Location of Abandoned Water Wells by Magnetic Surveys over the Edwards Aquifer in the San Antonio Area, Texas

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Abstract

The Cretaceous Edwards Aquifer of central Texas is a critical groundwater resource for human and ecological needs. Protecting the quality of this vital resource is the responsibility of all Texans. For many years, groundwater has been pumped from water wells in the region and the Edwards aquifer is a sole source aquifer for the City of San Antonio. Over the years, many wells around homes, farms, industrial sites, and urban areas have been abandoned without being properly plugged. These abandoned wells become potential avenues for groundwater contamination, but they can also constitute a safety hazard for children and animals. Part of the solution is first to locate these wells, most of which are concealed below the ground.

Use of magnetic geophysical survey of the shallow subsurface (0-15 ft) can easily locate ferrous metallic anomalies (in the shallow surface consisting of soils and sediments) that can be attributed to buried metallic objects such as well casing from abandoned wells. Magnetic surveys were conducted to locate three abandoned water wells in the San Antonio area. All three wells were below the ground surface. Results from ground magnetic surveys indicated major magnetic anomalies in and around the steel well casings. Maximum signals from these three wells were in the range of 2,000 nanoTesla (nT). Sources for these anomalies are interpreted to be from the steel-casings of the abandoned wells, and their locations were delineated in the field. Excavations of the marked locations encountered these abandoned wells at about 3 to 4 feet deep below land surface. It appeared that none of the wells had well heads, indicating they had been improperly plugged and abandoned. Two of the wells have been plugged and the casing of the third one has been extended to a few feet above the ground surface since their discovery.

The magnetic method approved to be a relatively fast and cost-effective in locating abandoned wells in this study. For this reason the magnetic method should be considered the primary tool to be employed before other methods are implemented, especially if competent, steel-cased wells are suspected.

1.0 Introduction

Groundwater derived from many aquifers in the state of Texas provides over half of the water used in the state. Protecting the quality of this vital resource is the responsibility of all Texans (TCEQ Regulatory Guidance, 2010). In the San Antonio area, the Cretaceous Edwards and Trinity aquifers of central Texas are critical groundwater resources for its human and ecological needs (Gary et al., 2011). For many years, groundwater has been withdrawn using water wells. Over the years, many wells around homes, farms, industrial sites, and urban areas have been properly plugged and abandoned (Figure 1).

However, it is suspected that there are many more abandoned wells (~300) in the San Antonio area whose locations are unknown and are abandoned without being properly plugged. Not only can these abandoned wells become potential avenues for groundwater contamination (Figures 2 and 3), but they can also constitute a safety hazard for children and animals. There are also instances where people unknowingly built homes, churches and commercial buildings on top of these wells.

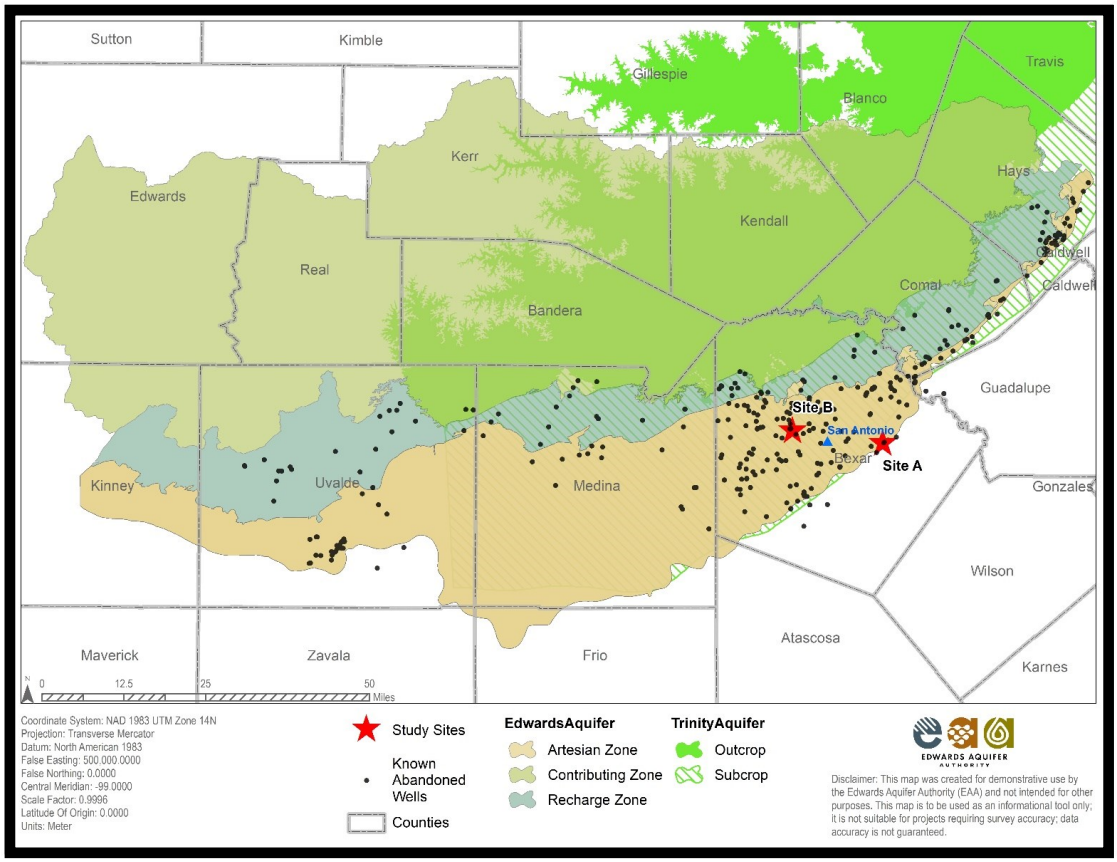

Figure 1. *Location of known abandoned wells (~145) over the Edwards and Trinity Aquifers. The red stars indicate the location of magnetic surveys (Sites A and B). The map is courtesy of Taylor Bruecher of EAA.*

Figure 2. *A unique way of utilizing an abandoned well (Courtesy of Geary Schindel of EAA). The white paper on and around the well is a toilet paper.*

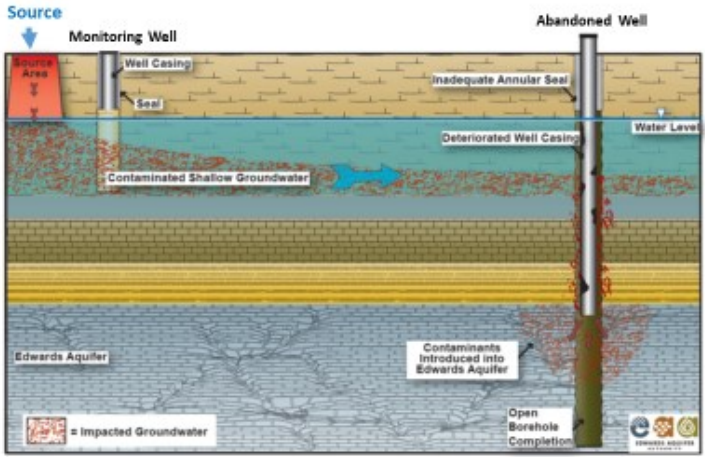

Figure 3. *Abandoned wells and groundwater contamination conceptual drawing over the Edwards Aquifer shows how contamination could make its way underground and into the aquifer via an abandoned well (Taken from Edwards Aquifer website at www.eaa.org).*

Abandoned water wells are usually concealed below the ground surface, and/or they are in remote areas. Direct excavation to find these wells is impractical over large areas, so abandoned well searches depend heavily on non-invasive techniques. These include methods for locating wells by searching historical records and reconnaissance of the area, and geophysical methods (magnetics, resistivity, gravity, radar, etc.) that detect physical properties of wellbores and well materials (Jordan and Hare, 2002).

Environmental Geophysics Associates (EGA) was contracted by the Edwards Aquifer Authority to locate abandoned water wells in the San Antonio area. In this study, magnetic surveys were conducted at two different sites (Sites A and B) for three buried abandoned wells (see Figure 1).

2.0 Magnetic Method

The magnetic method is one of the oldest geophysical survey methods. It has been used for many decades in the mineral and petroleum industries for mapping geologic basement trends, faults, and mineral or petroleum prospects. The magnetic method has been used in recent years for various engineering and environmental applications including locating abandoned wells, buried tanks, pipelines, and unexploded ordnance; delineating pits, trenches and landfills containing metallic debris; and mapping archaeological sites, shallow geology, and soils. The magnetic method is relatively fast and cost-effective compared to other geophysical methods, and it has a proven track record for locating abandoned wells. In most cases, it should be considered the primary tool to be employed before other methods are implemented, especially if competent, steel-cased wells are suspected (Jordan and Hare, 2002).

2.1 Earth's Magnetic Field

A material property called magnetic susceptibility is responsible for the degree to which a material is magnetized within the earth's magnetic field. The magnetic method measures the earth's magnetic field intensity. The earth's magnetic field is thought to be derived from fluid motions in the conductive outer core which are possibly coupled to thermally driven convection cells in the mantle. The field is manifested as a smoothly varying dipolar field with south and north magnetic poles roughly aligned with the earth's geographic north and south poles, respectively. The earth's magnetic field is a vector field, specified at a given location by the magnitude of the magnetic force (total field intensity) and its direction. The total field intensity is typically given in units of nanoTesla (nT) or gamma. Over the continental U. S., the total field intensity varies from about 47,000 (south Texas) to 60,000 nT (Montana) (Jordan and Hare, 2002).

2.2 Definition of Magnetic Anomaly

A magnetic anomaly is generated only when there are lateral variations in magnetic susceptibility, i.e. it is a susceptibility contrast that causes an anomaly, i.e., natural soil vs. steel casing of a well. Because the earth's field is dipolar, the shape of a magnetic anomaly from a particular source will vary with latitude. In mid-northern latitudes such as the conterminous U.S., local magnetic anomalies generally have a minor negative northern lobe and a larger positive southern lobe. Magnetic anomalies are caused by both induced and permanent magnetism of subsurface materials. The shape, dimensions, and amplitude of an induced magnetic anomaly is a function of the orientation, geometry, size, depth, and magnetic susceptibility of the body as well as the intensity and inclination of the earth's field at the survey site (Barret, 1931).

For the purposes of magnetic searches, many objects are approximated as either a magnetic dipole or, in the case of a steel well casing extending to depth, a magnetic monopole. For ease of modeling, geophysicists usually assume that an anomaly is entirely caused by induced magnetism. For a well casing however, there is likely to exist a significant component of permanent magnetism that could complicate modeling of the source. However, anomalies from well casings are generally quite sharp and large in amplitude, and as detection, rather than quantitative modeling, is of primary concern for magnetic searches, this is not a problem (Barret, 1931).

2.3 Magnetic Field Surveys Designs for Detection of Abandoned Wells

Magnetic surveys for abandoned water wells can be designed in two ways, depending upon a clients' purpose:

1) Locate them and provide a report;

2) No need for a magnetic report, only mark the locations in the field.

The first type of field survey requires that the client has a rough idea of the location of the wells. Thus a grid system of 100 x 100 or 200 x 200 feet is established depending on the available site information and conditions. Continuous magnetic data then can be collected along profiles. For the second type of survey, the client does not have a specific information on the location of the well and it could be in different parts of the site. In this case, the magnetometer equipment used for the survey is set to Scan Mode, and the entire site can be scanned for the abandoned wells.

In this study on both sites, A and B (Fig. 1), magnetic data were collected using a Geometrics-858 Cesium magnetometer and processed using Oasis Geosoft Montaj Software.

3.0 Magnetic Surveys for Site A and Site B

Site A was located at 2800 Ackerman Road, San Antonio, Texas. At this site two abandoned wells (wells #1 and #2) were located. Site B was located at Brisa Estate of Leon Valley, San Antonio, Texas. One abandoned well was located at this site.

For the first abandoned well site at Site A, a grid of 175 x 150 ft was established. For the second well, a grid of 100 x 140 ft was established. On both locations magnetic data were collected along with 5 ft profile spacing. The distance between the two wells was about 700 feet. Magnetic surveys took about a day for two wells.

At Site B, the magnetic survey was conducted across a 118 x 82 ft grid with a 5 ft profile spacing. The magnetic survey took three hours at this site.

4.0 Interpretation of Magnetic Data at Site A

Well #1

A magnetic map of the water well location #1 is given in Figure 4. The magnetic values across the site vary between 45,000 and 49,000 nT. The average magnetic value for the site is about 47,000 nT and is shown with the blue color. The magnetic map displays a significant anomaly at about x=47.5 and y=50 feet, and is shown with a pink color. The geometry of this anomaly is circular and probably caused by a steel-cased water well. This location was marked in the field with a stake for excavation.

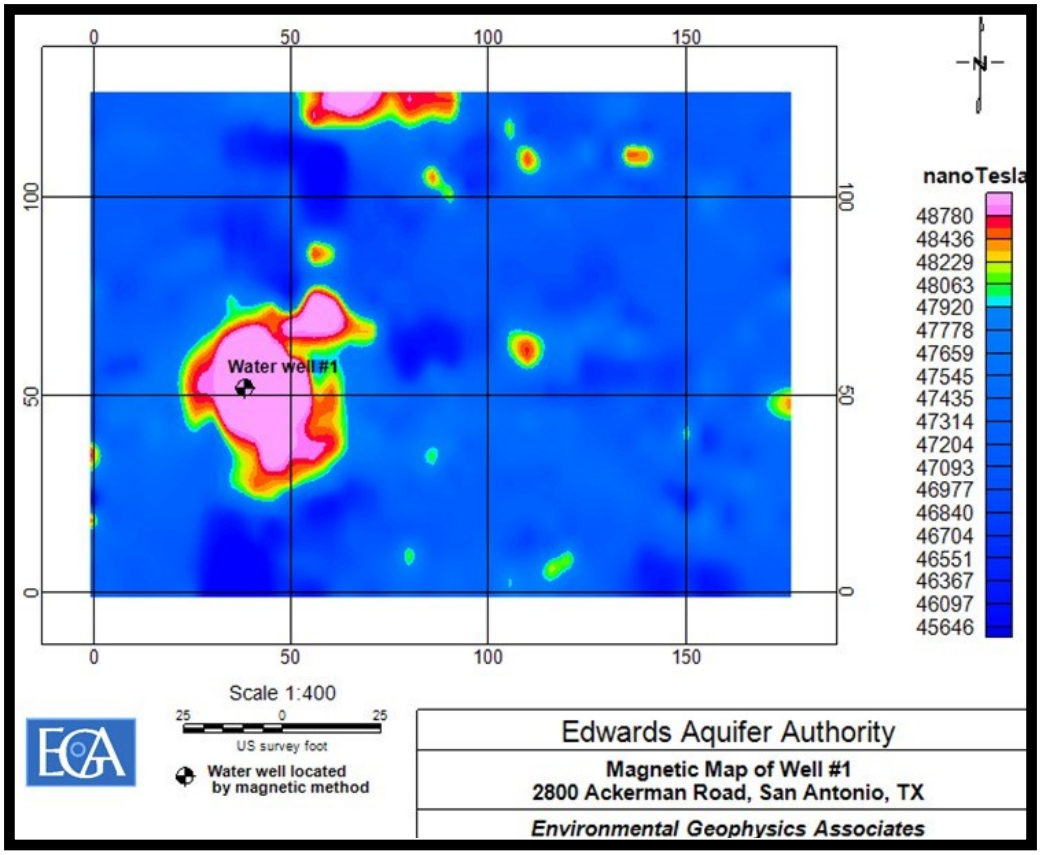

Figure 4. *Magnetic map of well #1 at 2800 Ackerman Road in San Antonio, Texas. The magnetic anomaly is similar to a magnetic monopole and is probably caused by a steel-cased abandoned well (see Section 2.2).*

A few weeks later, after the submission of the magnetic report, the Client excavated the location down to four feet and exposed the buried water well, which is shown in Figure 5.

Figure 5. *Picture of the abandoned well #1 after being excavated about 4 feet. The well is next to the stake with the pink flag.*

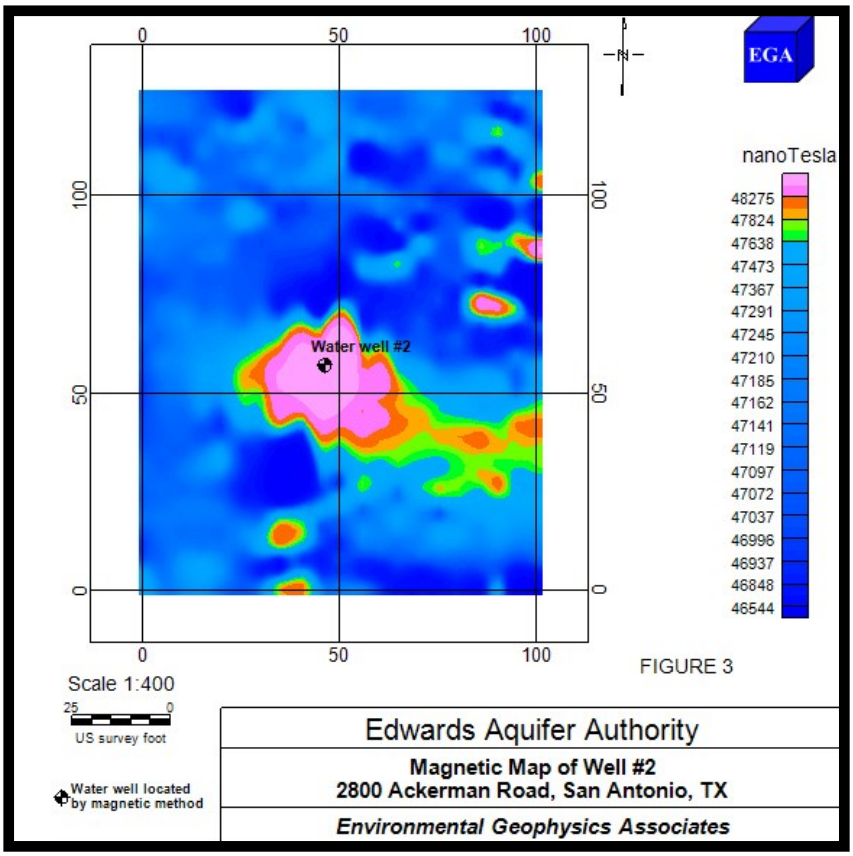

Figure 6. *Magnetic map of well #2 at 2800 Ackerman Road in San Antonio, Texas. The magnetic anomaly is similar to a magnetic monopole and is probably caused by a steel-cased abandoned well (see Section 2.2).*

The Client excavated the marked location for about 4 feet and exposed the buried abandoned well, which is shown Figure 7.

Figure 7. *Picture of the abandoned well #2 after being excavated and exposed. It is located next to the stake with the pink flag.*

Water Well #2

A magnetic map of the site for the water well #2 is shown in Figure 6. The magnetic values range between 46,000 and 49,000 nT across the site. The average background magnetic value is about 47,000 nT. The magnetic map shows a significant anomaly at x=48 and y=55 ft. The anomaly is circular and shown with a pink color. The anomaly is probably caused by a steel-cased water well. Its location was marked at the site during the magnetic survey.

There is also a linear magnetic anomaly to the south-southeast of the marked water well location, which is shown with combination of green, yellow and orange colors. This anomaly is probably caused by buried ferrous pipes.

5.0. Interpretation of Magnetic Data at Site B

This abandoned well is located at Brisa Estate in Leon Valley. The magnetic data were processed differently than two data sets of the Ackerman site. The reason for this was the presence of man-made materials in and around the site, such as curbs embedded with rebar, pipes sticking from the ground, parked cars on the road and at houses. Thus the magnetic data was filtered to eliminate the magnetic noise coming from the man-made materials as much as possible. The resulting magnetic map is shown in Figure 8. Magnetic values ranged between -1,650 and 1,650 nT. The average background value was about 120 nT.

The magnetic map indicates a significant anomaly at about x=55 and y=30 feet. This anomaly is shown with a pink color, and labeled with the letter **A**. This anomaly, which is presented with the pink color and is probably caused by a steel-cased water well. The location of the well was marked in the field during the magnetic survey. Note that this anomaly is not in the shape of a circle owing to the presence of man-made materials surrounding it.

There are two more anomalies to the north of the anomaly **A**, and are shown with letters **B** and **C**. The sources of these anomalies are ferrous but their causes are not known.

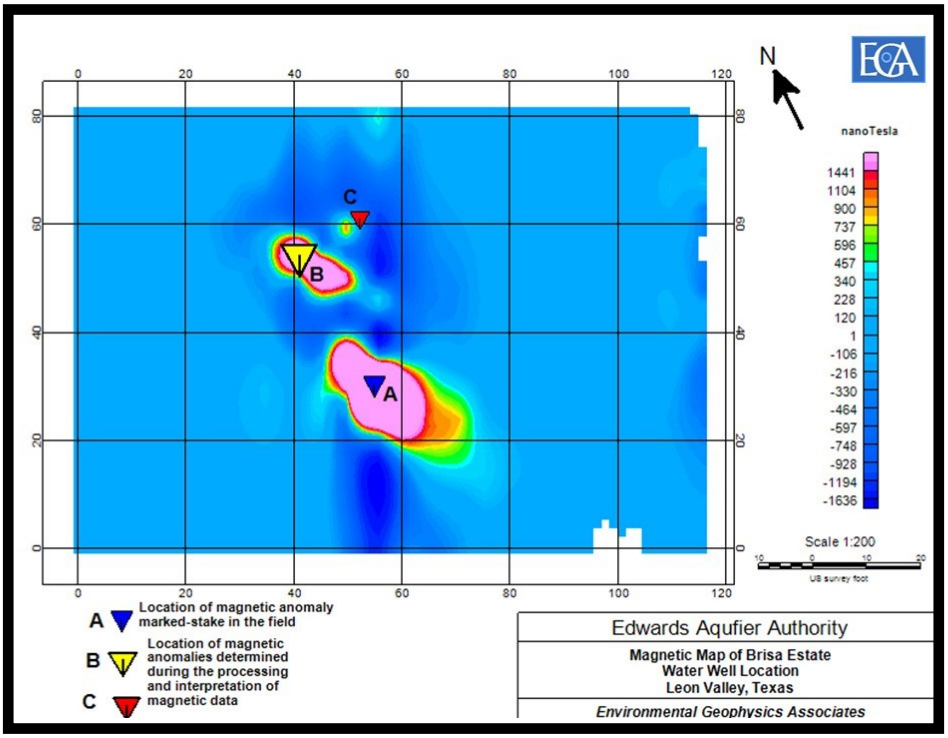

Figure 8. *Magnetic map of an abandoned water well at Brisa Estate in Leon Valley, Texas. The suspected anomaly causing the well was predicted to be the anomaly A. The geometry of the magnetic anomaly is elongated (not a monopole) and appears to be disturbed by near-by ferrous sources. This preceding observation and the magnitude of the anomaly (2,000 nT) indicates that the source is an abandoned well.*

A few days later, the location marked in the field was excavated to 3 feet depth and a steel casing for the well was exposed. The well had a 6 inch diameter and was partially filled with rocks and sediments (Figures 9a and 9b).

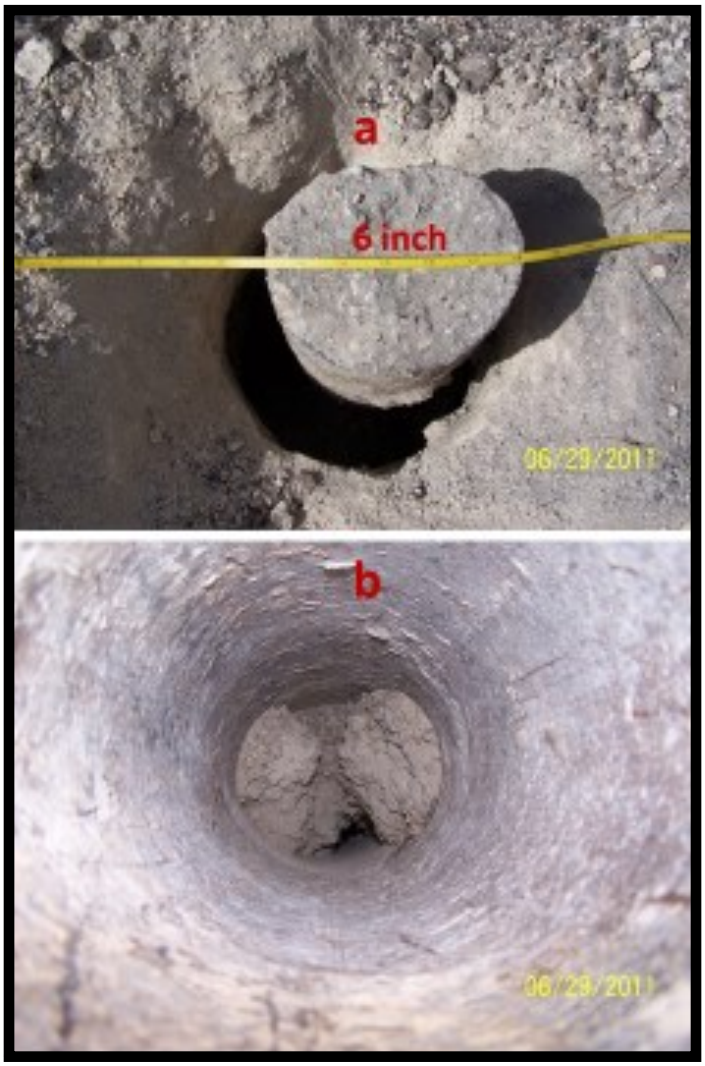

Figure 9. *Pictures of the abandoned well of Brisa Estate: a) exposed to the surface after excavation, and b) after having partially removed the fill from inside the well.*

6.0 Discussion and Conclusion

Results from ground magnetic surveys for locating three abandoned wells indicated major magnetic anomalies. Maximum anomalies from these three wells were in the range of 2,000- nT. The shape of two anomalies on the magnetic maps from Site A are nearly spherical. At Site B, owing to the interference of ferrous cultural features, the magnetic anomaly obtained from this site is elongated. Sources for these anomalies are interpreted to be from the abandoned wells, and, their locations were marked in the field. Excavations of the marked locations encountered the abandoned wells at about 3 to 4 feet deep below land surface. It appeared that none of the wells had well heads, meaning they were not properly plugged and abandoned.

The magnetic method is relatively fast and cost-effective compared to other geophysical methods. EGA has a proven track record for locating successfully more than 200 abandoned wells (water and oil &gas) using the magnetic method in the states of Texas, Oklahoma and Louisiana over the last 20 years. For this reason the magnetic method should be considered as the initial and primary tool to be employed before other methods are implemented, especially if competent, steel-cased wells are suspected.

7.0 Acknowledgment

We would like to thank to Geary Schindel of EAA for providing Figure 2 and Taylor Bruecher of EAA for preparing Figure 1 for us. We would also like to extend our thanks and appreciations to Dr. Roger Lee for his reviewing and his comments, which were very constructive.

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