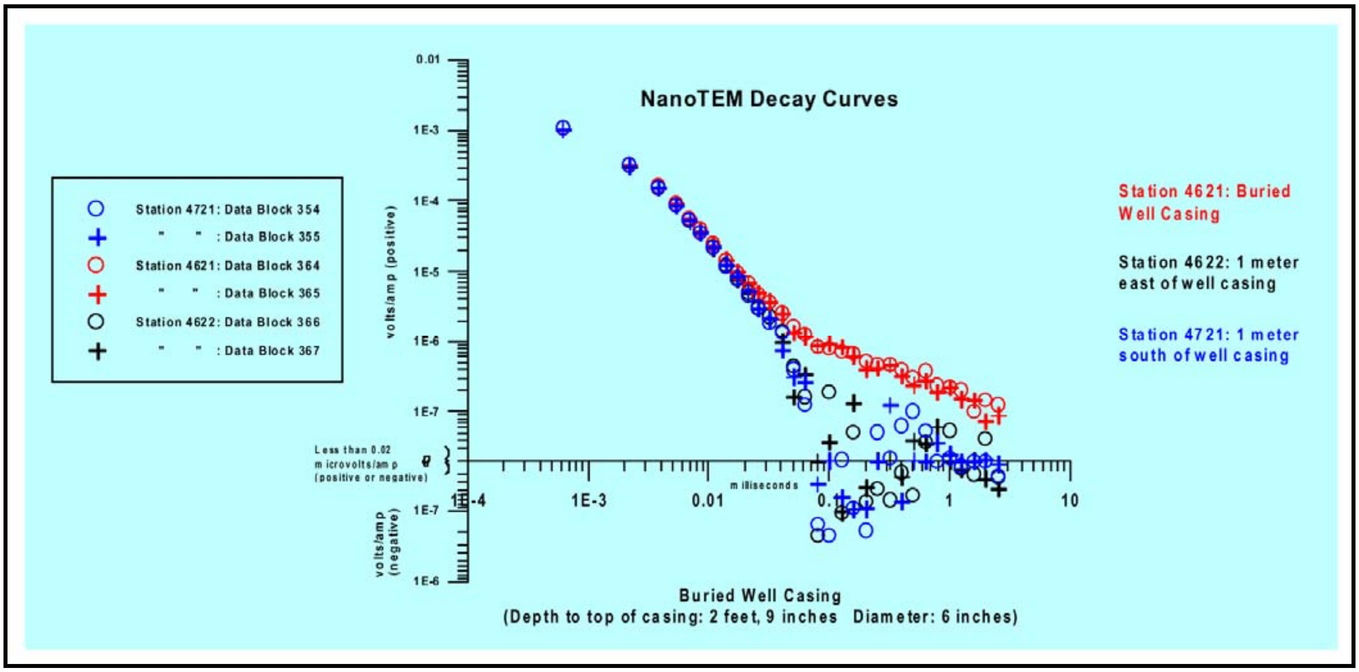
Case Histories of Buried Borehole Detection: An Exercise in Flexibility



Although the response of a particular target may be predictable, the local background resistivity also determines detectability of the target. This summary discusses the changes in loop sizes as well as the changes in data processing that were necessary for buried borehole detection in different environments.

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Case Histories of Buried Borehole Detection:
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Abstract

It is sometimes difficult to determine in advance exactly which equipment or technique is best suited to a given project. Although the response of a particular target may be predictable, the local background response may be more difficult to assess until field data have actually been gathered. This problem becomes economically significant when the job site is relatively remote, requiring downtime and/or additional airfreight expenses when the actual field results do not match expectations and a change in equipment systems becomes necessary. An example of this is a recent series of surveys in Indiana and Ohio, in which the goal was to ensure that no abandoned, buried oil wells were present within a prescribed radius of proposed injection wells. After local tests, both the physical survey layout and the data processing techniques were varied in order to detect the various possible targets in the different environments.

Introduction

Prior to drilling several proposed injection wells for a secondary oil recovery project at an old oil field, our client wanted to ensure that there were no old, buried oil wells within a 60 foot radius of each injection well (in order to avoid possible contamination of shallow aquifers via the old wells). In addition to historical research to establish the location of old wells, the oil company also performed geophysical surveys, with varying results. On this basis, we proposed using a very fast turn-off transient electromagnetics (TEM) system called NanoTEM in order to provide both a metal-detection capability as well as resistivity sounding data in order to characterize the upper 50 feet of the subsurface.

Survey Method

The TEM method itself is a well-established minerals exploration tool which is particularly useful in layered environments when good vertical resolution is required. In general, TEM surveys involve transmitting a 50% duty cycle, time domain, square wave signal into an ungrounded insulated loop of wire laying on the surface of the ground. This square wave signal is alternating between positive, zero, and negative voltages; a full cycle (in 50% duty cycle) would be seen as four equally long periods of positive, zero, negative, and zero voltages. In the NanoTEM system, this cycle is repeated 32 times per second (known as a 32 Hz repetition rate).

The actual measurements are made during the "off" periods, when the transmitter voltage is zero. During these times, decaying secondary magnetic fields from subsurface conductors can be measured. Normally, the vertical component of the magnetic field is measured, using a magnetic antenna of some kind (a ferrite core antenna with multiple windings, for example, or a loop of wire). An apparent resistivity sounding can be calculated from the strength of the measured vertical magnetic field and the way it decays with time during the off period. Shallow information is contained in the early part of the decay, with increasing time corresponding to increasing depth. The system used for this survey records the decay curve as 31 windows (or gates) from approximately 0.7 microseconds after transmitter turn-off to about 3 milliseconds after turn-off. In order to obtain very shallow information, the transmitted signal must go to zero very rapidly, without "ringing" or oscillations of either the electronics or the wire loops themselves. In this case, the transmitter turn-off time was measured as 1.2 microseconds. By recording all 31 windows of the decay curve (rather than just one or two fixed windows), there is enough information to perform data inversions to produce a resistivity sounding at each station (resistivity versus depth), and it also provides the flexibility necessary to detect targets in different environments.

Casing and Corehole Tests

Originally, we had planned to use the NanoTEM system with a one-meter square transmitter loop and a one meter square receiver loop. This decision was based on the results and problems encountered by the client with other geophysical techniques at one of the project sites. Testing of the system was done at two project sites in Ohio, one in Indiana, and at the University of Arizona's Ajo test site southwest of Tucson, Arizona. Start-up tests at the first project site showed that this geometry would probably detect buried casings, but would provide very little background information; the one-meter transmitter loop simply did not provide enough signal strength to acquire background resistivity information deeper than a few meters. Since the shallow layering information was considered important, additional tests were run over a known, cased hole at one of the sites using a variety of transmitter-receiver loop configurations. Transmitter loops were varied from one-meter square up to 20-meters square, and receiver loops were varied from one-meter square up to five-meters square. As a result of these tests, the original survey configuration (1-meter square transmitter, 1-meter square receiver) was changed to a 10-meter square transmitter loop with a one-meter square receiver loop. In this configuration, a well casing was detectable anywhere within a given receiver loop, but was not evident in any of the adjacent loops. Thus a well casing could be located to within one meter, and follow-up work with smaller loops or overlapping loops could further delineate the anomaly. This geometry also provided good layering information down to 40 feet at most locations, and down to 80 feet in many areas.

In tests, a well casing that extended to the surface was clearly evident to the operator in the field in the raw data, as well as in the smooth-model inversion results of the data, as expected. However, a six-inch diameter well casing buried (vertically) under three feet of soil was evident in the smooth-model inversion results but was substantially less obvious in the field. A six-inch well casing buried (vertically) 5.5 feet was not evident at all to the operator, and was barely detectable in the inversion results. (Note: the buried casings were six-foot lengths of casing; longer lengths of casing could be expected to produce larger anomalies.) Tests were then also run over a known, uncased corehole at the Indiana site (called the LE-1 Corehole), since it was considered possible that at one or more of the project sites some casings (or upper portions of casings) could have been pulled from the abandoned wells, or that some abandoned wells were so old that steel casings had not even been used. The uncased corehole was not evident in the field in the raw data or in the smooth-model inversion results, but it was repeatably detectable as a weak anomaly at window times measured after the earth response had decayed into background noise levels. The secondary fields from very conductive objects, and in particular metal, require longer to decay than the background earth response, and are thus often evident as a repeatable, anomalously high value in the voltage decay curve (see the front cover figure, for example). Figure 1 shows the window 13 data from a grid of 325 stations surrounding the LE-1 uncased corehole in Indiana. The grid was laid out such that the corehole was near the northeast corner of the receiver loop at grid location -1.5, -1.5. As an additional check, an extra receiver loop was also measured centered on the corehole, at grid location 0, 0. The corehole is seen as an obvious anomaly, strongest on the receiver loop centered directly over it, and only very slightly weaker in the loop centered at grid location -1.5, -1.5. Of the 325 stations, only two others

NanoTEM Survey Results
Plan View
LE-1 Uncased Corehole Test

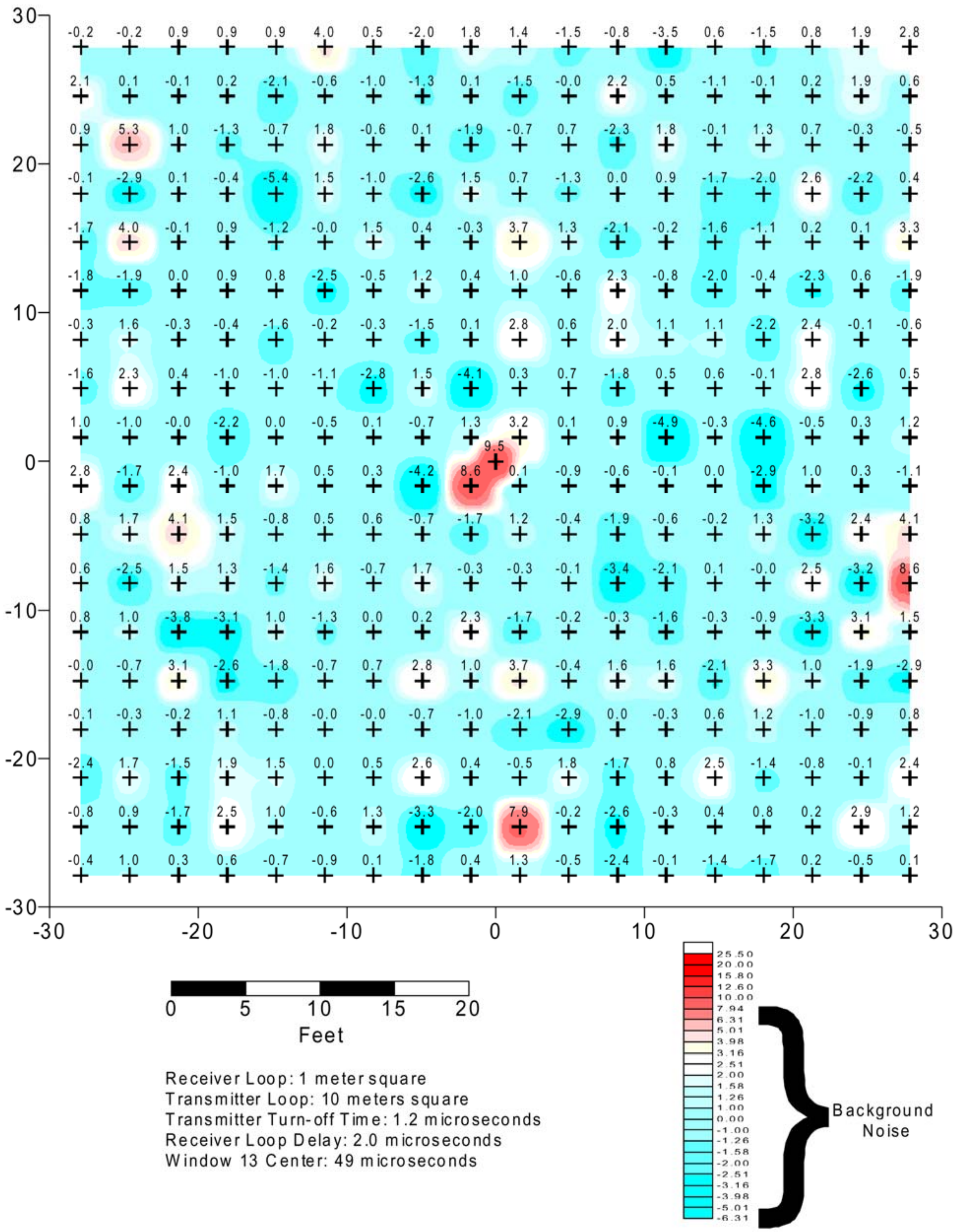


Figure 1: NanoTEM survey results over the LE-1 uncased corehole (located at grid location 0,0), showing normalized window 13 data in microvolts.

near the edges of the grid appear anomalous, and had this been one of the production grids, might have been excavated. Figure 2 shows a comparison of the central portion of a similar grid over a cased, buried well and the uncased corehole. The cased, buried well is clearly a stronger anomaly, as expected. The strong appearance of the buried well and uncased corehole relative to the low background noise, and the relatively few "false" anomalies provided the basis for a change in data processing. As a result, the data processing efforts for this project were expanded from inversion modeling (to provide background information) to also include examination of various late-time windows.

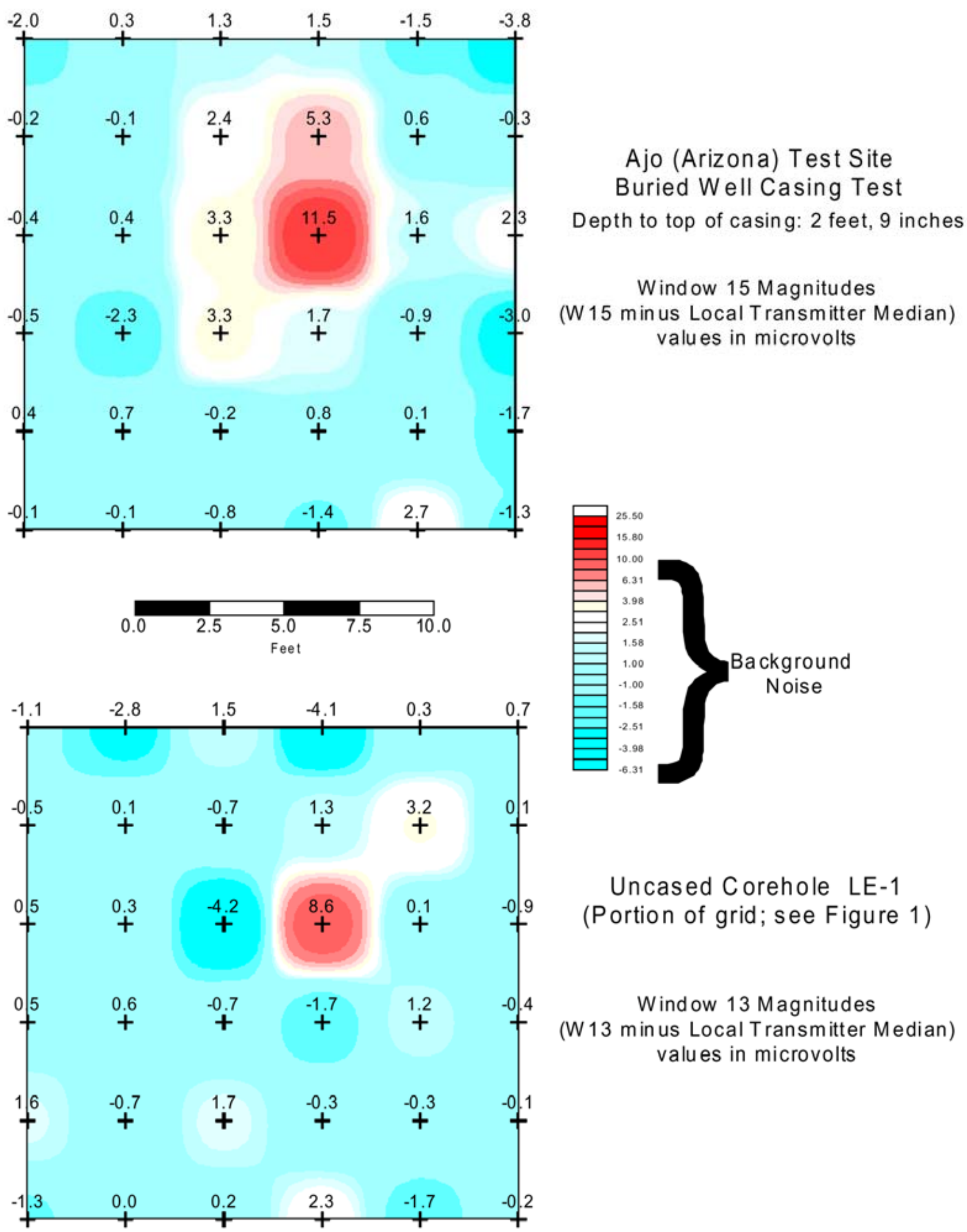


Figure 2: Comparison of plan views of NanoTEM survey results over a buried steel casing (top), and over the LE-1 uncased corehole (bottom).

Production Surveys

The production surveys were run by laying out the 10-meter square transmitter loop and reading, at one meter spacings, the central 6-meter by 6-meter grid within the transmitter loop (see Figure 3). In this arrangement, receiver loops were never closer than 2 meters to a transmitter loop wire, thus minimizing transmitter loop effects for the smooth-model inversion. At the completion of these central 36 receiver points, the transmitter loop was moved 6 meters, and the reading process was repeated.

At each receiver measurement point, at least 256 cycles (repetitions) were stacked, averaged, and stored in memory, constituting one reading. Each measurement included the decay voltage at all 31 window times from

0.7 microseconds to 3 milliseconds after transmitter turn-off. A minimum of 2 readings were made at all measurement points in order to establish repeatability. Also stored in memory were standard error values for each measurement in order to aid in data evaluation, as well as header information such as location, transmitter currents, etc.

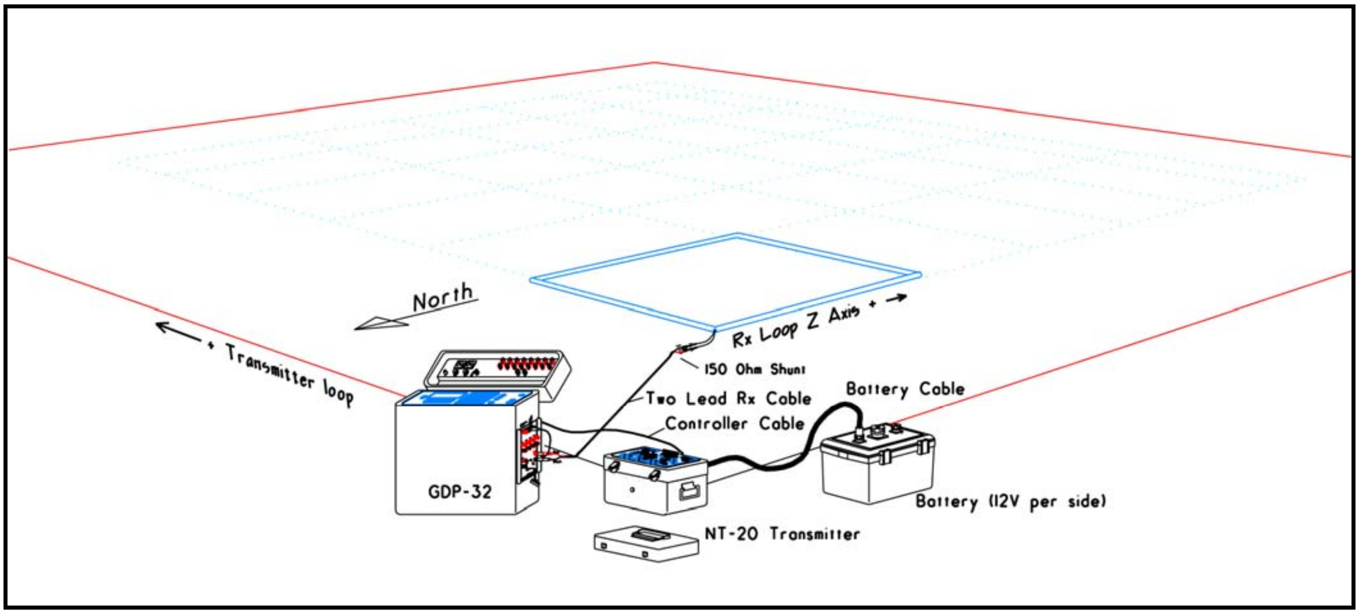


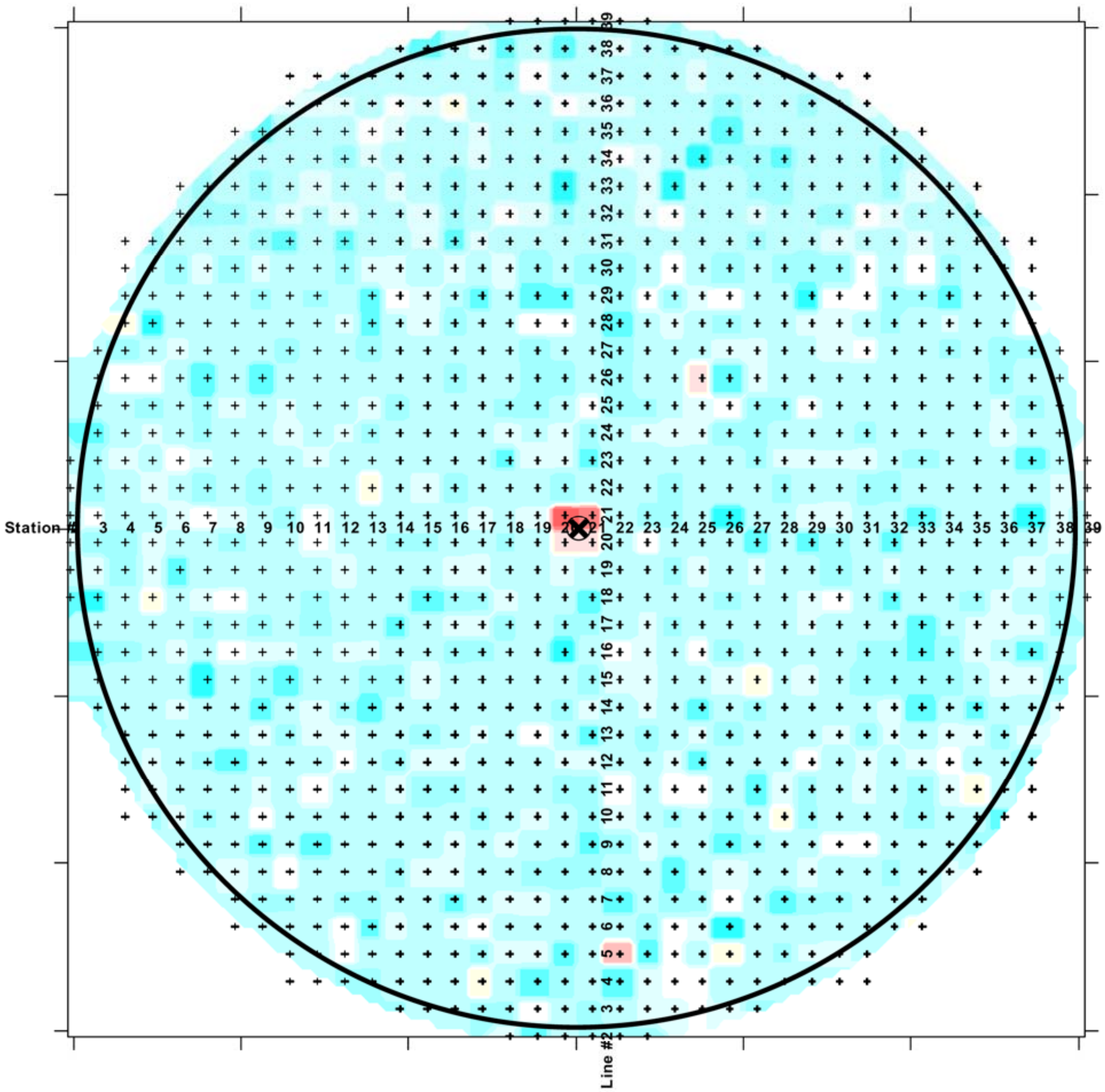
Figure 3: Lay-out diagram (not to scale) of 10-meter square transmitter loop and associated 1-meter square receiver loop positions for the buried borehole detection surveys

In this configuration, the two-person field crew was able to read from 300 to 500 stations per day, thus the 1150 stations required to clear a circular area of 120 feet in diameter around a proposed injection site required about 3 days to complete. This is significantly slower than a magnetometer survey or a towed-array TEM method such as an EM-61, but this data set provided both shallow layering information (from the smooth-model inversion) and metal detection (from the late-time data) for the entire grid.

It is important to note that the different background resistivity at each site required us to examine different time windows. The background signal decays more rapidly in higher resistivity ground, thus at one of the Ohio sites where resistivities were higher than the other sites, windows 8 and 9 (centered at approximately 16.8 and 20.6 microseconds respectively) were examined. At the lower resistivity Indiana site, however, window 13 (centered at 49 microseconds) proved to be the best window for detection. At the even lower resistivity Arizona Ajo site, background signals do not decay into noise until windows 15 and 16 (76.5 and 95.5 microseconds).

A total of 11 production grids, each comprised of approximately 1150 stations, were surveyed at two sites in Ohio and one site in Indiana, in addition to the test grids over two cased wells, one uncased corehole, and buried casings at the Arizona test site. Several production grids showed no anomalies, while several showed no anomalies other than a rebar survey marker in the center of the grid at some of the proposed injection sites (see Figure 4). Several other anomalous features were detected and excavated, however. One anomaly was the result of a clay lens at a depth of approximately 15 feet, while several of the single-station anomalies were never identified (possibly small metallic objects that were excavated but not noticed in the removal of the soil). No buried well casings were excavated, although this probably reflects the fact that historical searches were done prior to the survey in order to chose injection sites which were likely to be free of old oil wells. The combination of the historical research and the geophysical surveys was sufficient to convince state agencies that there was very little likelihood of abandoned oil wells within a 60 foot radius of the proposed injection sites.

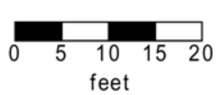
NanoTEM Survey **Indiana Project** **Grid 5**



Plan View

Window 13 Magnitude Values
(W13 minus local Transmitter Grid Median)

Stations: 1140
Receiver Loop: 1 meter square
Transmitter Loop: 10 meters square
Transmitter Turnoff: 1.2 microseconds



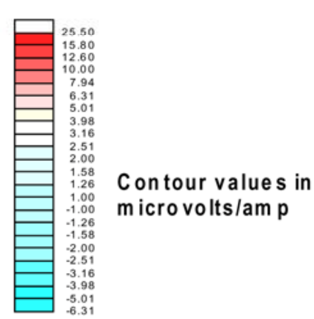


Figure 4

Summary and Caveats

The NanoTEM survey as completed was substantially different in both survey method and data processing compared to the original survey proposal. The changes were the result of varying background resistivity at the different sites, requiring a change in the loop array as well as a change in the decay time allowed for the background earth response. The TEM array used for this project (10-meter transmitter loop, 1-meter receiver loop) does not cover ground as rapidly as either a magnetometer survey or a towed TEM survey (such as an EM-61). It does, however, provide sounding information (rather than a simple profile) and stores all data so that all windows can be examined (rather than just one or two), allowing the flexibility needed for different environments. Depending on specific project needs, there are many environments where a detailed magnetometer survey or a towed TEM survey are preferable to the array described here. In some cases however, where a more complete subsurface picture is needed, the ability to vary loop sizes coupled with flexibility in data processing makes this a useful method. In our experience, the large volume of data acquired by the NanoTEM system has been particularly valuable in minimizing false anomalies by allowing comparisons of multiple windows to aid in the interpretation of the data.

The work done to date does not yet address the possible difference in response and detectability of very old boreholes relative to recent boreholes. Very deeply buried well casings have also not yet been researched. It is our strong recommendation that at each new site, test grids over known targets should be run in order to “fine-tune” both the array geometry and the data processing needs.