ELECTRICAL RESISTIVITY INVESTIGATIONS ON AND AROUND LANDFILLS

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Abstract: Electromagnetic induction (EM) and direct current resistivity (DC) surveys are proving useful in mapping subsurface conditions near, within and under closed landfills in northern Ohio. Geometrics *OhmMapper* EM profiles provided evidence that an old, poorly documented solid waste landfill does **not** extend under property being considered for industrial redevelopment. *OhmMapper* measures variations in apparent resistivity to depths of around 6 meters where buried waste or leachate are not present, but high conductivities decrease the skin depth, limited penetration through low resistivity leachate. DC measurements with Advanced Geosciences' *Supersting R1IP* and 28 electrodes (10 m spacing) reveals resistivity variations up to 50 m under the surface near the center of each dipole-dipole array of long, multi-array profiles, providing information on conditions within and under a landfill. We are extending these methods beyond traditional surveys in search of leachate outside the perimeter of landfills to mapping the base of buried waste within landfills, searching for ponded leachate within and vertically migrating leachate under landfills. Resistivity measurements contribute to conceptual models of what lies within and under poorly documented landfills, an important step in developing effective remedial actions.

Many old solid waste landfills lack accurate documentation regarding the configuration and composition of the surface upon which wastes were deposited. Vertical and lateral migration from landfills can pose a threat to ground and surface water quality. Leachate ponded within a landfill can be extracted and treated, but 'wildcat' exploratory drilling into or through buried waste is seldom recommended. If a conceptual model of a landfill and its underlying and surrounding hydrogeology can be developed, drilling costs for monitoring and remediation can be reduced.

Non-invasive geophysical methods (electromagnetic conductivity and electrical resistivity) have proven useful in mapping subsurface conditions just outside the boundaries of many landfills. Low electrical resistivities near landfills are usually associated with leachate (groundwater containing significant concentrations of dissolved solids) or clay-rich sediments. Silt and sand sediments are composed largely of minerals that are electrical insulators, so the electrical properties of these materials are dominated by the quantity and quality of water in the pore space between mineral grains. Water with low concentrations of dissolved solids exhibits a moderate electrical resistivity. In general, the lower the electrical resistivity of the water, the higher the concentration of dissolved solids.

Geometrics' **OhmMapper** uses electromagnetic induction (EM) to measure variations in the electrical properties of subsurface materials. Data are collected at a sample rate of 1/second as the transmitter-detector antenna array is pulled across the surface. Multiple passes with different configurations (larger separation of transmitter and detectors) are needed to observe vertical variations. Surveying in reference points usually takes longer than running the EM measurement. AGI's **SuperSting R1IP** transmits D.C. current into the ground via metal pins, reversing polarity to eliminate effects of spontaneous potential. We used a 28 electrode array and switching box. Interrogation depth depends on electrode separation. Wide separations measure more deeply and cover ground more rapidly than narrow spacing but with a corresponding loss in resolution.

Figure 12: OhmMapper profiles surveyed during 2 field days (reference flags were previously placed at 50 m intervals) towing the array behind a golf cart.

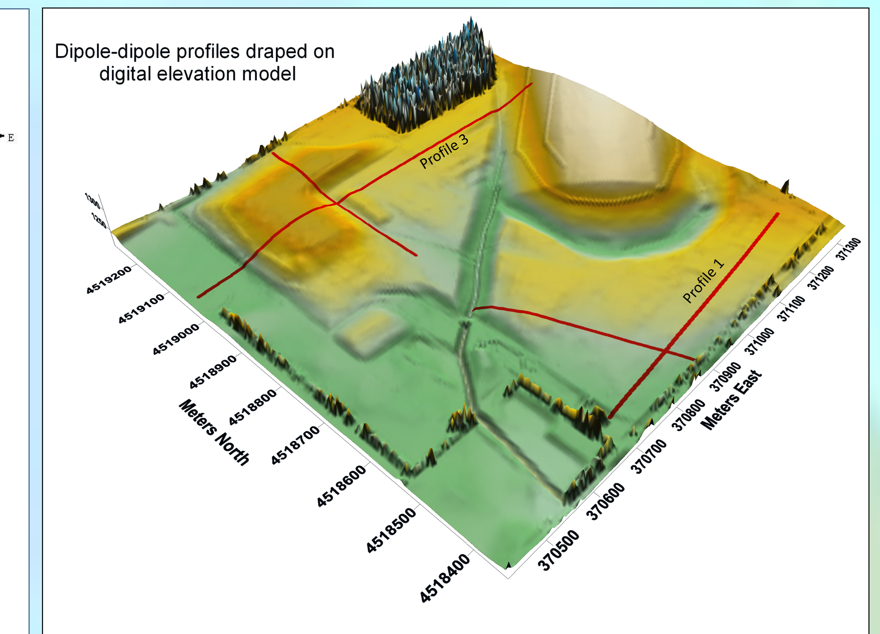
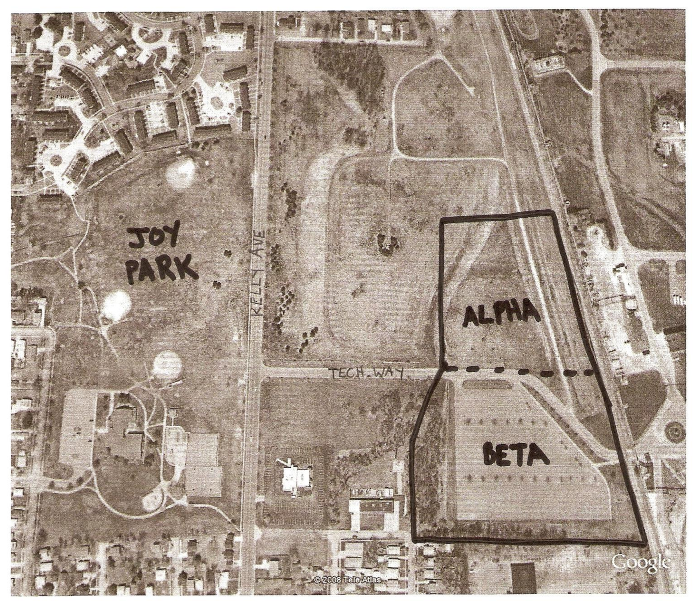


Figure 13: DC resistivity profiles (dipole-dipole configuration, 10 m dipoles) draped over digital elevation model of landfill. Topography (including trees) from the Ohio State Imagery Project's LiDAR. Aerial photograph in Figure 12 is also from the OISP Web site.

Problem: does an old, poorly documented solid waste landfill now used as a park extend under property under consideration for industrial redevelopment? The cost of drilling numerous soil boring is prohibitive.



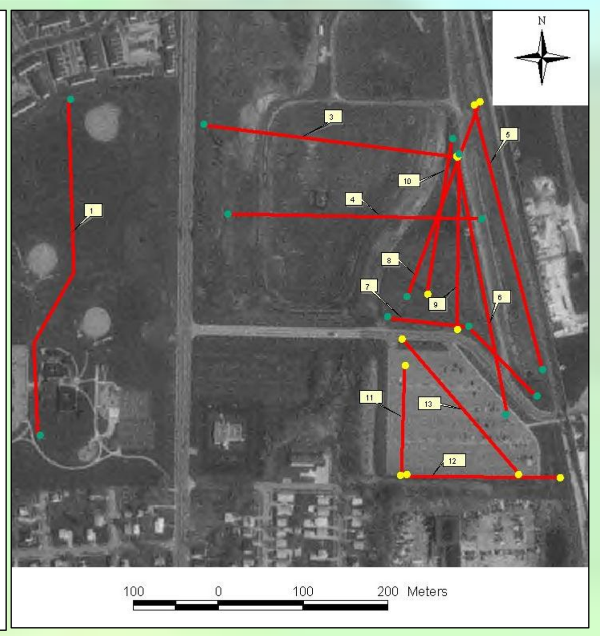


Figure 1a (left): Joy Park lies above old landfill. Figure 1b (right): OhmMapper profiles.

Proposed solution: OhmMapper profiles (5- and 10-m dipoles) are used to, first, determine the geophysical signature of buried waste (profile 1, Figure 1b) and then to measure apparent conductivity under profiles of the potential redevelopment.

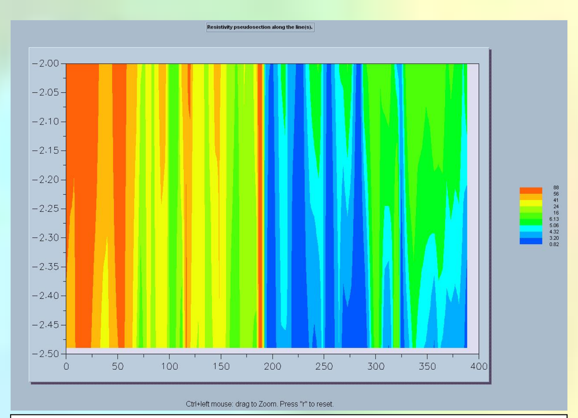


Figure 2: Variations in electrical resistivity under profile 1. Apparent resistivities in the single digits usually mean leachate in most of Ohio's rocks and sediments. Distances and depths are meters.

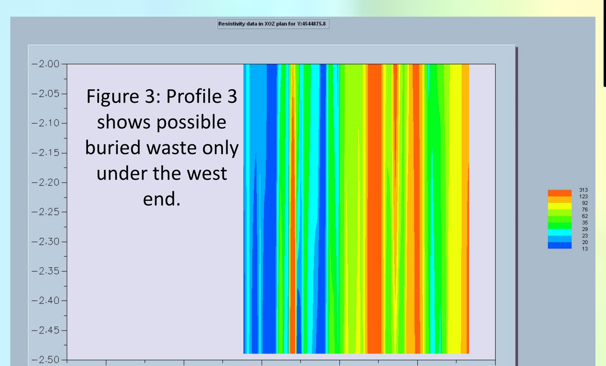


Figure 3: Profile 3 shows possible buried waste only under the west end.

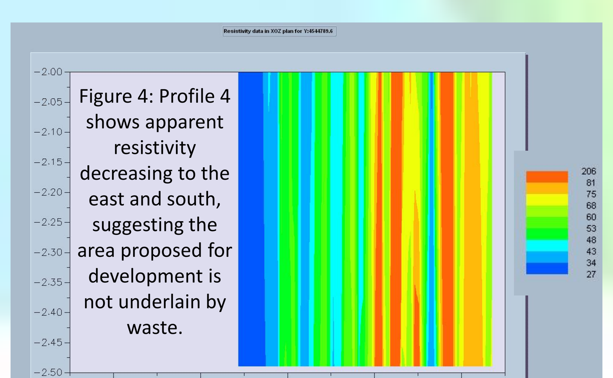


Figure 4: Profile 4 shows apparent resistivity decreasing to the east and south, suggesting the area proposed for development is not underlain by waste.

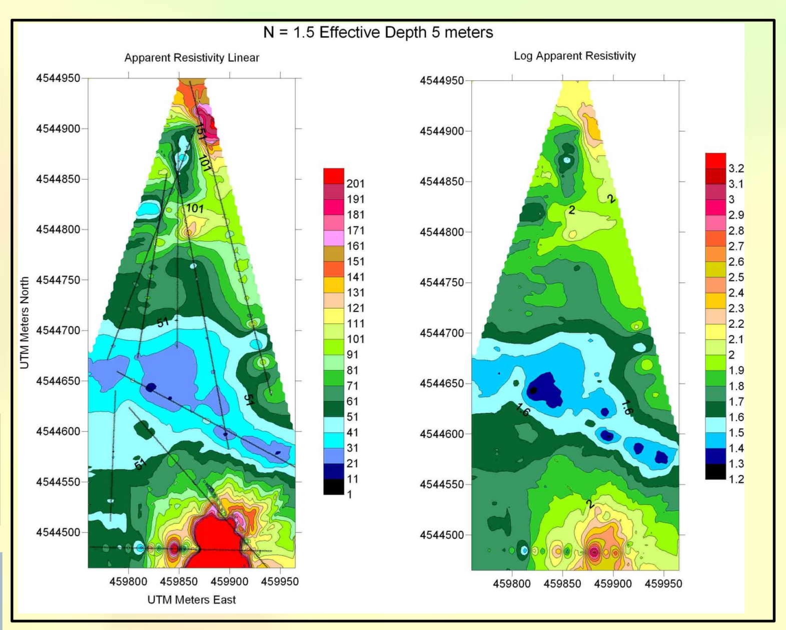


Figure 5: contour maps showing apparent resistivity variations under profiles 5 – 13, interrogating the area under the proposed industrial park. The lowest apparent resistivities lie under Tech Way Road and are most likely due to utilities known to be buried next to the road. The 'log' contour plot (right) best shows significant resistivity variations. Most of the signal is due to materials lying from 2 to 6 meters under the surface. Dark lines on the linear resistivity map (left) show profile locations.


Geometrics' OhmMapper (left) and AGI's SuperSting R1IP (right).

At a west central Ohio landfill, we sought to determine if leachate with migrating to the west, if leaching was ponding within the landfill, and if we could map the base of the solid waste fill.

Figure 6: aerial image of landfill and OhmMapper profiles.

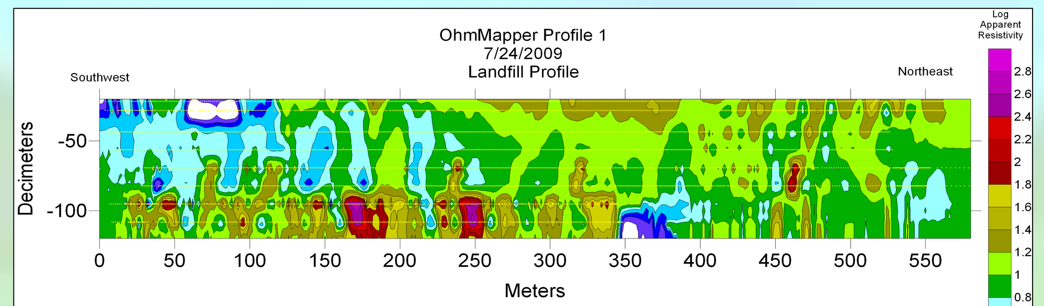


Figure 7: OhmMapper results for Profile 1. Low apparent resistivities suggest leachate under the southwest segment of this profile.

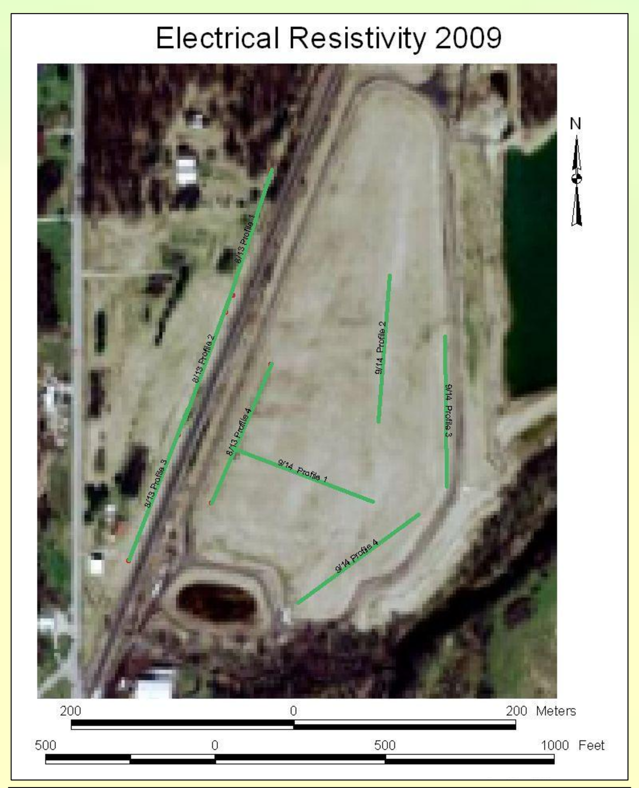


Figure 8: location map showing electrical resistivity profiles.

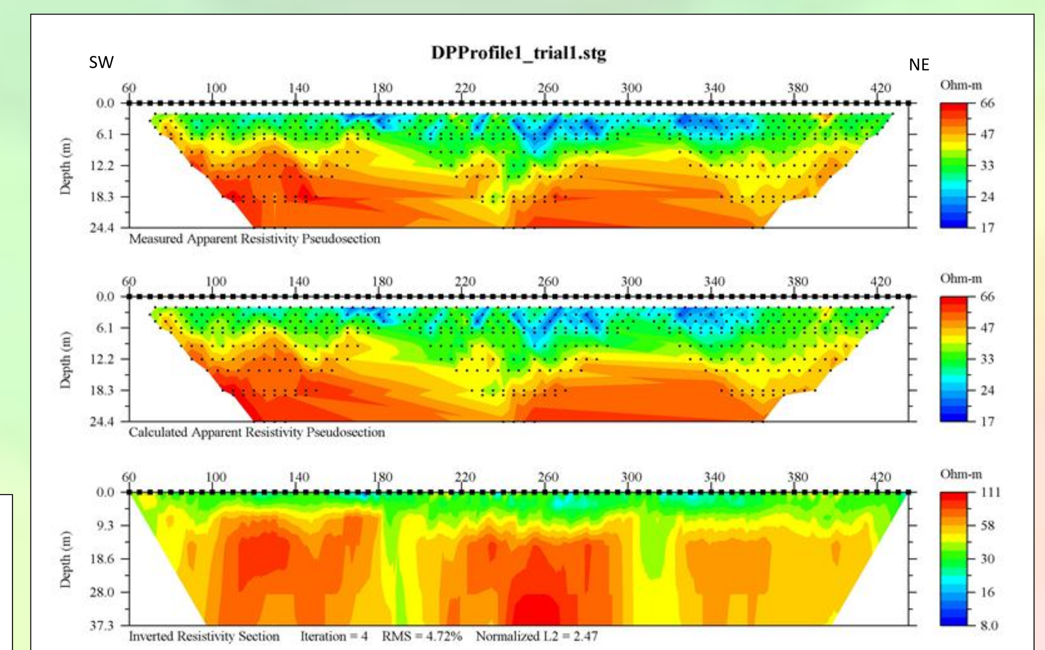


Figure 9: AGI's **EarthImager** software inverts field measurements (top) to obtain an electrical resistivity model (bottom) for resistivity profiles 1 – 3. Comparing the calculated values (forward model) (center) with the measured values (top) shows excellent agreement in this case. Note that vertical green and yellow (low resistivity zones?) under the 185 m and 310 m positions occur where there are no deep data points (black dots, top and center) so these are **artifacts** of the contouring process. There is no evidence of leachate migrating west from the landfill. The 30 Ω-m surficial material is probably clay till. Underlying material (> 60 Ω-m) is probably silt or sand.

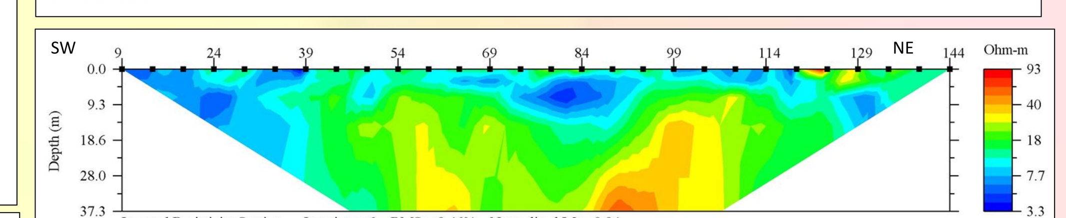


Figure 10: 8/13 Profile 4 dipole-dipole resistivity section. Resistivities < 10 Ω-m are probably ponded leachate. Resistivities in deeper sediments are significantly lower than those under profiles 1 – 3 (Figure 9) less than 100 m to the west. This suggests vertical percolation of leachate under landfill.

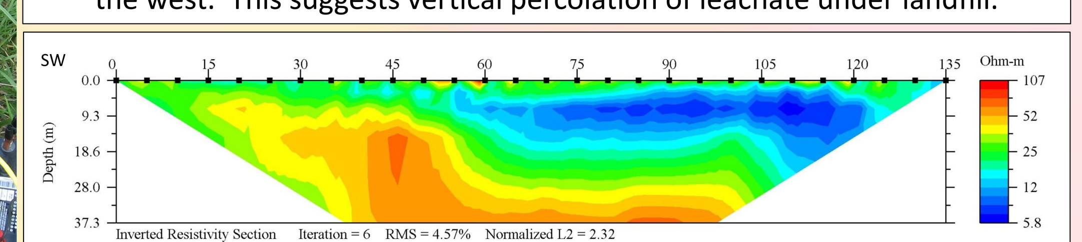
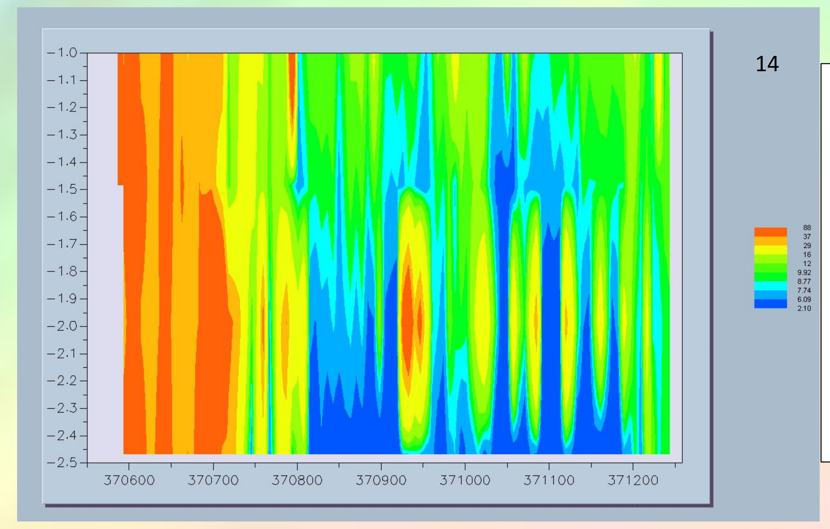
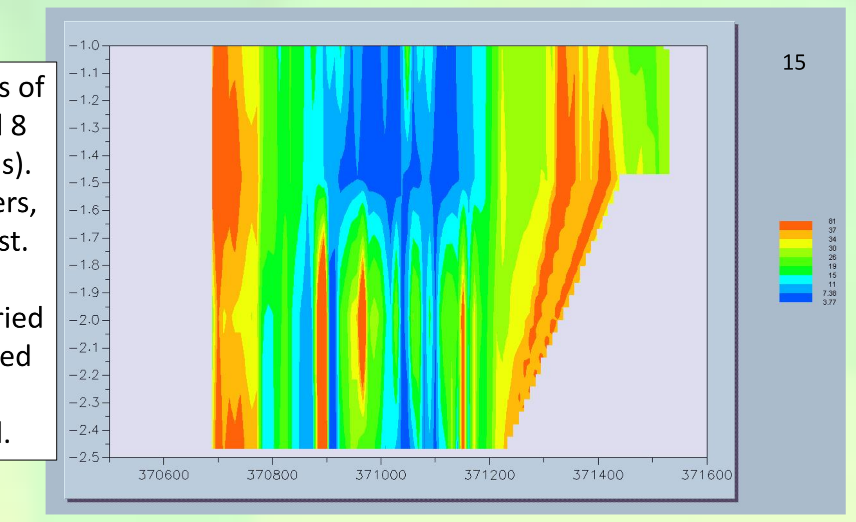


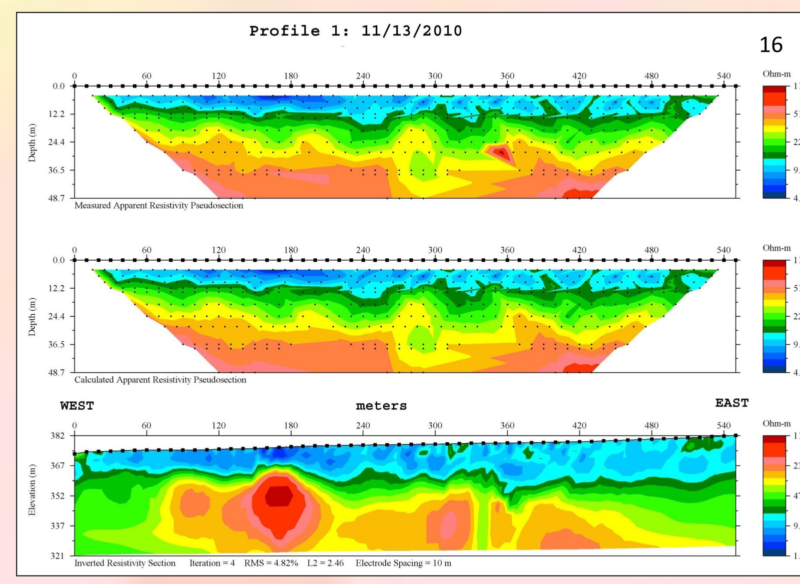
Figure 11: 9/14 Profile 4 dipole-dipole resistivity section. Profile crosses landfill border (45 m position). Leachate appears ponded in landfill, contained by dike. Vertical percolation is less severe than that inferred in Figure 10.

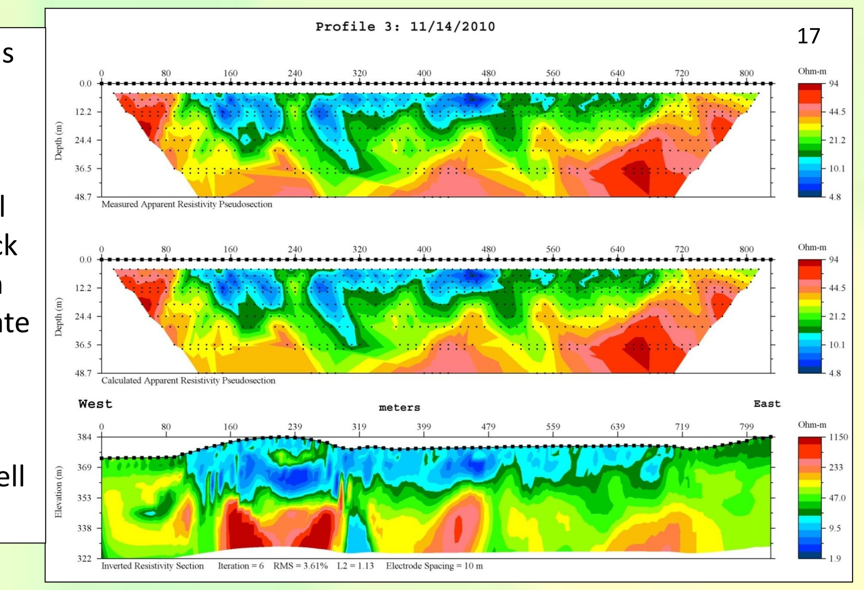
Figures 12 and 13 show a large landfill underlain by sand, gravel and sandstone. This landfill contains industrial and some hazardous waste in addition to solid waste. Cultural features prevent the effective use of geophysical methods commonly used to map underground leachate south of the landfill, the direction in which surface runoff drains. Each pair of crossing lines (Figure 13) represents one field day's effort by a team of 2 with a golf cart for transportation.





Figures 14 and 15: pseudosections of OhmMapper Profiles 1 (left) and 8 (right) (see Figure 12 for locations). West is on the left, depth in meters, horizontal coordinate in UTM East. Both show abrupt increase in apparent resistivity at edge of buried waste. Low resistivities attenuated signals, limiting depth of interrogation within the landfill.





Figures 16 and 17: pseudosections for dipole-dipole profiles 1 and 3 (locations shown in Figure 13). Profile 3 extends beyond the landfill, establishing a geophysical signature for uncontaminated rock and sediments. The only location where deep percolation of leachate appears probably lies under the 300 - 320 meter position under Profile 3 (right). In this case, the deep low resistivity anomaly is well sampled by data points.

Discussion: electrical resistivity (ER) was applied as a cost effective, non-invasive method for investigating subsurface conditions at several closed municipal waste landfills in Ohio that were releasing leachate and/or landfill gas to ground water. As part of ground water assessment activities, a conceptual site model (CSM) was developed to visualize landfill design, hydrogeological conditions surrounding the landfill, and the migration, extend and concentration of chemicals of concern in ground water. Electrical resistivity was applied to validate the CSM, and specifically to assess the thickness of waste and presence of liquids, along with the trench boundaries. These data were used to strategically target areas of interest for a subsequent intrusive exploration that included monitoring wells and potential areas for extraction wells to be completed as part of a corrective measures strategy. Pseudosections from the ER surveys were overlain onto existing geological cross sections and also referenced to data collected through the advancement of soil borings strategically located within the limits of fill.

The ER survey was conducted by selecting north-south and east-west profiles across the site (Figure 13). The 10-meter electrode spacing and 270-m cable spread length allows for an interrogation depth approaching 50 meters (about 150 feet). 35 soil borings were completed and 27 converted to 1-inch temporary piezometers to allow for the monitoring of leachate elevations and landfill gas within the limits of fill, and to assist in verifying interpretations from the ER survey. The findings of the ER survey were integrated into the CSM, and integration of data from all exploration efforts yields the following **conclusions**:

1. Geophysical signatures can clearly differentiate areas of fill relative to native non-fill areas of the landfill site as verified through advancement of soil borings.
2. Some apparent trench walls can be observed in geophysical pseudosections, suggesting some degree of separation of landfill cells.
3. Low resistivity values observed in many areas of the landfill suggested saturated waste, verified by soil borings.
4. Vertical variations in resistivity values were observed extending below the fill into native sediments, which may suggest vertical migration and/or mixing of leachate and ground water.
5. The base of fill could **not** be consistently mapped using ER. This might be due to the heterogeneous nature of buried waste and/or leachate (high total dissolved solids) or smearing (or weathering) as leachate interacts with underlying native sediments.