# Appendix I Methodology

## M1. Electromagnetic Conductivity Mapping

This is an electromagnetic (EM) technique used to investigate lateral variations in overburden material, waste extent and shallow leachate zones. This method operates on the principle of inducing currents in conductive substrata and measuring the resultant secondary electro-magnetic field. The strength of this secondary EM field is calibrated to give apparent ground conductivity in milliSiemens/metre (mS/m). Readings over material such as organic waste and peat give high conductivity values while readings over dry materials with low clay mineral content such as gravels, limestone or quartzite give low readings.

The EM31 survey technique determines the apparent conductivity of the ground material from 0-3 m or 0-6m bgl depending on the dipole mode used. Depending on the dipole mode used, the measured conductivity is a function of the different overburden layers and/or rock from 0 to 3m below ground level or 0 to 6m below ground level.

The EM31 equipment used was a GF EM31 Conductivity meter equipped with data logger. This instrument features a real time graphic display of the previous 20 measurement points to monitor data quality and results. Conductivity and in-phase values were recorded at accessible locations outside the bounds of the landfill. Local conditions and variations were recorded.

The conductivity and inphase field readings were downloaded, contoured and plotted using the SURFER 8 program (Golden Software, 2008). Data which was affected by metallic objects was removed. Assignation of material types and possible anomaly sources was carried out, with cross-reference to other data.

## M2. 2D Resistivity Profiling

This technique utilizes pairs of current and potential electrodes inserted into the ground. By measuring the voltage between the potential electrodes the apparent resistivity of the subsurface can be determined. By taking a large number of resistivity readings using different geometrical arrays a 2-dimensional profile of the subsurface can be generated. Typically leachate produces a very low resistivity response (<20 Ohm-m) which enables the resistivity technique to be widely used in the mapping of leachate plumes.

The geometrical array used for the survey was the Wenner resistivity array. The setup involved up to 32 electrodes connected to a Campus Tigre resistivity meter, using Imagepro 2006 computer software to control the process of data collection and storage. The recorded data was processed and viewed immediately after the survey.

The field readings were stored in computer files and inverted using the RES2DINV package (Campus Geophysical Instruments, 1997) with up to 5 iterations of the measured data carried out for each profile to obtain a 2D-Depth model of the resistivities.

The inverted 2D-Resistivity models and corresponding interpreted geology are displayed on Drawing 10083_01, Figure 4. The distance is indicated along the horizontal axis of the profile. All profiles have been contoured using the same contour intervals and colour codes.

## M3. Seismic Refraction Profiling

Seismic Refraction Profiling measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities. The results of the seismic survey are used to outline the overburden stratigraphy and the depth to bedrock. Without the seismic profiles it can be difficult, using the resistivity data only, to determine the stratigraphy within leachate plumes due to the low resistivity values of the leachate masking low soil or rock resistivity values.

Readings are taken using geophones connected via multi-core cable to a seismograph. A Geode high resolution 24 channel digital seismograph, 24 10HZ vertical geophones and a 10 kg hammer were used to provide first break information, with a 24 take-out cable (4m and 5m geophone spacing) and a trigger geophone.

First break picking in digital format was carried out using the FIRSTPIX software program to construct traveltime plots for each spread. Velocity phases were selected from these plots using the GREMIX software program and were used to calculate the thickness of individual velocity units. Topographic data were input. Material types were assigned and estimation made of material properties, cross-referenced to the 2D Resistivity data. The processed seismic data are displayed in on the relevant 2D resistivity profiles.

Approximate errors for Vp velocities are estimated to be +/- 10%. Errors for the calculated layer thicknesses are of the order of +/-20%. Possible errors due to the "hidden layer" and "velocity inversion" effects may also occur (Soske, 1959).

The survey was carried out using a combination of Ground Penetrating Radar (GPR), radio detection techniques and visual inspection (manhole survey).

## M4. Ground Penetrating Radar (GPR) & CAT

GPR is a reflective electro-magnetic technique that involves the transmission of high frequency radio waves (typically 100 to 1000MHz) into the ground and recording the subsequent reflections. These pulses are transmitted with a high repetition rate as the antenna is moved along the ground and the reflected pulses build up a cross section (time series) of the sub-surface. Partial reflections of the electromagnetic pulse occur at the boundaries of materials with different dielectric properties.

By understanding the material types under investigation, specifically the electromagnetic pulse velocity, it is possible to convert the reflected time series to an accurate depth section, using:

Depth [m] = Velocity [m/ns] x Reflected Time [ns] x 0.5

The velocity and depth of penetration of the GPR signal depends on the electrical properties of the material with highly conductive materials showing a low penetration due to high absorption rates. Clay-rich and water saturated soils have a lower penetration than gravelly and dry soils. Signal penetration and resolution limits are also governed by the centre frequency of the transmitted electromagnetic pulse. High frequencies give good resolution and shallow penetration. Lower frequencies give lower resolution and deeper penetration.

Services within the depth range of the signal give characteristic reflections, however the absence of features on the recorded data is not conclusive proof of the absence of these features in the ground as they may lie outside the range or resolution of the GPR signal, lie between survey profiles or are masked by shallower services or poor ground conditions.

A CAT manufactured by Radio Detection Limited was used for the survey. The cable avoidance tool works on the principle of measuring the electromagnetic field induced around electrical and other cables due to current flow. Metal pipes can also give a positive response in certain circumstances where induced currents are present.

The GPR survey was carried out using a MALA system, with a 500MHz cart-mounted antenna, with a built-in odometer wheel. The data were recorded on the hard disk in the operating console and later transferred to a computer for processing and printing. Notes were taken concerning the position of visible site details.

Electrical and radio frequency CAT readings in passive mode were taken along the GPR profiles. No CAT signals were noted.

**Note: The absence of features on the recorded data is not conclusive proof of the absence of these features in the ground as they may lie outside the range or resolution of the GPR signal, lie between survey profiles or are masked by shallower services or poor ground conditions.**