GEOPHYSICAL INVESTIGATIONS OF A GROUND WATER CONTAMINANT PLUME-ELECTRICAL AND ELECTROMAGNETIC METHODS

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INTRODUCTION

Electrical and electromagnetic geophysical methods are becoming increasingly accepted tools for the initial characterization of contaminant plumes from municipal and hazardous waste landfills (Greenhouse and Harris, 1983; Sweeney, 1984; Greenhouse and Williams, 1985). Successful geophysical plume mapping depends on a resistivity contrast between the plume and the ambient ground water and may substantially reduce the number of monitoring wells needed to determine the extent of contamination. This contrast is usually in the form of a resistivity low due to an increase in dissolved solids. The cost of sampling and analyzing for pollutants in ground water may also be reduced by the selection of appropriate tracer, or surrogate, compounds that represent groups of chemicals with similar fate and transport properties.

The aim of this study is to map the leachate plume from a hazardous waste landfill in the Georgia Piedmont using three ground geophysical methods: electromagnetic (EM) ground conductivity, direct current electrical resistivity, and very low frequency (VLF) electromagnetic. The reliability of the geophysical data is tested by sampling monitoring wells and homemade piezometers for a landfill constituent, tritium, which acts as an ideal tracer of leachate migration from the site.

LANDFILL HISTORY

The landfill (Figure 1), owned by the University of Georgia, is divided into two areas having separate histories. Area 1 was used prior to 1969 for the disposal of animal carcasses from radioisotope research. It received little or no chemical waste. Area 2 was used from 1969 until 1978 for burying waste solvents, organic compounds, pesticides, inorganic solids, acids and low-level radioactive waste consisting mostly of tritium and ^{14}C labeled compounds. Most of the tritium was in the form of tritiated water. Generally, radioactive waste was buried in the western half of Area 2 and chemical waste was placed in the eastern half. The site was operated within all state and federal guidelines in effect during the 1970's. Unfortunately, landfilling was state-of-the-art in waste disposal at the time.

Four monitoring wells were installed around the site in 1986 (Figure 1). Ground water was sampled and tested for 252 chemicals specified by the Georgia Environmental Protection Division (EPD). Monitoring wells W3 and W4 were found to contain a number of volatile organic compounds (VOC's) including benzene, toluene, xylene, chloroform, methylene chloride, as well as elevated levels of sodium, potassium, iron, and fluoride. These organic contaminants were also detected in the low-flow perennial stream northwest of the site. The Georgia EPD has ordered a Remedial Investigation of the site under the Resource Conservation and Recovery Act (RCRA). This study will commence in the Spring of 1989.

LOCAL HYDROGEOLOGY

The study area, in Clarke County, lies within the Inner Piedmont Belt of the southern Appalachians (Griffin, 1971). Information from monitoring well drilling logs and scattered outcrops indicate that bedrock in the area is predominantly a biotite gneiss. The gneiss is mantled by a saprolite layer of unknown, but likely quite variable, thickness. Relative amounts of clay, biotite, quartz, and feldspar in the saprolite are locally highly variable, as indicated by shallow hand augering during piezometer installation. Depth to the water table is about 27 feet at the lower edge of the landfill. Depth to bedrock is unknown.

Ground water in the Piedmont is stored mainly in the saprolite but may be locally concentrated in bedrock fractures, contact zones, fault zones folds, and shear zones (Cressler et al., 1983). Local hydraulic gradients around the landfill would generally be expected to be northward, approximating the surface topography. A perennial stream, normally a ground water discharge area in the Piedmont (Meinzer, 1949), begins flowing where marked on Figure 1, and empties into the Oconee River about one-half mile to the west. Except for the power line right-of-way, the area is forested.

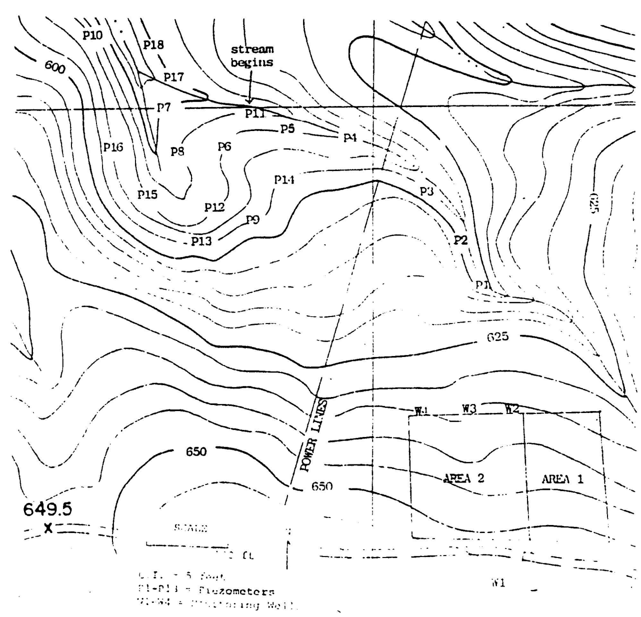

Figure 1. Topographic map of landfill vicinity.

GEOPHYSICAL SURVEYS

EM Ground Conductivity

An EM ground conductivity survey was done in the Fall of 1987 using a Geonics Ltd EM-34 instrument. The horizontal dipole (vertical loop) mode was used with 10- and 20-meter intercoil spacings and 10-meter station intervals. In this two-loop coplanar system the transmitter sends a signal which interacts with the subsurface materials to produce a secondary magnetic field. This resultant field is measured at the receiver, and the ratio of the secondary to the primary magnetic field is linearly proportional to the terrain conductivity at the low frequencies employed (McNeill, 1980). The use of the vertical dipole mode was precluded by the presence of high voltage lines.

Hand contoured data from the 20-meter intercoil spacing is presented on Figure 2, revealing a northwest trending anomaly. For horizontal dipoles, the effective depth of signal penetrtation is roughly 0.75 of the coil spacing and the maximum response is from the surface. The signal is attenuated more rapidly while passing through conductive media (McNeill, 1980). The 20-meter spacing allowed the signal to penetrate below the water table (35 feet at W1) throughout the field area. The 10-meter coil spacing data revealed no significant anomaly. The trend outlined in Figure 2 is presumably due to the response from electrolytic contaminants, such as sodium and fluoride ions, in the saturated zone.

Figure 2. EM ground conductivity contours (bold lines) superimposed on topo map. B-B' and C-C' are resistivity profile lines.

DC Resistivity Method

Direct current Wenner resistivity profiling of the area was performed in the spring of 1988. This method consists of injecting an electrical current into the subsurface through two outer electrodes and measuring the voltage drop across two inner electrodes. All four electrodes are separated by an equidistant A-spacing and are moved about a grid to yield data for preparing contoured resistivity maps. The resistance to the injected current is dependent on the A-spacing and on the geometry and electrical properties of the subsurface layers. For this reason, an apparent resistivity of the subsurface is calculated (Parasnis, 1979).

Wenner array profiling using 40-, 50-, 60-, and 70-foot A-spacings was done at 50-foot station intervals along five profile lines. The 60-foot A-spacing map (Figure 3) is representative of all four profile maps and shows a northwest trending anomaly similar to the ground conductivity map (Figure 2).

Pseudosections were prepared for profile lines B-B′ and C-C′ by stacking and contouring data from each A-spacing along these lines (Figure 4). The striped area in Figure 3 seems to illustrate the effects of dispersion as the plume moves northwest, but is not intended to represent the plume boundaries.

Very Low Frequency (VLF) Method

VLF electromagnetic measurements were made over the area in the summer of 1988, using an ABEM Wadi. This method relies on navigational transmissions from remote antennas which cause secondary fields to build up around conductive structures. It is used for locating vertical features such as fracture zones and geologic contacts as well as in contaminant plume mapping (Greenhouse and Harris, 1983). The ideal field method is to cross the target at right angles while tuning into a transmitter that lies along the strike of the target. Because the plume appeared to be traveling oblique to the expected hydraulic gradient, fracture control or a geologic contact was suspected. Unfortunately, crossing the target at right angles resulted in significant interference from the power lines.

Profile line 1401 (location on Figure 2) gave some indication of the presence of the plume. The real and imaginary value curves are presented in Figure 5. The similar shapes of the curves, together with the strong imaginary value component, indicate an anomalous increase in electrical conductivity with depth between profile distance points 108 and 171.

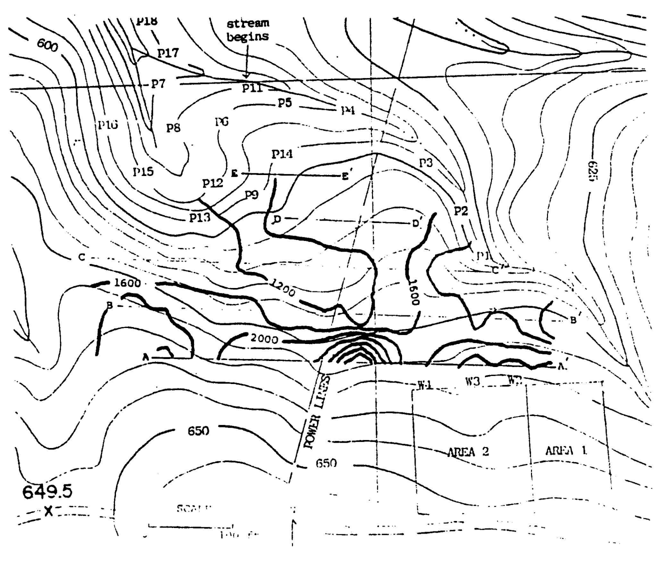

Figure 3. 60-foot A-spacing resistivity contours (bold lines) superimposed on topo map. Resistivity contour interval is 400 ohm-ft.

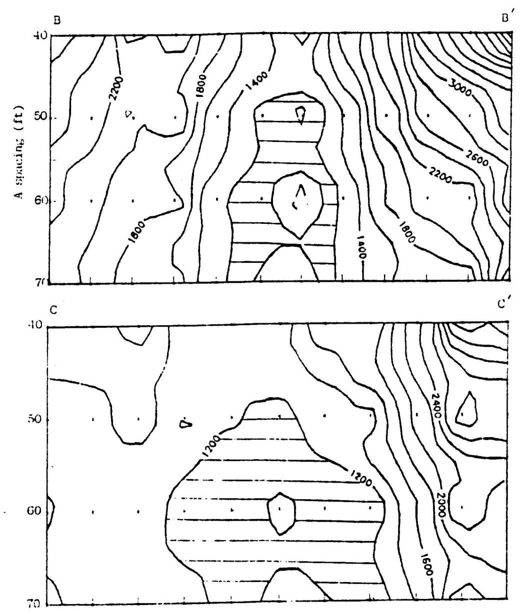

Figure 4. Resistivity pseudosections along B-B' and C-C'. Striped area is between 1000 and 1200 ohm-ft. contours.

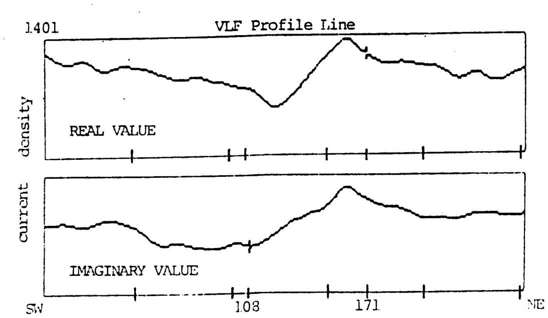

Figure 5. Current density along VLF profile line 1401.

TRACER STUDY

Ground water samples taken from piezometers and monitoring wells were tested for a representative landfill constituent (see Figure 1 for locations). Tritium was chosen because the leaching tritiated water acts as an ideal tracer of local groundwater flowpaths. Each sample was distilled, then placed in a liquid scintillation counter where beta emissions in the tritium energy spectrum were counted for 100 minutes. Stations marked ND on Table 1 were not significantly different from a blank standard at the 95% confidence level.

Locations with high tritium values also had noticeable organic solvent odors, as well as a coarser grained porous media and having more quartz than in uncontaminated areas. Testing for VOC's in the nearby stream showed highest levels of organics in surface water with the highest tritium activity.

Table 1. Tritium Activity (pCi/ml) in Ground Water.

location	activity	location	activity
W1	ND	P8	1.6
W2	ND	P9	15
W3	1.4	P10	0.7
W4	262.6	P11	ND
P1	ND	P12	1.9
P2	ND	P13	10.6
P3	ND	P14	1.9
P4	ND	P15	ND
P5	ND	P16	ND
P6	ND	P17	0.7
P7	8	P18	0.6

DISCUSSION

Ground conductivity and electrical resistivity surveying have provided a good indication of the direction of contaminant transport at the UGA landfill. The correlation between high tritium values and organic pollutants in ground and surface water indicate that the major flowpath of contaminants had been detected. This flowpath was not immediately evident from inspection of surface topography. VLF work will continue at the site to determine whether or not the power line effects can be minimized by walking parallel to the wires while tuning to a station perpendicular to them.

Ground conductivity measurements with the EM-34 provided rapid coverage with instantaneous display of conductivity curves in the field. Because electrical contact with the ground was not required, dry soil conditions did not affect signal penetration. However, cultural interference from power lines and metal objects, such as fences, introduced substantial noise. Because of the power lines in the study area, only the horizontal dipole mode could be used, and the power lines had to be crossed at right angles to minimize coupling between current in the wires and in the coils.

DC resistivity surveying was quite laborious, requiring at least three persons. Lack of rainfall, even during the late winter wet season, limited field time to just three weeks, after which the soil become prohibitively dry for establishing electrical contact. Forested areas were especially difficult to achieve good contact because of the thick litter and numerous roots. Resistivity surveys do not suffer the noise effects from overhead power lines, but electrical anomalies in the vicinity of the current electrodes will adversely affect measurements.

CONCLUSION

This study demonstrates the ability of surface geophysics to map a contaminant plume in the Georgia Piedmont. Success at this site was due to an increase in electrical conductivity of the contaminated ground water caused by an abundance of dissolved solids. Their suitability at other sites may be predicted based on knowledge of plume chemistry and associated electrical properties. As with many kinds of scientific investigations, more than one established method should be employed for better corroboration of results.

Ground conductivity surveys are rapid and may still be used when power lines are present. They should perform optimally where water tables are shallow but the signal can also penetrate to a deeper water table when the unsaturated zone is highly resistive. The Georgia Coastal Plain, with generally shallow water tables and sandy soil, would clearly be a more suitable environment for ground conductivity work than the Piedmont.

Conservative contaminants such as tritium or chloride ions, when present, should be employed as relatively inexpensive tracers for local ground water flow paths, thus providing additional preliminary information that may make better use of funds available for landfill studies.

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