Electrical Leak Detection System for Landfill Liners: A Case History

by C.C. White and R.D. Barker

Abstract

As landfill specifications become more stringent in the United Kingdom, the development of increasingly sophisticated monitoring methods is necessary to meet environmental protection goals. This case history describes the development of a 2-million-cubic-meter-capacity landfill, located in a sandstone quarry and 1 km from a public water supply borehole, where the sensitivity of the site to ground water contamination and the proximity to a public water supply borehole are particular issues.

The landfill design incorporated a more sensitive environmental monitoring system, using a geophysical technique. The monitoring system comprises a permanent grid of electrodes installed beneath the landfill, connected by multicore cable to a computer-controlled earth resistance meter and switching unit in the site weighbridge. It was designed to detect holes in the landfill liner prior to and after covering with waste and to monitor the migration of contaminants beneath the landfill before they reach the perimeter observation boreholes, should leakage occur.

Such monitoring can enable the integrity of the landfill to be routinely reviewed; holes can be repaired if they are readily accessible and, if not, monitoring provides an early warning to enable the implementation of any additional monitoring or corrective action, based on the environmental risk posed by the site.

The system was first used as a quality assurance test once the landfill liner, which covered an area of 3 hectares, was installed. The system proved sensitive, detecting a hole consisting of two narrow knife cuts. Such sensitivity allows a high degree of confidence to be placed upon the integrity of the liner, resulting in a significant contribution to public reassurance. The landfill is now operational, and monitoring using the geophysical system will be undertaken on a monthly basis for the first year, with the frequency of monitoring reviewed thereafter.

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Introduction

A prerequisite for the construction of any new landfill in the United Kingdom is a persuasively argued case for its need and demonstration that the resulting environmental impact will be acceptable. This case history describes innovative measures in ground water monitoring incorporated into the recent development of a disused sandstone quarry into a 2-million-cubic-meter-capacity landfill. The site, known as the Sandy Lane Landfill, is situated on the Wildmoor Sandstone Aquifer (a major aquifer in the United Kingdom) and within 1 km of a public water supply borehole near Bromsgrove, features which were focal issues in the environmental risk assessment.

One aspect raised early on, through consultation with the National Rivers Authority (now the Environment Agency), was the importance of improving the current system of monitoring for aquifer protection beyond the mere installation of perimeter observation boreholes. In response, an electrical monitoring system was incorporated into the overall landfill design, facilitating the successful outcome of planning permission following a public inquiry. This paper describes the monitoring system that was installed in 1995 and presents the first measurements.

Landfill Design

The landfill was designed to provide containment of wastes and their breakdown products by the installation of a composite liner.

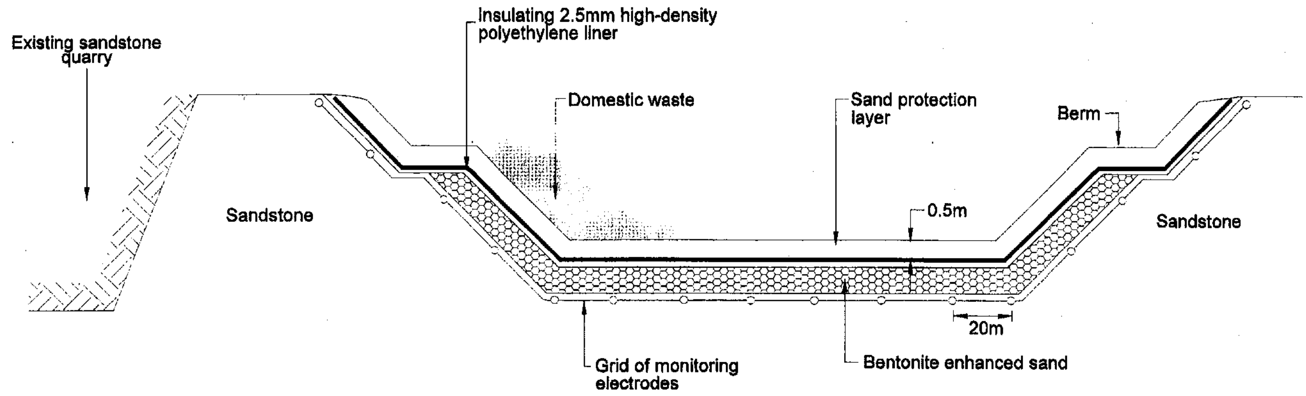

Figure 1. Cross section showing position of grid beneath the landfill.

The system, which has become an industry standard in the United Kingdom in recent years, employs two different materials. They are a 2.5-mm-thick flexible membrane liner (FML) made from high-density polyethylene (HDPE) providing the primary containment, which is placed in direct contact with a second liner comprising a 300-mm-thick layer of bentonite-enhanced sand (BES) with a maximum permeability of 1×10^{-10} m/sec. Once installed, the FML membrane is overlain by a 500-mm layer of sand that acts as a leachate drainage system (in combination with drainage pipes) and protection against physical damage. A section through the landfill is illustrated in Figure 1. The base of the landfill is approximately 7 m above the water table.

Electrical Liner Monitoring Systems

Monitoring within the vadose zone beneath a landfill liner has been much discussed, particularly in the United States. Most forms of monitoring require a high density of instruments to provide complete coverage or specific targeting, in zones of either highest vulnerability or optimum monitoring location (Cullen 1995). Such equipment, once buried, is usually irretrievable for routine maintenance or repair. Equipment simplicity and durability are therefore key factors in these situations. A further problem with using such equipment is that the time between the start of a leak and its detection may be so long that a considerable release of leachate occurs.

A method that can detect leaks soon after they develop is through use of electrical measurements. Such techniques may operate in two ways. First, the integrity of the liner can be tested by passing current from an electrode placed above the liner to an electrode planted into the earth outside the liner. As the liner is an electrical insulator, any attempt to pass current from one side to the other will be met with failure unless there is a leak. In this situation, current will flow and the distribution of voltage around the leak can be mapped (Parra and Owen 1988), the leak being identified by a strong increase in voltage in its immediate vicinity (Figure 2). Systems for carrying out preservice inspection surveys using a moving probe on the upper surface of the liner have been available for more than 10 years (Darilek et al. 1989; Laine and Mosley 1995).

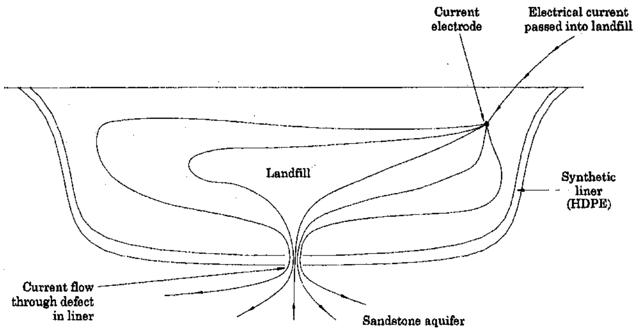

Figure 2. The flow of electrical current within a landfill with a defect in the synthetic liner.

Alternately, the distribution of voltage may be mapped using a grid of electrodes installed below the liner (Asch and Morrison 1989). Such systems have only recently been installed in the United States (Van et al. 1991) and in Poland (Frangos 1994). The advantage of a permanently installed system is that it can be used to monitor the state of the liner at any stage in its life. It was this type of system that was developed and installed at the Sandy Lane landfill.

The Design of the Sandy Lane Electrical Leak Detection System

The system installed at Sandy Lane is designed to fulfill the following four objectives of a monitoring system:

1. The buried instrumentation is simple and durable, designed to last several decades

Photo 1. Shallow trench lines for the geophysical cables map out the position of the grid during landfill.

2. It can provide 100 percent coverage for detecting the presence of holes anywhere in the FML liner
3. Any significant contamination leaking through both liners into the unsaturated zone, and saturated zone as a pollution plume, can be mapped as it migrates toward the perimeter monitoring boreholes
4. It provides an early warning system, giving time to determine the need for, or to implement, a remediation strategy in order to limit any environmental impact.

The leak detection system comprises a grid of electrodes installed just beneath the two liners, providing full coverage across the base and up the sides of the landfill (see Photo 1). The main components of the system are shown as a section in Figure 1 and in plan in Figure 3. A spacing of 20 m for the basic grid of electrodes was chosen after simple mathematical modeling studies and from the results of tests made using a small-scale 5-m-square model landfill built at the quarry site. These tests showed that it was difficult to estimate the actual size of hole that could be detected. Since the system installation, however, its sensitivity is being established in some detail.

Alternate east-west lines were given additional electrodes at 10-m intervals for electrical imaging measurements. The electrode grid is oriented with the lines of electrodes at 10 m spacing approximately perpendicular to the ground water flow direction. Figure 3 shows the area in which electrodes have been installed to date. A single electrode was also installed in Cell 1 within the protection sand above the FML liner.

Each electrode is constructed from 316 stainless steel (Photo 2) and connected to one of a series of multicore cables which are laid from the landfill to control equipment located in the weighbridge (Figure 3), where measurements can be taken remotely using a portable computer and a Campus Geopulse earth resistance meter. The system records the distribution of voltage beneath the landfill, normalized by dividing by the transmitted current. Although this yields units of resistance, this has little physical meaning, and it is more useful in this case to consider it is a voltage distribution per unit transmitted current.

The need for a system to operate for decades required high-quality materials and high-quality connections, backed by rigorous quality assurance. Careful consideration was given to the backfill material used to install each electrode, as this had to be conductive and produce a good electrical contact (i.e., low contact resistance). Through simple trials it was found that the BES produced on-site, to create the second landfill liner, was a suitable material.

The permanent system installed at the Sandy Lane Landfill can be operated in two ways. First, the integrity of the FML liner can be tested by passing current from the electrode placed above the FML liner to the electrode grid below. Second, the electrode grid can be used to detect the presence and extent of any contamination of the underlying strata by mapping changes in the resistivity of the sandstone beneath the liner or by con-

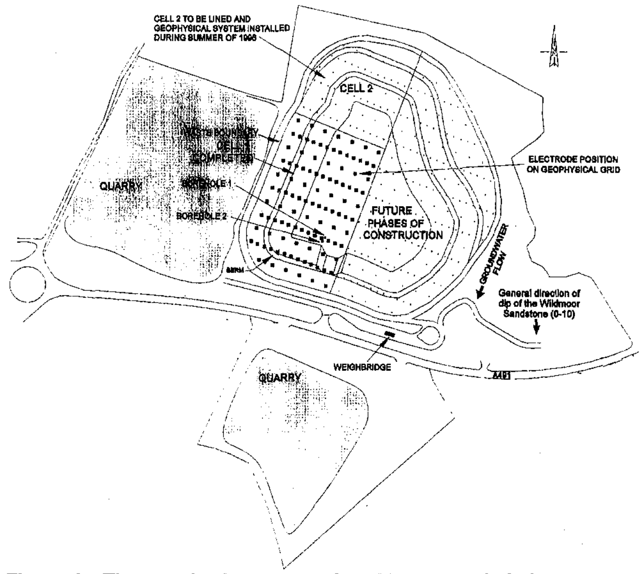

Figure 3. The geophysical electrode grid and borehole installation.

Photo 2. Electrode and geophysical cable installation.

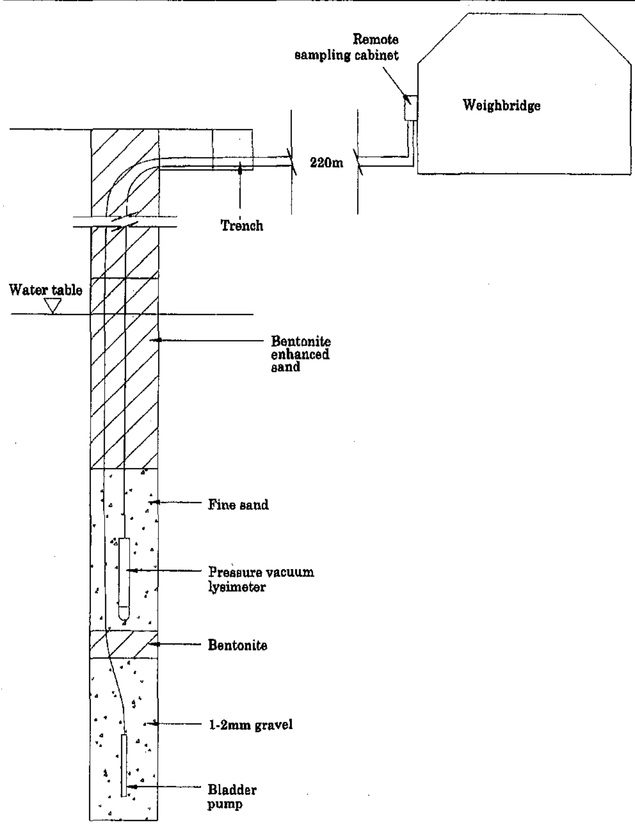

Figure 4. Borehole 2 — Remote ground water sampling instrumentation installed.

structing electrical images (tomographs) of the subsurface (Loke and Barker 1995) beneath the landfill. By monitoring over a period of time, changes in resistivity will indicate the movement of any significant volume of leachate from a leak. Changes in resistivity would be due to the difference in electrical conductivity of leachate compared to ground water.

Once the liner is buried with waste it is unlikely to be repairable. Yet knowing the approximate position of the leak within the landfill will enable its significance to be assessed and the migration route of contaminants within the ground water to be predicted.

Additional monitoring is also supplied by two boreholes that were drilled at the base of the landfill prior to the installation of the liners. A cable carrying an array of 26 equally spaced electrodes was installed into one to provide additional information on the variation of resistivity with depth below the liner, which can be used in combination with resistivity sections produced from the electrode grid.

The second borehole (Figure 4) houses two ground water sampling devices, a pressure vacuum lysimeter (PVL) from Soil Moisture Equipment Corp., and a stainless steel bladder pump from QED Ground Water Specialists, to provide a comparison between resistivity measurements and ground water quality (mainly electrical conductivity) at that location. Both sampling devices were installed just within the saturated zone and operate with 220 m of tubing between instrument and sample collection point (the weighbridge) and with a difference in elevation of approximately 35 m.

It was our preference to provide a representative pumped sample using the bladder pump until such time should the bladder fail; then the PVL would be used as a backup device. Although the latter device is primarily designed for the vadose zone and does not allow purging of ground water, its simple design (minimal moving parts) was considered a good alternative choice where both devices are irretrievable. In order to collect a purged sample from the bladder pump, it was important to take account of the volume of the 220 m of tubing, as it can take up to one hour of purging to evacuate it before formation ground water is brought to the sample collection point.

Leak Detection Monitoring Results

The first test of the monitoring system was to check the integrity of the FML liner immediately after completion of the sand protection layer. Initial measurements showed the system to be extremely sensitive with current flowing over the edges of the FML liner where the sand protection layer was in contact with the surrounding ground. For example, the access road for lorries into and off the landfill had to be severed temporarily during testing as all the current flowed out through the sand protection layer from Cell 1 via this route, producing a major anomaly (Figure 5). The causes of such high anomalies were removed in order to ensure that false negatives caused by the masking of smaller anom-

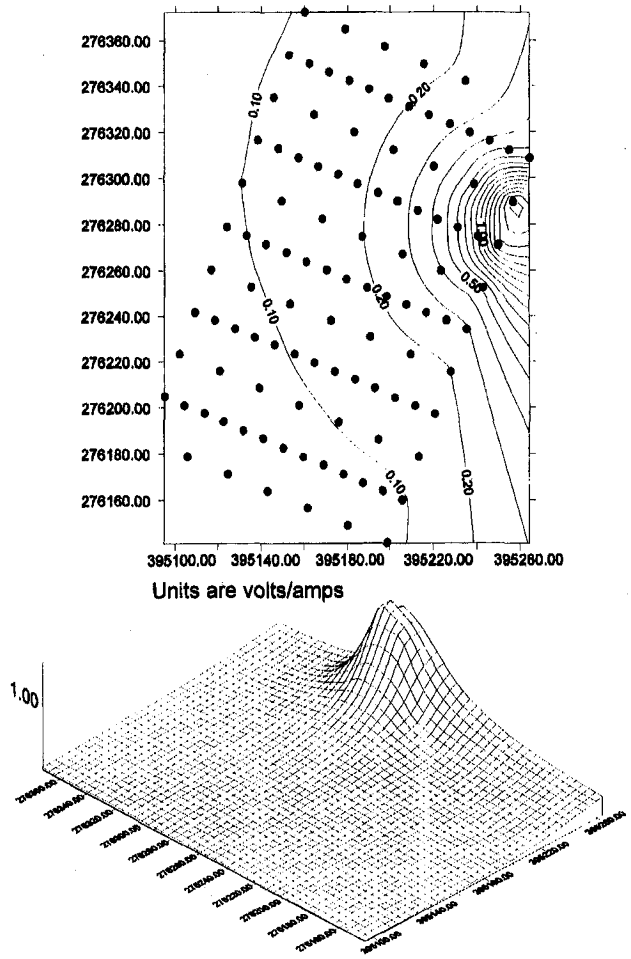

Figure 5. Liner integrity test showing effect of the access ramp.

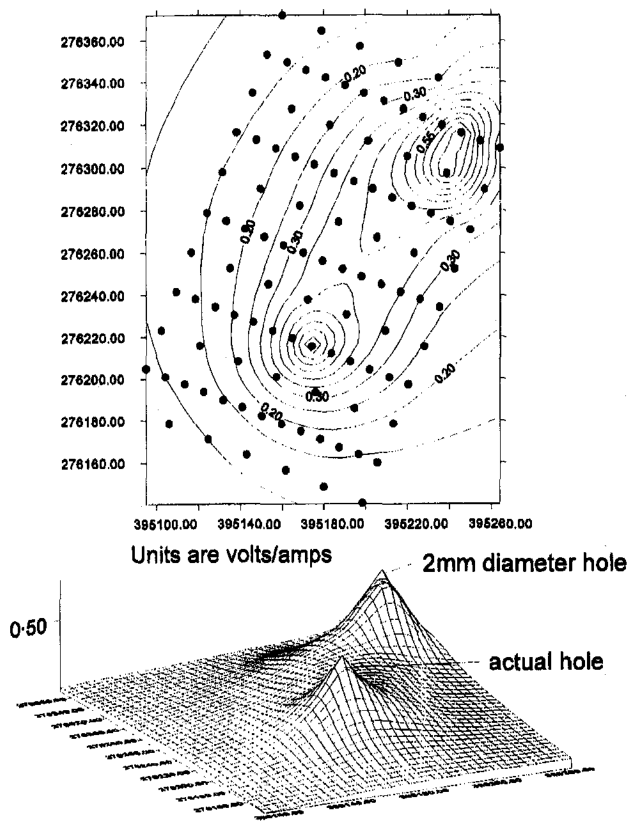

Figure 6. Liner test identifying the first hole.

alies representing holes did not occur. Modifications to the access road have since been made to eliminate this problem. It was even observed that a sand bag, temporarily weighing down the edge of the FML but bridging and making contact with the surrounding ground would result in a detectable anomaly.

Once all edge leakage had been removed, one anomaly within the landfill liner, indicating a hole, became clear. The isometric plot of voltage distribution across Cell 1 shows two such anomalies (Figure 6).

The larger of the two is caused by an artificial 2-mm-diameter hole, intentionally made on the edge of the liner to assess whether the anomaly did represent a hole and the likely size of the actual hole before excavation to expose the liner commenced.

Using the measurements obtained with the leak detection grid, the hole was located to within 5 m in one of the 20-m grid squares. The hole was subsequently pinpointed to within 2 cm using a portable voltmeter and probe on the upper surface of the liner. The actual hole that was detected comprised two small knife cuts, less than 1 mm in width and up to 10 mm in length, this being the only leak found within an area of some 3 hectares.

The hole was repaired by welding a new section of FML across the damaged area. The site was subsequently retested with the monitoring system to check that the repair was sound and also to check that the anomaly created by the hole had not created a false negative by masking any smaller holes in its immediate vicinity.

The area of FML liner monitored using geophysical systems is dependent on the ability of the electrical current to flow over its upper surface as well as beneath it. In the first test, the electrical current flowed through the sand protection layer, which had only been installed across the landfill base and 2 m up the sides of the landfill in preparation for the first intake of waste. Therefore, the upper sections of the landfill remained exposed and could not be monitored at this stage.

During landfill operations, the sand protection layer was progressively installed up the sides of the landfill as the imported waste volume became greater. Routine monthly monitoring of the liner has since exposed two further holes halfway up the side of the landfill along the berm. The detected anomalies are shown in Figures 7 and 8. These holes also resulted from knife cuts (less than 1 mm in section and less than 50 mm in length) caused during the liner installation, which again demonstrates the sensitivity of this technique to identifying small defects. Both holes were repaired, and the geophysical system used to check the integrity of the liner was again established. To date, all anomalies identified by the geophysics were found to be caused by holes through the FML. The creation of false positives has therefore not been an issue.

The pattern of measured potential difference that relates to an FML liner with no holes is shown in Figure 9. The resulting broad anomaly across the landfill is a capacitance effect from the FML material itself

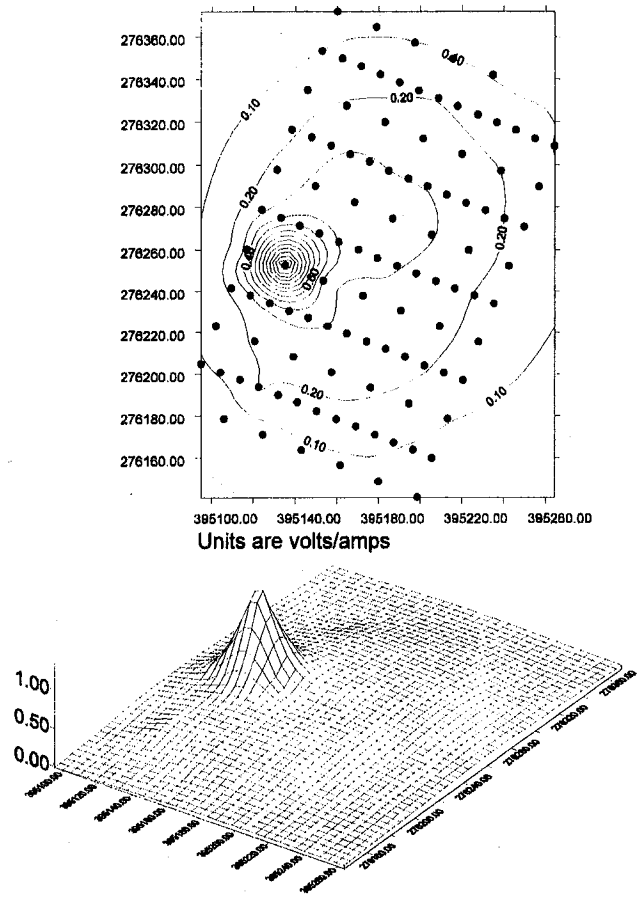

Figure 7. Liner integrity test detecting second hole.

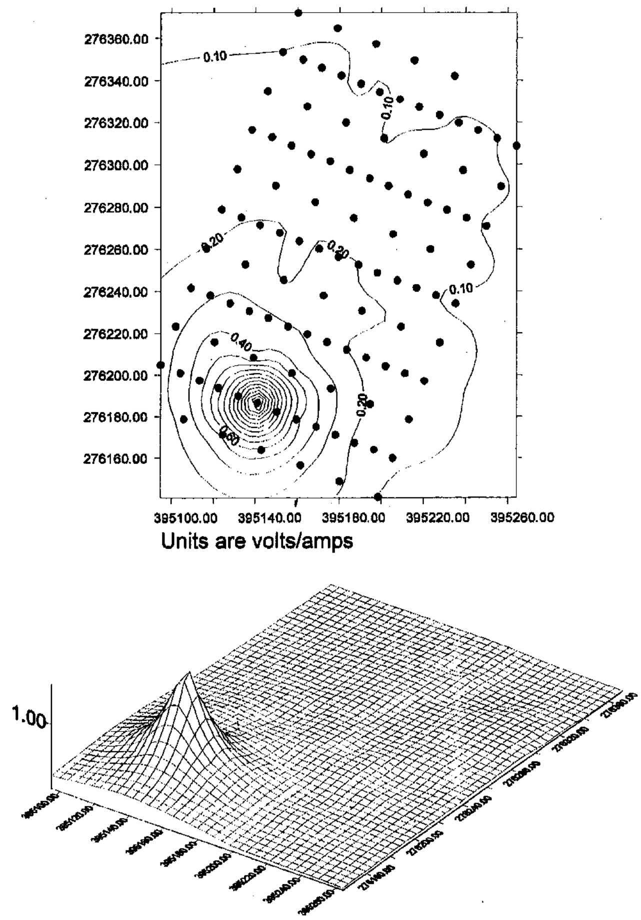

Figure 8. Liner integrity test detecting third hole.

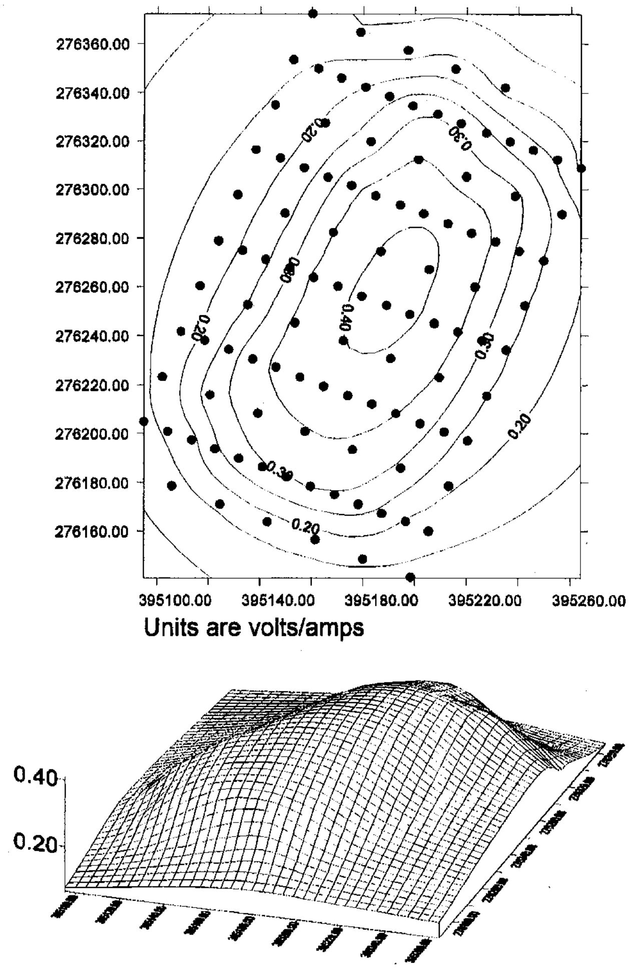

Figure 9. Integrity test results with no holes present.

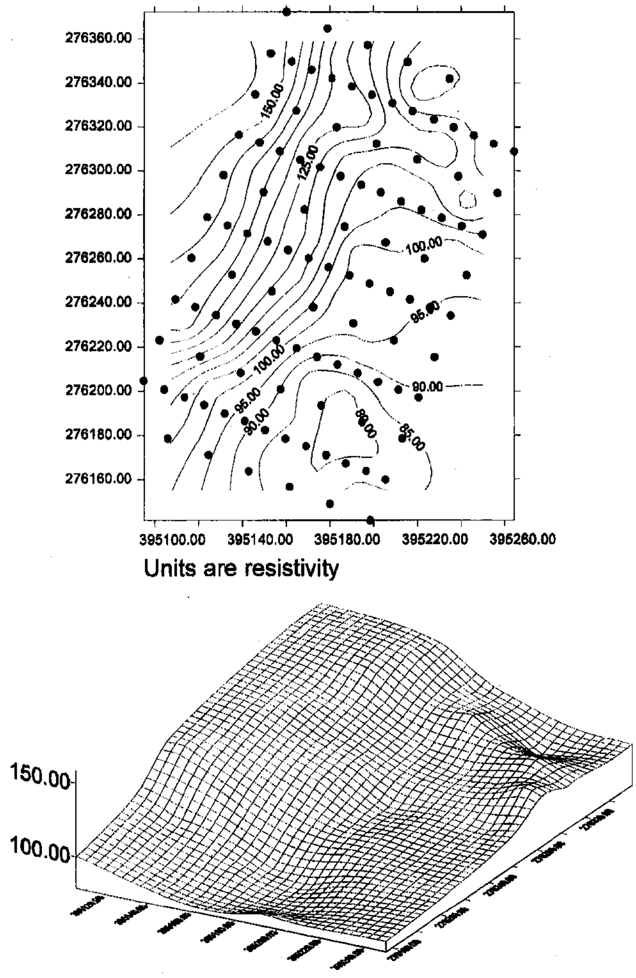

Figure 10. Variation in sandstone resistivity beneath the landfill.

brought about through use of a low-frequency alternating current during measurement.

Monitoring Contaminant Migration Through the Underlying Sandstone

Data are being collected presently on sandstone resistivity in order to establish background conditions and any seasonal variations. Should a leak occur in the future, any identifiable contamination would be detected as a result of the resistivity contrast between leachate and ground water. Typical conductivities of leachate in the first years of the life of a landfill are around 6000 to 50,000 μS/cm (United Kingdom Department of Environment 1995), while the present ground water beneath the site has a measured conductivity of approximately 400 μS/cm. Future measurements will therefore be compared with background data. Anomalies identified will be carefully monitored and their significance established.

It is estimated that should a significant hole be created through the FML liner it is still likely to be some years before any leachate will migrate through the BES liner underneath it and then into the unsaturated zone and finally into the ground water. Hence, background measurements could be collected over several years.

The sandstone resistivity is being measured on a monthly basis for the first year using a 20-m-square array configuration, which has a depth of investigation of around 10 m. The results are plotted as maps of sandstone resistivity at this depth below the liner. A typical map is illustrated in Figure 10. Overall, the changes in resistivity are consistent and show a general increase in resistivity toward the northwest. The increase in resistivity generally coincides with a narrow ridge of sandstone that separates the landfill from an adjacent quarry. A broader ridge of sandstone also separates the southern end of the quarry with an adjacent quarry on the other side of the A491 main road (Figure 3), but this does not produce a corresponding increase in resistivity, probably because of the greater distance between quarries.

Resistivity images can also be produced along any line of electrodes within the grid. One such image is illustrated in Figure 11, which has been produced using a Wenner electrode arrangement and a data collection method described by Griffiths and Barker (1993). Comparison of future images with background data presently being collected will again enable contaminant migration to be mapped and direction of movement determined. This will indicate which perimeter borehole it is likely to intercept or indeed whether the existing spacing of perimeter boreholes is likely to be sufficient.

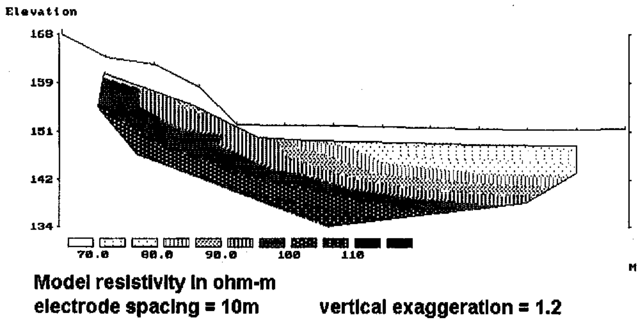

Figure 11. East-west resistivity section beneath the landfill.

Conclusion

The installation of a permanent geophysical leak detection system beneath a landfill composite liner has provided an additional level of environmental monitoring within a sandstone aquifer used locally for ground water supply. Its permanent nature will allow an assessment of landfill integrity and environmental impact throughout the life of the landfill through to post-closure. It has proved sensitive to the detection of holes in the FML liner to the extent that the holes located were not easily visible to the naked eye at close inspection.

Such sensitivity allows a high degree of confidence to be placed upon the integrity of the liner and is a significant contribution to public reasssurance. Should future holes develop that are not accessible to repair due to burial by waste, the system provides the ability to map the migration of identifiable contamination beneath the landfill, toward the perimeter boreholes. Such information will enable a focused, predefined strategy to be put into operation to limit any environmental impact.

Monitoring is presently being conducted monthly until the end of the first year, at which time an assessment will be made regarding the future frequency of monitoring. The process of data collection on site typically takes one to two hours. The system will expand during the next five years as more cells of the landfill are constructed. The adoption of these new measures of environmental monitoring will be of benefit to other future sites where environmental impact via contamination of underlying aquifers is a sensitive issue.

Acknowledgments

The authors wish to thank Cleanaway Ltd., the landfill operators, for their support and contribution to this work, and Professor Donald Griffiths, Michael Morrey, and Chris Cunnell, who contributed to its successful implementation.

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