GEOPHYSICAL APPLICATIONS TO SOLID WASTE ANALYSIS

Peter J. Hutchinson, PhD, PG
Laura S. Barta
The Hutchinson Group, Ltd.
4280 Old William Penn Highway
Murrysville, Pennsylvania 15668

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Peter J. Hutchinson, PhD, PG
The Hutchinson Group, Ltd.
4280 Old William Penn Highway
Murrysville, Pennsylvania
pjh@geo-image.com

Laura S. Barta
The Hutchinson Group, Ltd.
4280 Old William Penn Highway
Murrysville, Pennsylvania
lsb@geo-image.com

Abstract: Case studies of regional landfills show that electromagnetic geophysical methods can accurately and inexpensively define boundaries and thickness of waste. Degradation of putrescible solid waste generates conductive leachate that can be imaged with a frequency-domain terrain conductivity meter. Terrain conductivity measurements can be modified through a simple algorithm based upon native soil conductivity to produce plan maps showing a detailed three-dimensional image of the waste mass. Further, seismic records and borings confirm that a linear relationship exists between measured waste terrain conductance and thickness of waste. Consequently, waste volume can be estimated to within 15% of the true mass volume by employing terrain conductivity mapping.

Keywords: geophysical methods; terrain conductivity; waste boundaries; waste thickness; waste volume

Introduction

Electromagnetic terrain conductivity surveys have been useful for landfill investigations for many years. These inexpensive surveys can delineate waste, conductive fluids, and buried metal; and provide a three-dimensional overview of the buried waste. Degradation of organic material in field-saturated conditions produces a terrain conductance signature that is elevated above background conditions. The elevated signature, through simple mathematical operations, can locate waste, delineate the waste boundary and provide a rough estimate of depth of waste. The footprint of the landfill can be used with the terrain conductivity estimation of the depth to waste to calculate an in-place waste volume.

Electromagnetic terrain conductivity

Electromagnetic terrain conductivity (EM) surveys have been employed for landfill investigations for over 20 years (McNeill, 1980). Advantages of electromagnetic terrain conductivity survey mapping over other geophysical methods include: excellent resolution in conductivity; no current injection problems; simple multi-layered earth calculations; and easy, rapid measurements. Disadvantages of EM for exploratory investigations are few but include: limited dynamic range; setting and maintaining the instrument zero; and limited vertical sounding capability.

EM surveys are principally used for landfill boundary detection (Mack and Maus, 1986; McQuown et al., 1991; Rumbaugh et al., 1987; Scaife, 1990; Stenson, 1988) and detection of leachate contaminant plumes (Hall and Pasicznyk, 1987; Mack and Maus, 1986; Russell, 1990; Walther et al., 1986). Several workers have been successful in using EM surveys to identify volatile organic plumes such as gasoline (Fawcett, 1989; Olhoeft, 1986; Olhoeft and King, 1991; Saunders and Cox, 1987). McNeill (1990) contends that "...EM measurements will also undoubtedly be used to assist in locating new sanitary landfills..." (p.209).

While groundwater monitoring wells are aerially limited and are a somewhat expensive sentinel strategy, EM surveys have proven to be inexpensive and effective for establishing compliance (McNeill, 1990; Rumbaugh et al., 1987). EM surveys can also be used to monitor the efficacy of a treatment system (Medlin and Knuth, 1986).

The electrical conductivity of soil is a function of the porosity, permeability, and fluids in the pore spaces (McNeill, 1980). Degradation of putrescible solid waste generates conductive leachate that fills pore spaces and can be easily imaged with a frequency-domain terrain conductivity meter (Hutchinson 1994). The absolute values of conductivity obtained in a survey are not necessarily diagnostic but the variations in conductivity can be used to identify anomalies (Benson et al., 1988).

The field-collected electromagnetic terrain conductivity measurements can be modified through a simple algorithm based upon native soil conductivity to produce plan maps showing waste boundaries. Further, case studies of regional landfills confirm that a linear relationship exists between measured waste (terrain) conductivity and thickness of waste. This relationship can be used to estimate waste volume without the need for seismic reflection surveys (the most effective geophysical tool for measuring depth of waste) or for intrusive methods (i.e., borings).

Tool Geometry

The EM meter consists of a transmitter coil that radiates an electromagnetic field (Figure 1). The electromagnetic field induces eddy currents in the earth that generate a secondary electromagnetic field that is proportional to the magnitude of the current flowing within the coil. Quadrature and in-phase components of the secondary magnetic field are captured by the receiver in the form of an output voltage that is linearly related to subsurface conductivity (McQuown et al., 1991). The quadrature phase component (terrain conductivity) is measured in milliSeimens/meter (mS/m) and provides a measurement of soil conductivity (Figure 2). The in-phase mode, measured in parts per thousand (ppt), is responsive to highly conductive, buried metallic objects.

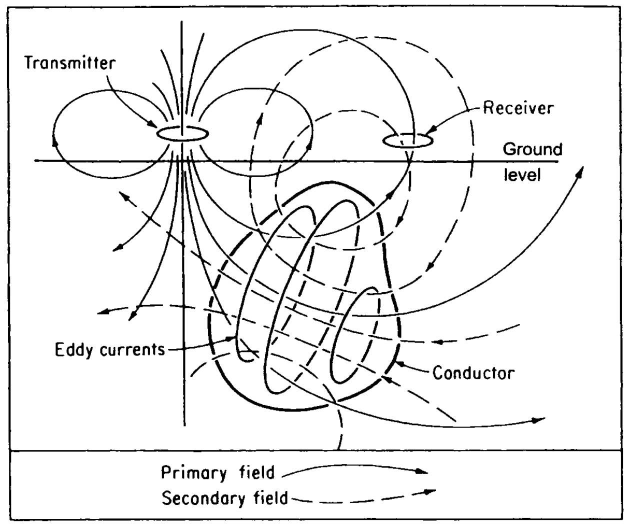

Figure 1 Schematic diagram of the electromagnetic surveying method (Grant and West, 1965).

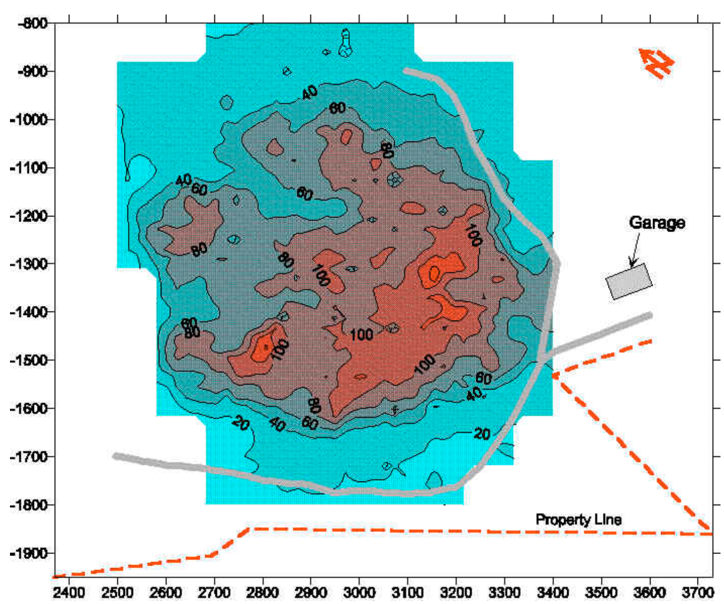

Figure 2 Electromagnetic terrain conductivity map (in mS/m) of Laurel Ridge Landfill, Lily, Kentucky (in feet). The higher conductivity values (>40 mS/m) represent areas of buried waste.

The terrain conductivity value is an average conductivity of the effective depth of the survey tool. The effective depth is determined to be about 1.5 times the intercoil spacing (i.e., the distance between the receiving and the transmitting coils). The Geonics EM31-DL terrain conductivity meter, with an intercoil spacing of 12 feet, has an effective penetration depth of 18 feet in the vertical dipole mode (Geonics Limited, 1994). The tool measures the bulk conductivity of the entire skin depth specified by the intercoil spacing (18 feet for the EM31-DL). Consequently, the tool averages the response determined through the skin depth such that the response at a depth of 4.8 feet gives maximum contribution to the secondary magnetic field but that at 18 feet there is still a contribution to the bulk conductivity (McNeill, 1980).

Near-surface material has a very small contribution to the secondary magnetic field and the orientation of the dipoles in a vertical coplanar fashion is insensitive to near-surface changes in conductivity. This phenomenon, however, is not true for surface soundings where high layer conductivities dramatically decrease the depth of penetration (Weber and Flatmen, 1986).

Normalized Data Presentation

Conductivity values of soil vary considerably (Benson et al. 1988; McNeill 1980; Schutts and Nichols 1991). Jordan et al. (1991) found that wet clay has a conductivity of 20 to 80 mS/m and they considered 30 mS/m an acceptable number for conductivity readings in wet clay. Fill materials have been observed to have a terrain conductivity of greater than 45 mS/m (Hutchinson 1998, McQuown et al., 1991). A simple algorithm, based upon the background conductivity of soil at the site, can be used to normalize the EM data to a background value. The conversion is plotted in decibels (dB) from the following equation (Greenhouse and Slaine, 1983):

$$L = c \; x \; Log_{10}\left(\frac{\sigma_{app}}{\sigma_{arb}}\right)$$

Where, σ'_{arb} is the background value for terrain conductivity, *c* is a constant value, σ_{app} is the measured apparent conductivity, and *L* is the apparent terrain conductivity. The logarithmic ratio has the advantage of producing whole numbers based on expected (i.e., background) conditions at the site. Negative numbers indicate sub-background conditions whereas positive numbers indicate a condition that is above the background conductivity for the site soil. Greenhouse et al. (1989) indicate that 6 dB is a factor of 2 above background. The normalized presentation of the surveyed area displays the landfill margins effectively (Figure 3).

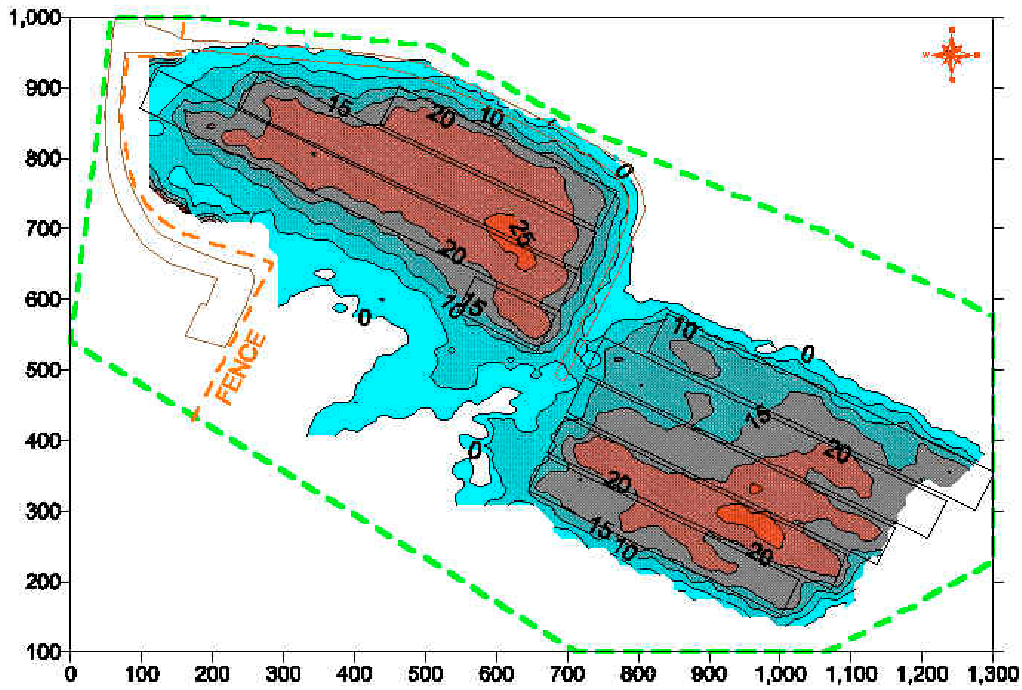

Figure 3 Apparent terrain conductivity map (in dB) of Amelia County Landfill, Winterham, Virginia (in feet). Note that trench locations are approximate and that readings of 6 dB or greater represent waste placed in trenches.

Further, we found that a linear relationship exists between the apparent terrain conductivity and depth of waste. The relationship is based upon the theory that a thick accumulation of field-saturated waste (i.e., greater mass) generates a stronger response than a thin deposit of waste. Consequently, a linear relationship exists between the apparent conductivity and waste thickness. This relationship between apparent conductivity and waste thickness is governed by many variables that can minimize the calculation of depth of waste, including; pockets of ferrous and non-ferrous debris, old waste, pit-burned waste, low field-saturated conditions, thick soil cover, and weak background conductivity characterization. This relationship, however, has been tested against boring-derived waste depths and seismically-derived waste depths and found to be a useful and inexpensive method to derive waste thickness and volume. Errors relating to the use of this method will usually be less than actual conditions, by virtue of how the information is processed. Consequently, this method provides a waste volume that is within 15% of the actual waste mass volume.

Case Studies

Amelia County Landfill is a small closed and clay-capped trench-type waste containment facility. An EM survey was conducted to determine the source of offsite landfill gas within the trenches, since the locations of the trenches had not been surveyed (Figure 3). Subsequently, landfill gas extraction wells were installed into the waste mass. The borings show that the EM-derived depth to waste was slightly greater than that observed from the well logs (Figure 4).

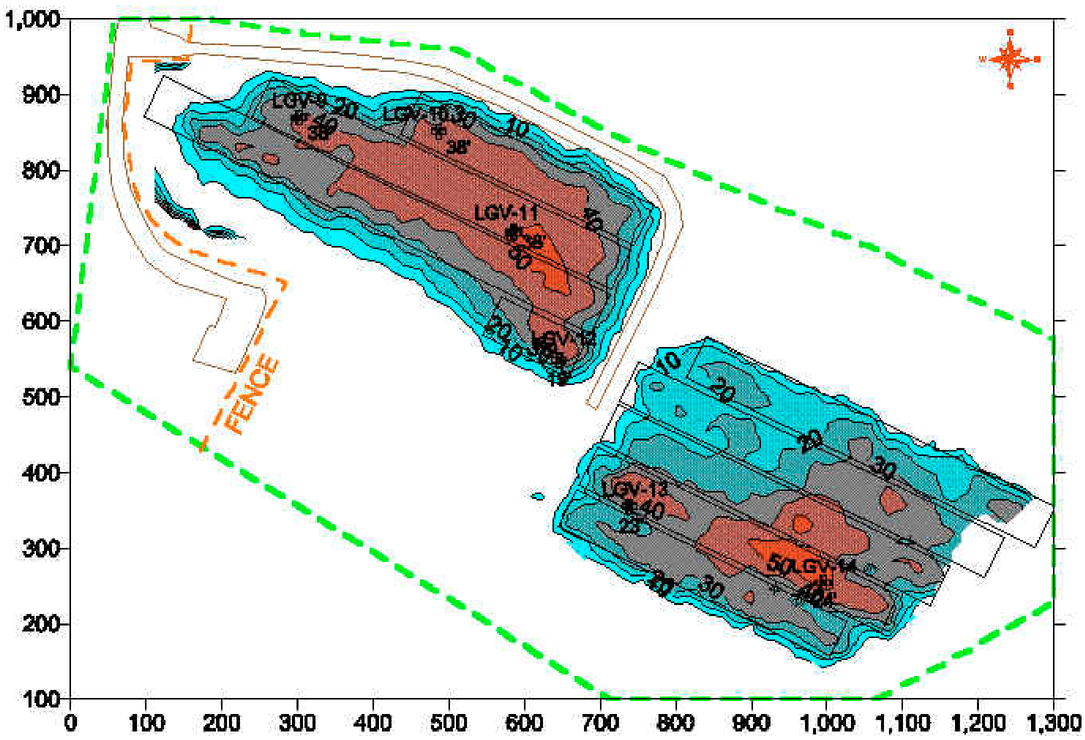

Figure 4 Waste thickness map (in feet) based on apparent terrain conductivity for Amelia County Landfill, Winterham, VA showing depth of waste (in feet) from gas extraction borings.

The discrepancy between the derived thickness and the measured thickness is based upon the vagaries of the waste mass (i.e., partial saturation, concentrations of ferrous and non-ferrous material). The waste thickness derived from the terrain conductivity measurements is based upon the strength of the signal, which is based upon the decomposition of the waste.

Interestingly, the derived thickness map shows that in the pit access ramp areas (western side of the western trenches) the thickness of waste thins (Figure 4). Nevertheless, assuming that the western pits were filled evenly with 38 feet of waste, the western pits hold an estimated 100,000 cubic yards of waste. The EM-derived calculations show that the waste mass is estimated at 85,000 cubic yards, which is 85% of the inferred waste volume, assuming that the trenches are evenly filled with waste.

At McKean County Landfill, PA, depth of waste was derived from multiply-stacked single-fold seismic reflection records. The depth of waste derived from the apparent conductivites agreed well with seismically-derived depth of waste (Figure 5). The depth of waste for the seismic reflection record was provided by a time-depth conversion at the first "break" between the base of waste and the underlying soil.

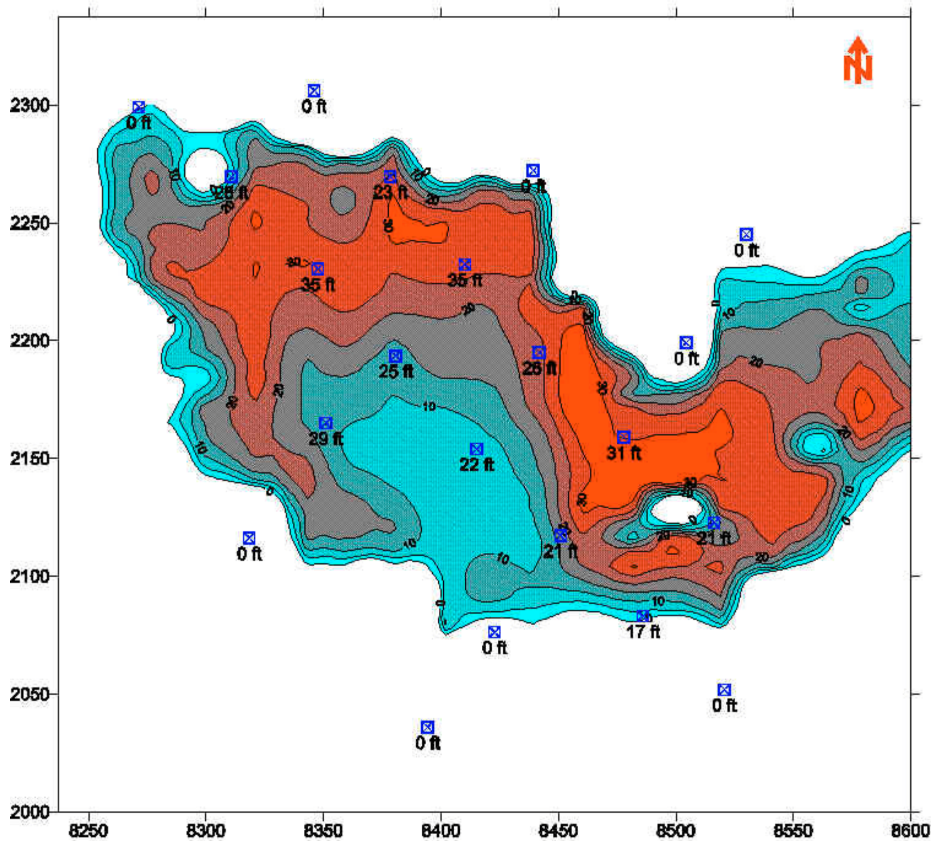

Figure 5 Depth to waste map modeled after the apparent terrain conductivities showing seismically determined depth to waste (feet) in the old Kness Landfill area of McKean County Landfill, Mt. Jewett, Pennsylvania.

The volumetric calculation of the waste mass (from the EM-derived footprint) using the seismic records indicates that the landfill contains 96,000 cubic yards of waste. The volume of waste derived from the apparent terrain conductivity conversion is 82,000 cubic yards of waste. The discrepancy is attributed to shallow buried metal, to the age of the waste, and to the apparent random disposal pattern. Nevertheless, the derived waste volume is within 15% of the measured volume, and demonstrating that the apparent conductivity conversion can provide a good estimate of waste in place.

Summary

Electromagnetic terrain conductivity mapping has proven to be an effective and inexpensive aid for delineating waste boundaries. Normalizing the terrain conductivity readings to background terrain conductivity provides a method for displaying the footprint of the landfill. Further, the normalized terrain conductivity readings have a linear relationship to the depth of waste; consequently, the depth of waste can be inferred and a volume calculation can be generated. The accuracy of the volume calculation is dependent upon the use of a representative background conductivity, waste that is degrading in field-saturated conditions, and limited cultural noise. The depth to waste measurement and the volumetric calculation of waste can be collected non-intrusively and inexpensively and provide the landfill operator with an estimate of waste-in-place to within a reasonable degree of accuracy.

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