Geophysical Prospecting for Oil and Gas Well Effluent

Paul F. Hudak and **George Maxey**

Introduction

Sand formations in the Cretaceous Trinity Group are an important source of groundwater in northern Texas. Thousands of oil and gas wells penetrate the unconfined outcrop zones of these formations, tapping underlying Paleozoic reservoirs (RCT, 1995). Saline water and drilling fluids from these wells are potential sources of surface water, soil, and groundwater contamination (Baker, 1990). In 1969, the Texas Railroad Commission prohibited the unauthorized use of saltwater disposal pits (RCT, 1993). However, pits used for drilling fluid and emergency salt water storage are still used during oil and gas production. These are also potential sources of environmental pollution (RCT, 1993). Efficient methods for detecting abandoned pits and past spills can enable the implementation of remedial measures to curtail environmental pollution. The objective of this study was to evaluate the utility of an earth resistivity system for detecting drilling effluent at a site in the Trinity Group outcrop zone.

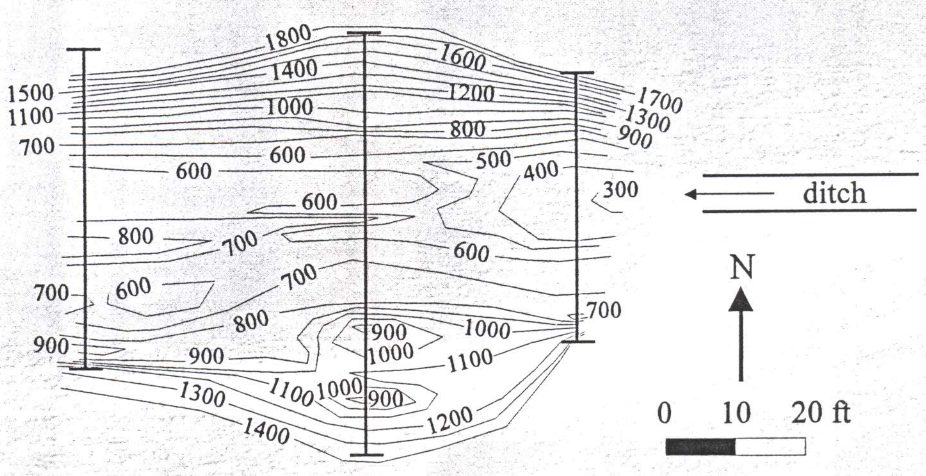

Figure 1. Apparent resistivity contours (ohm-ft).

Background

Electrical resistivity has been used in various prospecting, civil engineering, and environmental investigations. The method is advantageous because it yields useful information over a broad area at low cost, in a short amount of time, and without disrupting the subsurface.

In rock and mineral prospecting, lateral profiling has been used to locate faults, dikes, shear zones, veins, buried stream channels, and ore bodies (Zohdy et al., 1984; Telford et al., 1990). Applications of electrical resistivity to civil engineering include locating surface faults (Kreitler and McKalips, 1978), measuring depth of overburden, and evaluating structural properties of bedrock (Font, 1994). Environmental applications of the resistivity method include characterizing the layering of refuse in hazardous waste facilities (Carpenter et al., 1990; Westphalen, 1994), determining the location and properties of clay aquitards (Kalinski et al., 1993; Westphalen, 1994), and delineating zones of groundwater contamination (Subbarao and Subbarao, 1994; Ebraheem et al., 1997).

In this study, we used electrical resistivity to delineate a small area in the Trinity Group outcrop that was inundated by gas well drilling effluent. Alternative methods for surveying shallow brine contamination include measuring the salinity of soil samples in a laboratory, ground-based electromagnetic induction, and airborne methods (Paine et al., 1997). Collecting and measuring the salinity of soil samples is the most accurate method, but cost-prohibitive and impractical for surveying large areas of potential brine contamination. Above-ground, transmitter and receiver coils are employed during electromagnetic induction surveys. Electromagnetic surveys lack the resolution and depth penetration of resistivity surveys, but are relatively rapid and inexpensive (Zohdy, 1984). Airborne methods are more appropriate for surveying a broad region covering several square miles than detecting conductivity variations over a small area. They have been used to identify anomalies in ground conductivity, which were explored in greater detail with ground-based methods (Paine et al., 1997).

Methods

A Bison 2350B earth resistivity system was used to survey a grassy area below the mouth of an earthen ditch (Figure 1). The ditch was used to drain pits containing gas well drilling effluent. Near-surface deposits at the site include a thin layer of sandy loam soil and semi-consolidated fluvial sand. To detect areal variations in electrical resistivity, an identical electrode configuration was used at 73 measuring points. Each point coincided with the center of a Schlumberger array. The measuring points were spaced evenly, at 2-foot increments, along three linear transects (Figure 1).

In a Schlumberger array, there are two outer current electrodes and two inner potential electrodes, all of which are collinear and symmetric about the midpoint of the array (Zohdy et al., 1984). In this study, we employed a spacing of 5 feet between the current electrodes and 1 foot between potential electrodes. A small spacing was used to acquire information for near-surface deposits. At each station, an apparent resistivity (ρ_a) was calculated as

$$\rho_a = \frac{2\pi\Delta V}{I}\left(\frac{\overline{AB}^2}{8\overline{MN}} - \frac{\overline{MN}}{8}\right)$$

where I is the current transmitted between the outer electrodes, ΔV is the voltage drop across the inner electrodes, $\overline{AB}$ is the distance between the current electrodes, and $\overline{MN}$ is the distance between the potential electrodes. The earth resistivity instrument outputs a value for $2\pi\Delta V/I$. For the electrode configuration used in this study, the quantity in parentheses is equal to 3 ft. The calculated resistivity values were contoured to depict spatial variations across the site.

Results

Apparent resistivity values ranged from 318 ohm-ft near the middle of the east transect to 3090 ohm-ft at the northern end of the west transect. The highest value is representative of background conditions at the site. The ability of earth material within the survey area to conduct an electrical current was enhanced by saline effluent and clay sediment from the recirculation pit. Lower resistivity values correspond to more highly conductive materials, which would indicate an impact of salt water and drilling effluent.

Lower resistivity values were observed along an east-west axis, oriented collinear with the drainage ditch (Figure 1). This zone was probably inundated by a large fraction of the total volume that was discharged from the ditch. Much of the liquid and sediment settled near the mouth of the ditch, accounting for the low resistivity values which were observed in that area. In general, the resistivity values increased to the north and south of the east-west axis. Superimposed on that trend were small areas of anomalously high or low resistivity. For example, two low anomalies are apparent at the southern end of the middle transect.

Collectively, the apparent resistivity contours suggest that effluent drained out of the ditch, flowed along the east-west axis, and dispersed laterally. The lateral spreading was asymmetric, with greater inundation occurring to the south. Possibly, the resistivity anomalies were caused by subtle, local-scale troughs and ridges in the terrain. Respectively, these troughs and ridges would pool or disperse the liquid effluent, causing lower or higher apparent resistivity values. The anomalies are more common near the middle and west survey transects. Further from the source, slow-moving sheet flow in those areas would more likely be impacted by subtle topographic features.

At the western margin of the study area, it is apparent that the flow bifurcated into two smaller branches. This result is consistent with the site topography. West of the surveyed area, there is a small mound that separates two swales.

The entire survey was done by a two-person crew in approximately two hours. In comparison, it would take at least the same amount of time to collect 73 soil samples. At $100/sample, the analytical costs would be prohibitive. There would also be a lag time before obtaining the laboratory results. An airborne survey would be most expensive and not provide the level of detail in Figure 1. The cost for such a survey would be on the order of $10,000. Electromagnetic induction is the most competitive alternative to electrical resistivity for this study. An electromagnetic survey would take less time, but provide less detail than the electrical resistivity survey. Leased or purchased, electrical resistivity and electromagnetic induction devices provide real-time data and can be used repeatedly for environmental investigations.

Conclusions

Effluent from oil and gas wells is a potential source of soil and groundwater contamination in northern Texas. Brine and drilling effluent increase the ability of subsurface deposits to conduct an electrical current. Consequently, these liquids and their residues can be detected by electrical resistivity surveys. These relatively inexpensive surveys are a useful reconnaissance tool. In situations where oil and gas well effluent pose a major threat to water resources, resistivity surveys can be followed with conventional sampling and laboratory analysis methods to prioritize areas for possible remediation.

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Paul F. Hudak and George Maxey, P.O. Box 305279, Department of Geography, University of North Texas, Denton, Texas 76203-5279, (940) 565-4312, HUDAK@.UNT.EDU.

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