed red line.

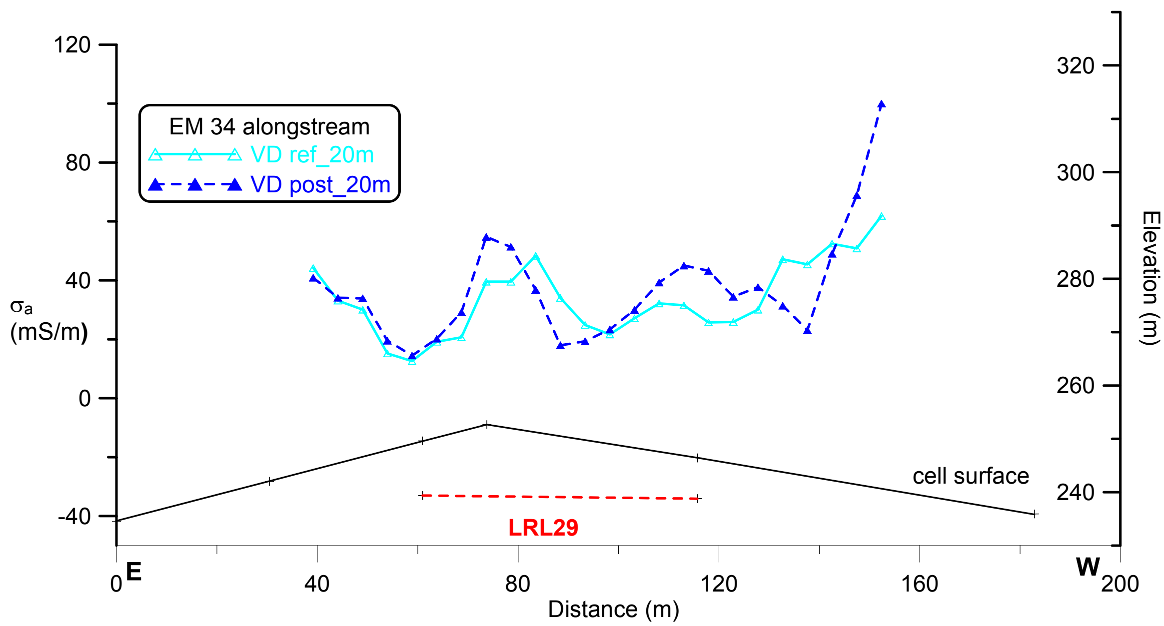


**Figure 6:** Apparent conductivity ($\sigma_a$) measured with the EM34 in a VD orientation on the alongstream line, 20 m coil spacing, during recirculation on LRL29, after 3-point moving average filtering. The pre-injection measurements are denoted "ref" and the post-injection measurements "post." The LRL29 injection interval is shown as the dashed red line.

***Upstream Line***

During the June recirculation experiment along LRL29 the EM34 recorded a slight increase in HD conductivity north of LRL29, but a similar increase occurred also near LRL28, along which no leachate was recirculated. The 20 m coil spacing apparent conductivities show an increase in conductivity south of LRL28 and a decrease north of LRL29. With the 20 m coil spacing, the trend is exactly opposite to that expected if leachate recirculation was being observed: the conductivity decreases around LRL29. These complex results suggest the EM34 could not be reliably used to map leachate infiltration along the upstream line. Too many other factors affect apparent conductivity along this line.

***Long-term Conductivity Changes***

EM surveys were repeated in July, 2007, to assess long-term changes in landfill conductivity. EM31 surveys show a 20-40 mS/m drop in apparent conductivity along all lines, perhaps reflecting the influence of vegetation or drying of the cover and upper refuse. Repeated surveys with the EM34, which sees deeper into the landfill, suggest conductivity has increased over time. For example, Figure 7 shows the change in apparent conductivity on the alongstream line as recorded with the EM34 at a 10 m spacing in HD and VD orientations. Substantially higher apparent conductivities were recorded in 2007, most consistently for the VD orientation, which are as much as 40 mS/m higher in 2007 than in 2006. Repeated surveys with the 20 m dipole spacing reveal VD apparent conductivities 20-90 mS/m higher than those measured in 2006. A similar pattern was recorded along the upstream line. The greater increase in VD conductivity suggests the deeper refuse is more conductive, perhaps as a result of the repeated leachate injections, waste degradation or higher temperatures in the waste mass.

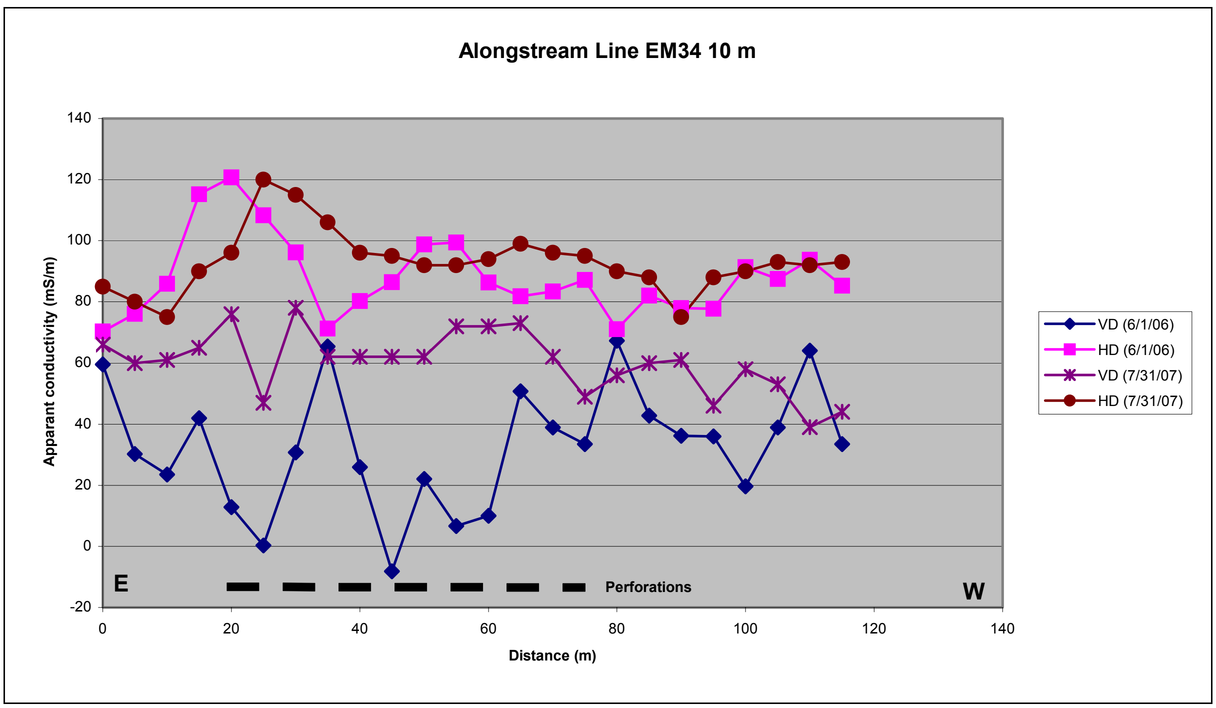


**Figure 7:** Long term apparent conductivity changes on the alongstream line, as recorded with the EM34 at a 10 m dipole spacing. Dates of each measurement are shown at right. The perforated interval of LRL29 is shown by the black dashed line.

## Ground-penetrating Radar Surveys

The ground-penetrating radar (GPR) tests conducted over the leachate recirculation cell at Orchard Hills were designed to: (1) determine the penetration depth of GPR signals in highly conductive waste and cover materials, (2) measure the radar wave velocity, and (3) see if the GPR technique could image subsurface targets, such as a leachate recirculation pipe, trench or leachate accumulations within the waste. GPR profiles were made adjacent to, and across two LRLs in the eastern part of the cell to meet these objectives.

***Data Collection and Processing***

All GPR data were collected with a Sensors and Software pulseEKKO IV GPR system with antenna frequencies of 25, 50 and 100 MHz. Surveys included common-midpoint (CMP) lines to assess velocity, south-to-north traverses across LRL29 approximately 10 m west of the LRL29 inlet (east end), where the LRL was approximately 5 m below the GPR line, as well as traverses across LRL29 further upslope where LRL29 was 10 m deep, and, finally, a single south-to-north profile across LRL28, located 22 m west of the inlet for LRL28.

***CMP Surveys to Determine Velocity***

The location of the CMP surveys was about 10-20 m south of LRL29, to avoid encountering anomalous ground conditions associated with the LRLs. The GPR signal was recorded at 0.2 m separation intervals to a total separation of 5.2 m. Figure 8 shows the CMP record that exhibits a ground-wave velocity of about 0.086 m/ns. This value seems reasonable for clayey materials comprising the cover and underlying refuse/clay mixtures. This velocity was used to convert reflection times to depth on the GPR sections.

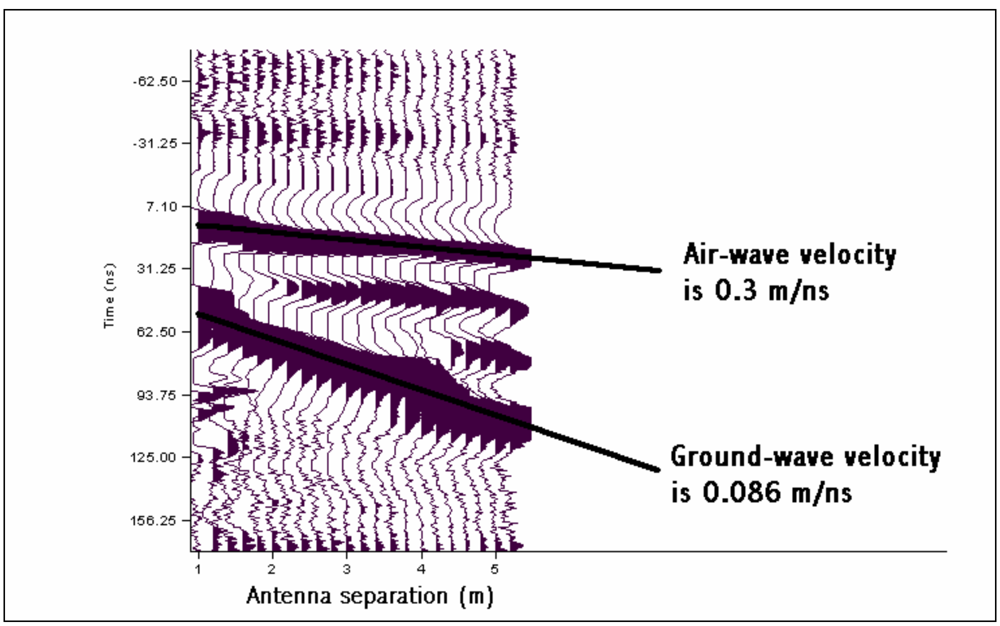


**Figure 8:** CMP survey at the Veolia ES Orchard Hills Landfill. Time is in nanoseconds (ns).

***Surveys with 100 MHz Antennas***

One 100 MHz high-frequency line was collected crossing LRL29 (Figure 9). The only subsurface feature visible was a strong reflection at a two-way time of about 50 nanoseconds (ns), corresponding roughly to a depth of 2.0 m. This is most likely a reflection from the top of the refuse beneath the clay cover (the reflection from the 1 m deep geomembrane within the clay cover was obscured by the air- and ground-wave transmit pulse). The irregular nature of this reflector also supports a waste interpretation, since the waste below the cover is highly heterogeneous. No deeper reflections are visible. The GPR signal penetration depth along this line was thus about 2.5 m; reflections are absent below this depth.

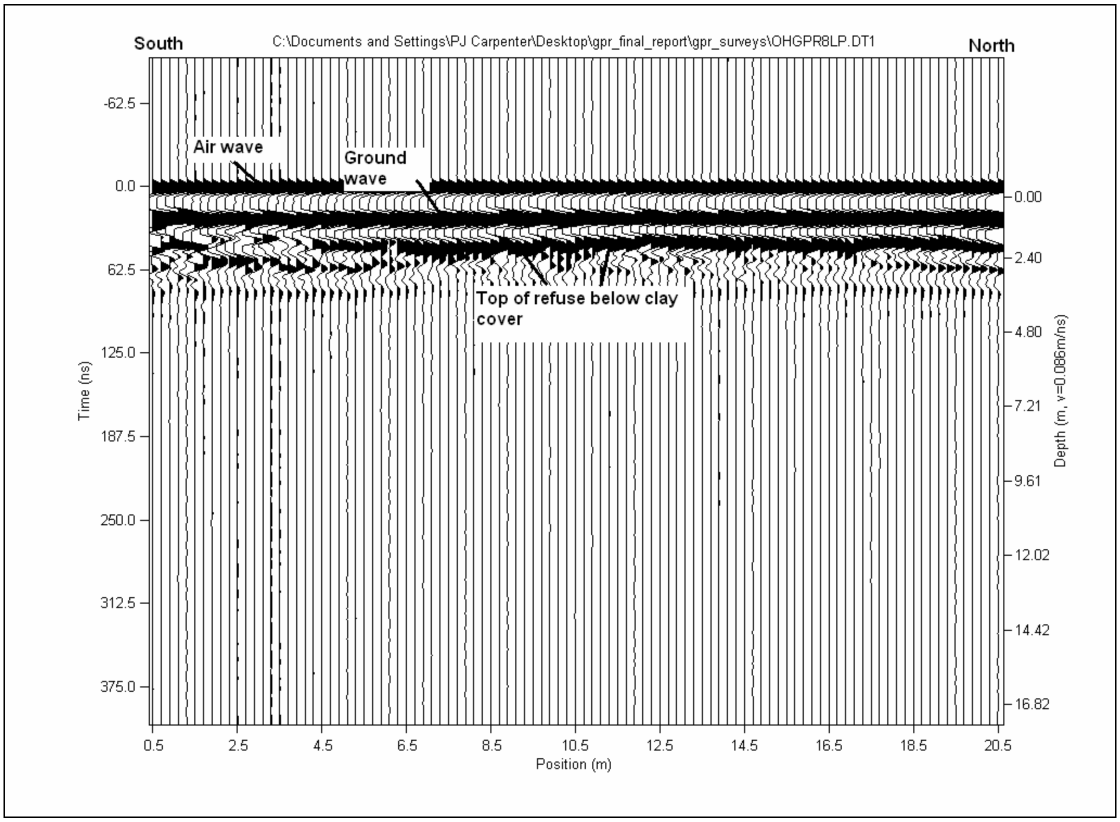


**Figure 9:** GPR line with 100 MHz antennas along north-south profile line.

***Surveys with 50 MHz Antennas***

Several 50 MHz sections were recorded across LRL29, generally with traces spaced 0.2 m or 0.4 m apart. Figure 10 shows a GPR section across LRL29 with troughs shaded. Between 80 and 160 ns (about 3.5-7 m depth) the refuse layer appears as discontinuous reflections. An apparent diffraction occurs near where LRL should be.

Probably the most intriguing feature on the 50 MHz sections is the strong reflection at about 210 ns (about 8-9 m deep), extending from position 6 m to 17 m along the line. This feature shows up best with reverse-shading and color plots. Additional GPR profiles were repeated with the 50 MHz antennas to verify the existence of this reflection The 210 ns reflection shows up on all the GPR sections. This reflection could be from an intermediate cover layer within the refuse, a different type of waste, or an accumulation of leachate that was recently injected. The leachate accumulation interpretation is probably the least likely, since this profile is almost 20 m east of the start of the perforations along LRL29.

One profile was obtained over LRL28. The depth of LRL28 should be about 5 m at this location. This profile is shown in Figures 11 and 12. A faint diffraction is visible from LRL28. No other distinct reflections are visible below LRL28, however.

***Surveys with 25 MHz Antennas***

LRL29 was about 10 m deep below the upslope GPR profile, approximately 30 m west of the LRL inlet. The 50 MHz antennas were unable to image LRL29, or record a diffraction. However, surveys with the 25 MHz antennas appear to image the top of LRL29 (or the associated aggregate trench), and possible underlying leachate, despite the sections being very noisy due to ground coupling and fiber optic problems.

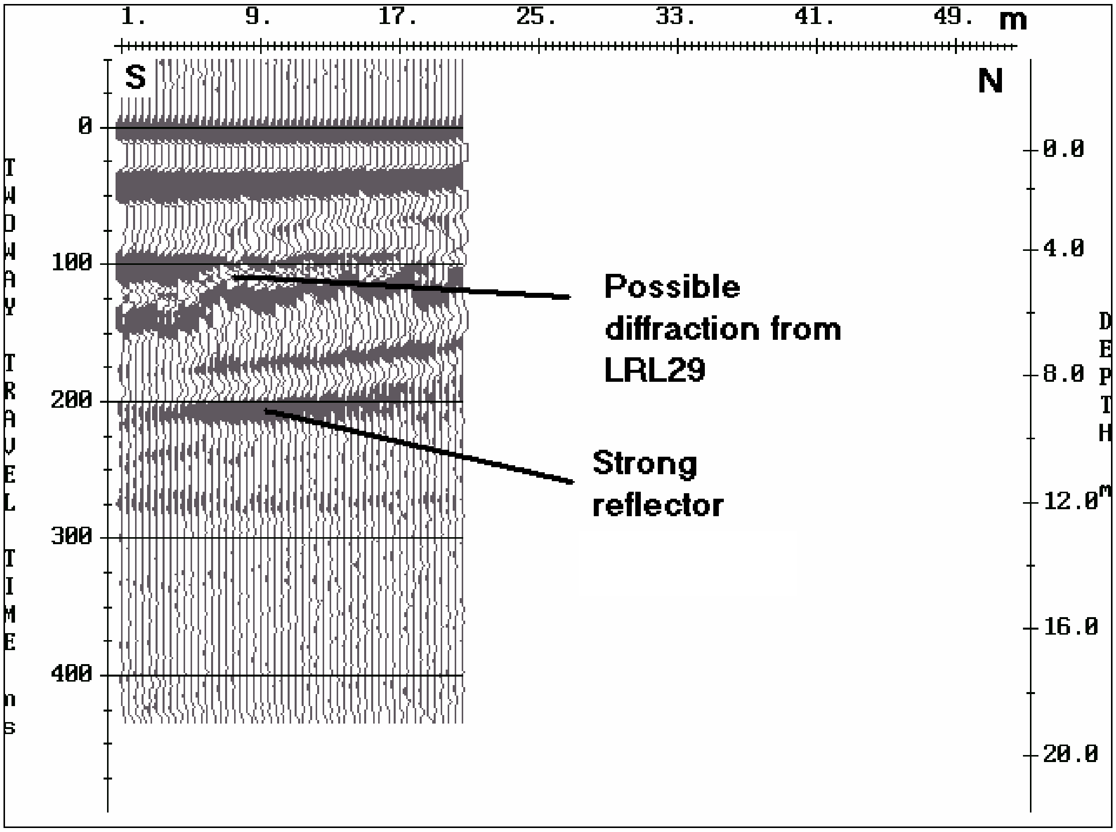


**Figure 10:** A 50 MHz GPR line across LRL29.

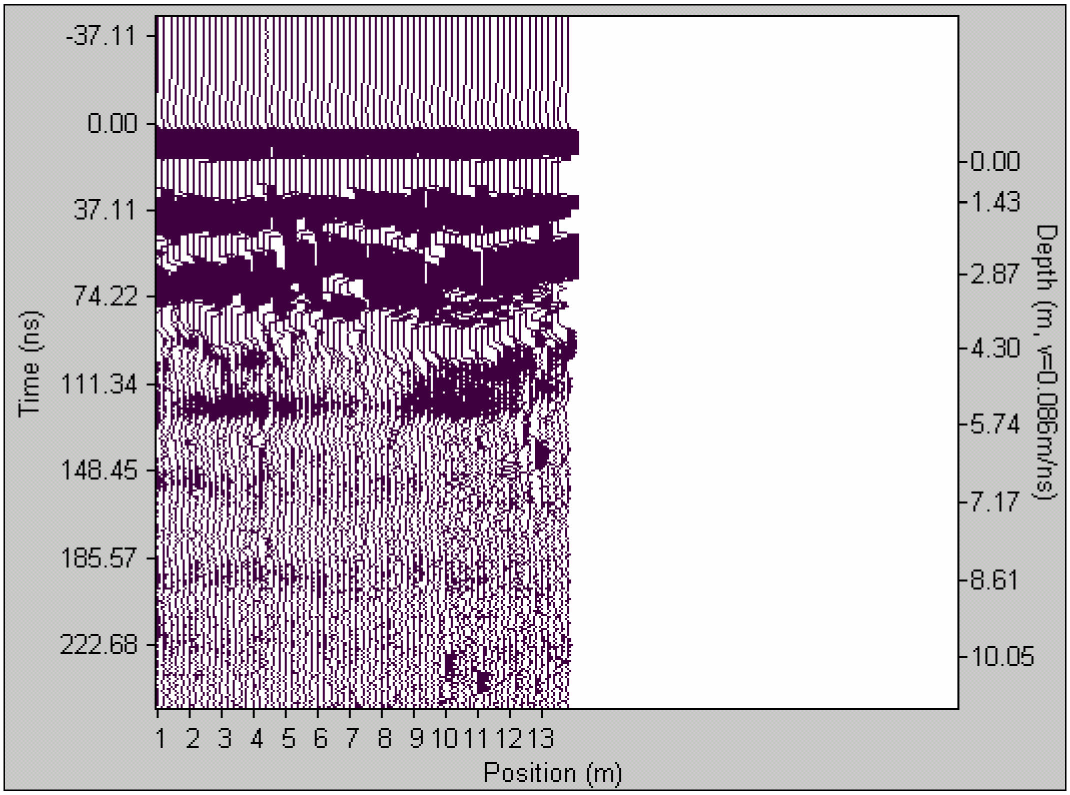


**Figure 11:** Uninterpreted south-to-north GPR section across LRL28.

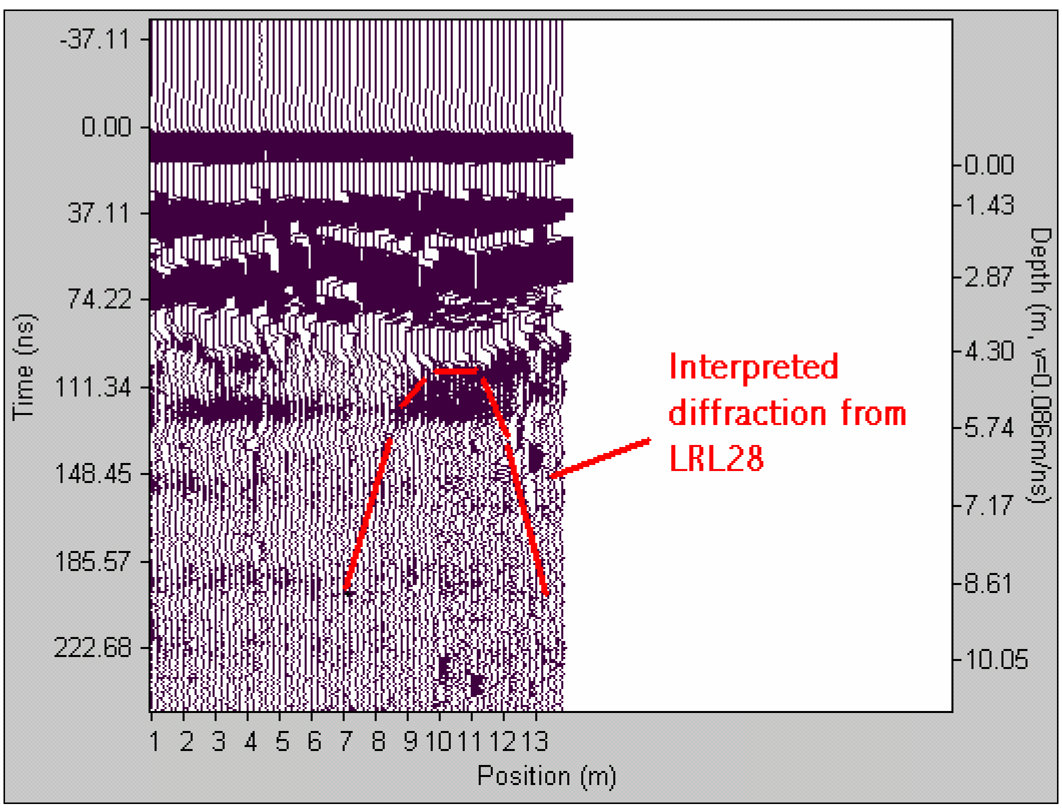


**Figure 12:** Interpreted south-to-north GPR section across LRL28.

## Conclusions

At the Veolia ES Orchard Hills Landfill conductivity measurements must be made with EM coils separated by at least 10 m to have sufficient depth sensitivity to detect recirculating landfill leachate. Surveys over a perforated leachate injection line showed significant post-injection conductivity increases at the east, center and west ends of the perforated interval, as measured with the EM34 at 10 and 20 m vertical dipole spacings. Leachate injection may thus be non-uniform, with larger volumes entering the refuse at the beginning, middle and end of the injection interval, assuming the conductivity changes are caused by leachate and not other factors.

EM conductivity profiles perpendicular to the leachate recirculation lines exhibited complicated patterns of increases and decreases and were of little use in identifying leachate Approximately one year after final cover emplacement the near-surface conductivity had decreased substantially, whereas conductivity of the deeper refuse had increased along all lines. Shallow cover materials may have dried out, leading to lower conductivity, whereas the higher conductivity of the lower refuse over time suggests permeation by leachate, waste degradation, or higher subsurface temperatures.

Ground-penetrating radar (GPR) is a useful tool for imaging the interior of landfill cells with leachate recirculation. Profiles with 100 MHz antennas imaged the top of the refuse as a strong reflection that was somewhat irregular. The relatively high frequency 100 MHz signal, however, could not penetrate deeper than about 2.5 m. The 50 MHz antennas were able to image the recirculation pipe (or associated aggregate trench) along two profile lines – these appear as weak diffractions. Surveys with 50 MHz antennas also show deeper reflections that could represent intermediate cover, different types of refuse, or leachate accumulations. Under ideal circumstances it appears the 50 MHz signal may penetrate as deep as 8-9 m. Profiles with the 25 MHz antennas were noisy, and difficult to carry out in the field. However, a survey with the 25 MHz antennas appears to have imaged a leachate recirculation line and /or possible leachate accumulations at about 10 m depth.

Additional GPR experiments are required over the leachate recirculation cell with leachate injection under more controlled conditions, similar to those employed for the EM surveys. In addition, modeling of the GPR response for the LRLs, and for a pulse of injected leachate, is needed to see if the strong reflection at 210 ns in Figure 10 with 50 MHz antennas is realistic for a leachate accumulation within the waste.

## References

Grellier, S., Reddy, K.R., Carpenter, P.J., Bogner J.E., and J. Gangathulasi, 2007, Leachate Distribution and Geotechnical Stability of Bioreactor Landfills, Progress Report, August, 2005 – January, 2007, University of Illinois at Chicago, Department of Civil and Materials Engineering, Chicago, IL, 272 p.

McNeill, J.D., 1980, Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers, Geonics, Ltd. Technical Note 6, Geonics Ltd, Mississauga, Ontario, 15 p.