EXTREMELY FAST IP USED TO DELINEATE BURIED LANDFILLS

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Abstract: Determining the location of old, poorly documented buried landfills has become a significant concern in many places where development is hindered. Today new methodology provides a means for the efficient acquisition of induced polarization and resistivity data. Case studies of six landfills verified the accuracy of the technique and the acquisition speed of the system. At all sites, IP anomalies (> 3 milliseconds) correspond to solid waste verified by drilling and trenching.

Introduction: While induced polarization (IP) is a well-established minerals exploration tool, it has historically been too expensive for most environmental applications. In the past, research has indicated that some buried landfills exhibit an IP effect, but studies have been limited by the fact that IP data are relatively slow and expensive to acquire relative to other geophysical methods such as magnetics or conductivity. New equipment, including multi-channel receivers, computer-controlled multiplexers, and 2-D smooth-model inversion processing now allow very fast, high resolution IP acquisition, resulting in significantly less expensive data sets. A large, statistically significant amount of data has now been acquired over a variety of buried landfills, confirming the correlation between buried waste and IP effects. In delineating landfills, the IP method often has significant advantages over several other geophysical methods, including greater flexibility in depth of investigation than ground penetrating radar and better vertical resolution than most existing conductivity systems. In addition, since the IP effect does not appear to depend on large metallic objects, the IP method has been successful at delineating buried, non-metallic waste that could not be detected with a magnetometer. As a result, the IP method has become our method-of-choice in landfill mapping projects, particularly when thickness of soil cover and thickness of waste are of concern to our clients.

Landfill Database: Our conclusions are based on work at six different buried landfills, all of which are in the vadose zone. Depth to groundwater is substantially deeper than any of the landfills, although perched water is known to exist seasonally in at least one of the landfills. The work to date includes the following:

Number of landfills studied:	6	
Total number of survey lines:	248	
Total number of stations:	18,635	
Total length of line coverage:	41,822	meters
Total area of coverage:	49.2	hectares

Interpretation and verification of the survey results is supported by 145 borings and trenches. At some sites, trenching had been done prior to the surveys, while numerous borings were performed after the surveys to confirm the geophysical work.

Equipment and Methodology: Although other systems and arrays were also used, the vast majority of the data were acquired in the dipole-dipole array, using 4.57 m (15.0 ft) dipoles with station spacings of 2.29 m (7.5 ft). Readings were made at 12 n-spacings for each dipole, from n=0.5 to n=6.0 at 0.5n increments. This array provided a large amount of high-resolution data for 2-D inversion modeling. Measurements were in the time domain, using a 50% duty cycle square wave signal with a repetition rate of 0.5 Hz. Thirteen time slices were measured, and each measurement consisted of 8 cycles stacked and averaged. Each measurement was also repeated at least once to establish repeatability of data blocks.

In order to increase survey speed and reduce survey costs, a computer-controlled multi-channel system was used. The receiver acquired data on 13 channels simultaneously, corresponding to 12 receiver dipoles (12 n-spacings from a given transmitter dipole), and one channel devoted to monitoring and recording the transmitter. A spread of 30 electrodes was connected to a multiplexer switching unit, which was controlled by a laptop computer. This allowed very fast, automated switching of transmitter and receiver dipoles along the 30-electrode spread. The transmitter was a battery-powered, voltage-controlled transmitter, capable of up to 400v output. Electrodes were tin-coated copper braids, approximately 0.3 m in length. Along lines, each spread of data overlapped the prior spread by 50% of the spread length to ensure consistently deep coverage. This overlap also provided additional repeatability checks.

In the configuration described, data acquisition time for each spread was approximately 20 minutes. During data acquisition of one spread, the field crew prepared the next spread; a field crew of three or four people is able to acquire data on 16 to 22 spreads in a typical 10 hour field day. This corresponds to approximately 580 to 790 meters of coverage per day.

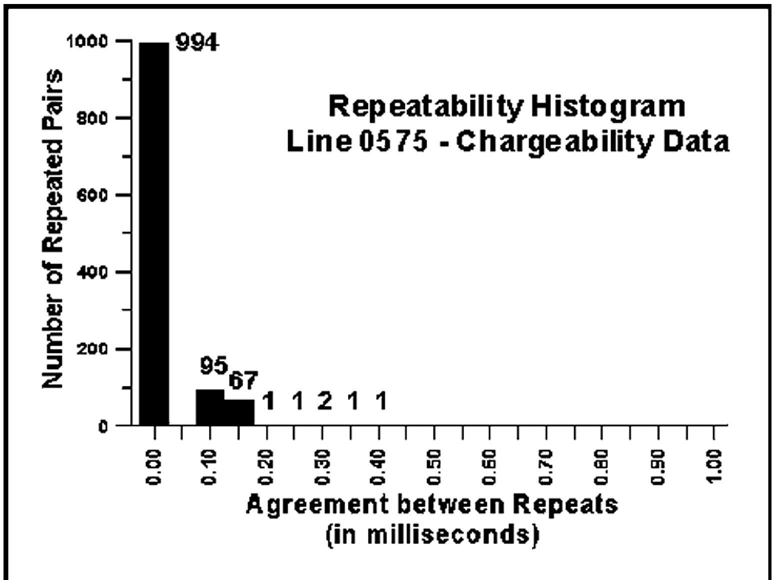

Figure 1

Data Quality: With recent improvements in electronics, the data quality and repeatability were extremely good. For example, Figure 1 shows a histogram of the agreement between repeated measurements along a line at the Los Reales Landfill, which is an active landfill in Tucson, Arizona, USA. Of the 1,162 data points along this line, the chargeability measurement on more than 99% of the data points repeated within 0.25 milliseconds. This excellent repeatability allows valid interpretation of very weak features, which has proven to be important in landfill delineation. Similarly, resistivity data along the same line repeated within 0.2 per cent at more than 99% of the data points.

Data Examples: A comparison of data over a typical background area and an area subsequently proven to contain buried waste is shown in Figures 2a and 2b. Both lines of data are from the Rio Nuevo North Landfill project area in Tucson, Arizona, USA, and these lines are approximately 425 meters apart. Figure 2a shows the IP and resistivity cross sections (2-D smooth-model inversion results) for the background area (called Line 180). All IP values are less than 2 milliseconds, and resistivity data are relatively layered. In Figure 2b, however, an IP anomaly is clearly evident in the central portion of Line 450, and this area has since been confirmed as buried waste with approximately 3 meters of soil cover. Note also that the resistivity data are very irregular, and are not layered similar to Line 180. Historical photographs from the 1950s and 1960s of the Line 450 area indicate numerous pits and excavations from gravel operations.

This relationship between subsurface characteristics (background, buried waste, disturbed areas) and IP/ resistivity data has been relatively consistent throughout all the landfills we have studied. Undisturbed background areas tend to show very small or no IP effects (<1 or 2 milliseconds) with layered or homogeneous resistivity. Disturbed areas with no subsurface waste tend to show very small or no IP effect also, but irregular resistivity (laterally and vertically). Areas of subsurface waste show well-defined IP anomalies (>3 milliseconds) and irregular resistivity. Thus both data sets are important in locating the subsurface waste and reconciling the geophysical data with historical records.

A more extensive example of our results can be seen in the complete Rio Nuevo North Landfill case history. This site, covering approximately 9 hectares, provided a very interesting test of the IP method. Records of dumping activities were very poor, the area was extensively excavated at various times for sand and gravel operations, and the area had been haphazardly cleaned to a depth of approximately 5 meters during the 1980s. Thus there are numerous back-filled pits, some of which contain soil and some of which contain waste, and waste was suspected to be under more than 5 meters of cover in some areas. Portions of the site, which is in an urban environment, have already been developed, and the geophysical survey was intended to characterize the remaining, undeveloped lots.

Rio Nuevo North
Lots 1, 2, and 3
Line 180

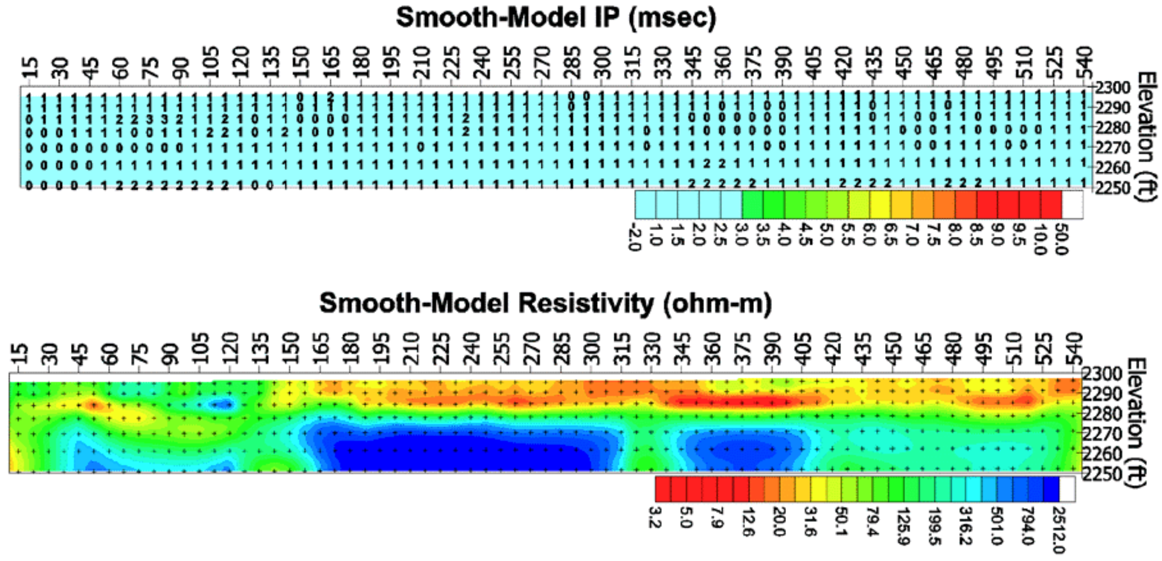

Figure 2a

Rio Nuevo North
Lots 17 and 18
Line 450

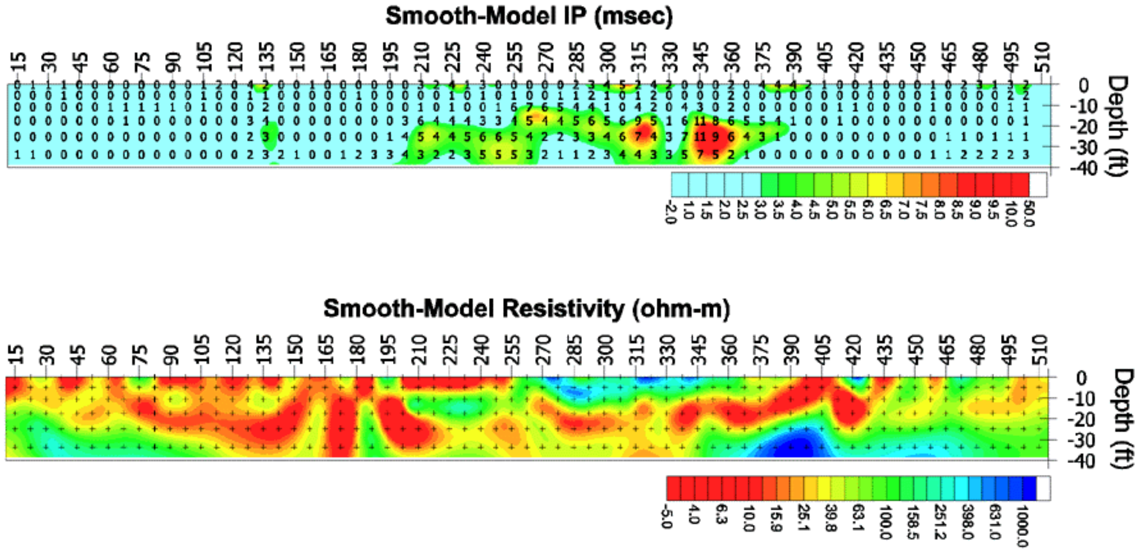

Figure 2b

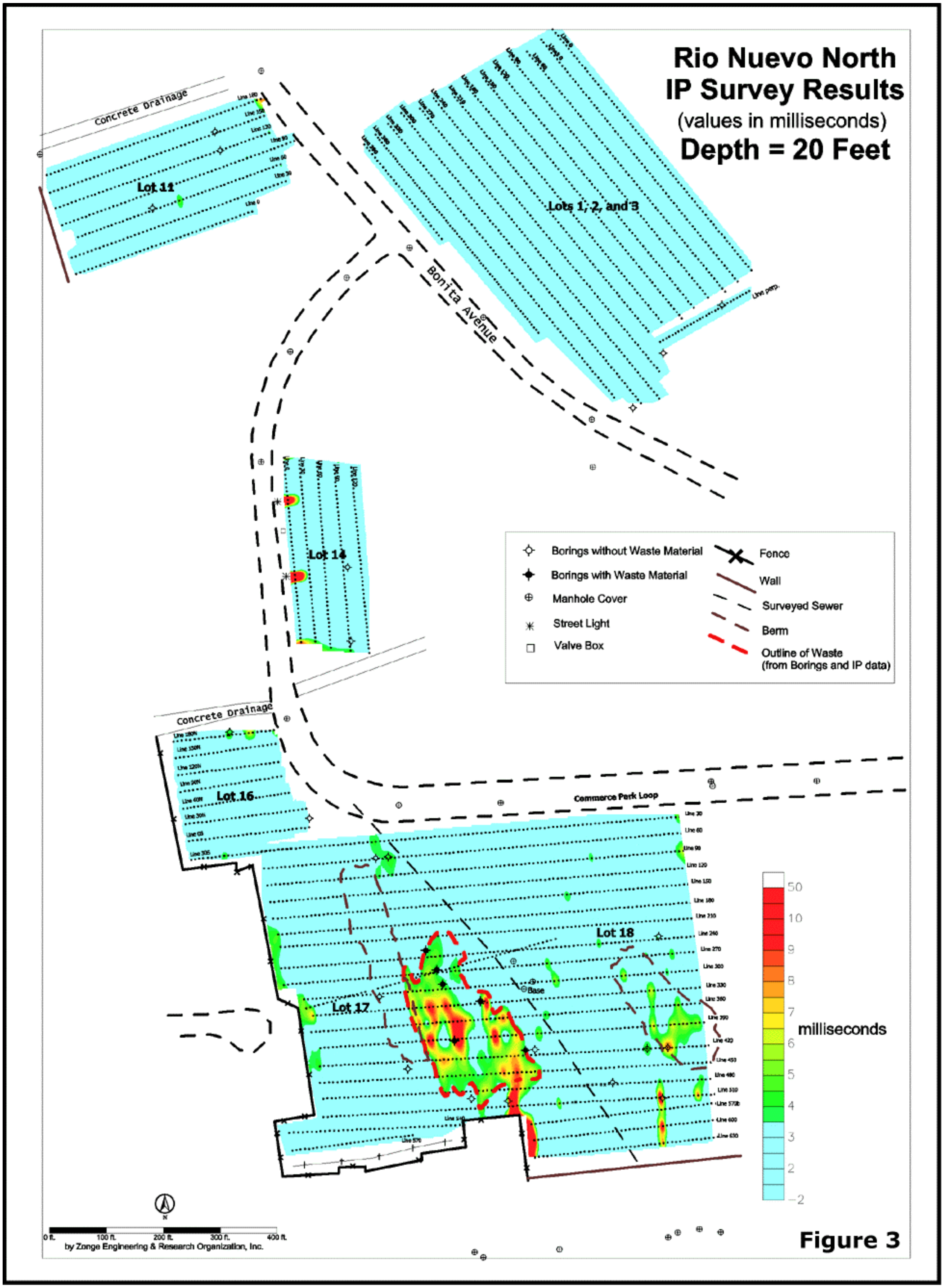
Rio Nuevo North
IP Survey Results
(values in milliseconds)
Depth = 20 Feet
Concrete Drainage
Lot 11
Lots 1, 2, and 3
Bonita Avenue
Line perp.
Lot 14
Concrete Drainage
Lot 16
Commerce Park Loop
Lot 17
Lot 18
Base
Borings without Waste Material
Borings with Waste Material
Manhole Cover
Street Light
Valve Box
Fence
Wall
Surveyed Sewer
Berm
Outline of Waste (from Borings and IP data)
50
10
9
8
7
6
5
4
3
2
-2
milliseconds
0 ft.
100 ft.
200 ft.
300 ft.
400 ft.
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Figure 3

Figure 3 shows the IP results (2-D smooth-model inversion) in plan view for the entire site at a depth of 6.1 m (20 ft). These results are comprised of more than 14,000 data points at 3,767 stations along lines that were spaced 9.1 meters (30 ft) apart. IP anomalies attributed to waste were evident only on Lots 17 and 18, on the southern part of the site. Figure 4 shows the grid of data in more detail on Lots 17 and 18, with the interpreted waste outlined with a red dashed line. (Note that the interpreted outline of the waste is from the IP data at all depths, thus there is a slight discrepancy between the IP anomaly in Figure 4 at a depth of 6.1 meters and the outlined waste.) Subsequent borings confirmed the outline of the waste based on the IP data, as well as the thickness of soil cover (>4.5 meters for most the anomalous area). Some borings were positioned very close to the edge of the anomaly to verify the resolution of the IP data, and in all cases the IP data were confirmed.

Outside of the anomaly attributed to waste, several other anomalous areas were identified. In some cases, these anomalies could be attributed to other cultural features; the linear anomaly in the southeastern part of the grid on Figure 4 is interpreted to be an old utility line, for example. A weak, shallow anomaly near the northwestern edge of the Figure 4 grid was drilled, but no waste was evident. This anomaly, and a small number of other small features, are attributed to possible clays or unknown cultural features.

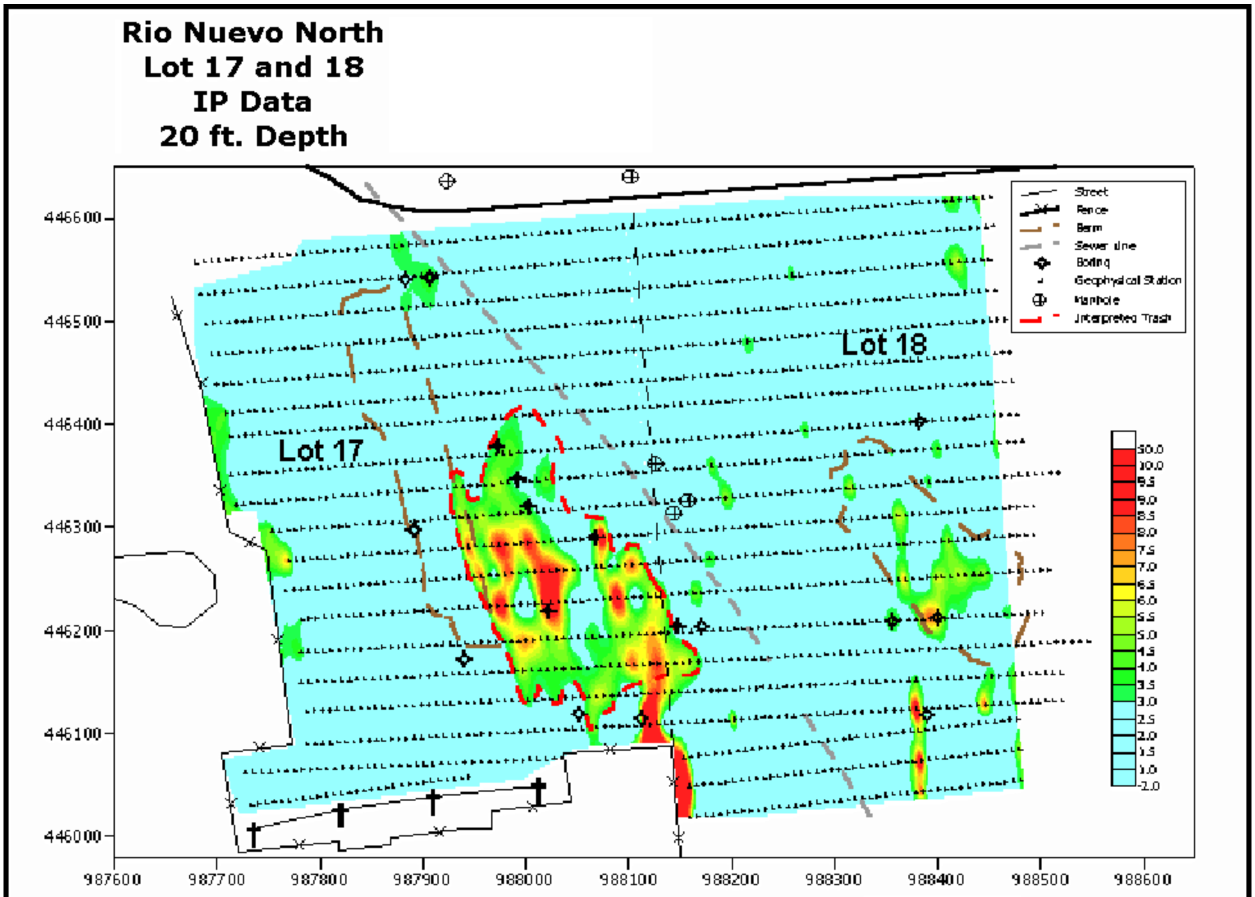
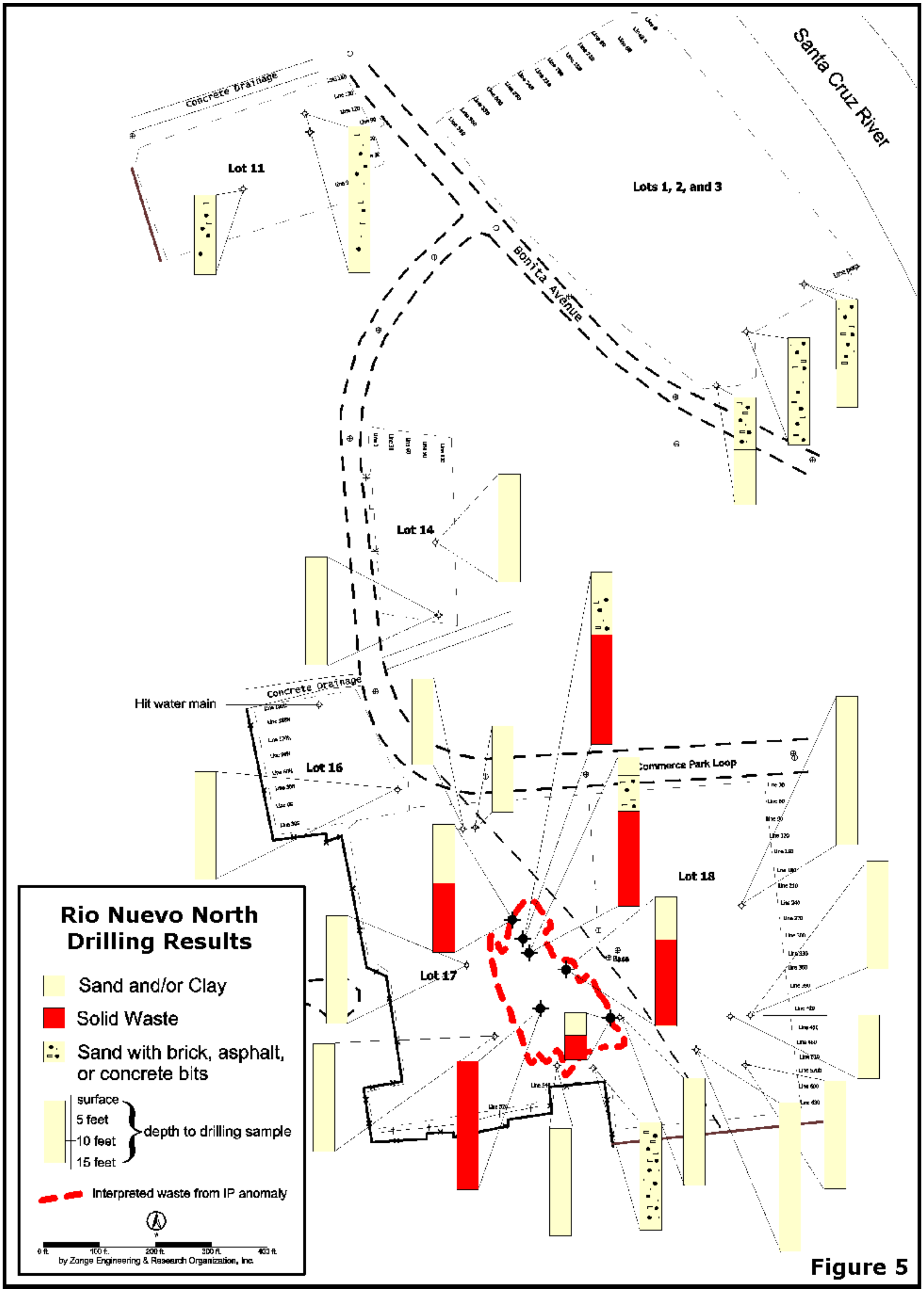


Figure 4


Rio Nuevo North
Drilling Results
Sand and/or Clay
Solid Waste
Sand with brick, asphalt, or concrete bits
surface
5 feet
10 feet
15 feet
depth to drilling sample
Interpreted waste from IP anomaly
0 ft
100 ft
200 ft
300 ft
400 ft
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Santa Cruz River
Concrete Drainage
Lot 11
Lots 1, 2, and 3
Bonita Avenue
Lot 14
Concrete Drainage
Hit water main
Lot 16
Commerce Park Loop
Lot 18
Lot 17
Base

Figure 5

Drilling results for the entire site are summarized on Figure 5. All borings within the outline of the waste interpreted from the IP data did encounter waste. Several borings were positioned specifically to test areas likely to contain waste (based on historical records) but that showed no IP anomalies. For example, three boreholes were located on the southeast edge of Lot 3 because subsurface waste had previously been encountered during the construction of a restaurant adjacent to that lot. Drilling on the edge of Lot 3 did not encounter any waste, however, confirming the interpretation of the IP data. Similarly, none of the boreholes that were drilled in areas that showed background IP values (<3 milliseconds) encountered waste, regardless of the historical expectations.

After the location of the waste had been delineated by the IP survey and confirmed by drilling, the area was also surveyed using a magnetometer and a boom-style conductivity system (EM-31). Since no significant metal was encountered in the drilling, the magnetometer was not expected to delineate the subsurface waste. Only minor anomalies resulting from surface metal objects were evident in the magnetometer survey.

The results of the conductivity survey (vertical coil orientation) are shown in Figure 6. There is no correlation between the conductivity results and the subsurface waste, probably due to the depth of the waste and the disturbed nature of the area as a whole. The conductivity results do agree relatively well with the 2-D smooth-model resistivity results (Figure 7), as expected, although the conductivity results fit best with the resistivity data at depths of 10 to 14 feet. This is somewhat shallower than expected, based on the coil orientation of the system.

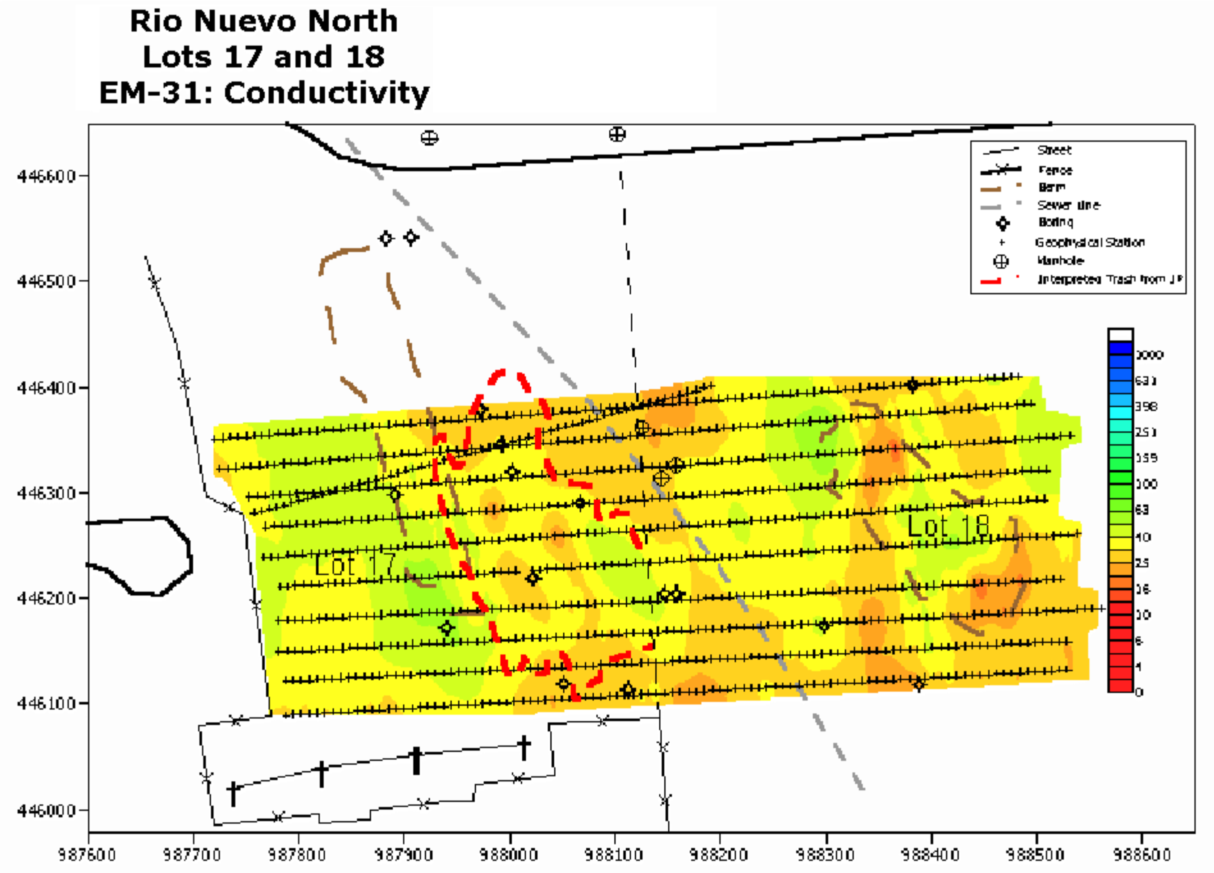

Figure 6

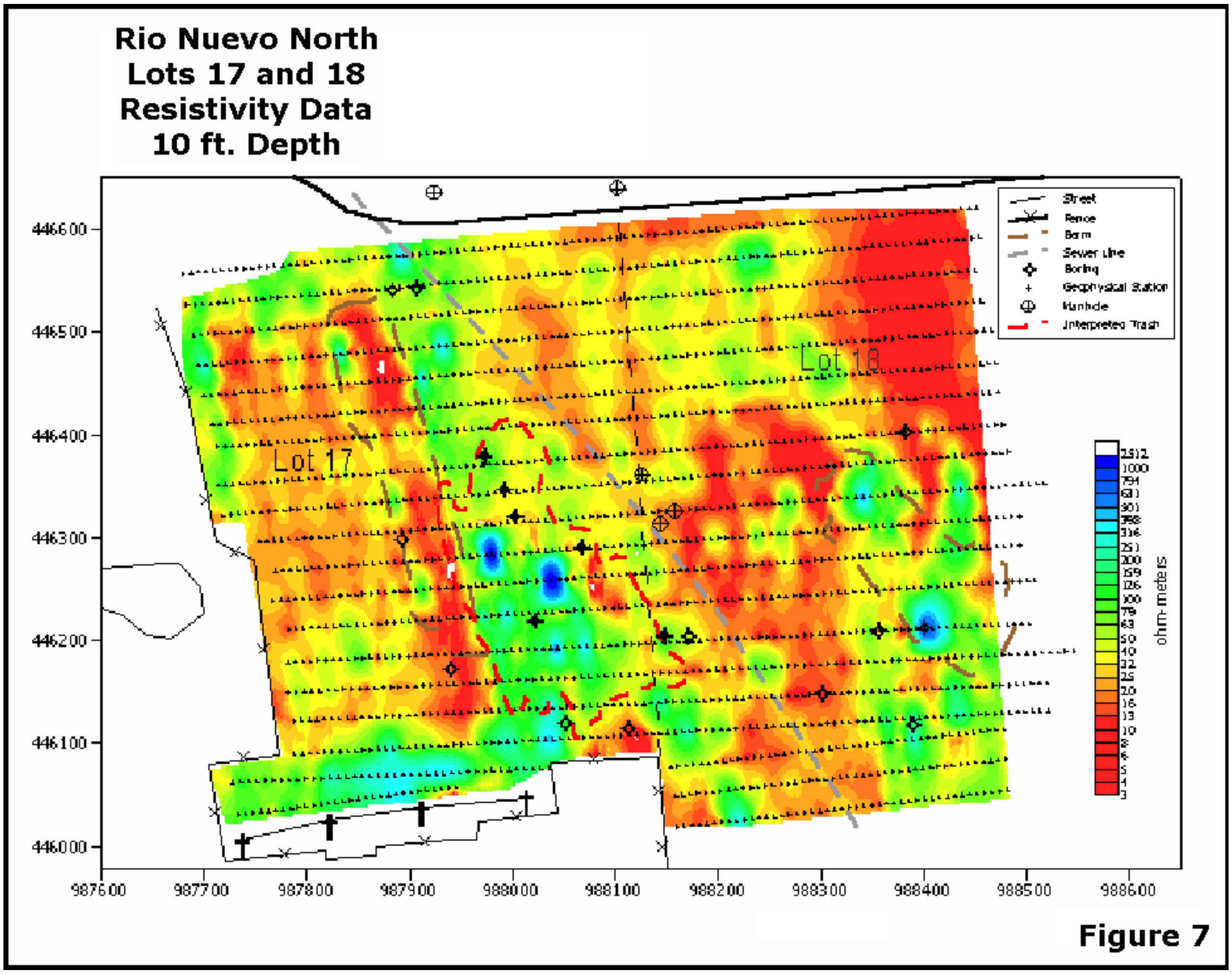

Figure 7

Five other landfills have shown similar results, with IP anomalies consistently associated with buried subsurface waste. These landfills contain primarily municipal solid waste (household garbage), green waste (organics such as branches, wood, clippings, etc.), and some construction waste. At only one site was a significant amount of metal encountered in the borehole, indicating that the IP response can not be attributed solely to metallic debris.

<u>Conclusions:</u> A large amount of data, with a significant number of confirmatory trenches and boreholes, indicates that buried waste material produces a measurable IP effect. Although the source mechanism(s) of the IP effect has not yet been established, it is evident that the IP response is not solely the result of metallic debris in the waste.

In the research to date, this IP effect has been shown to be a more reliable indicator of subsurface waste than other geophysical methods such as conductivity or magnetics, and the depth of investigation of the IP method is significantly deeper than ground penetrating radar. With recent improvements in equipment allowing very fast data acquisition, the IP method is now an economic, non-intrusive method for determining the thickness of soil cover as well as the thickness of waste in buried landfills. Research continues into using the IP method for differentiation of types of waste.