COMPARISONS OF IP AND RESISTIVITY DATA AT SEVERAL OLD, BURIED LANDFILLS

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Abstract

While resistivity and conductivity continue to be two of the most common methods used for mapping old, buried landfills, we continue to encounter sites where the resistivity contrast between the landfill and the background material is either non-existent or inconsistent. Several recent examples are presented, including two landfill pits located just 2500 feet apart. Based on boring results, at one of the landfills both resistivity and induced polarization (IP) data clearly delineated the waste boundaries, but at the other landfill, in the same geological background material, resistivity (and conductivity) failed to delineate the waste while there was a clear, well-defined correlation between IP effects and waste. The location and volume of waste would have been severely misjudged had we relied on resistivity or conductivity in advising the environmental firm tasked with evaluating the property.

Introduction

Although IP effects were measured over a landfill thirty years ago (Angoran, et. al., 1974), IP surveys have not been applied regularly to landfill studies due to the difficulty and expense of acquiring good quality data. During this time, resistivity and its inverse, conductivity, and magnetics (in cases where significant amounts of ferrous metal are present) have been the traditional "tools of choice" for buried landfill mapping. With improvements in field equipment and inversion modeling, however, during the last few years we have been able to acquire both resistivity and IP data at several dozen landfills during projects for various environmental firms and government entities. In this paper, we summarize several general results based on these surveys, with specific examples comparing resistivity and IP data.

General Survey Goals and Results

Figure 1 shows the locations of 15 of the landfills in the metropolitan Tucson area where we have acquired both IP and resistivity survey data. Our generalized conclusions are based on these surveys, in addition to numerous other surveys in other states. In almost all cases, the projects consisted of grids of lines or many intersecting lines crossing the target areas; in a few cases, however, the surveys included only one or two research lines and those interpretations are fairly limited as a result.

The geophysical surveys had several different goals at these landfills. In some cases, the geophysics was used to help target monitor wells where contamination was known or suspected to exist. In other cases, the goal was simply to verify the presence or absence of waste and determine the volume of waste for estimating remediation costs.

For the most part, the data were acquired in the dipole-dipole array in the time domain, using a repetition rate of 0.5 Hz. Readings were usually made at 12 n-spacings, most often from 0.5n to 6.0n at 0.5n increments to provide good lateral resolution in the 2D inversion modeling. Dipole sizes varied from project to project, but usually ranged from 15 feet (4.57m) to 30 feet (9.14m), depending on depth of investigation necessary to meet the project goals. In order to acquire the data economically, a computer-controlled 16-channel receiver was used in conjunction with a 30-channel multiplexer to allow very rapid, low-cost data acquisition.

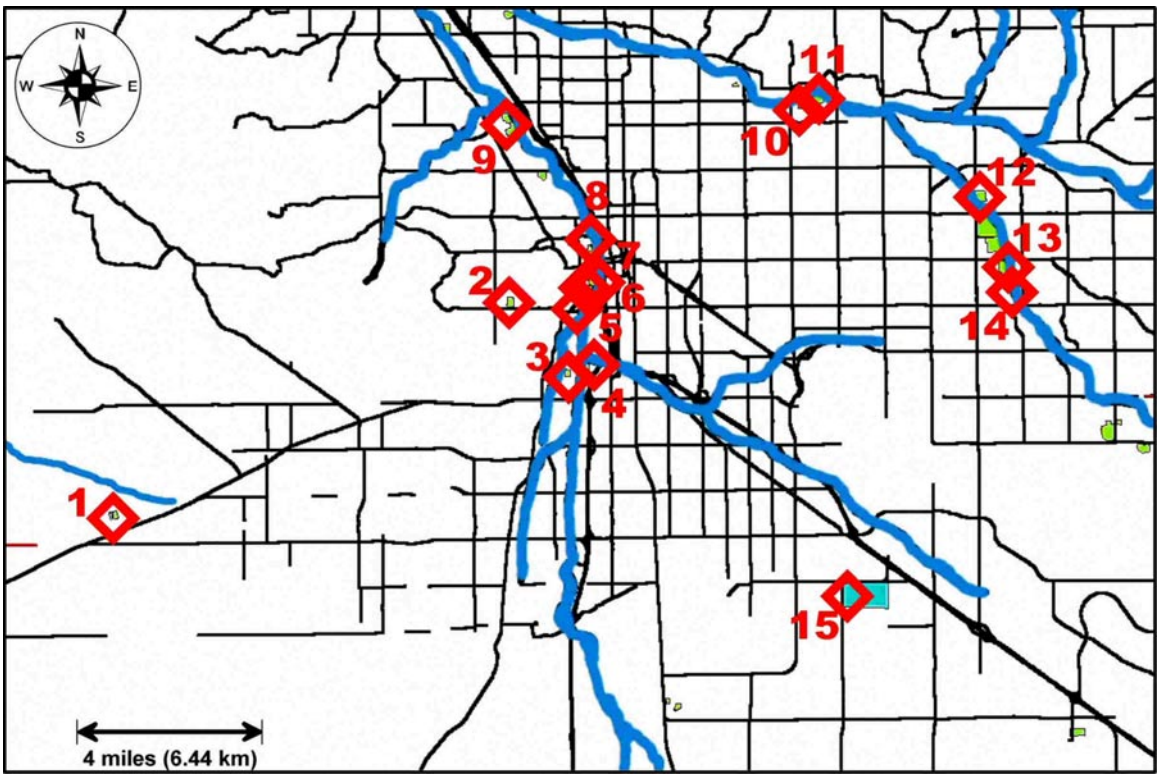

Figure 1: Map of metropolitan Tucson area showing the locations of major streets (black), major drainages (blue) and buried landfills where IP and resistivity data have been acquired (numbered red diamonds).

One interesting result of these projects is the realization that the measured IP effects are not primarily the result of metal in the waste. IP effects are evident in areas found to contain very little metal, and are clearly evident over landfills used for "green waste" (landscaping waste such as trees and vegetation cuttings). Recent research indicating measurable IP effects from wood (in both the laboratory and in the field) seems to confirm this finding (Thierry, et.al., 2001), and our own anecdotal evidence from borings seems to suggest that plastics are one of the sources of IP anomalies in landfills (Carlson, et.al., 2001).

Of particular interest is the result that resistivity data are substantially less definitive in delineating waste than we expected, with far more ambiguity in the interpretations than the IP data. In one case, discussed below, two landfills located relatively close to each other (2500 feet apart, or 760 meters), adjacent to the same major drainage channel, and both containing municipal solid waste, exhibited different resistivity contrasts relative to background material. At one site, resistivity results

accurately located the buried waste; at the other, no anomalous values relative to background (either high or low) were evident where waste was present.

Comparisons of Resistivity and IP

The Ryan Air Field landfill (site number 1 on the map in Figure 1) is a one good example of the contrasting results of resistivity and IP over buried waste. A total of 19 survey lines were run across this landfill; Figure 2 shows the IP (top) and resistivity (bottom) results for Line 6 from this project. The IP data show elevated IP values associated with the waste, in contrast to the very uniform, near-zero background values outside the buried pit. Resistivity data show neither a well-defined high nor low resistivity feature associated with the waste or pit, however.

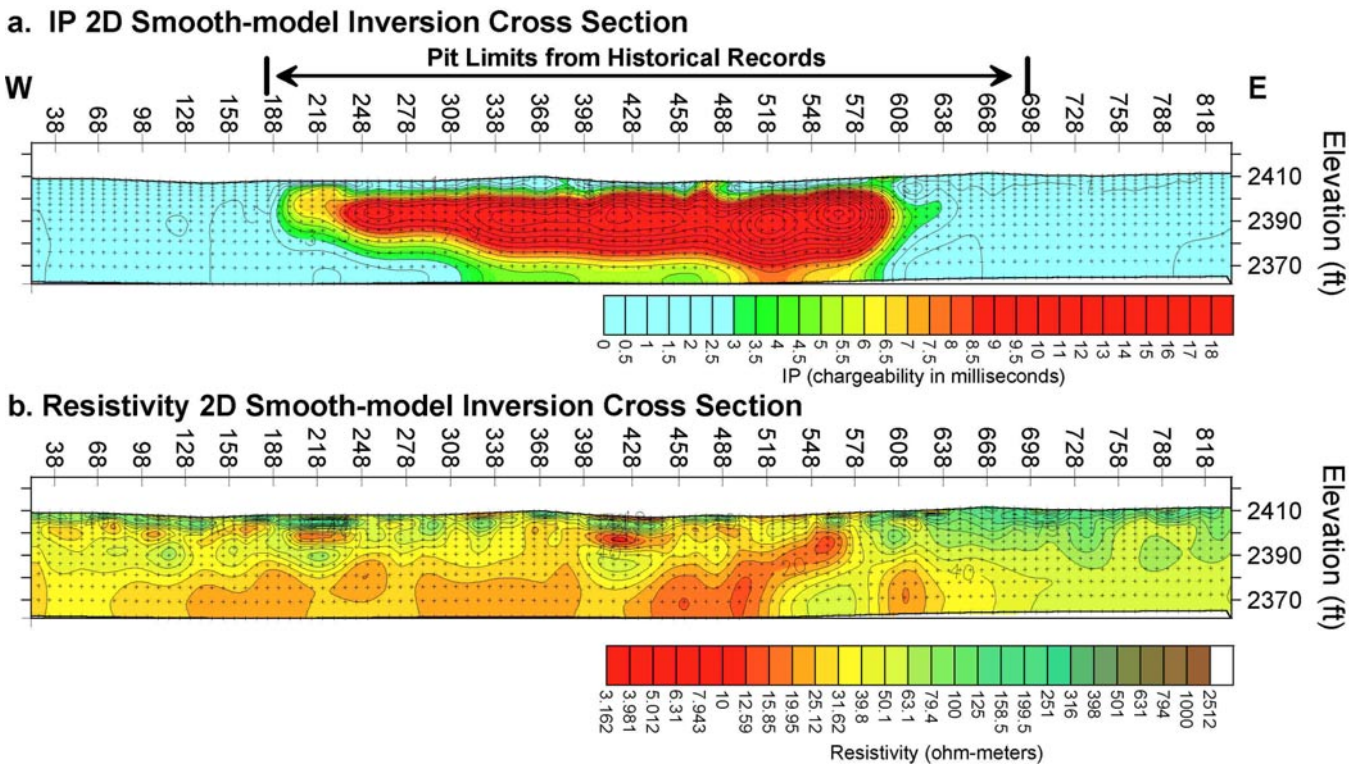

Figure 2: Survey results for Line 6 at the Ryan Air Field Landfill. Vertical exaggeration of both plots is 1.5 to 1. Station numbers are in feet. a.) IP results; contour interval is 1 millisecond. b.) Resistivity results; logarithmic contour interval.

The geophysical survey at the Ryan Air Field landfill was used to assist in placing deep monitoring wells. The objective was to place the wells as close as possible to the waste without actually intersecting waste, in order to avoid introducing a new pathway for contaminants emanating from the landfill. Figures 3 and 4 show the survey results in plan view at a depth of 30 feet, with the locations of the four subsequent monitor wells (labeled A, B, C, and D). Based on the IP results (Figure 3), it was actually possible to place monitor wells A and B within the limits of the known excavations (heavy dashed green lines) without intersecting waste. Note however, that the resistivity results (Figure 4) are far more ambiguous, and well placement would have been very different. For example, the well-defined

pocket of waste evident due east of monitor well B in the IP data is not evident at all in the resistivity data. Had we used the resistivity data for site selection, we could have easily mistaken this part of the excavation area as being clean, and inadvertently drilled into the waste.

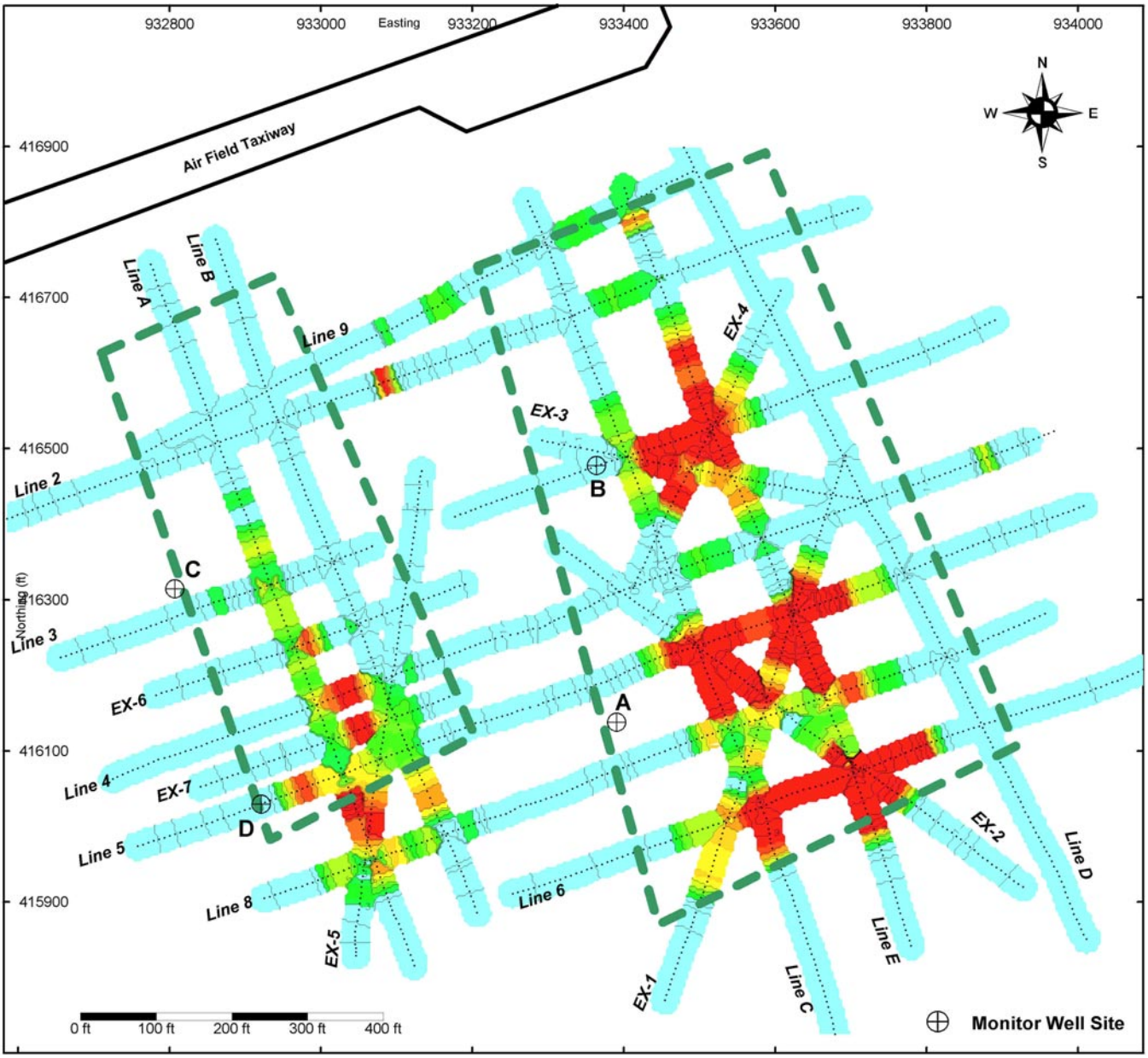

Figure 3: Plan view of IP survey results at the Ryan Air Field landfill at a depth of 30 feet. Color shading is the same as in Figure 2. Heavy green dashed lines indicate outlines of excavations from historical photographs.

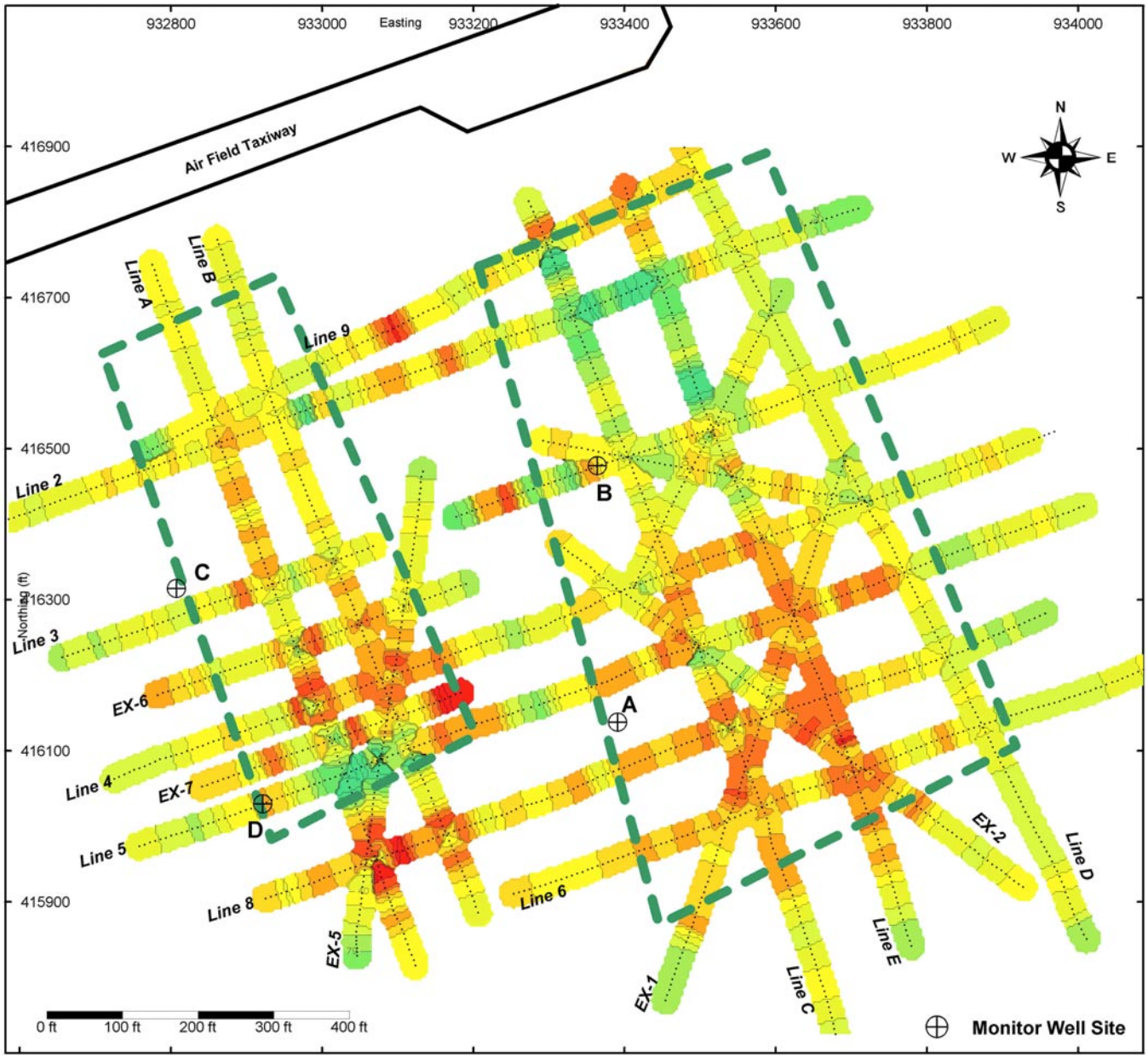

Figure 4: Plan view of resistivity survey results at the Ryan Air Field landfill at a depth of 30 feet, for comparison to the IP results in Figure 3. Color shading is the same as in Figure 2.

A second, similar example is shown in Figure 5, from the Tumamoc Landfill (site 2 on the map in Figure 1). Good correlation is again seen between the elevated IP response and the known location of the buried waste. The resistivity data present a very different picture, however. A broad, strong low resistivity area, which could easily be mistaken for a typical landfill resistivity anomaly, is seen west of the waste, where no waste is present. Based on the seven lines of data acquired at the Tumamoc landfill, it appears that the low resistivity feature is actually a pre-dump drainage path or structural feature that is acting as a conduit for contaminants. In this case, the IP data accurately maps the landfill waste, but the resistivity data are providing important information regarding fluid flow.

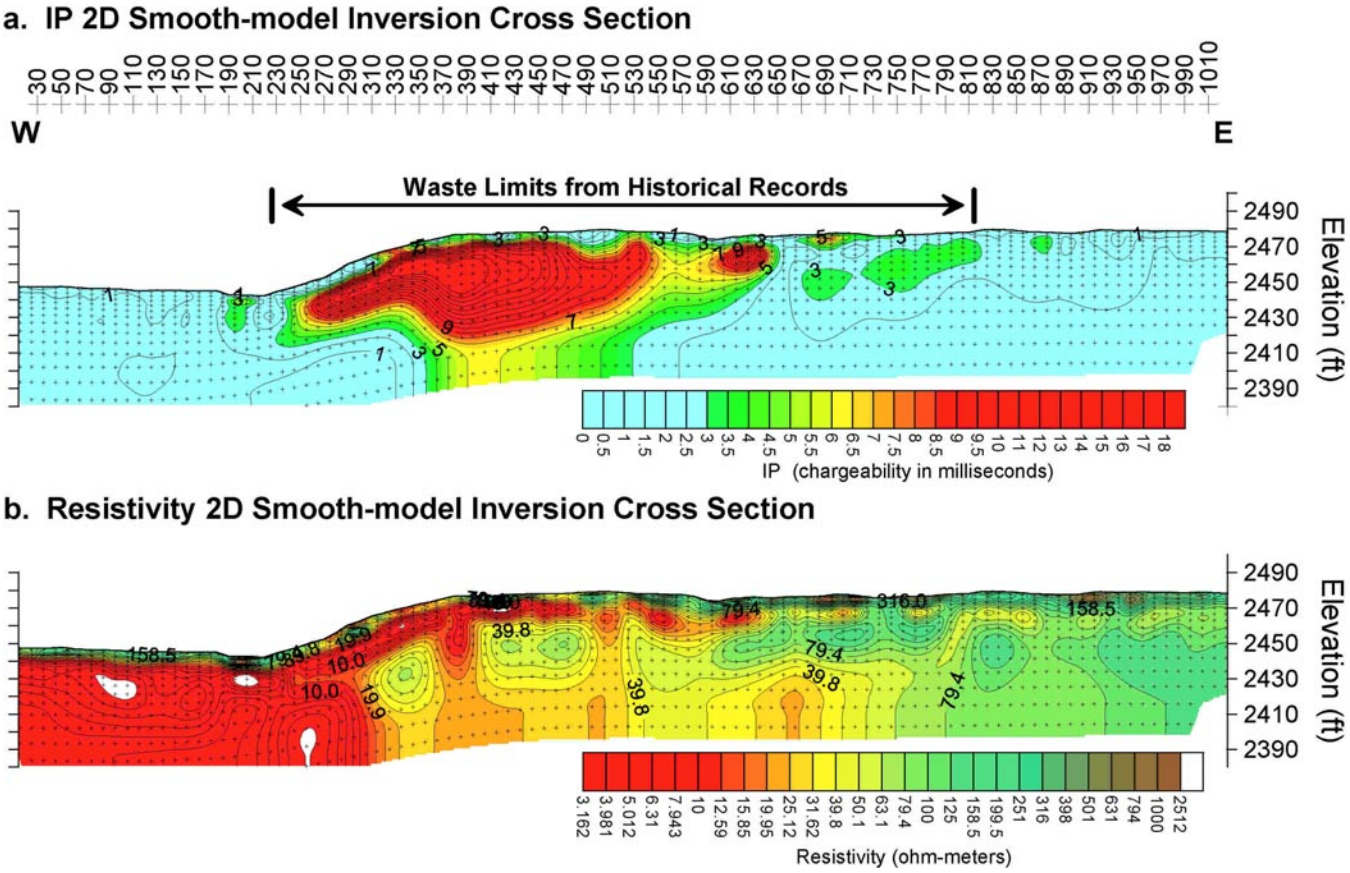

Figure 5: Survey results for Line A at the Tumamoc Landfill. Vertical exaggeration of both plots is 1.5 to 1. Station numbers are in feet. a.) IP results; contour interval is 1 millisecond. b.) Resistivity results; logarithmic contour interval.

Sites 7 and 8 on Figure 1 represent the Nearmont landfill (part of the Rio Nuevo South landfill) and the Rio Nuevo North Landfill, located approximately 2500 feet from each other, both adjacent to the Santa Cruz River. Both sites were formerly gravel and clay quarries, and both were used by the City of Tucson for disposal of solid waste at approximately the same time (Rio Nuevo North: 1960-1971, Rio Nuevo South: 1960-1967). Given the very close proximity, similar environment, and similar histories, the expectation would be that the two sites would be similar in survey results. Figure 6 shows one of the survey lines from the Nearmont landfill; this line is similar to the other 17 lines at this site, in that both resistivity and IP are in very good agreement with the location of the buried waste.

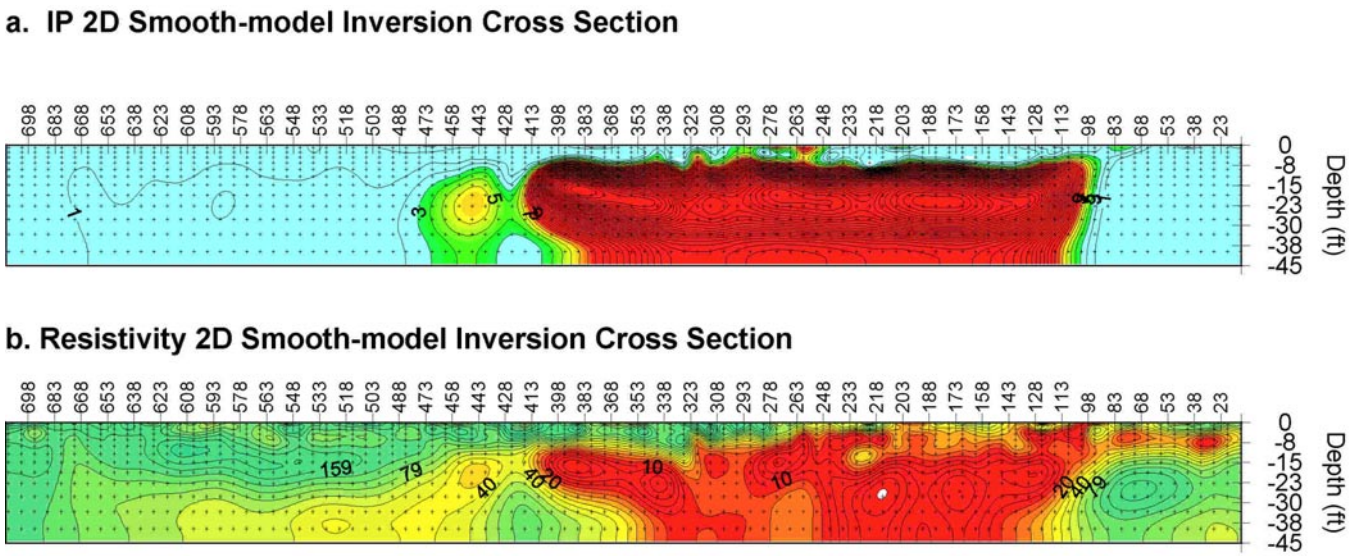

Figure 6: Survey results for Line O at the Nearmont landfill. Vertical exaggeration of both plots is 1.5 to 1. Station numbers are in feet. a.) IP results; contour interval is 1 millisecond. b.) Resistivity results; logarithmic contour interval. (Same color scales as Figure 2.)

However, this relationship does not hold true at Rio Nuevo North. Figure 7 shows the plan view results of 19 lines of data at a depth of 20 feet. The interpreted outline of waste based on the IP data at all depths is shown as a red dashed line, and these waste limits were subsequently confirmed by numerous boreholes. Figure 7a shows the IP data, and Figure 7b shows the corresponding resistivity data. The resistivity data show a large low resistivity feature west of the IP anomaly; two different boreholes tested this anomaly, but no waste was encountered. This resistivity low appears to be a pit that has been back-filled with sand and soil, but not waste. Clearly the solid waste at Rio Nuevo North is not identifiable at all in the resistivity data, even though the nearby waste pits at Nearmont were clearly delineated. Fortunately, waste at both sites exhibited well-defined IP effects.

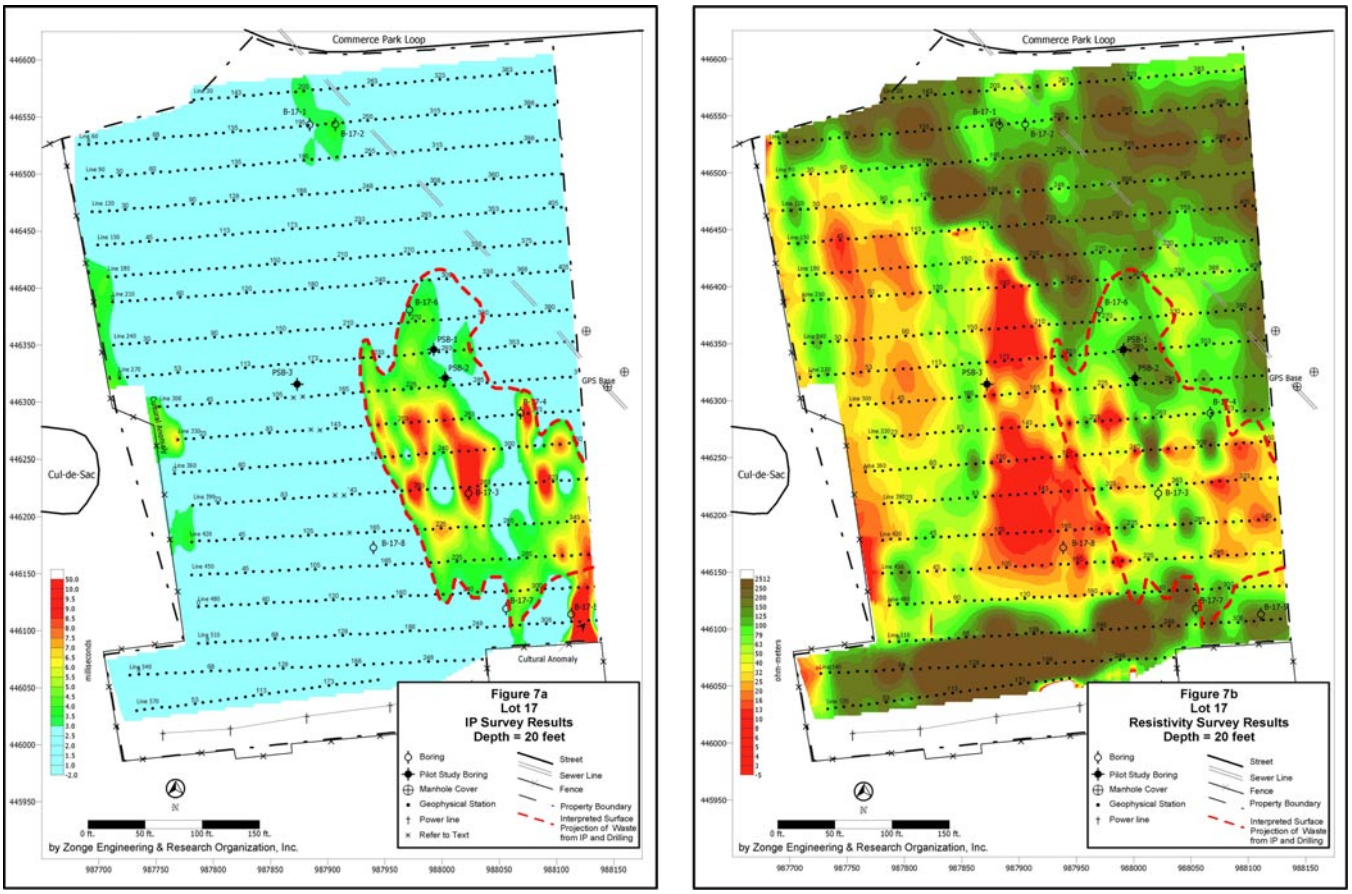

Figure 7: Comparison of plan views of IP and resistivity 2-D smooth-model inversion results at a constant depth of 20 feet (6.1m) at the Rio Nuevo North landfill. The outline of buried waste (shown by the red dashed line) was subsequently confirmed by numerous boreholes. (from Carlson and Zonge, 2003)

Conclusions

Given the relatively large amount of data we have now acquired over old buried landfills, several general impressions about these types of surveys have changed. We have found that resistivity (and conductivity) are far less consistent in delineating waste than we previously thought, but that IP is a far more useful tool than expected. It also appears that the IP effects evident over landfills are not solely the result of metallic debris in the landfill, but that there are likely several other source mechanisms, including wood and possibly plastics. As a result, we now strongly recommend combined IP and resistivity surveys for landfill delineation.

References

Angoran, Y.E., Fitterman, D.V., and Marshall, D.J., 1974, Induced polarization: a geophysical method for locating cultural metallic refuse", *Science,* 21 June, vol. 184, pp. 1287-1288.

Carlson, N.R., and Zonge, K.L., 2003, Minerals exploration methods modified for environmental targets, *Exploration Geophysics*, Australian Society of Exploration Geophysicists, V 34, #1/2, pp114-119.

Carlson, N.R., Hare, J.A., and K.L. Zonge, 2001, "Buried Landfill Delineation with Induced Polarization: Progress and Problems", Proceedings of the Symposium on the Application of Geophysics to Environmental and Engineering Problems (SAGEEP), Environmental and Engineering Geophysical Society), March, 2001, Denver, Colorado.

Thierry, B., Weller, A., Schleifer, N., and Westphal, T., 2001, Polarisation effects of wood, 7th Meeting, Environmental and Engineering Geophysics, Birmingham, England, Proceedings.

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