HIGH-RESOLUTION MAGNETIC SURVEY IN LOCATING ABANDONED BRINE WELLS IN HUTCHINSON, KANSAS

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Abstract

The City of Hutchinson designed seven sites with a total area of 512,000 ft^2 to search for abandoned brine wells after the City researched literature of the salt mining history in Hutchinson area. A high-resolution magnetic survey was conducted on these seven sites in May 2002. Twenty-three anomalies were verified by excavation with a backhoe, of which are five were identified as brine wells, four as suspected brine wells, one probable water well, and one probable gas pipe. A monopole anomaly with more than 12,000 nanoteslas in amplitude is a basic criterion to identify a well with an 8-inch metal case. A monopole anomaly with several thousand nanoteslas in amplitude is a basic criterion to identify a 2.5-inch or 4-inch well. The high-resolution magnetic method with theodolite-defined grids was successful in locating the abandoned brine wells in the City of Hutchinson, Kansas.

Introduction

On January 17, 2001, a natural gas explosion and fire destroyed two downtown Hutchinson businesses. The next day another explosion occurred at a mobile home park three miles away. Two residents died of injuries from the explosion, which forced the evacuation of hundreds of people as gas geysers began erupting in the area. The geysers spewed a mixture of natural gas and saltwater. The pathways to the land surface at both the explosion sites and the geysers were abandoned brine wells used for solution mining of salt (http://www.kgs.ukans.edu/Hydro/Hutch/Background/index.html, Allison, 2001).

To find these abandoned brine wells is a part of the Hutchinson Response Project. Some known wells in the mobile home park had steel cased pipes. The length of vertical steel pipe normally is 400 – 700 ft. An electromagnetic (EM) method was used to successfully locate one abandoned brine well at a depth of 5 ft (Xia, 2002a). Uniquely identifying well-generated EM anomaly in historical salt mining sites remains as a challenge. In addition, the investigation depth of the EM method is still an attractive research topic. However, Relatively much higher anomalies could be observed in high-resolution magnetic measurements based on forward calculations. The maximum magnetic signal caused by this pipe can be higher than 15,000 nanoteslas (nT) on the top of the normal geomagnetic field in Hutchinson, Kansas. This huge anomaly shows great promise in locating brine wells in the City noise environment.

Methodology

The survey areas were normally defined as 100 ft × 100 ft grids using a theodolite (Figure 1a). The accuracy of horizontal location within each grid is higher than ±0.5 ft by rechecking directly with a tape measurement. A portable cesium magnetometer G-858 (Figure 1b) was used to measure the total component of the geomagnetic field. The sensitivity of the meter is 0.01 nT. The overall accuracy of magnetic measurements is in the order of 1 nT. The sensor high is kept 2.5 ft from the ground surface during the survey. The density of a high-resolution magnetic survey along a line is 2.3 measurements/ft.

Magnetic anomalies on the sites of wells C4, C8, and C12 were first acquired to serve as signatures in locating brine wells. Once the anomaly signature at these known wells was determined, line spacing was chosen to be 3 ft. The total line length is around 35 miles in the survey areas of 512,000 ft^2.

The normal geomagnetic field in the City of Hutchinson is 53,600 nT. The maximum change of the geomagnetic field in the quiet period (Kp < 4) is less than 15 nT/hour. Because we completed the survey grid by grid individually during the quiet period of the geomagnetic field, the time to finish each 10,000 ft^2 grid was about 15 minutes, and the amplitude of well anomalies were on the order of several thousands nanoteslas, no drifting correction of the geomagnetic field is necessary. The Kp Index is a 3-hourly planetary geomagnetic index of activity generated in Gottingen, Germany, based on the K Index from 12 or 13 stations distributed around the world. The K Index is a 3-hourly quasi-logarithmic local index of geomagnetic activity relative to an assumed quiet-day curve for the recording site. Range is from 0 to 9. The K index measures the deviation of the most disturbed horizontal component (http://www.maj.com/sun/status.html).

Figure 1a. A theodolite was used to define grids for high-resolution magnetic survey. David Laflen (left) and Gang Tian (right) are defining grids.

Figure 1b. A portable cesium magnetometer G-858 was used to measure the total component of the geomagnetic field. Xia is performing the magnetic survey. A traffic cone is acting as a line guide.

Measurements were first assigned field geometry, then corrected for the sensor locations based on shapes of known anomalies by shifting odd numbered lines by 1.2 ft – 2 ft, and finally adjusted for data drop outs that are zero readings due to extremely high anomalies (> 100,000 nT). Measurements were then grided into 1 ft × 1 ft grids by the Kriging method (Surfer®, 1999). Grided measurements were correlated with anomalies from known wells. Anomalies were picked based on their amplitudes, shapes, or correlation coefficients. Some anomalies were also inverted to find their magnetization and depths to the top of an anomaly source.

High-resolution magnetic data were displayed using Surfer® in a color scale to enhance anomalies potentially caused by brine wells.

Magnetic Signals from Known Wells

We acquired high-resolution magnetic data at sites of wells C4, C8, and C12. The survey area at each site is 40 ft × 40 ft with line spacing of 2 ft (Figure 2). To make sure that the anomaly shape is not related to a line (survey) direction, we acquired data in both the east-west direction and the north-south direction at site C4 (Figures 3a and 3b). The monopole anomaly (p. 24, Breiner, 1973) at well C4 is almost perfectly imaged in both directions, so in the production phase we may perform the survey in either the north-south or the east-west direction depending on field accessibility and efficiency of data acquisition. The monopole anomaly at C13 (Figure 3c) is as high as 83,000 nT that is an almost 30,000 nT (≈ 83,000 – 53,600) anomaly. The reason for this is that the wellhead is on the ground surface. Measurements at well C8 (Figure 3d) showed the same shaped anomaly. The centers of bull-eyes are the location of wells. The amplitudes of the anomalies at these wells are over 20,000 nT. These huge anomalies showed promise in locating abandoned brine wells in the Hutchinson area.

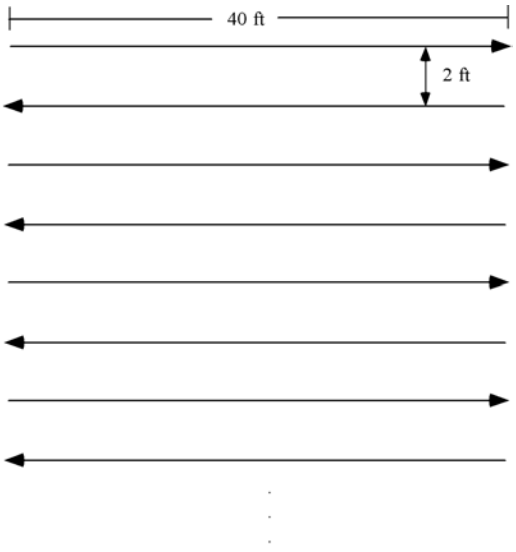

Figure 2. A grid with arrows indicating the walking direction.

Magnetic Survey in Hutchinson

A high-resolution magnetic survey was performed at seven sites chosen by the City of Hutchinson after review of the historical literature on salt mining in the Hutchinson area (Figure 4). The magnetic data were normally acquired at 100 ft × 100 ft grid with line spacing of 3 ft. Verified anomalies are summarized in Table 1. Complete results of the high-resolution magnetic survey can be found in Xia (2002b).

1. Five identified brine wells

Two brine wells were found at Union Salt site (Figure 4). Anomaly U1_1 in grid U1 (left, Figure 5) at location (15, 75) is due to an 8-inch brine well at a depth of 1 ft (right, Figure 5). The total

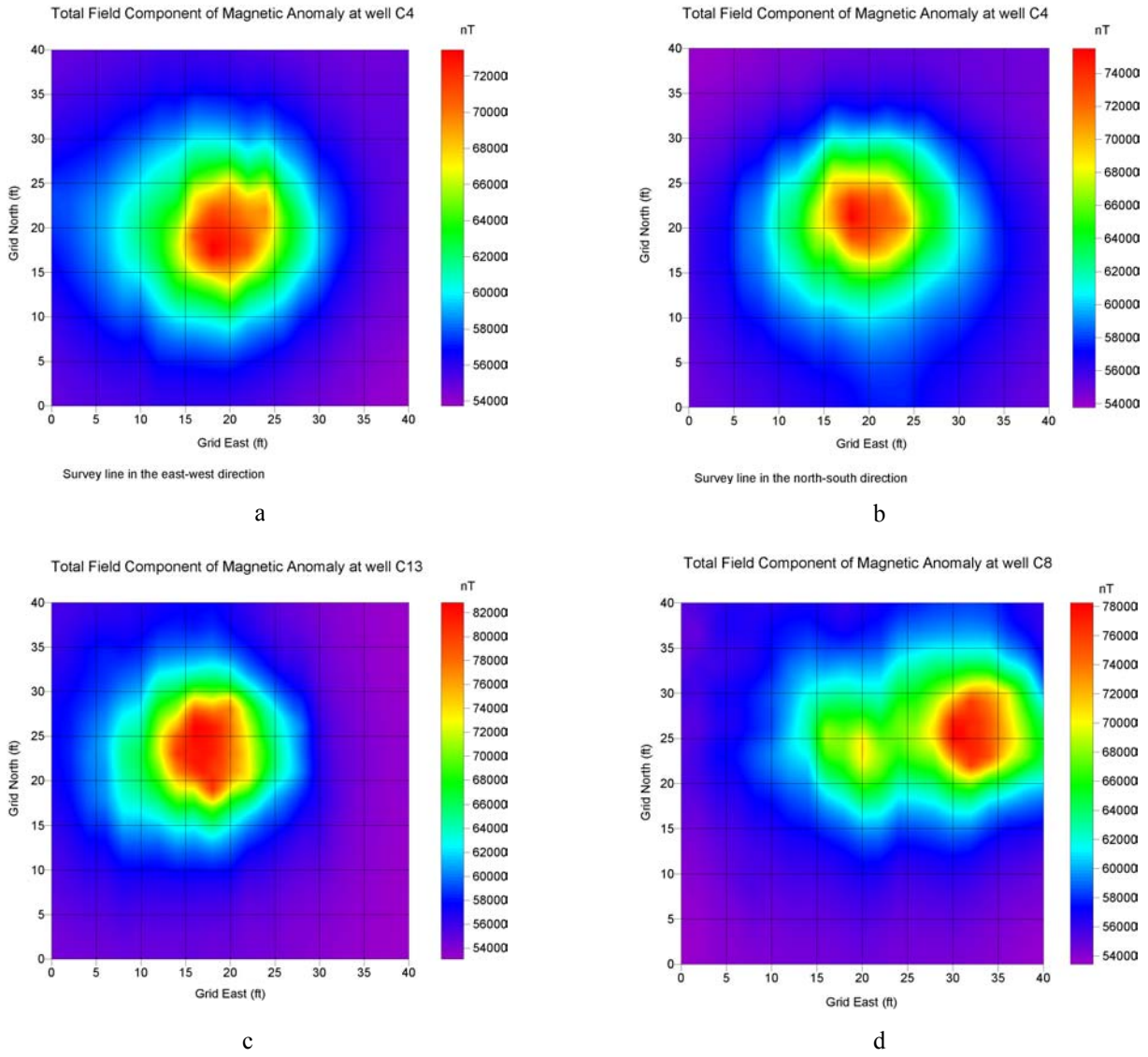

Figure 3. Total field component of magnetic anomalies at known brine wells C4 (a and b), C13 (c), and C8 (d). The peaks of anomalies directly indicate the locations of these wells.

component of geomagnetic field is over 80,000 nT, which indicates the anomaly has an amplitude of over 26,000 nT (= 80,000 – 53,600). The shape of anomaly is similar to anomalies at known wells (Figure 3). An anomaly at (67, 80) is due to a well head 2.5 ft above the ground. An anomaly (6,000 nT) at location (36, 36) is caused by several pieces of slag. An anomaly (6,000 nT) at (66, 81) is due to a brine well on the ground surface.

Anomaly U5_1 (left, Figure 6) in grid U5 at location (42, 23) is due to an 8-inch brine well at a depth of 1 ft under 6 inch thick concrete (right, Figure 6). It has the same shape as anomaly U1_1 with a little lower amplitude (25,000 nT).

One brine well was found at Salvation Army Eagle Park (Figure 4). Anomaly S2_1 in grid S2 (left, Figure 7) at location (100, 70) is due to an 8-inch brine well at a depth of 7 ft (right, Figure 7). The amplitude of the anomaly (12,000 nT) is lower than previous anomalies because of its depth and a

thinner steel case. Clearly, the anomaly shows its monopole property. An anomaly (2,000 nT) at (54, 94) and an anomaly (1,800 nT) at (60, 70) are due to park chairs.

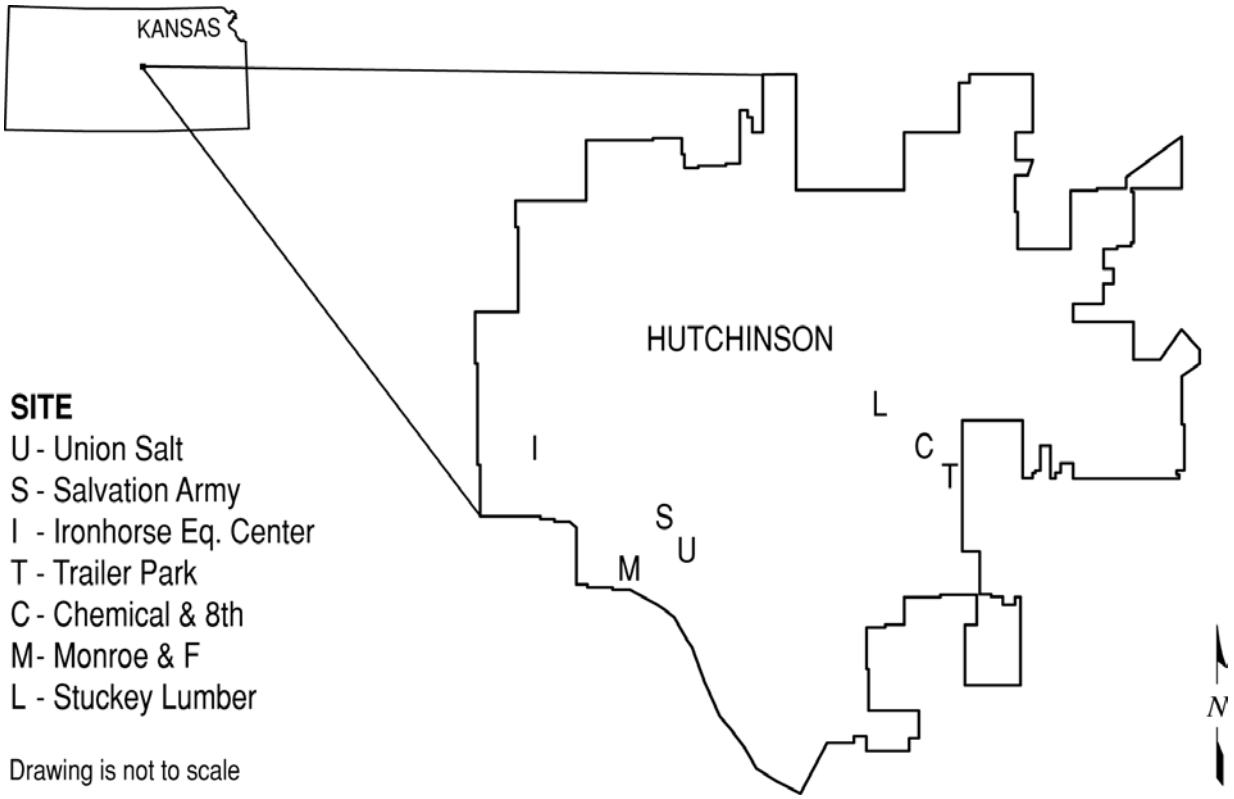

Figure 4. Site map showing the locations of the seven high-resolution magnetic surveys performed in the City of Hutchinson.

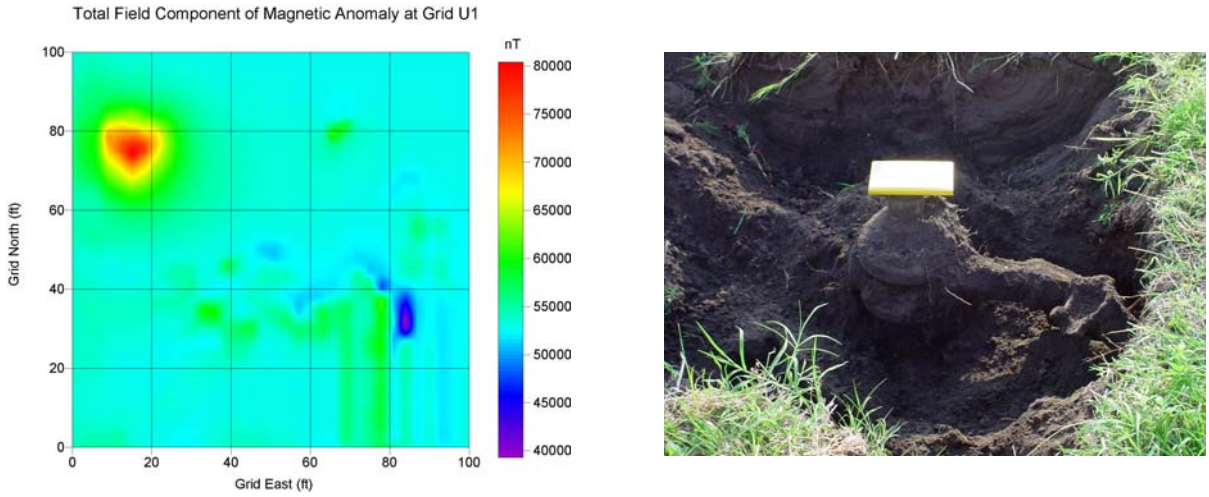

Figure 5. The total field component of the magnetic anomaly in grid U1 at Union Salt site (left). The anomaly at (15, 75) is due to a brine well. Depth to the top of the well is 1 ft. The length of the field notebook is 7.5 inch (right).

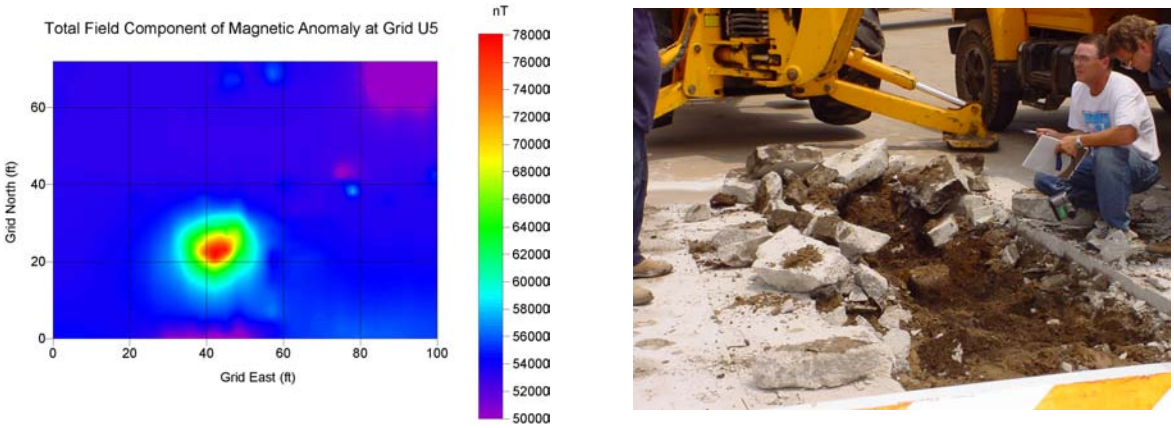

Figure 6. The total field component of the magnetic anomaly in grid U5 at the Union Salt site (left). The anomaly at (42, 23) is due to a brine well under 6 inches of concrete. Depth to the top of the well is 1 ft (right). Richard Harper of Kansas Department of Health & Environment is taking a note.

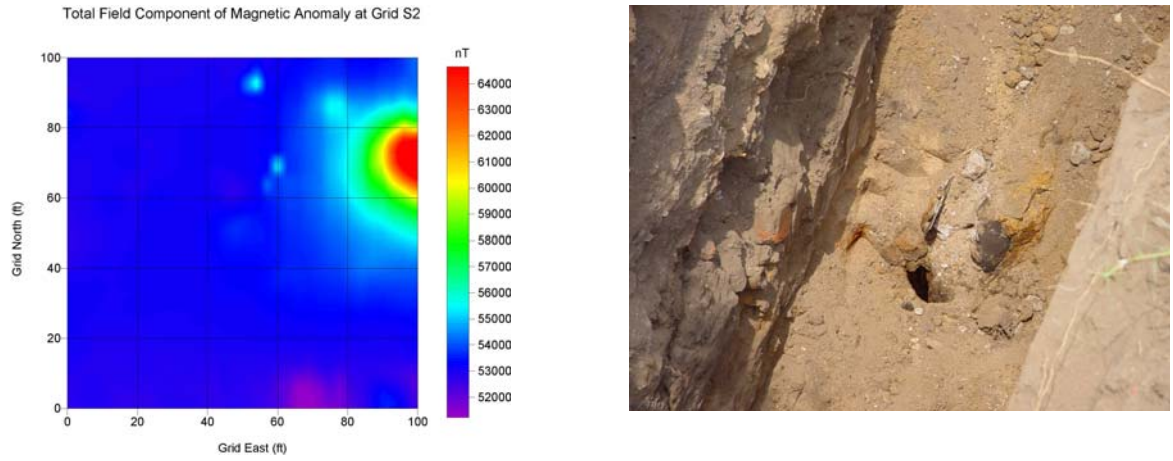

Figure 7. The total field component of the magnetic anomaly in grid S2 at the Salvation Army Eagle Park site (left). The anomaly at (100, 72) is due to a brine well at a depth of 7 ft (right).

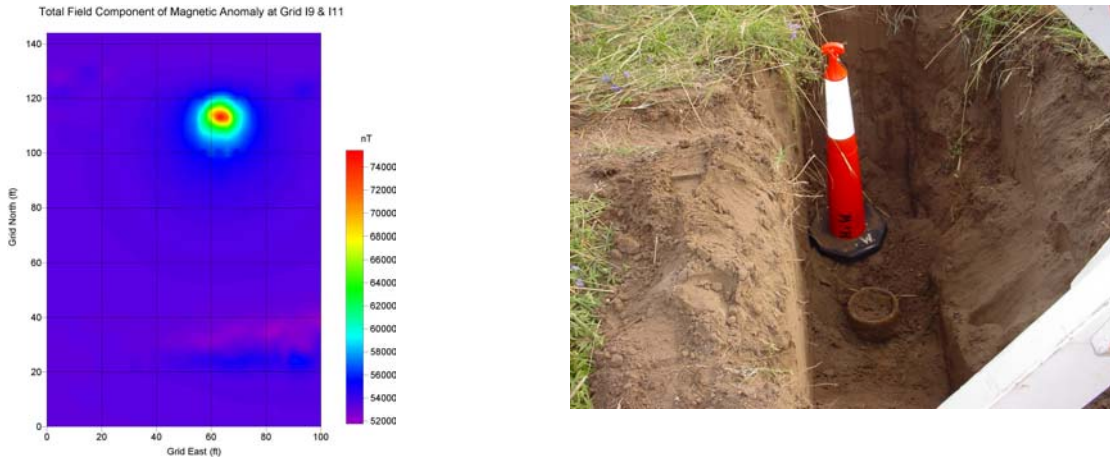

Figure 8. The total field component of the magnetic anomaly in grids I9 and 11 at the Ironhorse Equestrian Center (left). The anomaly at (63, 114) is due to a brine well at a depth of 4.5 ft (right).

One brine well was found at Ironhorse Equestrian Center (Figure 4). Anomaly I9&11_1 in grid I9&I11 (left, Figure 8) at location (63, 114) is due to an 8-inch brine well at a depth of 4.5 ft (right, Figure 8). he anomaly is a monopole and with an amplitude of over 21,000 nT.

One brine well was found at Monroe & Avenue E and F (Figure 4). Anomaly M3_1 in grid M3 (left, Figure 9) at location (62, 90) is due to an 8-inch brine well at a depth of 2 ft (right, Figure 9) under a 1-ft thick asphalt pavement. The anomaly is a monopole and with an amplitude of over 20,000 nT.

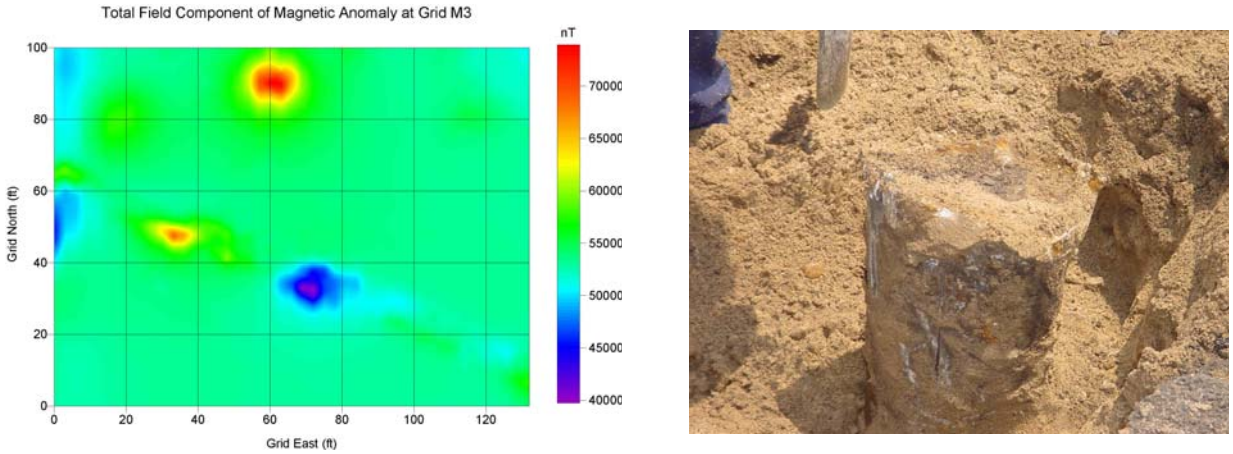

Figure 9. The total field component of the magnetic anomaly in grid M3 at Monroe & Avenues E and F (left). The anomaly at (62, 90) is due to a brine well at a depth of 2 ft under 1 ft of asphalt pavement of Avenue F (right).

2. Four suspected brine wells

One suspected brine well was found at Union Salt site (Figure 4). Anomaly U2_1 in grid U2 (left, Figure 10) at location (76, 55) is due to a 2.5-inch vertical pipe at a depth of 4 ft (right, Figure 10). The pipe is suspected to be an inner pipe of a brine well. The anomaly is a monopole shape with an amplitude of 3,700 nT.

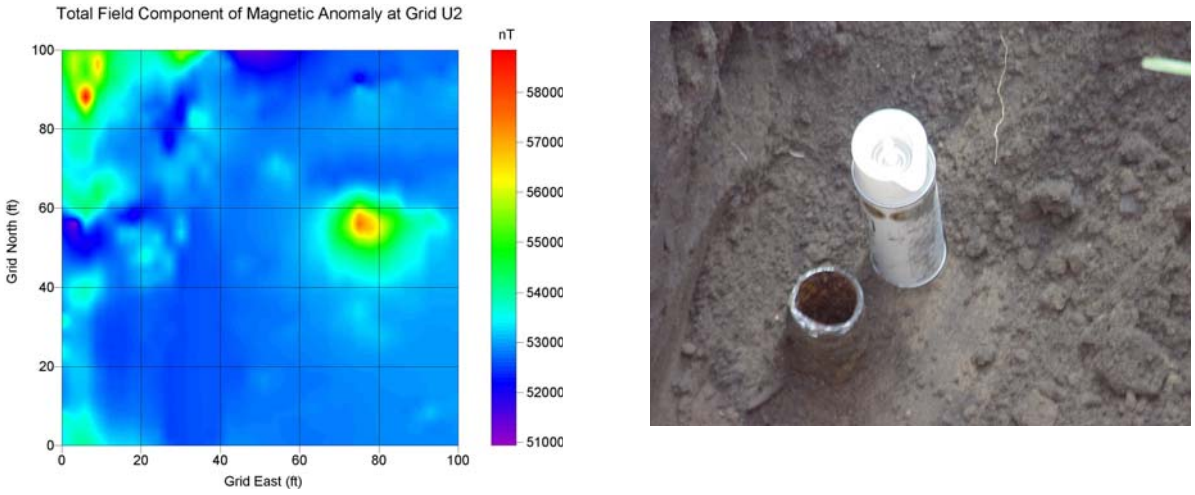

Figure 10. The total field component of the magnetic anomaly in grid U2 at the Union Salt site (left). The anomaly at (76, 55) is due to a suspected brine well (2.5-inch) at a depth of 4 ft (right). A spray paint can is shown for scale. We dug up to 7 ft deep to make sure it was not just a junk pipe.

One suspected brine well was found in Salvation Army Eagle Park (Figure 4). Anomaly S4_2 in grid S4 (left, Figure 11) at location (23, 55) is due to a 2.5-inch vertical pipe at a depth of 2 ft (right, Figure 11). The pipe is suspected to be the inner pipe of a brine well. The anomaly is a monopole shape and with an amplitude of 4,400 nT. An anomaly high at location (0, 72) is a part of anomaly S2_1 (Figure 7). An anomaly at location (93, 82) is due to metal junk (see Table 1). An anomaly at location (132, 85) is due to a meter cap on the ground surface. An anomaly at (95, 9) is due to an electric pole.

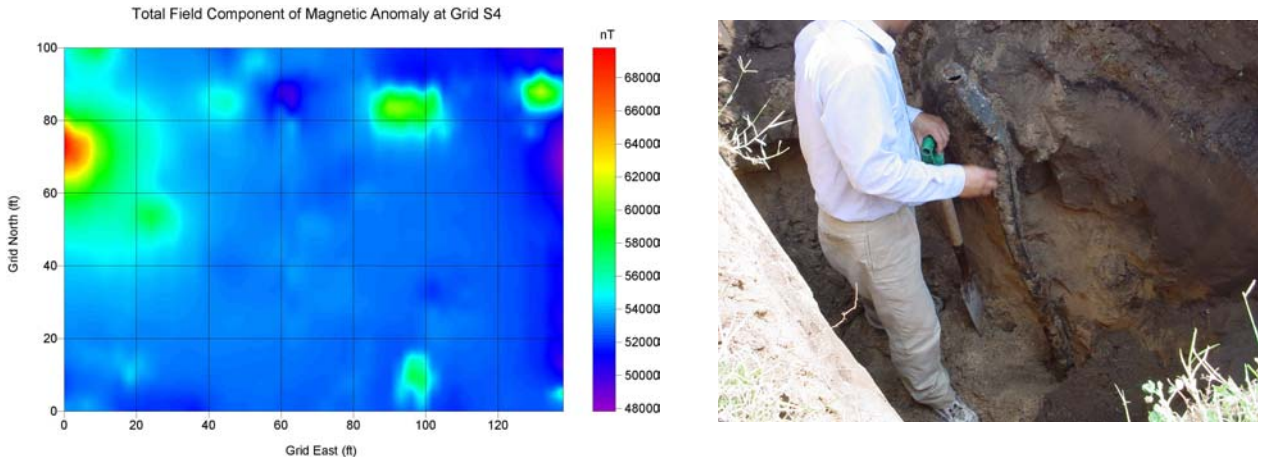

Figure 11. The total field component of the magnetic anomaly in grid S4 of at the Salvation Army Eagle Park site (left). The anomaly at (23, 55) is due to a suspected brine well (2.5-inch) at a depth of 2 ft (right). We dug up to 7 ft deep to make sure it was not just a junk pipe. Xia is checking the depth.

One suspected brine well was found in Ironhorse Equestrian Center (Figure 4). Anomaly I10_2 in grid I10 (left, Figure 12) at location (92, 62) is due to a 4-inch vertical pipe at a depth of 2 ft (right, Figure 12). The pipe is suspected to be the inner pipe of a brine well. The anomaly only has an amplitude of 1,300 nT and a non-monopole shape that may be caused by our non-constant walking speed or aiming errors in the walking direction. We hit this vertical pipe by digging out two nearby anomalies I10_3 and I10_4 (see Table 1).

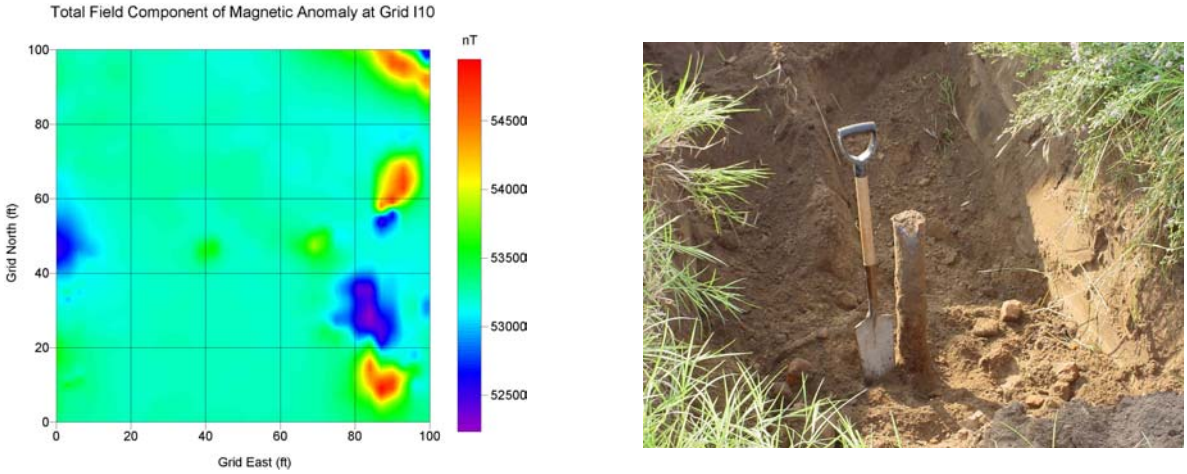

Figure 12. The total field component of the magnetic anomaly in grid I10 at the Ironhorse Equestrian Center site (left). The anomaly at (92, 62) is due to a suspected brine well (4-inch) at a depth of 2 ft (right). We dug down 4 ft to make sure it was not just a junk pipe.

One suspected brine well was found in the Trailer Park site (Figure 4). Anomaly T10_1 in grid T10 (left, Figure 13) at location (10, 90) is due to a 2.5-inch vertical pipe at a depth of 1 ft (right, Figure 13). The pipe is suspected to be the inner pipe of a brine well. The anomaly has a monopole shape and an amplitude of over 3,000 nT. This is a perfect isolated anomaly with a monopole shape.

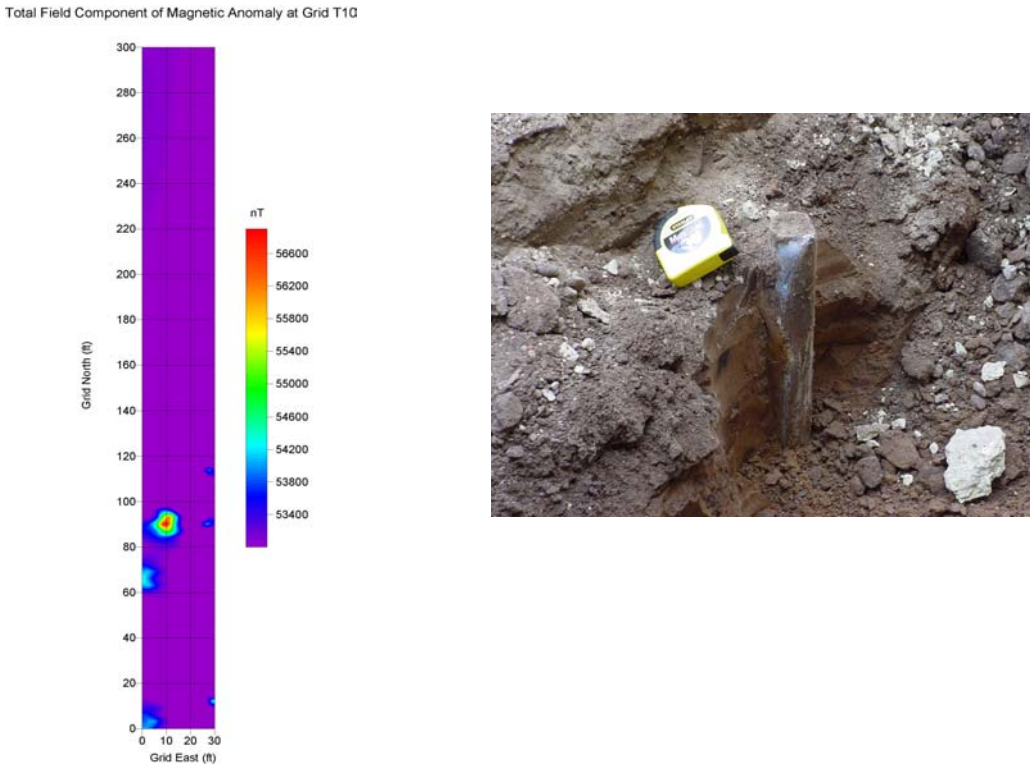

Figure 13. The total field component of the magnetic anomaly in grid T10 at the Trailer Park site (left). The anomaly at (10, 90) is due to a suspected brine well (2.5-inch) at a depth of 1 ft under a gravel pavement road (right). We dug down 2.5 ft to make sure this was not just a junk pipe. A 30' tape measure (3.5 inches tall) is shown for scale.

3. One probable water well

One probable water well was found at Chemical & 8th Street (Figure 4). Anomaly C_1 in grid C (left, Figure 14) at location (50, 123) is due to a 1.5-inch vertical pipe at a depth of 1 ft (right, Figure 14). The pipe is suspected to be a water well. The anomaly has a monopole shape and an amplitude of over 3,000 nT. This is a perfect isolated anomaly with a monopole shape. Anomalies at locations (7, 40) (12, 135), and (30, 133) are due to electric poles.

4. One probable gas/water pipes

One probable gas/water was found at Union Salt site (Figure 4). Anomaly U4_1 in grid U4 (left, Figure 15) at location (36, 40) is due to a 4-inch vertical pipe at a depth of 1 ft (right, Figures 15) under a 6-inch concrete and a group of horizontal pipes that cause the drop outs of the anomaly. The pipe is suspected to be a utility pipe. The anomaly was so high so the magnetometer dropped the reading. The anomaly at (105, 45) is due to a hydrant.

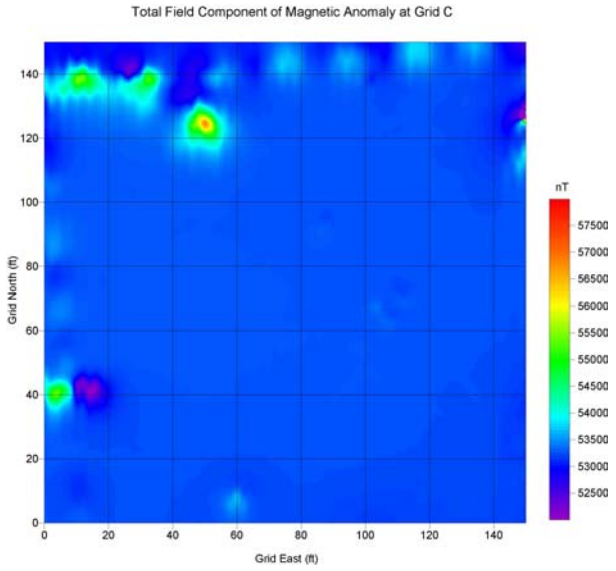

Figure 14. The total field component of the magnetic anomaly in grid C at the Chemical & 8th Street site (left). The anomaly at (50, 123) is due to a probable water well (1.5-inch) at a depth of 1 ft (right). We dug down 4 ft to make sure this was not just a junk pipe. Sihao Xia is measuring the depth.

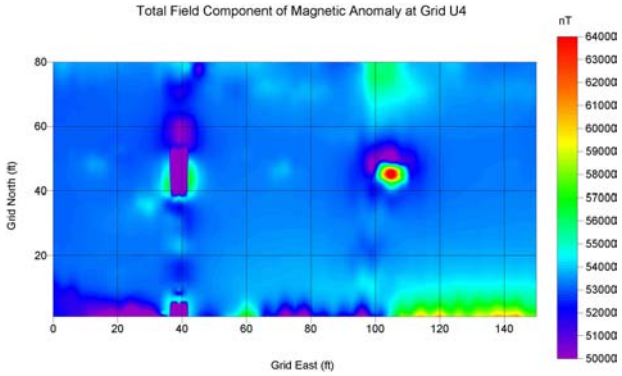

Figure 15. The total field component of the magnetic anomaly in grid U4 at the Union Salt site (left). The anomaly at (36, 40) is due to a group of utility pipes (4-inch) at a depth of 1 ft under 6 inches of concrete (right). Mike Cunningham of the City of Hutchinson is examining the pipes.

Conclusions

The high-resolution magnetic method was successful in locating abandoned brine wells in Hutchinson, Kansas. The anomalies due to brine wells with an 8-inch steel case have an almost perfect monopole shape with an amplitude of over 12,000 nT. The anomaly due to suspected brine wells with a 2.5 or 4-inch pipe also has an almost perfect monopole shape with the amplitude of over 2,000 nT. With anomalies at these levels, the high-resolution magnetic method can surely locate abandoned brine wells in a noise environment like the City of Hutchinson.

Acknowledgements

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Table 1. List of Verified Anomalies.

The origin of the coordinate system is at the southwest corner of each grid except grids at Stuckey Lumber where the origin of the coordinate system is at the northeast corner. The name of anomaly starts with a letter that indicates the site and is followed by a number that indicates the grid number. The number after "_" is a serial number of anomalies in each grid. The anomalies listed in **bold** are caused by brine wells, suspected brine wells, or probable utility wells/pipes.

1. Grids at Union Salt (Avenue C & Walnut Street)

Name of Anomaly	x	y	Source of anomaly
U1_1	**15**	**75**	**An 8-inch brine well at a depth of 1 ft**
U1_2	66	81	A brine well on the surface (no digging)
U1_3	36	36	Several pieces of slag
U2_1	**76**	**55**	**A 2.5-inch suspected brine well at a depth of 4 ft**
U4_1	**36**	**40**	**A 4-inch probable gas pipe at a depth of 1 ft**
U5_1	**42**	**23**	**An 8-inch brine well at a depth of 1 ft**

2. Grids at Salvation Army Eagle Park (Avenue C & Main Street)

Name of Anomaly	x	y	Source of anomaly
S1_1	24	51	Rebars (junk)
S2_1	**100**	**72**	**An 8-inch brine well at a depth of 7 ft**

Table 1. (continued)

Name of Anomaly	x	y	Source of anomaly
S2_2	54	94	Park chairs (no digging)
S2_3	60	70	Park chairs (no digging)
S4_1	93	82	Metal junk
S4_2	**23**	**55**	**A 2.5-inch suspected brine well at a depth of 2 ft**

3. Grids at Ironhorse Equestrian Center (K-96/Nickerson Blvd & Hendricks Street)

Name of Anomaly	x	y	Source of anomaly
I2_1	21	37	Electric pole (no digging)
I3_1	40	48	A horizontal 8-inch pipe (northwest-southeast)
I4_1	16	68	Electric pole (no digging)
I5_1	36	30	Right along a gas line (no digging)
I8_1	44	20	Steel pipes (junk)
I9&11_1	**63**	**114**	**An 8-inch brine well at a depth of 4.5 ft**
I10_2	**92**	**62**	**A 4-inch suspected brine well at a depth of 2 ft**
I10_3	69	46	Junk metal
I10_4	85	15	Junk metal

4. Grids at Trailer Park (8th Street & Grand Street)

Name of Anomaly	x	y	Source of anomaly
T1_1	150	6	The end of a horizontal 2.5-inch pipe 1 ft deep
T9_1	-3	81	No permit to dig out
T10_1	**10**	**90**	**A 2.5-inch suspected brine well at a depth of 1 ft**

5. Grids at Chemical & 8th Street

Name of Anomaly	x	y	Source of anomaly
C_1	**50**	**123**	**A 1.5-inch possible water well at a depth of 1 ft**

6. Grids at Monroe & Avenues E and F

Name of Anomaly	x	y	Source of anomaly
M2_1	28	83	A 24-inch culvert along the e-w direction 2 ft deep
M3_1	**62**	**90**	**An 8-inch brine well at a depth of 2 ft**
M3_2	122	84	Rebars (junk)
M4_1	53	78	Rebars (junk)

7. Grids at Stuckey Lumber

Name of Anomaly	x	y	Source of anomaly
L1_1	36	81	A 6-inch horizontal 10 ft pipe (n-s) 1.5 ft deep