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GEOPHYSICAL SURVEYS INTEGRATED IN PREREMEDIAL SITE
INVESTIGATIONS FOR A LANDFILL IN NEW MEXICO

By

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ABSTRACT

Surface geophysical surveys were integrated in a preremedial site investigative program at a landfill in New Mexico belonging to the Bureau of Land Management. The purpose of this program was not only to conduct the investigation but also to establish a sound technical framework for future site investigations in that geologic and hydrogeologic setting. The emphasis was on identifying initial characterization procedures that would decrease the need for sampling and drilling on a random grid. A prior preliminary assessment and site investigation indicated the presence of some hazardous waste compounds but yielded contradictory information about the locations of trenches and pits.

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Geologic and site history models were generated to guide the selection of geophysical techniques to be used. Four different geophysical techniques and five different instruments were employed. This approach allowed different objectives to be addressed and different depth ranges to be explored. Moreover, when the existence of certain subsurface features was indicated by more than one technique, confidence in interpretation was enhanced.

Significant results of the program included the following: (1) previously unmapped trenches and pits were located, and boundaries of a known septage pit were altered; (2) the principal controls on subsurface pathways for contaminant migration were delineated; and (3) critical sampling locations were identified.

INTRODUCTION

It is not uncommon to begin preremedial site characterization with little information about the locations of contaminant sources and the detailed local geology, from which to infer potential pathways of migration. A phased site investigative program integrating (1) geologic and geophysical investigations to select optimal sampling locations, (2) sampling and analytical work, and (3) placement of monitoring wells can reduce time, cost, and intrusive activities. Analytical work and drilling are two of the most expensive and intrusive activities undertaken in preremedial characterization programs. The objective of this paper is to show through a case history from a preremedial site characterization

program for a landfill in New Mexico that geophysical surveys can decrease the need for sampling and drilling on a random grid. Prior preliminary assessments (PA) and site investigations (SI) were performed without the benefit of geophysical surveys, so an evaluation can be made of the benefits derived from including geophysics in an integrated program.

Important aspects of an effective geophysical program include the following:

1. The generation of sound geological and site history models. Such models are used to guide the selection of geophysical techniques and survey parameters.
2. The use of multiple surface geophysical techniques. The use of multiple techniques allows different objectives to be addressed and depth ranges to be explored. Moreover, confidence in inferring geological features or the locations of contaminant sources from geophysical data is enhanced when the inference is supported by more than one technique.
3. In-field (real-time) data interpretation by experienced technical staff. With in-field data interpretation, investigative programs can be altered or redirected to maximize their effectiveness and to better accomplish the objectives. Real-time interpretations generally require data acquisition in solid state memory loggers for transfer to

personal computers, versatile software for data analysis, and personnel experienced with the full range of geophysical methodologies.

4. An integrated approach to interpretation. Geophysical interpretations clearly must be consistent with all available geologic and drilling data. Proof of specific features must exist both in geophysical interpretations and in geologic mapping, sampling, or drilling.

SELECTION OF GEOPHYSICAL METHODOLOGIES AND RESULTS

The location of the landfill is shown in Figure 1. The Flora Vista Landfill is an inactive landfill previously operated in New Mexico by the Bureau of Land Management (BLM). It covers 13 acres and is a modified sanitary (not covered daily) landfill that was used from 1978 through 1989. During part of its operation, large quantities of petroleum, industrial, or other wastes were suspected to have been deposited in septage waste pits without authorization. The BLM authorized a PA in 1986 and an SI in 1987. These investigations yielded contradictory maps about the locations of trenches and pits. Analytical results from both the PA and SI programs indicated the presence of some hazardous compounds in one septage pit area of the landfill. On the basis of the PA and SI, operation of the landfill was suspended, and the landfill was covered with approximately 2 ft of sandy soil. The subsequent expanded site investigation is the focus of this case history.

The geologic information available prior to the expanded site investigation program consisted of regional geologic data and the visual inspection of several nearby outcrops. These outcrops indicated that the Tertiary Nacimiento Formation could be present as an erosional bedrock surface. The Nacimiento is a hard, lithified, fairly impermeable sandstone. It was difficult to predict the depth to bedrock under the landfill from regional information. In addition, the clay layers observed in the alluvium above the bedrock could be a common occurrence.

Thus, at the beginning of this program information about geology and disposal history was sparse. The landfill had been covered with 2 ft of sandy soil, fenced, and closed. In addition to the exterior fence, one interior area in the southwest corner had been fenced where a septage pit was supposedly located. Except for this area, no records indicated the locations of contaminants at the landfill site. As the first phase of the investigative program, a geophysical and surface mapping program was designed to address the following two major objectives:

1. To map the contaminant source areas (the trenches and pits)
2. To define geologic features controlling contaminant movement from these source areas (bedrock surfaces, clay lenses, surface drainage patterns, etc.)

Surface geophysical surveys were conducted with four techniques and five instruments. Table 1 summarizes the objectives and rationale for selecting these methods. Table 1 also lists the equipment employed,

the survey parameters, and references about the principles of operation.

Results of the electromagnetic (EM) surveys and the seismic refraction survey are given in Figures 2a, 2b, and 2c in the form of contour maps. The major inferences about locations of waste sources and pathways of contaminant migration were drawn primarily from these three maps. Total magnetic field data provided complementary information about the locations of solid waste trenches, but because the pits of interest were expected to be conductive rather than magnetic, total magnetic field measurements were less diagnostic than EM-31 measurements for locating these source areas. In addition, because of rapid lateral changes in ground resistivity, the interpretation of vertical resistivity stratification from direct current soundings was not considered reliable.

INTERPRETATION AND SELECTION OF SAMPLING AND DRILLING LOCATIONS

The burial of wastes invariably causes changes in physical properties (e.g., electrical conductivity, magnetic susceptibility, seismic velocity), but such changes can also occur naturally because of lateral and vertical changes in soil types, depth to bedrock, and other geologic conditions. To identify buried wastes from surface geophysical measurements requires distinguishing between variations due to local geology and those with human causes. Integrating interpretations of results obtained by several geophysical techniques and instruments can

assist in making that differentiation, as is illustrated by the following discussion.

The three contour maps have in common an anomalous area in the NE corner of the site. This anomalous area is manifested by apparent conductivities in excess of 100 millimhos/m for both the EM-31 and EM-34 recordings and by bedrock elevations above 5,840 ft above MSL, derived from the seismic refraction lines. The logical interpretation for the high apparent conductivities is the presence of clay layers overlying the bedrock surface which occurs at shallower depths in the NE corner. Figure 3 shows the computed dependence of EM-31 and EM-34 readings on the depth to a clay layer. In these computations, realistic values of conductivity for near-surface alluvium and clay were used. The variation in apparent conductivity values in the background, caused by variation in the depth to the clay strata across the site, is predicted to be larger in the EM-34 apparent conductivity contour map than in the EM-31 contour map, for clay at a depth of more than 5 m below the surface. Another difference between the two apparent resistivity contour maps is that with the EM-31, reliable measurements can be made within 5 m from metallic fences. Fences influence EM-34 measurements within about 15 m. Therefore, no reliable measurements could be made with the EM-34 within the interior fenced area. In the EM-34 contour map, the interior fenced area is blanked.

Because of the interferences with the EM-34 data discussed above, more reliance was placed on the contour conductivity map derived from EM-31 surveys. Areas of anomalously high apparent conductivity values

where buried wastes were expected are labeled with capital letters on Figure 2a. Several areas are indicated both by EM-31 and EM-34 high apparent conductivities, strengthening the evidence for their existence (Figures 2A and 2B). Area D is indicated only by the EM-31 apparent conductivity map. In this area a septage pit was supposedly located. The area was enclosed by an interior fence. The boundaries of the anomalous high-conductivity area D, however, extend well beyond the fence line. The EM-31 data imply that burial was shallow.

The relative shallow depth to bedrock (15-45 ft below the surface) was not predicted from regional geologic information. Because it was believed that this impermeable surface might play an important role in unsaturated flow from the trenches and pits, a comprehensive seismic refraction survey was conducted within and immediately around the landfill. The bedrock elevation contour map in Figure 2c shows the bedrock surface to have valleys and depressions. Potential subsurface flow paths are superimposed on the contour elevation map.

The data on source areas and potential migration pathways were combined to prioritize sampling locations. Source areas and potential subsurface migration pathways were derived from the geophysical survey results discussed above. Surface migration paths were generated by topographic mapping. Figure 4 summarizes the source areas (with a combination of magnetic and electromagnetic data), the subsurface migration paths inferred from the bedrock elevation map (Figure 2c), and surface migration pathways derived from topographic maps. Sampling and soil boring locations selected on the basis of these results were to test

for movement or leaching of materials without drilling into a trench or pit in the first phase of the program. This precaution eliminated the possibility of introducing contamination into the subsurface by drilling through such waste locations. The sampling locations are shown in Figure 4.

The only pit area drilled was the fenced area indicated by an anomalously high apparent conductivity measured by the EM-31 (Area D, Figure 2a). The accuracy of prediction of all the trenches and pit boundaries, better than ± 5 ft, was primarily constrained by station spacing (10 ft). None of the other sampling locations, purposely placed outside trenches or pits, intercepted buried petroleum product waste. The depth to bedrock was predicted by the seismic refraction survey to an accuracy of ± 7.5 ft. The geologic model derived from an integrated program of geophysical surveys, sampling and analytical work, and drilling along a cross section through the septage pit in the interior fenced area is given in Figure 5. Above the cross section the apparent conductivity values recorded with the EM-31 are shown. Drilling confirmed that the septage pit extended well beyond the interior fence and basically conformed to the shape predicted by the EM-31. However, drilling and sampling demonstrated no evidence for lateral or vertical migration of contaminants from this pit. The clay layer, inferred to be continuous from the EM-34 apparent conductivity measurements, would retard vertical migration.

CONCLUSIONS

The value of geophysical surveys to the preremedial site investigation program can be assessed by comparing conclusions about contaminant sources and leachate migration derived from prior PA and SI programs conducted without geophysical surveys and the preremedial site investigation program described here in which geophysics was extensively employed. During the SI programs two drill holes, WB2 and WB1 (Figure 5) were placed to investigate the septage pit. One drill hole was placed inside the interior fenced area, and one was drilled just south of the fenced area. Because contaminants were encountered in both drill holes and because the interior fence was accepted as the pit boundary, the conclusion of previous contractors was that lateral and vertical migration of contaminants had occurred.

Without the ability to map the boundary of the pit from the EM-31 apparent conductivities and the ability to derive depth to bedrock from seismic refraction data, considerable time and effort would have been expended with intrusive programs to arrive at the geologic and contaminant source model derived in the present study and shown in Figure 5.

In the overall investigative program, surface geophysical surveys were used to prioritize sampling and drilling locations and to provide continuity in subsurface information between sampling and drilling points. The use of multiple geophysical techniques and iterative interpretational logic as new information was added to the database provided a higher

degree of confidence in predictive quality. Geophysical interpretations were verified by sampling and drilling so that proof of specific features (waste trenches and pits, clay layers, bedrock) exists.

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ACKNOWLEDGMENTS

This work was supported by the State of New Mexico Bureau of Land Management through interagency agreement YA651-1A9-34002 with the

U.S. Department of Energy. The New Mexico BLM staff provided assistance in the field and critically reviewed the documents generated.

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Jacqueline C. Burton received a Ph.D. in geology from the University of Tennessee in 1978. She worked for Exxon for eight years in minerals research after completion of her Ph.D. During her employment with Exxon, Dr. Burton led numerous research programs emphasizing the integration of geology, geochemistry, and geophysics in understanding the origin of uranium and epithermal gold deposits. Dr. Burton joined Argonne National Laboratory in 1986 to develop environmental programs emphasizing the integration and application of all geological disciplines in remedial characterization and design. She was principal investigator for the landfill study reported in this paper.

Lyle D. McGinnis has 36 years of experience in environmental geophysics and geology. He joined Argonne in 1985 and there has been involved in environmental geology and geophysical studies throughout the United States. Former positions include professorships and chairmanships at two universities and work with state and federal surveys; the Desert Research Institute; the University of Nevada; the United Nations Development Program in Kabul, Afghanistan; National Science Foundation in Antarctica; and Carter Oil Company in the Rocky Mountain region. He has more than 100 publications and has served as the senior advisor on more than 20 graduate student theses.

John Walker received his Ph.D. in 1964 in geology and applied geochemistry at Imperial College of Science and Technology, London, England. He has spent a large part of his career as a consultant to major mining companies, government agencies, and the United Nations. He has been in the forefront in the development and application of field geochemical techniques to advance geologic and hydrogeologic studies. During the past five years, he has been involved in a number of environmental studies in which he has applied his extensive knowledge of surface conditions to the integration and interpretation of geology, geochemistry, and geophysics.

Pieter Hoekstra holds an M.Sc. degree from McGill University and a Ph.D. from Cornell University. He has been involved in the application, testing, and development of geophysical methods to groundwater, engineering, and resources exploration. He is a member of the SEG and the AGU and is a Certified Ground-Water Professional of the NWWA. He is currently president of Blackhawk Geosciences, Inc.

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Table 1
Geophysical Methods Selected for
Preremedial Site Characterization at Flora Vista Landfill, New Mexico

Method	Equipment	Survey Parameters	References	Rationale For Use
Electromagnetic induction profiling (EM)	Geonics EM-31 Geonics EM-34	Line spacing, 40-ft Station spacing, 10 ft for EM-31, 20 ft for EM-34	McNeill (1990)	<p>With the EM-31 and EM-34 lateral variation in ground conductivity can be mapped with good lateral resolution and high survey productivity. Effective exploration depth with the EM-31 is about 12 ft; it is about 50 ft with the EM-34 at 20-m coil separation and horizontal dipoles. Utility of ground conductivity arises from the following facts:</p> <ul style="list-style-type: none"> • The replacement of native soils by wastes or the introduction of wastes in native soils generally changes conductivity. • Leachates of total dissolved solids (TDS) increase conductivity, so that major TDS plumes can be traced. • Soil types can be identified by characteristic ranges of conductivity.
Direct current (DC) resistivity	ABEM Terrameter plus booster	Soundings with Schlumberger array	Ward (1990)	With DC resistivity soundings, vertical conductivity stratification in the subsurface can be evaluated, and, e.g., the presence of clay layers determined.
Magnetic surveys	EDA PPM 500	Measurements of total magnetic field, 10-ft station spacing, 40-ft line spacing	Schlenger (1990)	Certain waste types contain ferromagnetic materials such as cans, drums, and bedsprings. Other wastes do not (e.g., sludges). Measurements of magnetic field, therefore, may allow detection of waste trenches and pits and some classification of waste type.
Seismic refraction surveys	EG&G Geometrics 1225	10-ft and 50-ft geophone spacing, reverse shooting, General Reciprocal Method of Analysis	Lankston (1990)	Seismic refraction surveys were used to determine depth to bedrock. Bedrock elevations placed a lower limit on depths of pits and trenches and might control subsurface contaminant migration pathways.

List of Figures for:

**"Geophysical Surveys Integrated in Preremedial Site
Investigations for a Landfill in New Mexico"**

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- Figure 1: Location map of Flora Vista Landfill in New Mexico.
- Figure 2a: Apparent conductivity contour map of Geonics EM-31 with vertical dipoles.
- Figure 2b: Apparent conductivity contour map of Geonics EM-34 at 20 m coil separation and with horizontal, coplanar dipoles.
- Figure 2c: Contour map of bedrock elevation derived from seismic refraction survey.
- Figure 3: Computed influence of depth to clay layer on apparent conductivity readings with Geonics EM-31 (vertical dipoles) and EM-34 at 20 m separation and horizontal coplanar dipoles.
- Figure 4: Integrated interpretation map derived from different geophysical surveys and mapping of surface topography.
- Figure 5: Hydrologic cross-section through septage pit (see Fig. 2a for cross-section location). Above the cross-section, the relative response measured with Geonics EM-31 is shown.

LOCATION OF CROSS SECTION

← Direction of Subsurface Drainage

- Magnetic Anomalies
- EM 31 Anomalies
- EM 34 Anomalies
- Sampling Locations
- Surface drainage
- Subsurface Drainage
- Surface drainage Divide

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