

# Using the High-Resolution Magnetic Method to Locate Abandoned Brine Wells in Hutchinson, Kansas

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## **Final Report to**

Dennis Clennan, City of Hutchinson, P.O. Box 1567, Hutchinson, KS 67504-1567

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October 2002

KGS Open-file Report No. 2002-43



# **Using the High-Resolution Magnetic Method to Locate 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<sup>2</sup> 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 nT in amplitude is a basic criterion to identify a well with a metal case. A monopole anomaly with several thousand nanoteslas in amplitude is a basic criterion to identify a 2.5-inch well. The high-resolution magnetic method was successful in locating the abandoned brine wells.

## **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. The maximum magnetic signal caused by this pipe can be higher than 15,000 nT on the top of the normal geomagnetic field in Hutchinson, Kansas (Appendix A). This huge anomaly shows promise in locating brine wells in the City noise environment.

## **Methodology**

A portable cesium magnetometer G858 (Figure 1a) was used to measure the total component of the geomagnetic field. The sensor high is 2.5 ft from the ground surface. Magnetic anomalies on the sites of wells C4, C8, and C12 were first acquired to serve as signatures in locating brine wells. The survey areas were normally defined as 100 ft × 100 ft grids using a theodolite (Figure 1b). The accuracy of horizontal location within each grid is less than ±0.5 ft by rechecking directly with a tape measurement. Once the anomaly signature at known wells was determined, line spacing was chosen to be 3 ft. The density of a high-resolution magnetic survey along a line is 2.3 measurements/ft. The total line length is around 35 miles in the survey areas of 512,000 ft<sup>2</sup>.



The normal geomagnetic field in the City of Hutchinson is 53,600 nT. The maximum change of the geomagnetic field in the quiet period ( $K_p < 4$ ) is less than 15 nT/hour. Because we completed the survey individually grid by grid during the quiet period of the geomagnetic field no geomagnetic field correction is necessary. The time to finish each 10,000 ft<sup>2</sup> grid was about 15 minutes, and the amplitude of well anomalies were on the order of several thousands nanoteslas. 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>).

Measurements were first assigned field geometry and then corrected for the sensor locations based on shapes of known anomalies by shifting odd numbered lines by 1.2 ft – 2 ft and by adjusting for data drop outs. 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 8C (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.

### **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. Appendix B contains all final maps of high-resolution magnetic survey in the seven sites. Verified anomalies are summarized in Table 1.



**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 (see site maps). 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, May 23, 2002)**

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

**2. Grids at Salvation Army Eagle Park (Avenue C & Main Street, May 24, 2002)**

Name of Anomaly	x	y	Source of anomaly
S1_1	24	51	Rebars (junk)
<b>S2_1</b>	<b>100</b>	<b>72</b>	<b>An 8-inch brine well at a depth of 7 ft</b>
S2_2	54	94	Park chairs (no digging)
S2_3	60	70	Park chairs (no digging)
S4_1	93	82	Metal junk
<b>S4_2</b>	<b>23</b>	<b>55</b>	<b>A 2.5-inch suspected brine well at a depth of 2 ft</b>

**3. Grids at Ironhorse Equestrian Center (K-96/Nickerson Blvd & Hendricks Street, May 29, 2002 and June 1, 2002)**

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)
<b>I9&amp;11_1</b>	<b>63</b>	<b>114</b>	<b>An 8-inch brine well at a depth of 4.5 ft</b>
<b>I10_2</b>	<b>92</b>	<b>62</b>	<b>A 4-inch suspected brine well at a depth of 2 ft</b>
I10_3	69	46	Junk metal
I10_4	85	15	Junk metal

**4. Grids at Trailer Park (8<sup>th</sup> Street & Grand Street, May 22, May 23, and May 28, 2002)**

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
<b>T10_1</b>	<b>10</b>	<b>90</b>	<b>A 2.5-inch suspected brine well at a depth of 1 ft</b>

**5. Grids at Chemical & 8<sup>th</sup> Street (May 22, 2002)**

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



**Table 1.** (continued)

**6. Grids at Monroe & Avenues E and F (May 30 and May 31, 2002)**

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

**7. Grids at Stuckey Lumber (May 31, 2002)**

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

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**1. Five identified brine wells**

Two brine wells were found at Union Salt site (Figure 5). Anomaly U1\_1 in grid U1 (top, Figure 6) at location (15, 75) is due to an 8-inch brine well at a depth of 1 ft (bottom, Figure 6). The total component of geomagnetic field is over 80,000 nT, which indicates the anomaly has an amplitude of over 27,000 nT (80,000 – 53,000). 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.

Anomaly U5\_1 (top, Figure 7) 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 (bottom, Figure 7). 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 8). Anomaly S2\_1 in grid S2 (top, Figure 9) at location (100, 70) is due to an 8-inch brine well at a depth of 7 ft (bottom, Figure 9). 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.

One brine well was found at Ironhorse Equestrian Center (Figure 10). Anomaly I9&11\_1 in grid I9&I11 (top, Figure 11) at location (63, 114) is due to an 8-inch brine well at a depth of 4.5 ft (bottom, Figure 11). The 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 12). Anomaly M3\_1 in grid M3 (top, Figure 13) at location (62, 90) is due to an 8-inch brine well at a depth of 2 ft (bottom, Figure 13) under a 1-ft thick asphalt pavement. The anomaly is a monopole and with an amplitude of over 20,000 nT.

**2. Four suspected brine wells**

One suspected brine well was found at Union Salt site (Figure 5). Anomaly U2\_1 in grid U2 (top, Figure 14) at location (76, 55) is due to a 2.5-inch vertical pipe at a depth



of 4 ft (bottom, Figure 14). The pipe is suspected to be the an inner pipe of a brine well. The anomaly is a monopole shape with an amplitude of 3,700 nT.

One suspected brine well was found in Salvation Army Eagle Park (Figure 8). Anomaly S4\_2 in grid S4 (top, Figure 15) at location (23, 55) is due to a 2.5-inch vertical pipe at a depth of 2 ft (bottom, Figure 15). 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.

One suspected brine well was found in Ironhorse Equestrian Center (Figure 10). Anomaly I10\_2 in grid I10 (top, Figure 16) at location (92, 62) is due to a 4-inch vertical pipe at a depth of 2 ft (bottom, Figure 16). The pipe is suspected to be the inner pipe of a brine well. The anomaly does not have a monopole shape and has an amplitude of only 1,300 nT. We hit this vertical pipe by digging out two nearby anomalies I10\_3 and I10\_4 (see Table 1).

One suspected brine well was found in the Trailer Park site (Figure 17). Anomaly T10\_1 in grid T10 (top, Figure 18) at location (10, 90) is due to a 2.5-inch vertical pipe at a depth of 1 ft (bottom, Figure 18). 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.

### **3. One probable water well**

One probable water well was found at Chemical & 8<sup>th</sup> Street (Figure 19). Anomaly C\_1 in grid C (top, Figure 20) at location (50, 123) is due to a 1.5-inch vertical pipe at a depth of 1 ft (bottom, Figure 20). 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.

### **4. One probable gas/water pipe**

One probable gas/water was found at Union Salt site (Figure 5). Anomaly U4\_1 in grid U4 (top, Figure 21) at location (36, 40) is due to a 4-inch vertical pipe at a depth of 1 ft (bottom, Figures 21) under a 6-inch concrete. 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.

### **5. Horizontal pipes**

The end of small horizontal pipes (2.5-inches) can show a perfect monopole anomaly. An example of this is anomaly T1\_1. Anomalies due to large horizontal pipes (6-inches or 8-inches) show elongation consistent with the orientation of the pipes as well as negative anomalies associated with positive anomalies. Examples of this would be anomalies I3\_1 and L1\_1 (Figure 22).



## **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**

I greatly appreciate Stephen William and Dennis Clennan of the City of Hutchinson for their literature research on the salt mining history in Hutchinson area in order to assign the survey sites, their assistance in permitting, clearances, and access issues, and providing digital site maps. I would like to thank Michael Cochran and Mary Daily of Kansas Department of Health and Environment for discussion and materials on the salt mining history in Hutchinson. I would like to thank Sihao Xia of the University of Kansas for his assistance in data acquisition and data processing and David Laflen, Brett Bennett of Kansas Geological Survey, and Gang Tian of Jinlin University, PRC, for their assistance in data acquisition. I would also like to thank Reg Jones and his crew at the City of Hutchinson for their help in field operation. Finally, I would like to thank Mary Brohammer for her efforts in preparation of this report.

## **References**

- Allison, M.L., 2001, Hutchinson, Kansas: A geologic detective story: *Geotimes*, v. 46, no. 10, p. 14-18.
- Breiner, S., 1973, Application manual for portable magnetometers: Geometrics, Inc.
- Surfer®, 1999, User's guide: Golden Software, Inc.





Figure 1a. A portable cesium magnetometer G858 was used to measure the total component of the geomagnetic field. Xia is performing the magnetic survey.



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



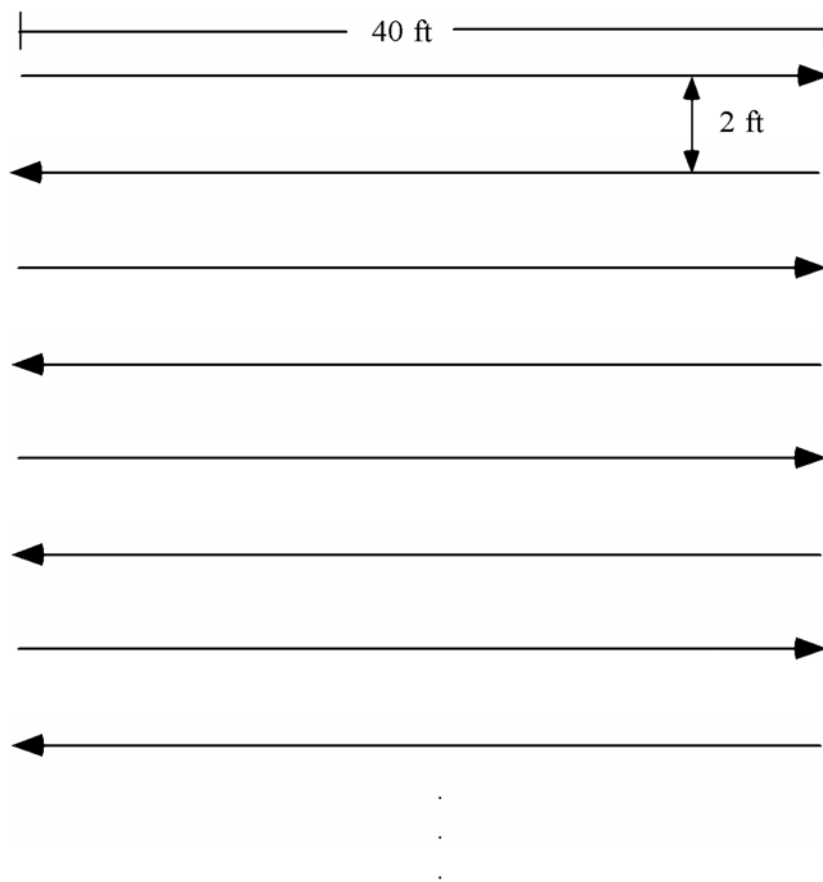


Figure 2. Arrows indicate the walking direction.



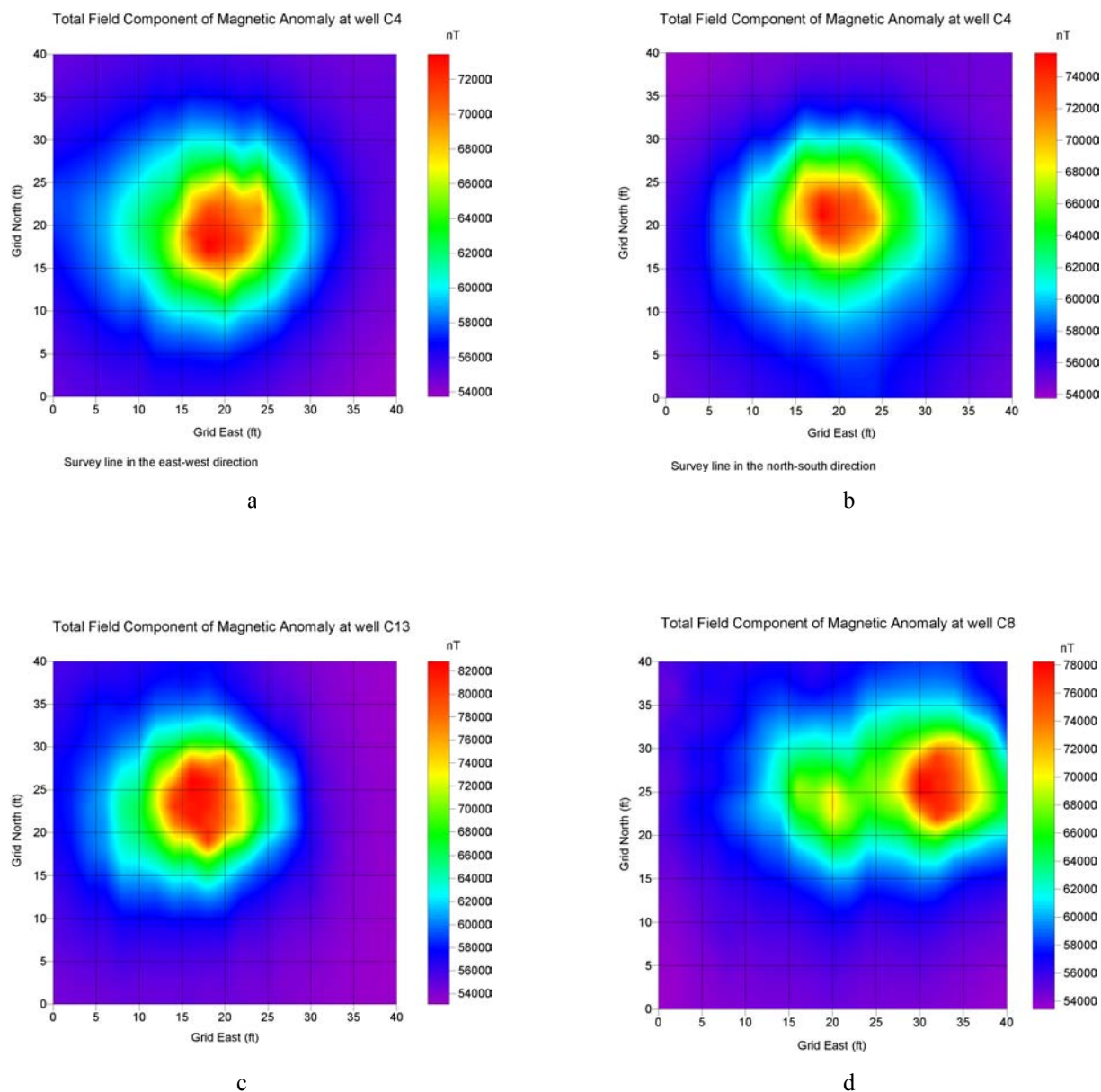


Figure 3. Total field component of magnetic anomalies at known brine wells C4, C8, and C13.



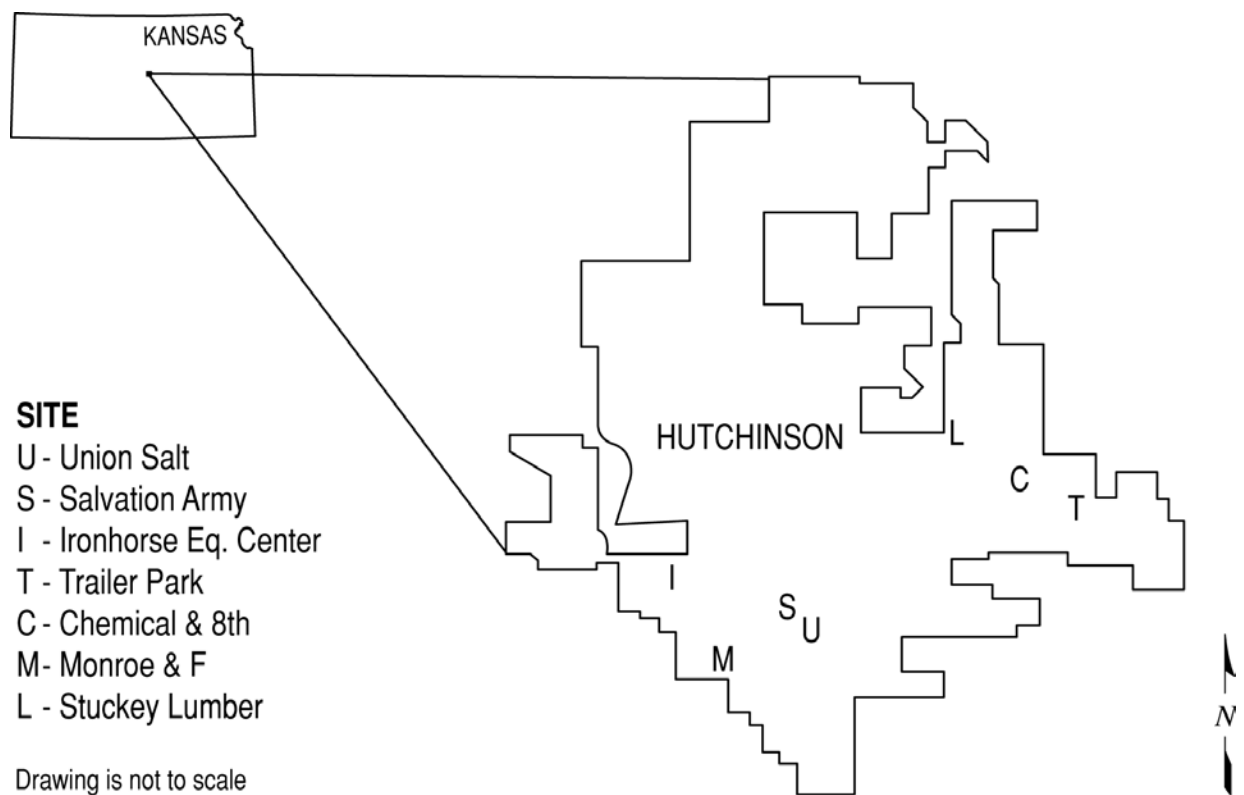


Figure 4. Site map showing the locations of the seven high-resolution magnetic surveys performed in the City of Hutchinson.



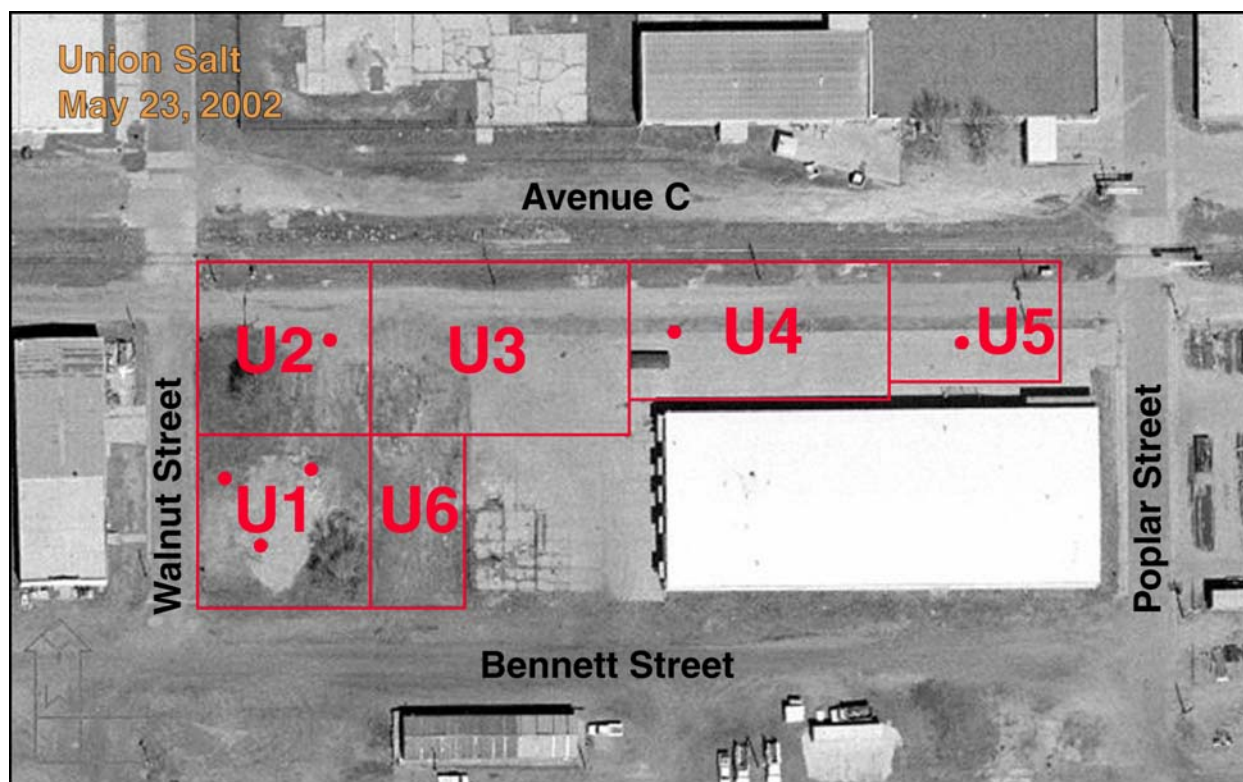


Figure 5. Aerial photo showing the Union Salt site. Red dots denote the locations of verified anomalies.



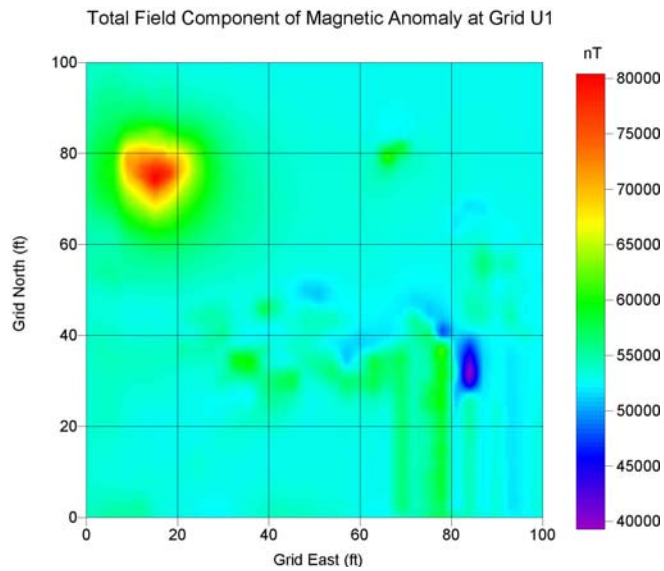


Figure 6. The total field component of the magnetic anomaly in grid U1 at Union Salt site (top). The anomaly at (15, 75) is due to a brine well. Depth to the top of the well is 1 ft. The length of the field notebook is 7.5 inch (bottom). Mike (James) Cunningham of the City of Hutchinson is making sure what we found is a brine well.



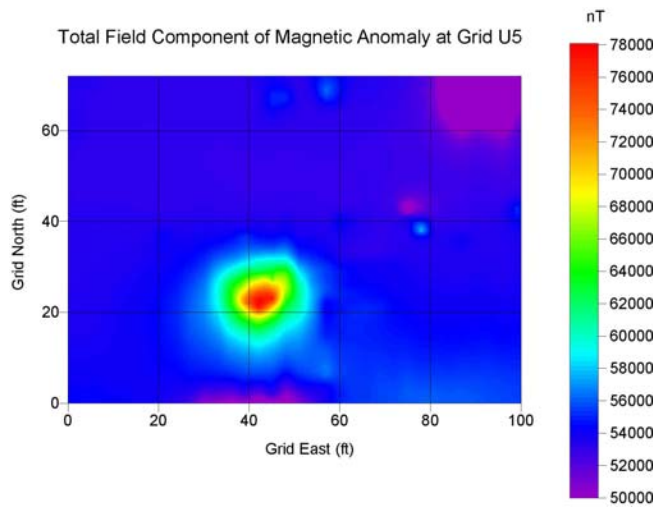


Figure 7. The total field component of the magnetic anomaly in grid U5 at the Union Salt site (top). The anomaly at (42, 23) is due to a brine well under 6 inches of concrete. Depth to the top of the well is 1 ft (bottom). Richard Harper of Kansas Department of Health & Environment is taking a note.



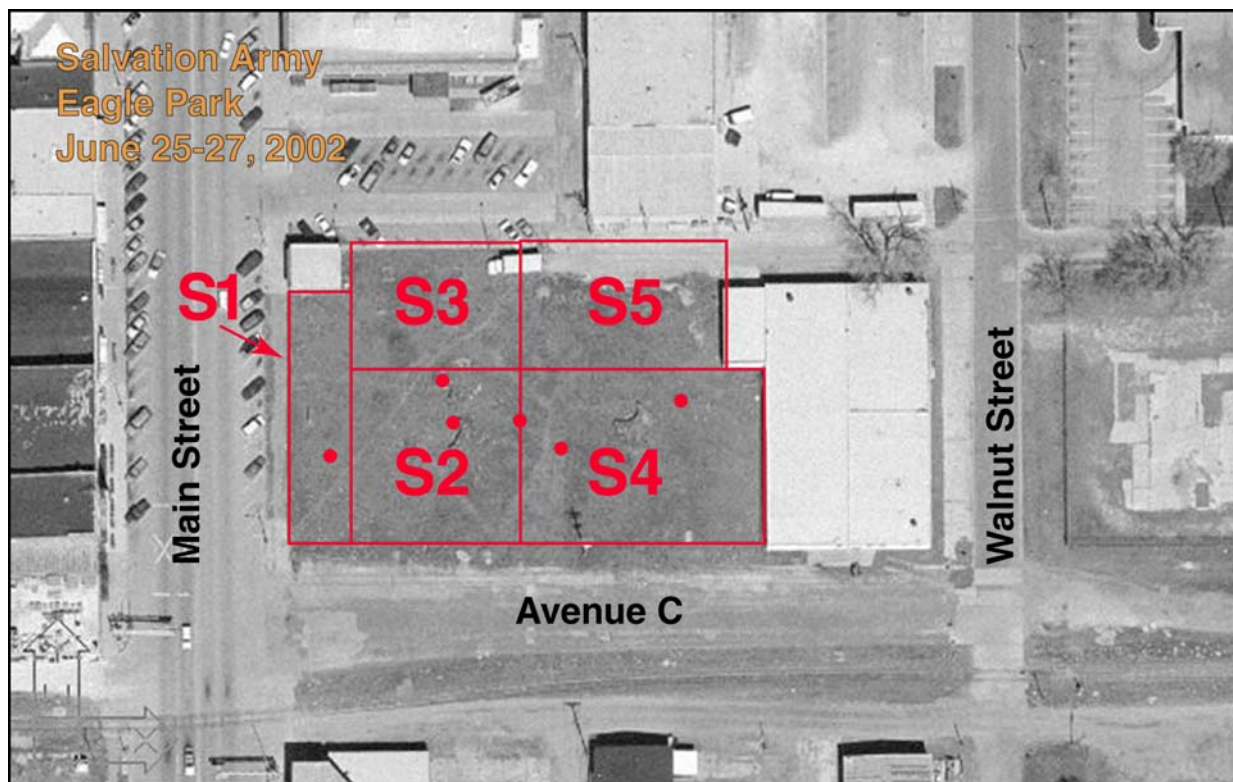


Figure 8. Aerial photo showing the Salvation Army Eagle Park site. Red dots denote the location of verified anomalies.



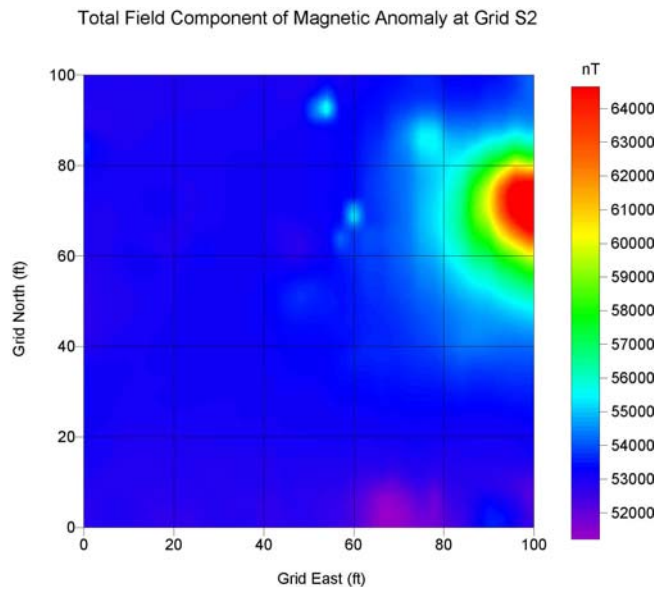


Figure 9. The total field component of the magnetic anomaly in grid S2 at the Salvation Army Eagle Park site (top). The anomaly at (100, 72) is due to a brine well at a depth of 7 ft (bottom).



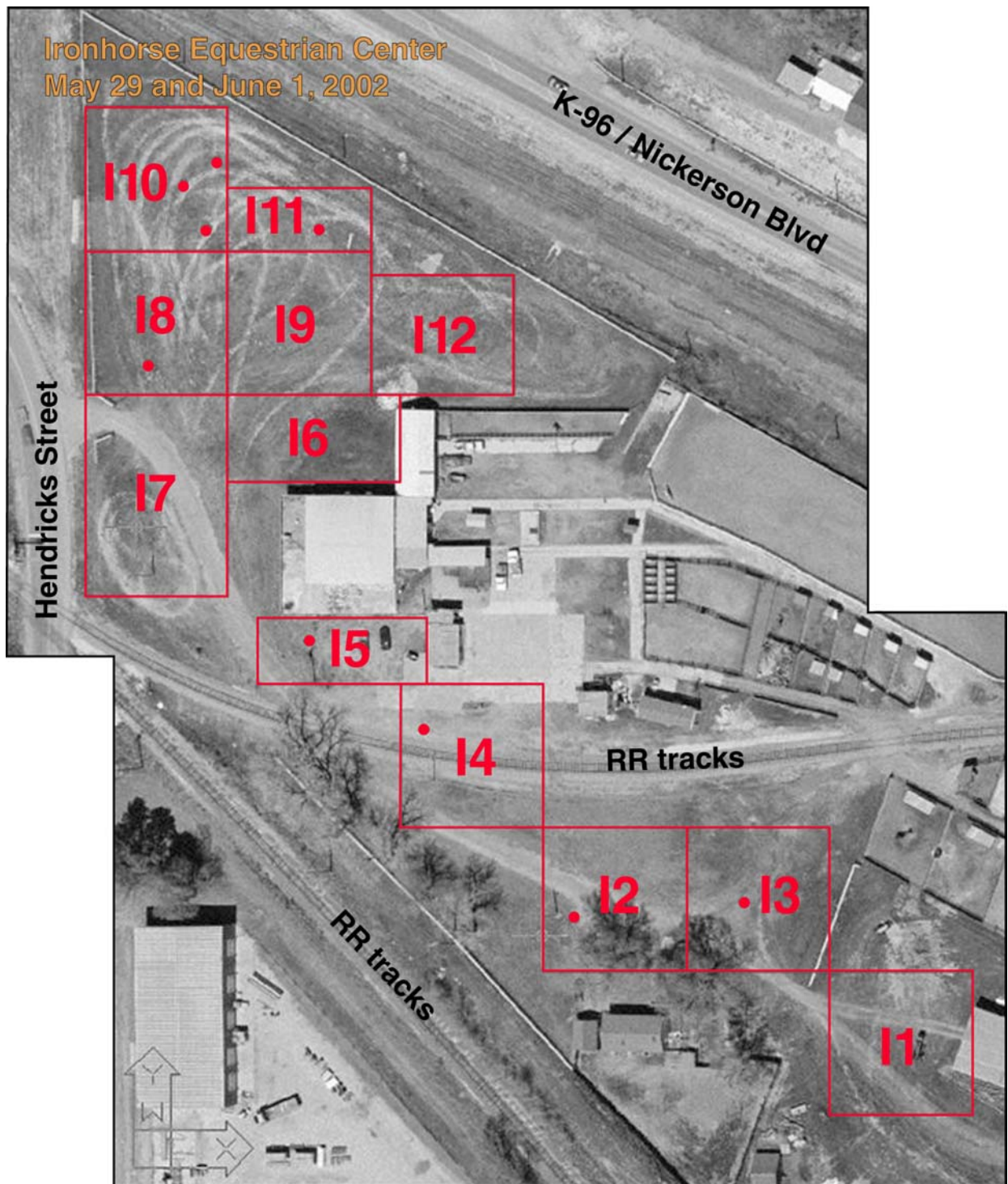


Figure 10. Aerial photo showing the Ironhorse Equestrian Center site. Red dots denote the locations of verified anomalies.



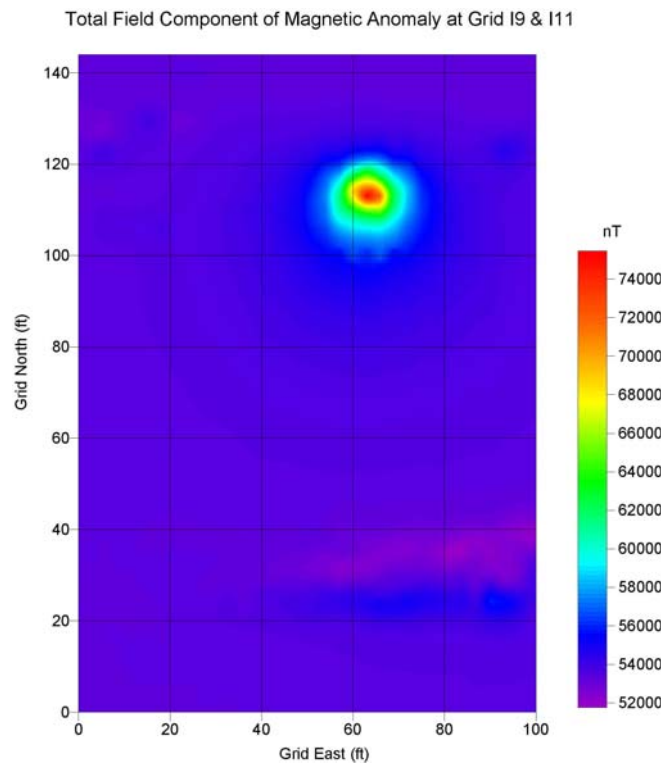


Figure 11. The total field component of the magnetic anomaly in grids I9 and I11 at the Ironhorse Equestrian Center (top). The anomaly at (63, 114) is due to a brine well at a depth of 4.5 ft (bottom).



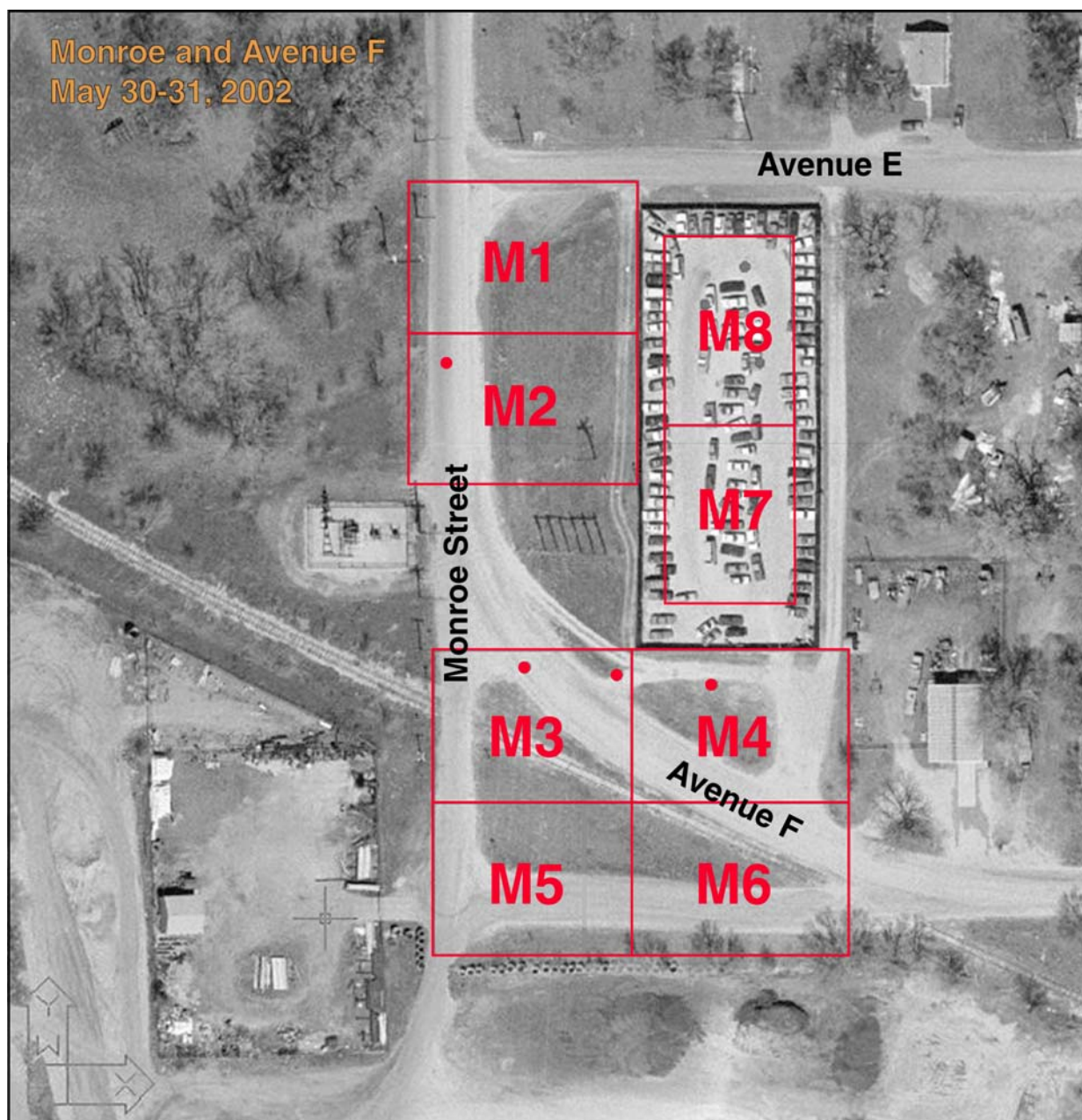


Figure 12. Aerial photo showing the Monroe Street & Avenues E and F site. Red dots denote the locations of verified anomalies.



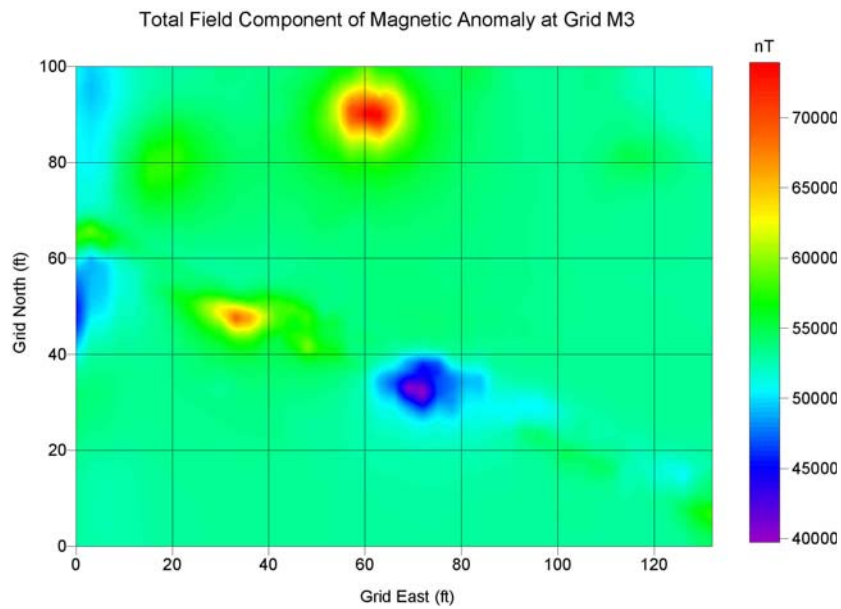


Figure 13. The total field component of the magnetic anomaly in grid M3 at Monroe & Avenues E and F (top). The anomaly at (62, 90) is due to a brine well at a depth of 2 ft under 1 ft of asphalt pavement (bottom).



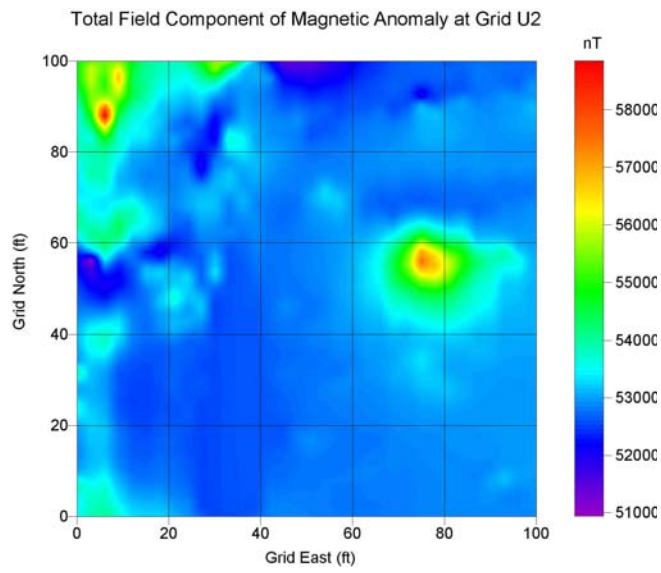


Figure 14. The total field component of the magnetic anomaly in grid U2 at the Union Salt site (top). The anomaly at (76, 55) is due to a suspected brine well (2.5-inch) at a depth of 4 ft (bottom). A spray paint can is shown for scale. We dug up to 7 ft deep to make sure it was not just a junk pipe.



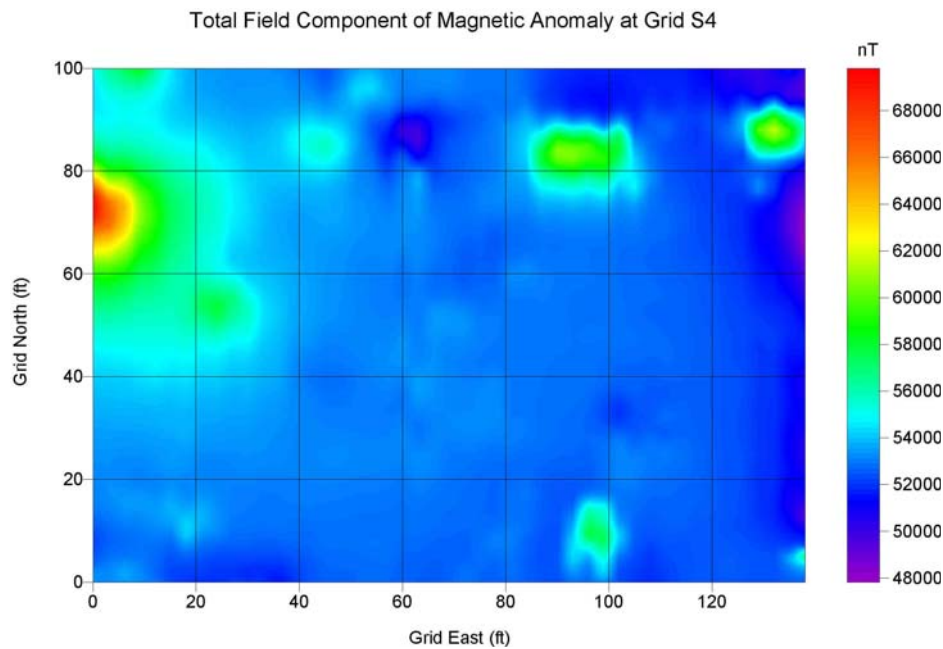


Figure 15. The total field component of the magnetic anomaly in grid S4 of at the Salvation Army Eagle Park site (top). The anomaly at (23, 55) is due to a suspected brine well (2.5-inch) at a depth of 2 ft (bottom). We dug up to 7 ft deep to make sure it was not just a junk pipe. Xia is checking the depth.



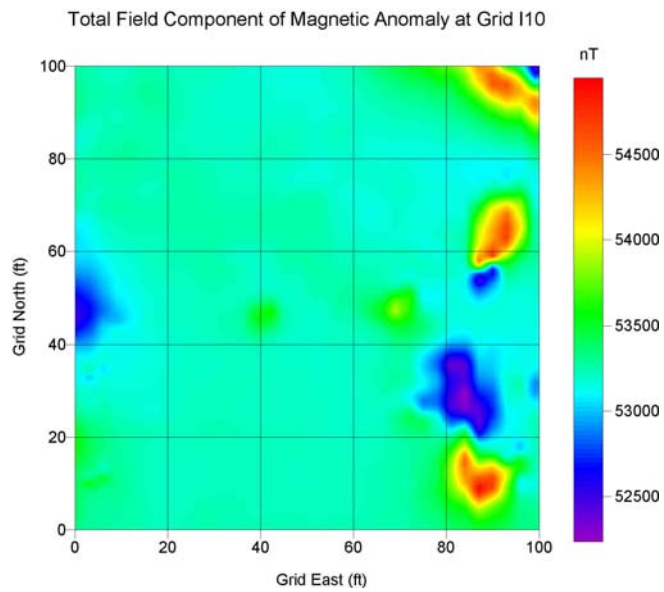


Figure 16. The total field component of the magnetic anomaly in grid I10 at the Ironhorse Equestrian Center site (top). The anomaly at (92, 62) is due to a suspected brine well (4-inch) at a depth of 2 ft (bottom). We dug down 4 ft to make sure it was not just a junk pipe.



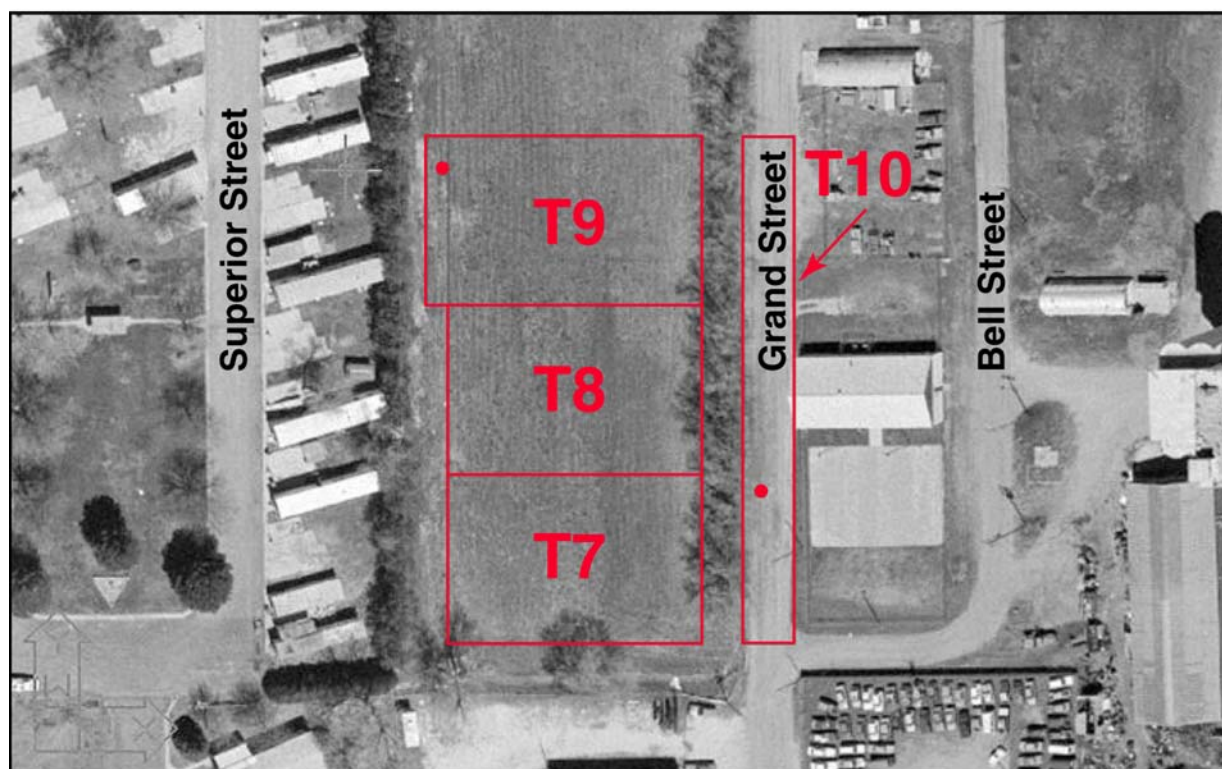
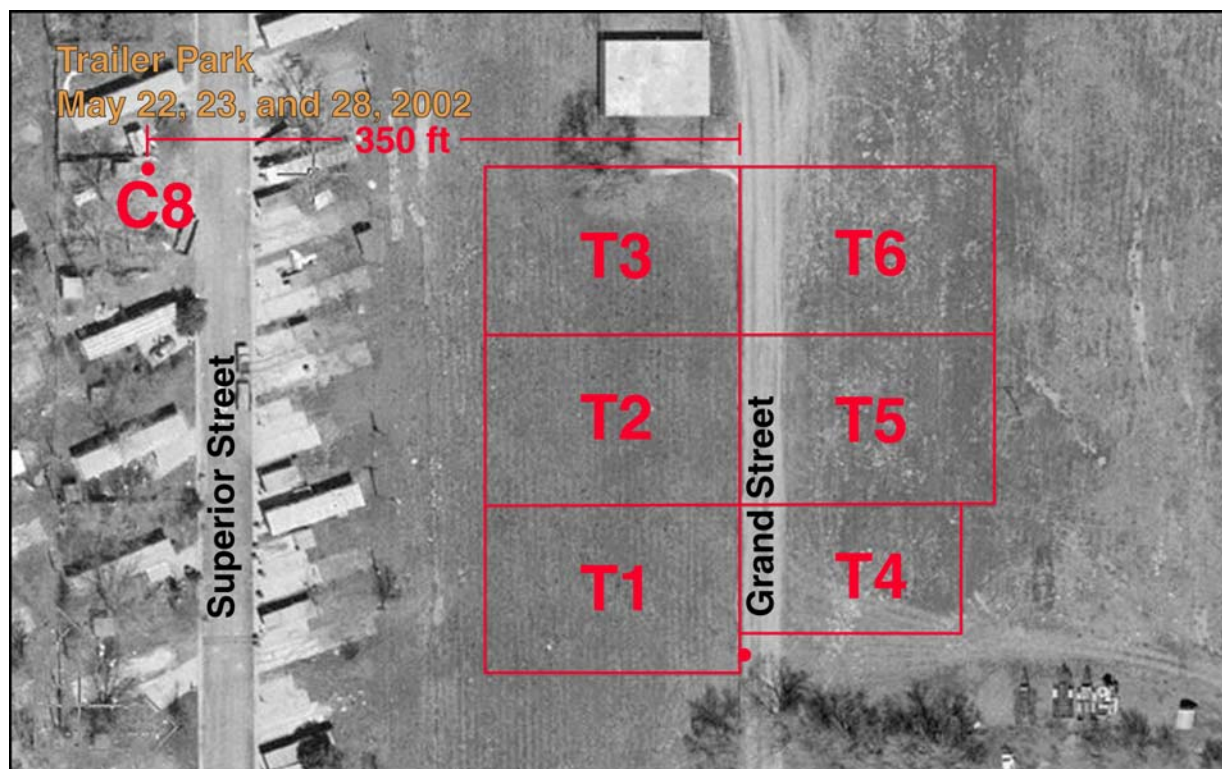


Figure 17. Aerial photo showing the Trailer Park site. Red dots denote the locations of verified anomalies.



Total Field Component of Magnetic Anomaly at Grid T10

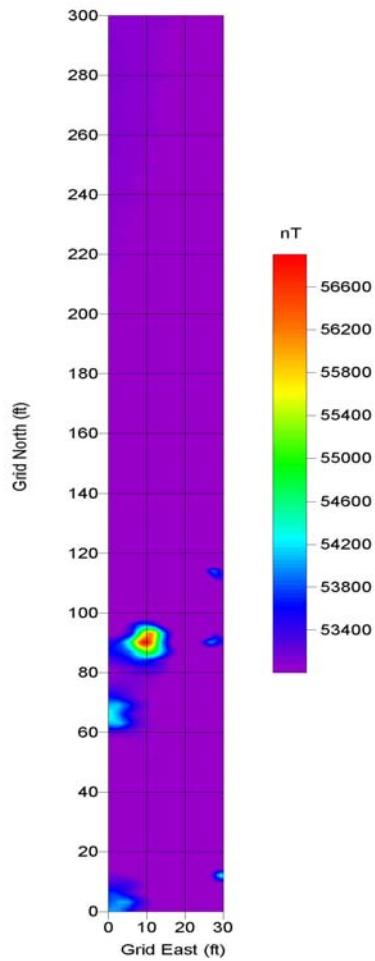


Figure 18. The total field component of the magnetic anomaly in grid T10 at the Trailer Park site (top). The anomaly at (10, 90) is due to a suspected brine well (2.5-inch) at a depth of 1 ft under a gravel pavement road (bottom). A 30' tape measure (3.5 inches tall) is shown for scale. We dug down 2.5 ft to make sure this was not just a junk pipe.



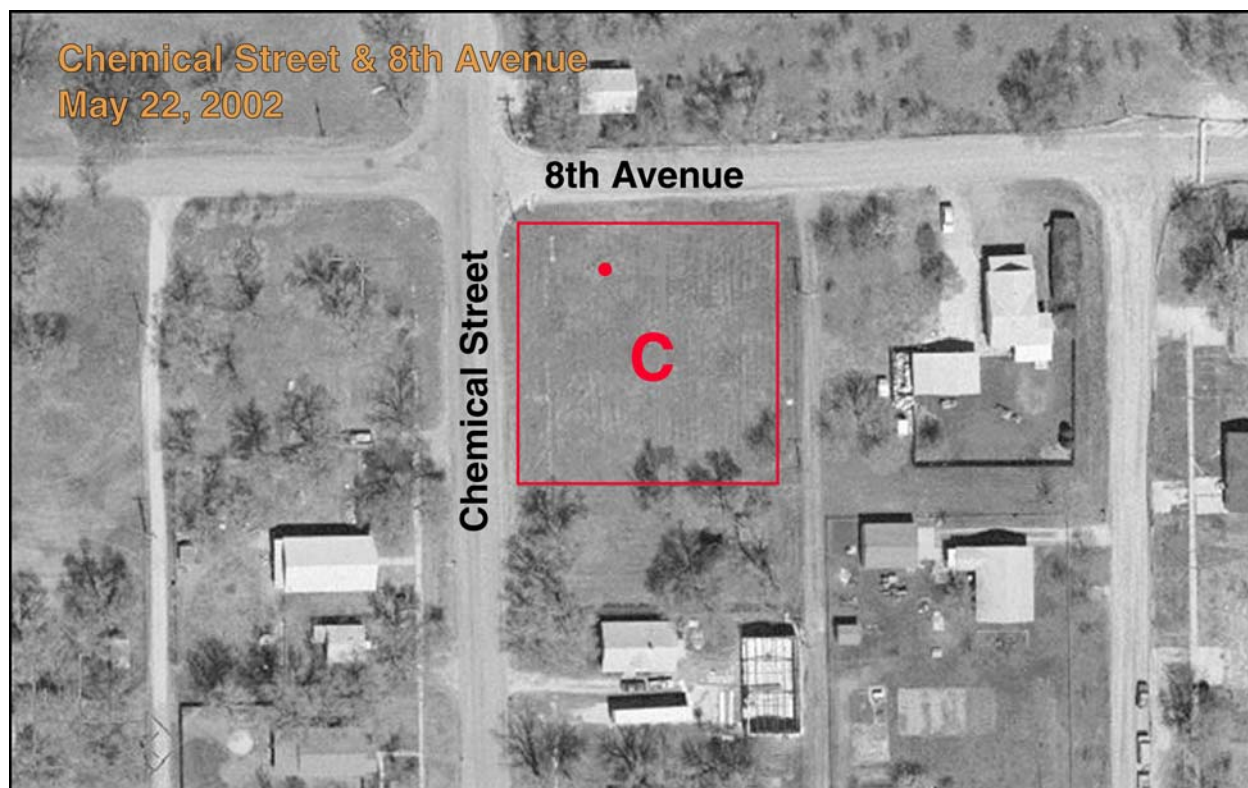


Figure 19. Aerial photo showing Chemical & 8<sup>th</sup> Street site. The red dot denotes the location of the verified anomaly.



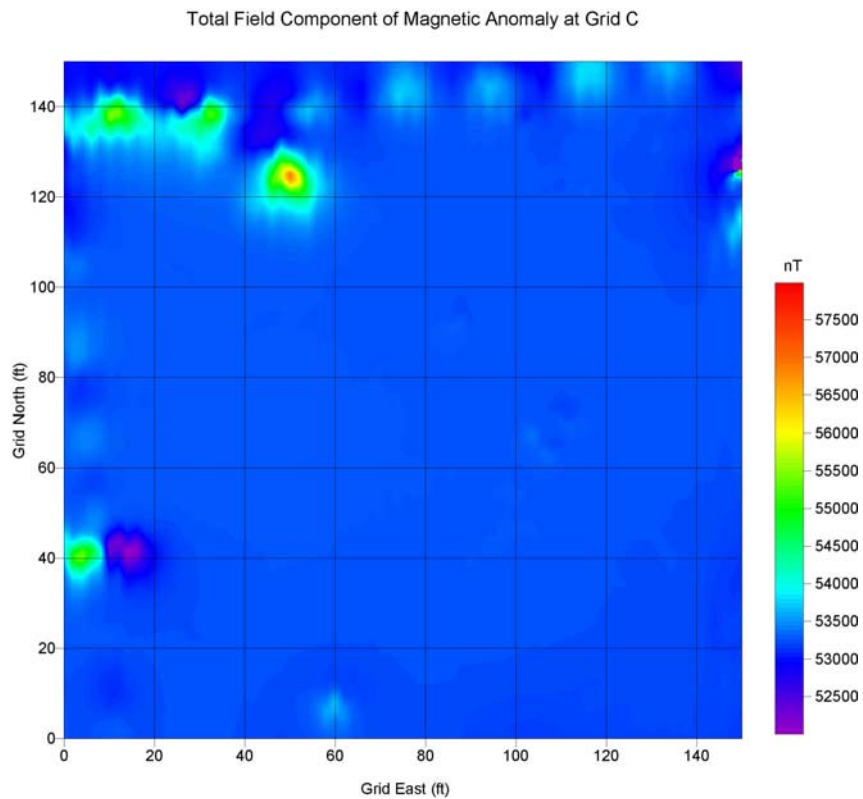


Figure 20. The total field component of the magnetic anomaly in grid C at the Chemical & 8<sup>th</sup> Street site (top). The anomaly at (50, 123) is due to a probable water well (1.5-inch) at a depth of 1 ft (bottom). We dug down 4 ft to make sure this was not just a junk pipe. Kyle Parker (bottom left) of Kansas Department of Health and Environment is checking the well and Sihao Xia (bottom right) is measuring the diameter of the well.



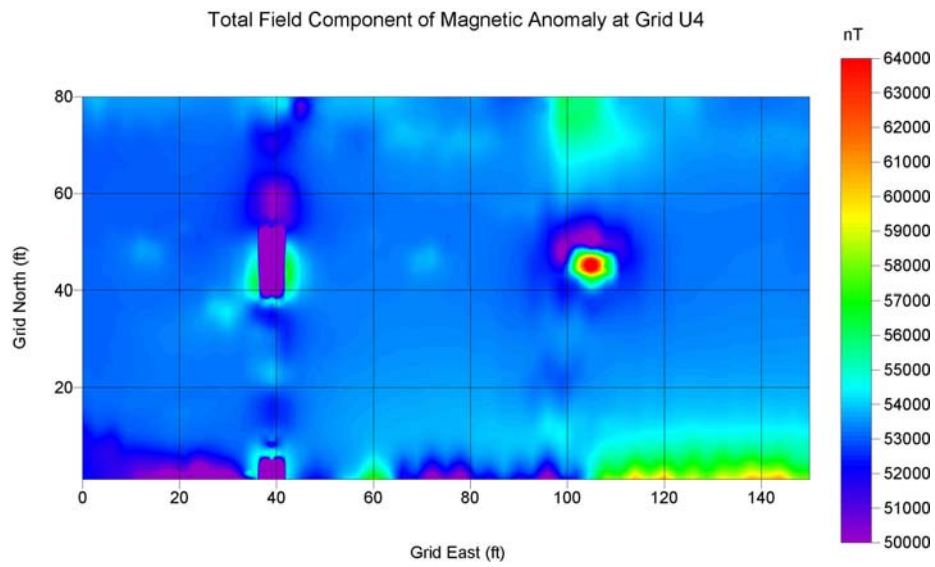


Figure 21. The total field component of the magnetic anomaly in grid U4 at the Union Salt site (top). The anomaly at (36, 40) is due to a probable utility pipe (4-inch) at a depth of 1 ft under 6 inches of concrete (bottom). Mike Cunningham of the City of Hutchinson is checking the pipe.



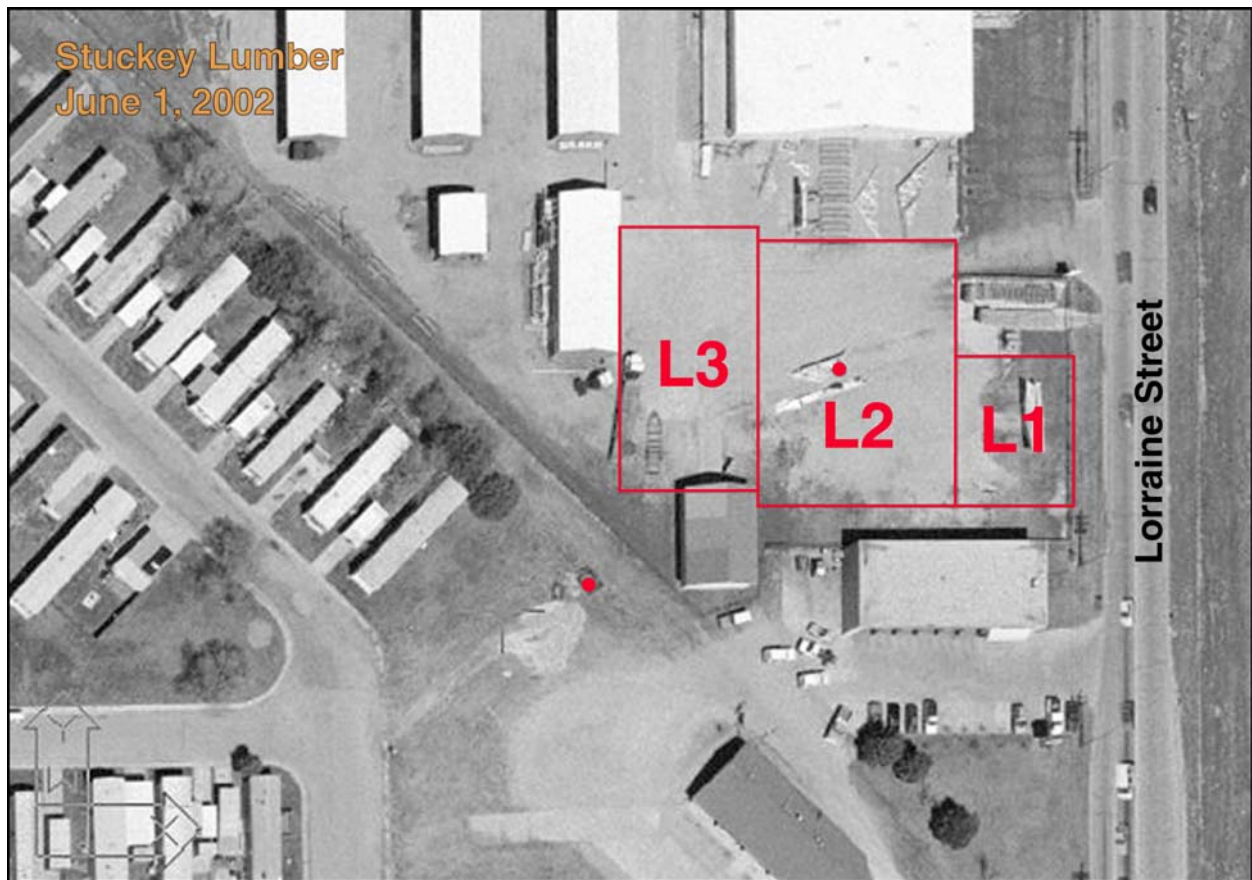


Figure 22. Aerial photo showing the Stuckey Lumber site. Red dots denote the locations of verified anomalies (top). Anomaly is due to a 6-inch horizontal 10 ft pipe at a depth of 1.5 ft (bottom).



**Appendix A. Normal Geomagnetic Field in Hutchinson, Kansas**  
<http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnt1.pl>

Model: IGRF2000  
 Latitude: 38 deg, 3 min, 54 sec  
 Longitude: -97 deg, 54 min, 50 sec  
 Elevation: ~0.50 km  
 Date of Interest: 5/22/2002

D		I		H	X	Y	Z	F
(deg)		(deg)		(nt)	(nt)	(nt)	(nt)	(nt)
5d	50m	66d	35m	21307	21197	2166	49203	53618
dD		dI		dH	dX	dY	dZ	dF
(min/yr)		(min/yr)		(nT/yr)	(nT/yr)	(nT/yr)	(nT/yr)	(nT/yr)
-6		-1		-16	-12	-39	-92	-91

### Definitions

#### D: Magnetic Declination

Magnetic declination is sometimes referred to as the magnetic variation or the magnetic compass correction. It is the angle formed between true north and the projection of the magnetic field vector on the horizontal plane. By convention, declination is measured positive east and negative west (i.e. D -6 means 6 degrees west of north). For surveying practices, magnetic declination is the angle through which a magnetic compass bearing must be rotated in order to point to the true bearing as opposed to the magnetic bearing. Here the true bearing is taken as the angle measured from true North.

Declination is reported in units of degrees. One degree is made up of 60 minutes. To convert from decimal degrees to degrees and minutes, multiply the decimal part by 60. For example, 6.5 degrees is equal to 6 degrees and 30 minutes (0.5 x 60 = 30).

If west declinations are assumed to be negative while east declination are considered positive then

$$\text{True bearing} = \text{Magnetic bearing} + \text{Magnetic declination}$$

An example: The magnetic bearing of a property line has an azimuth of 72 degrees East. What is the true bearing of the property line if the magnetic declination at the place in question is 12 degrees West?

A magnetic declination of 12 degrees West means that magnetic North lies 12 degrees West of true north.

$$\begin{aligned} \text{True bearing} &= 72 \text{ degrees} + (-12 \text{ degrees declination}) \\ &= 72 \text{ degrees} - 12 \text{ degrees declination} = 60 \text{ degrees East} \end{aligned}$$



It should be noted that the magnetic declination becomes undefined at the North and South magnetic poles. These poles are by definition the two places where the magnetic field is vertical. Magnetic compasses become quite unreliable when the magnetic field vector becomes steeply inclined.

D is defined as  $D = \arctan(Y / X)$ .

dD: The change in declination with respect to time.

### **I: Magnetic Inclination**

Also called magnetic dip, this is the angle measured from the horizontal plane, positively down to the magnetic field vector. If the vector components of F are X, Y, and Z then

$$I = \arctan(Z / \sqrt{X^2 + Y^2})$$

or

$$I = \arctan(Z / H)$$

The north magnetic pole is defined as that position where I=90 degrees i.e. straight down. Similarly, the south magnetic pole is defined as that position where I= -90 degrees i.e. straight up.

dI: The change in inclination with respect to time.

### **H: Horizontal Component of the Magnetic Field**

This is the magnitude of vector constructed by projecting the total field vector onto the local horizontal plane. In terms of the vector components of the field

$$H = \sqrt{X^2 + Y^2}$$

dH: The change in the horizontal component with respect to time

### **X: North Component of the Magnetic Field**

This is the magnitude of vector constructed by projecting the total field vector onto an axis lying in the direction of the Earth's rotational pole or true North.

dX: The change in X with respect to time.

### **Y: East Component of the Magnetic Field**

This is the magnitude of vector constructed by projecting the total field vector onto an axis in the Eastward direction i.e. perpendicular to the X-axis.

dY: The change in Y with respect to time.



### **Z: Vertical Component of the Magnetic Field**

This is the magnitude of vector constructed by projecting the total field vector onto an axis in the local vertical direction i.e. perpendicular to the horizontal plane.

dZ: The change in Z with respect to time.

### **F: Magnetic Field Vector**

The Earth's magnetic field, referred to as the geomagnetic field is a vector field i.e., at each point in space this field has a strength and a direction. This vector, F is referenced to a local coordinate system as follows: the vector is decomposed into three mutually perpendicular (orthogonal) vector components, which are referred to as the X, Y, and Z components of the field, where the X and the Y components lie in the horizontal plane with X lying in the northward direction, Y lying in the eastward direction, while the Z component is taken in the local vertical direction. The strength of the magnetic field is usually given in units of nanoteslas (nT) and is taken in the usual mathematical fashion i.e.

$$\text{magnitude } (F) = \text{square root}(X*X + Y*Y + Z*Z)$$

The X, Y, and Z components completely describe the magnetic field vector, F however in the study of the Earth's magnetic field it is often convenient to describe this vector's direction through the use of two so-called "angular components" called the declination and the inclination. In addition the strength of the projection of the vector F onto the horizontal plane or the H component is often studied.

dF: The change in F with respect to time.

### **Magnetic Field Components**

There are seven magnetic field elements: the total field vector (F), the X component or northward component, the Y component or eastward component, the Z component or vertical component, and the H or horizontal component. These five elements are often referred to as the force elements while the last two components, the declination and the inclination are referred to as the angular elements.

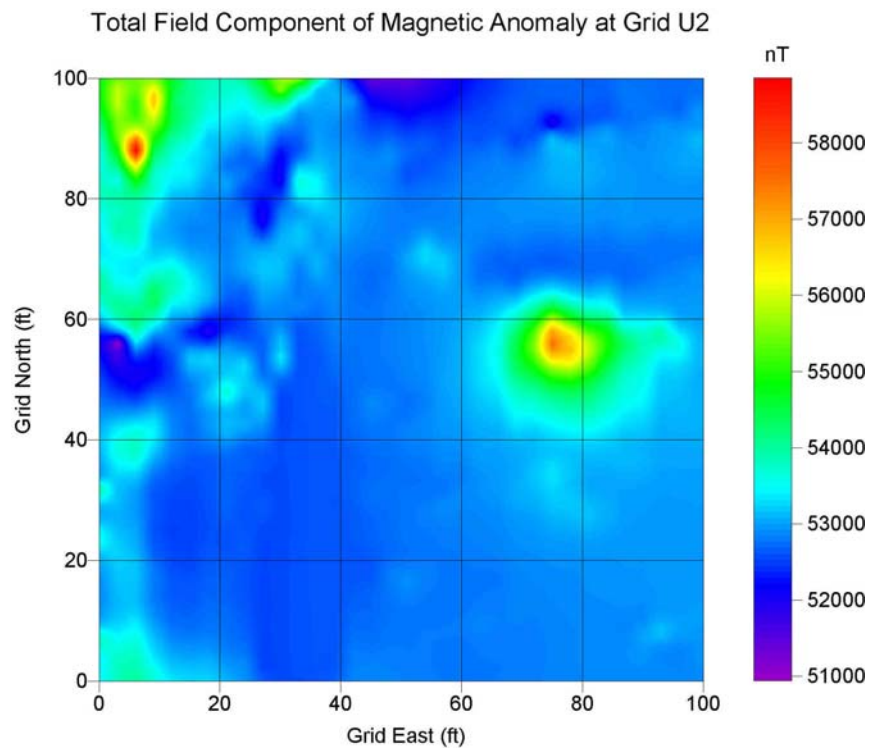
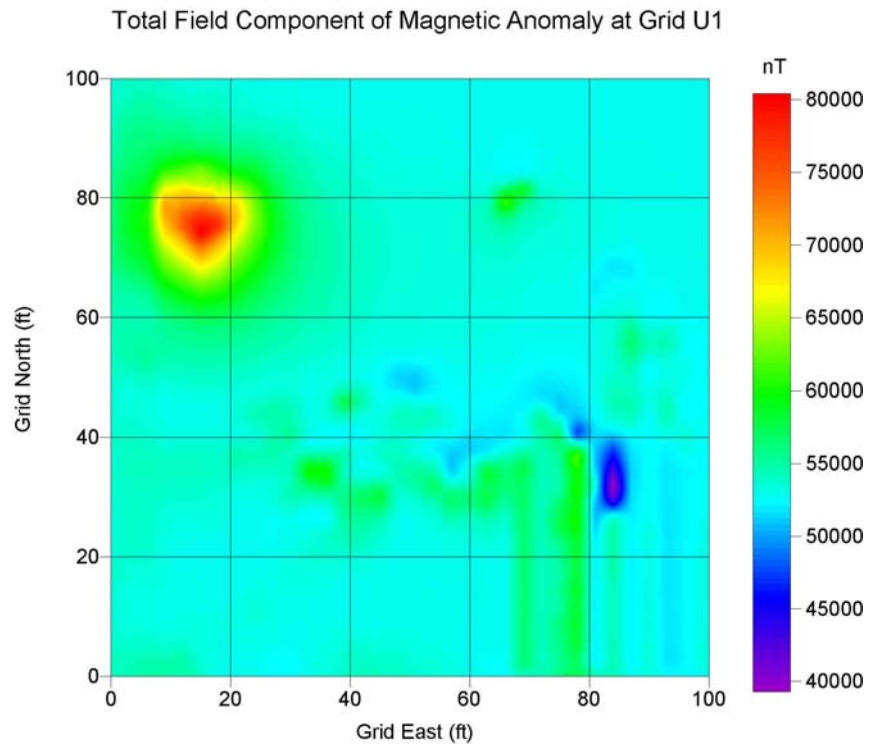


**Appendix B. Total Filed Component of Magnetic Anomaly in Seven Sites in Hutchinson,  
Kansas**

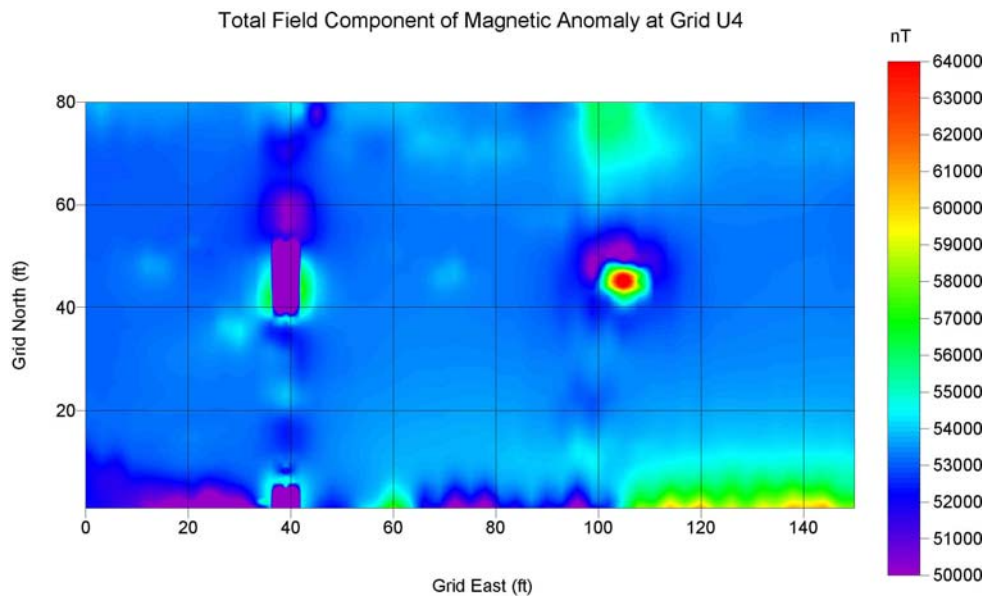
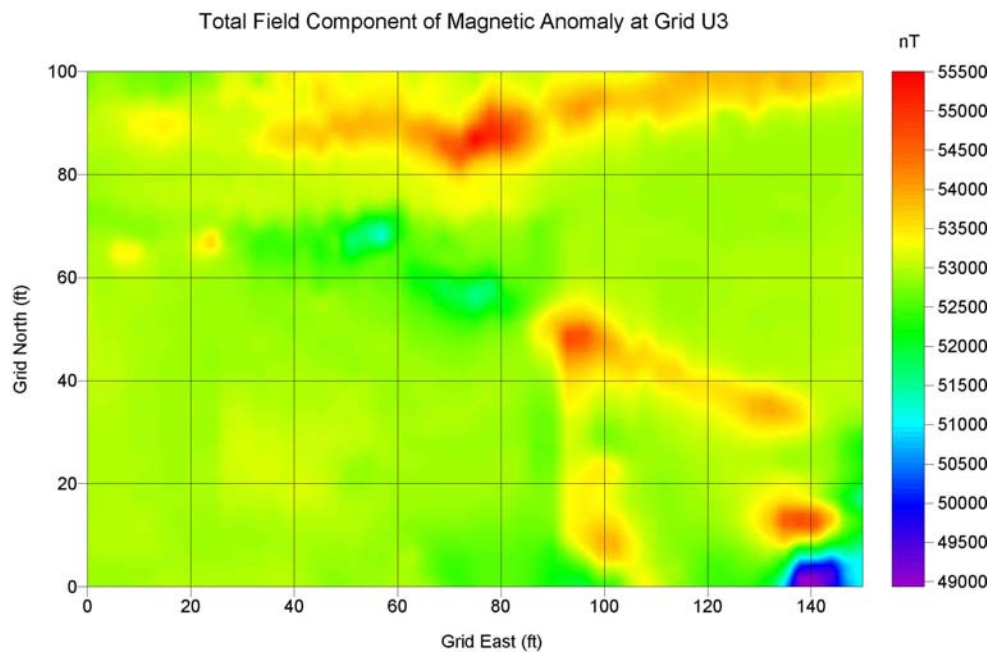
1. Grids U1 - U6 at Union Salt
2. Grids S1 - S5 at Salvation Army Eagle Park
3. Grids I1 - I12 at Ironhorse Equestrian Center
4. Grids T1 - T10 at Trailer Park
5. Grid C at Chemical & 8<sup>th</sup> Street
6. Grids M1 - M8 at Monroe Street & Avenues E and F
7. Grids L1 - L3 at Stuckey Lumber



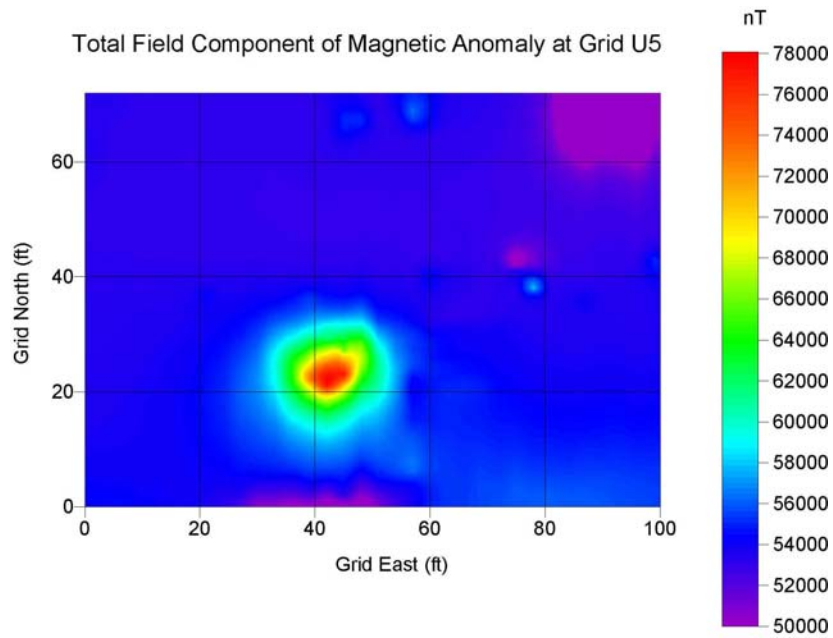
## 1. Grids U1 - U6 at Union Salt



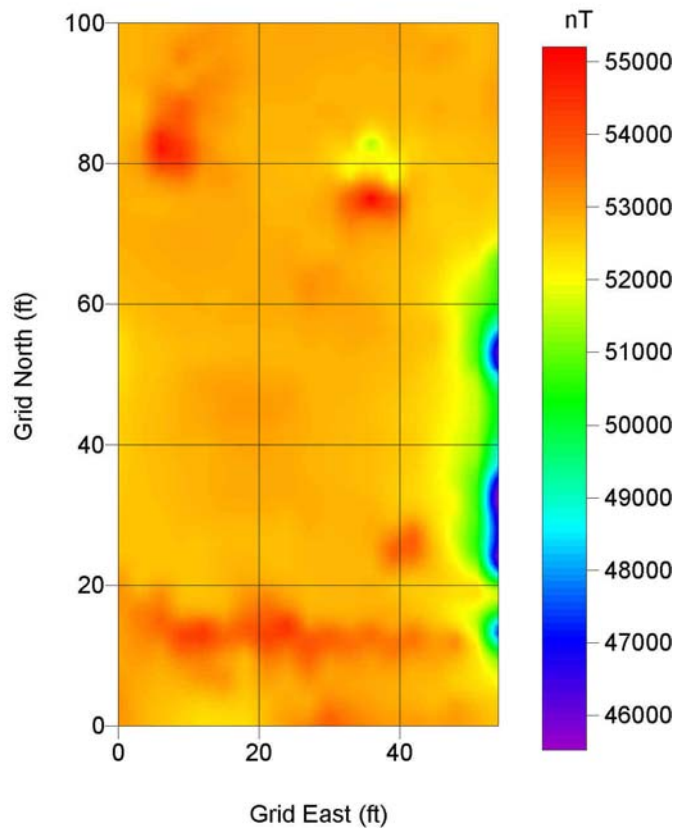








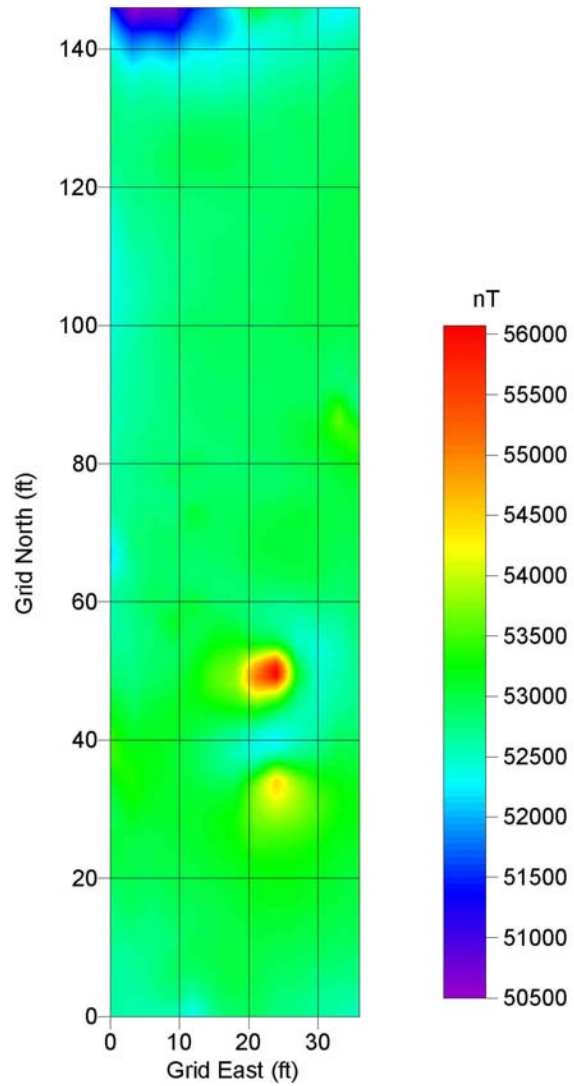
Total Field Component of Magnetic Anomaly at Grid U6





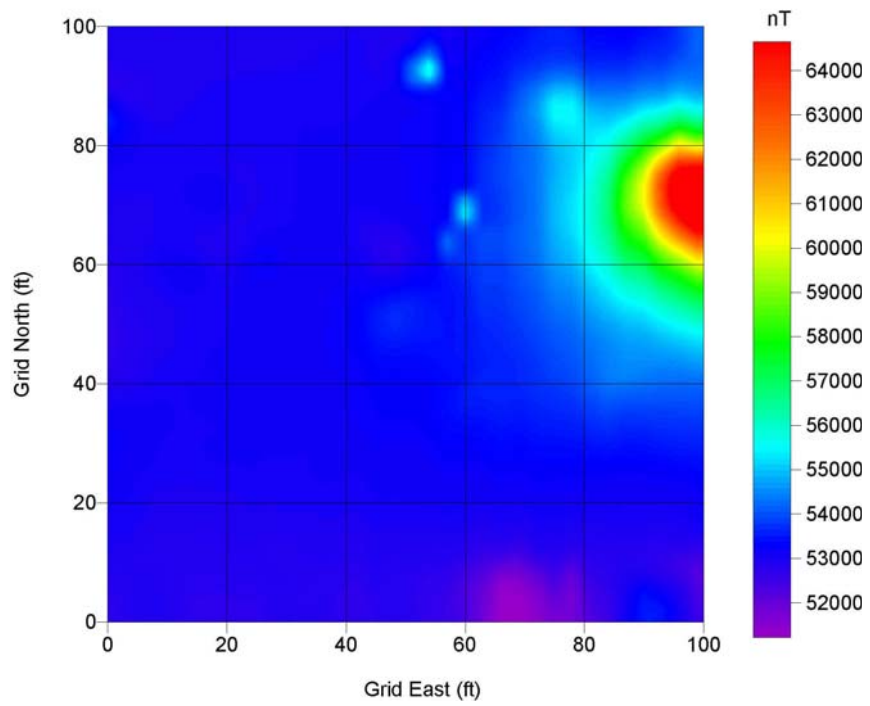
## 2. Grids S1 - S5 at Salvation Army Eagle Park

Total Field Component of Magnetic Anomaly at Grid S1

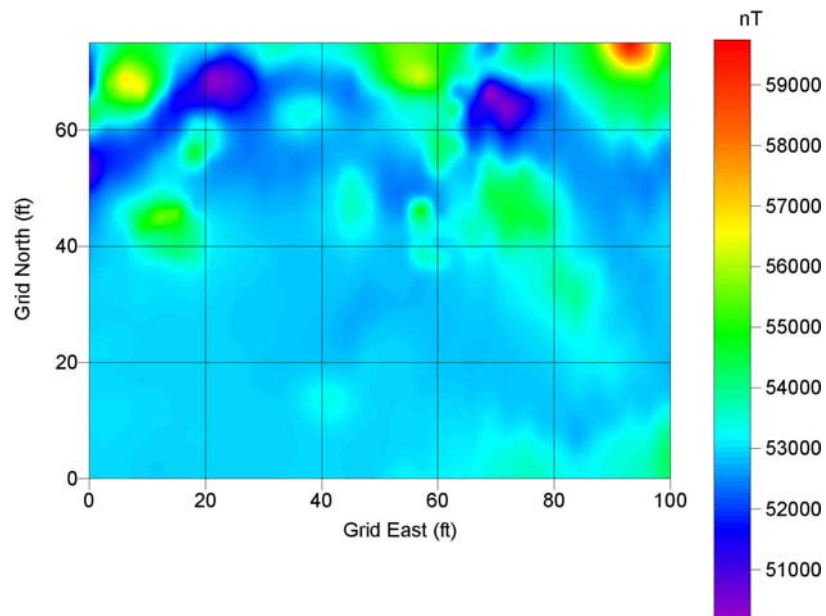




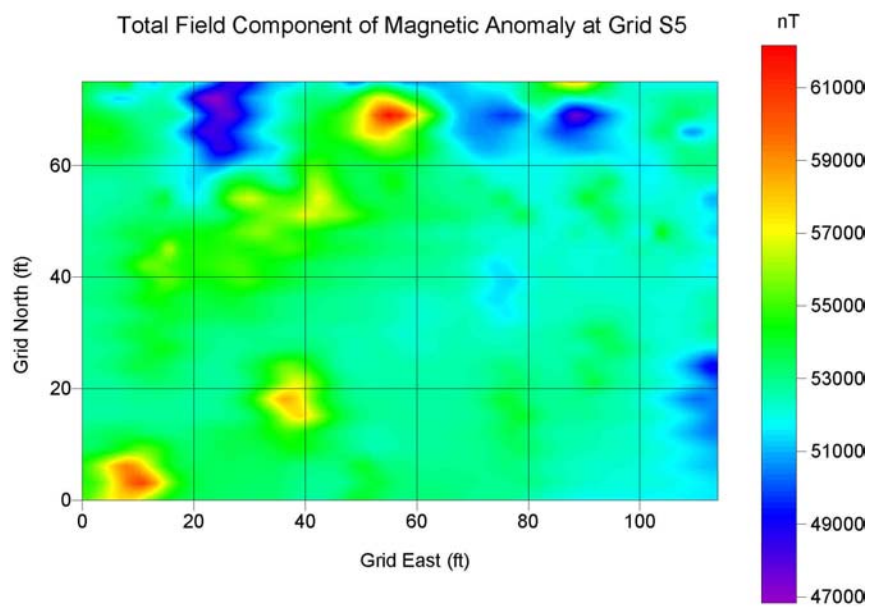
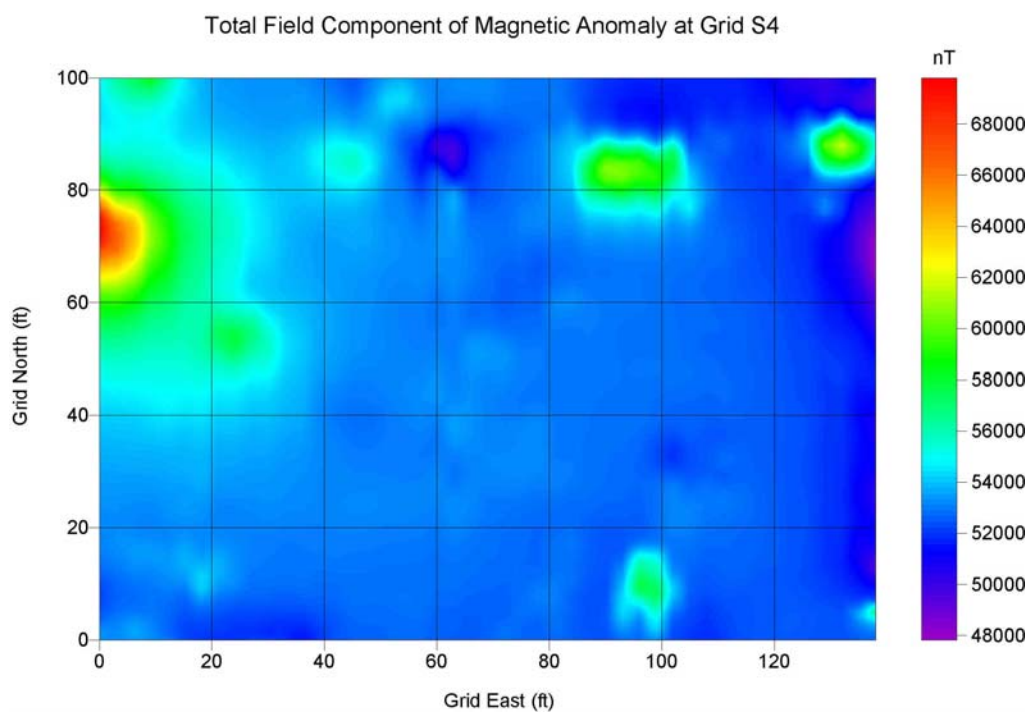
Total Field Component of Magnetic Anomaly at Grid S2



Total Field Component of Magnetic Anomaly at Grid S3

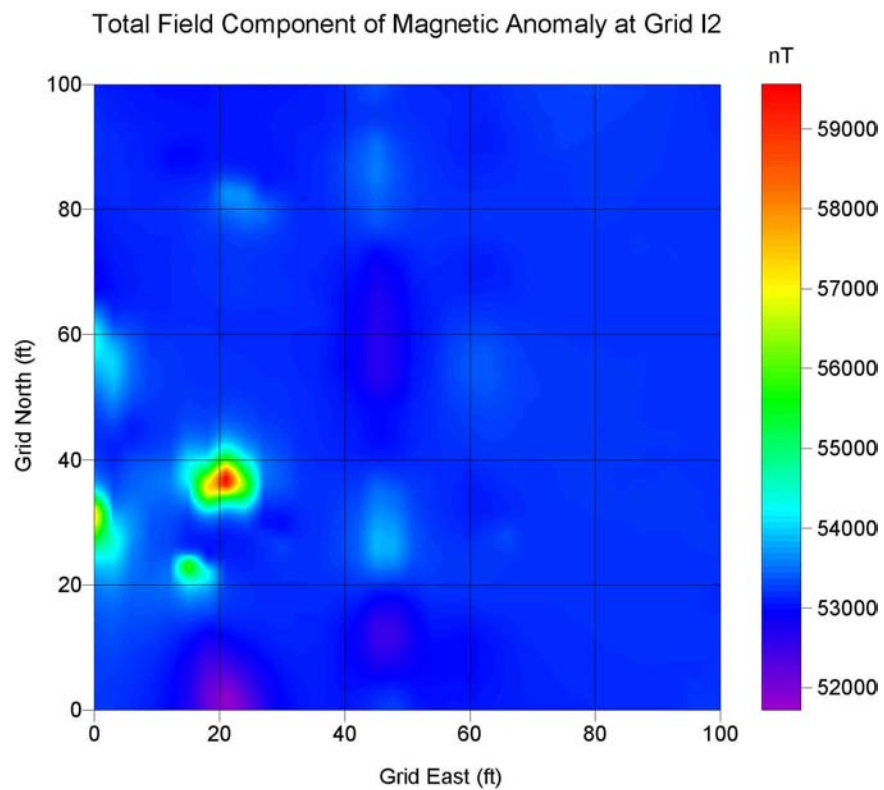
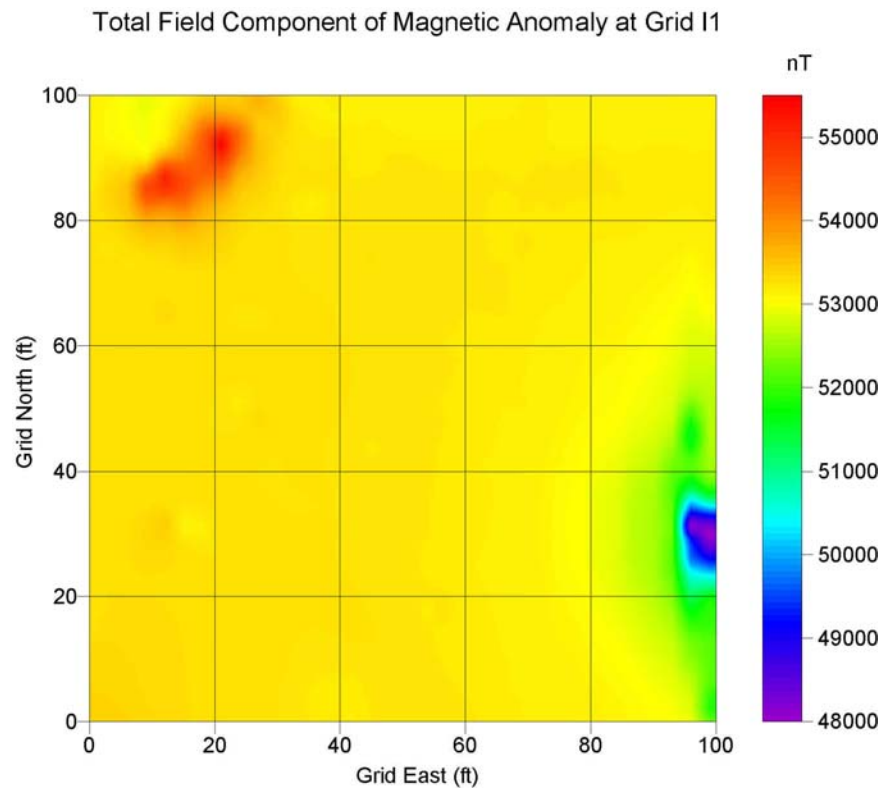






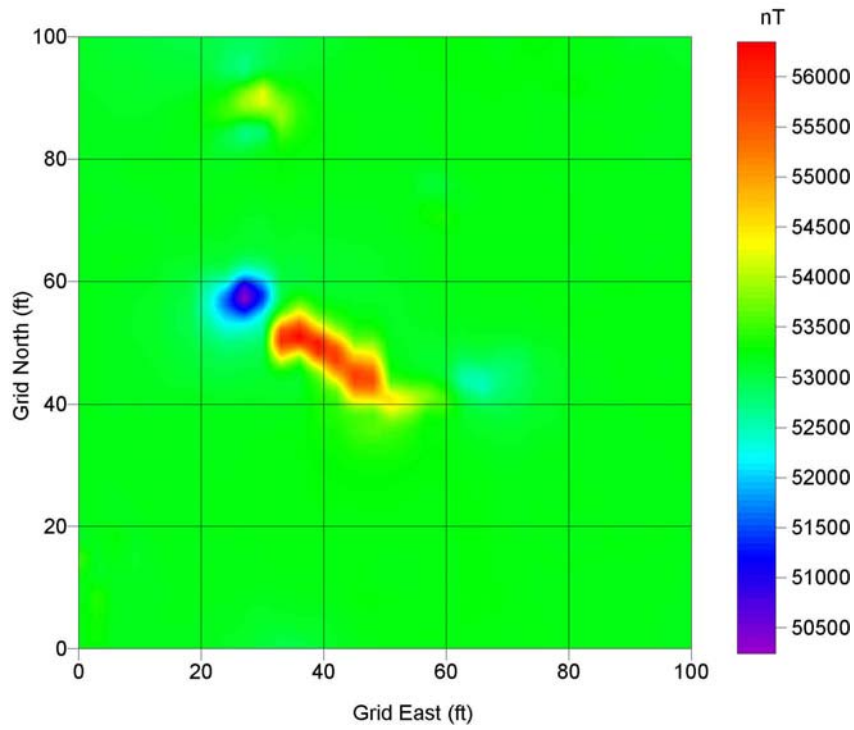


### 3. Grids I1 - I12 at Ironhorse Equestrian Center

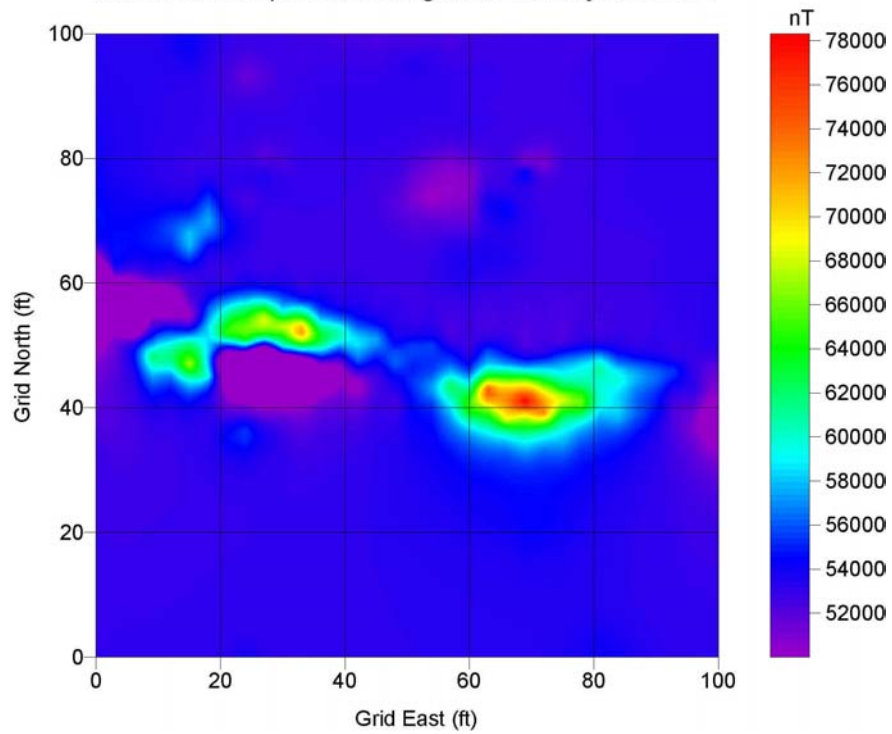




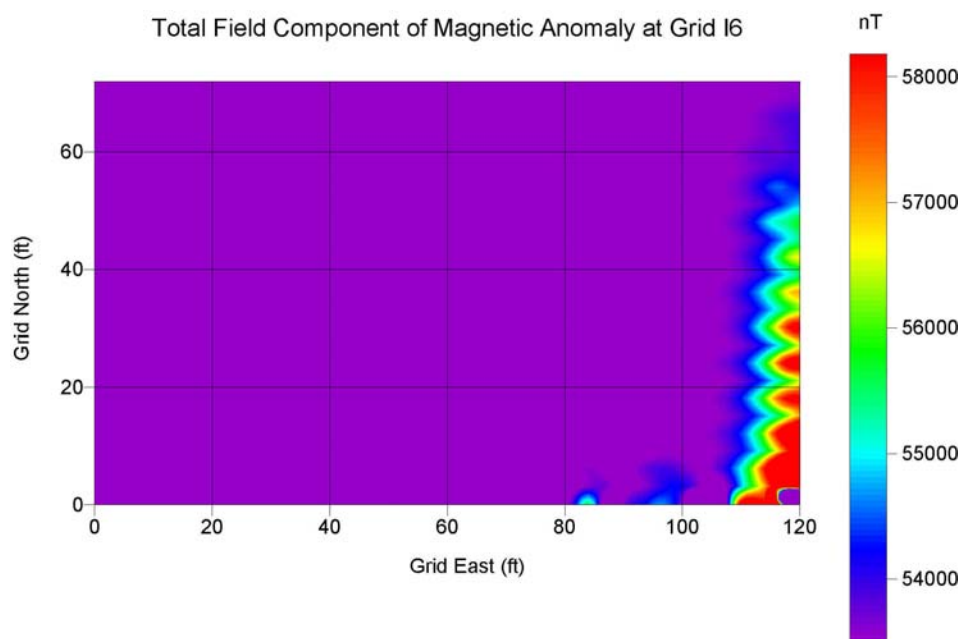
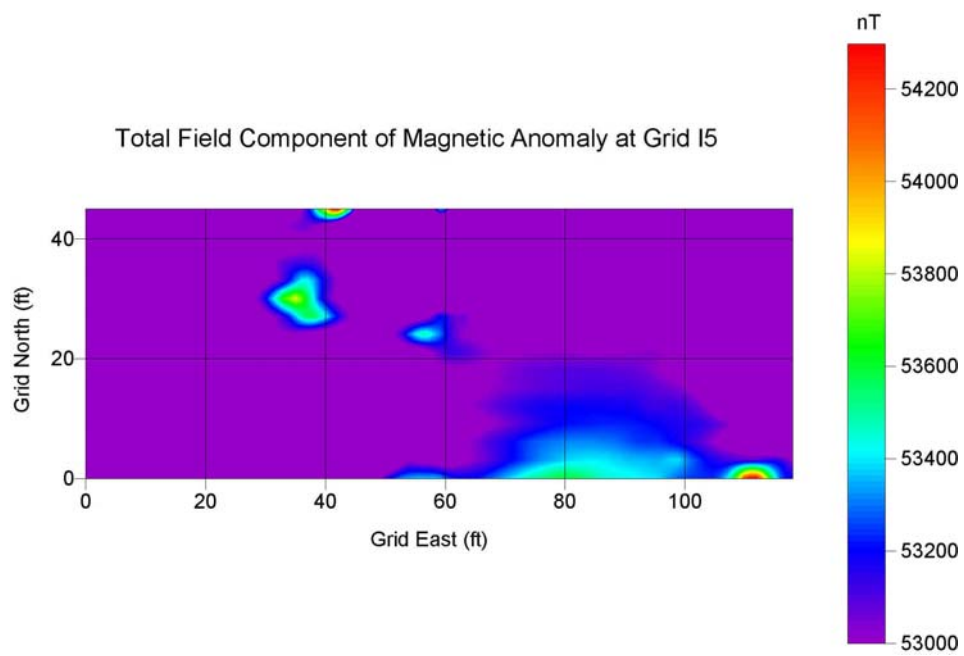
Total Field Component of Magnetic Anomaly at Grid I3



Total Field Component of Magnetic Anomaly at Grid I4

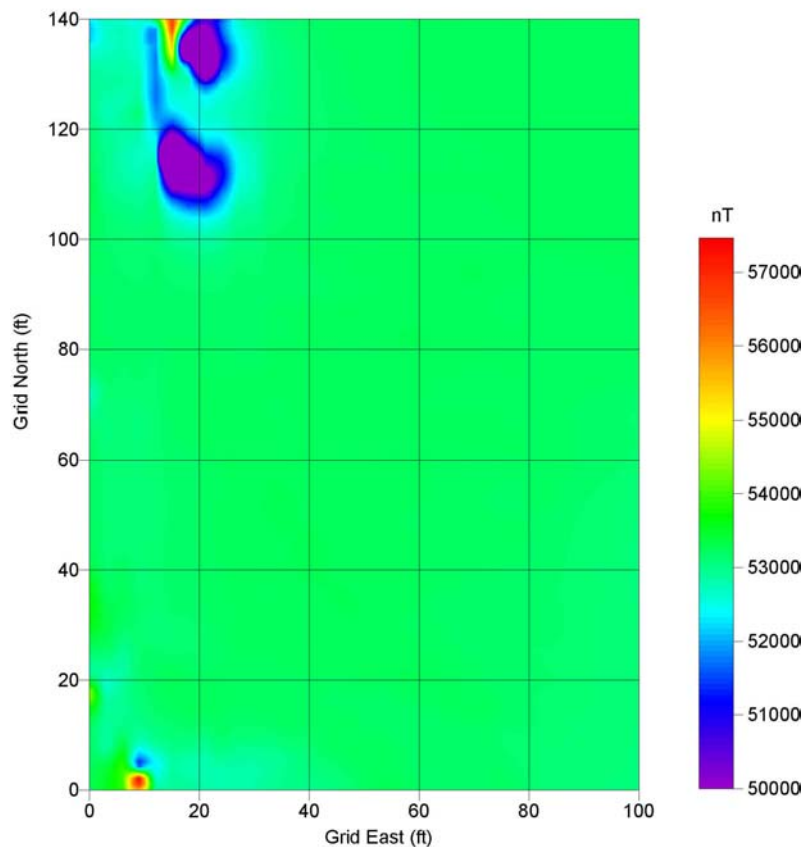




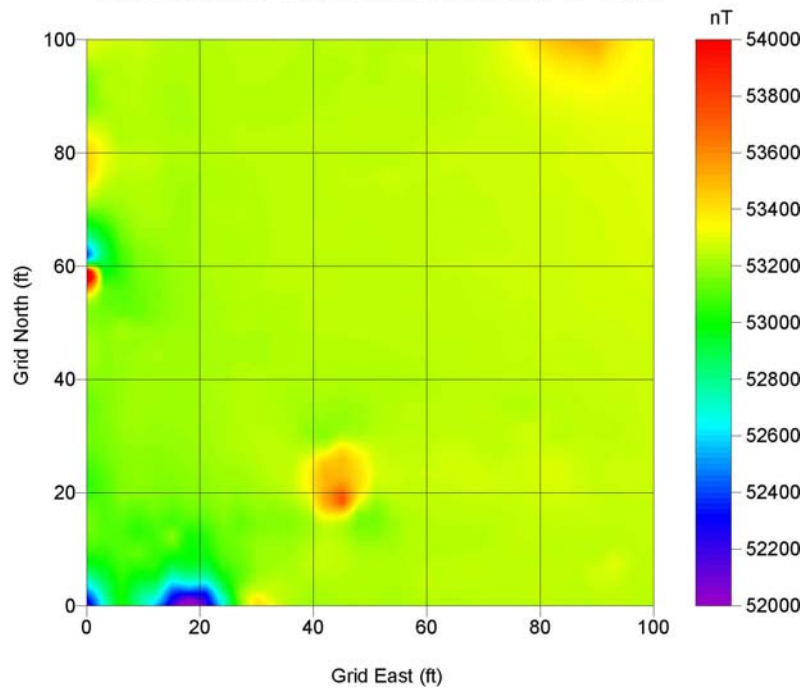




Total Field Component of Magnetic Anomaly at Grid I7

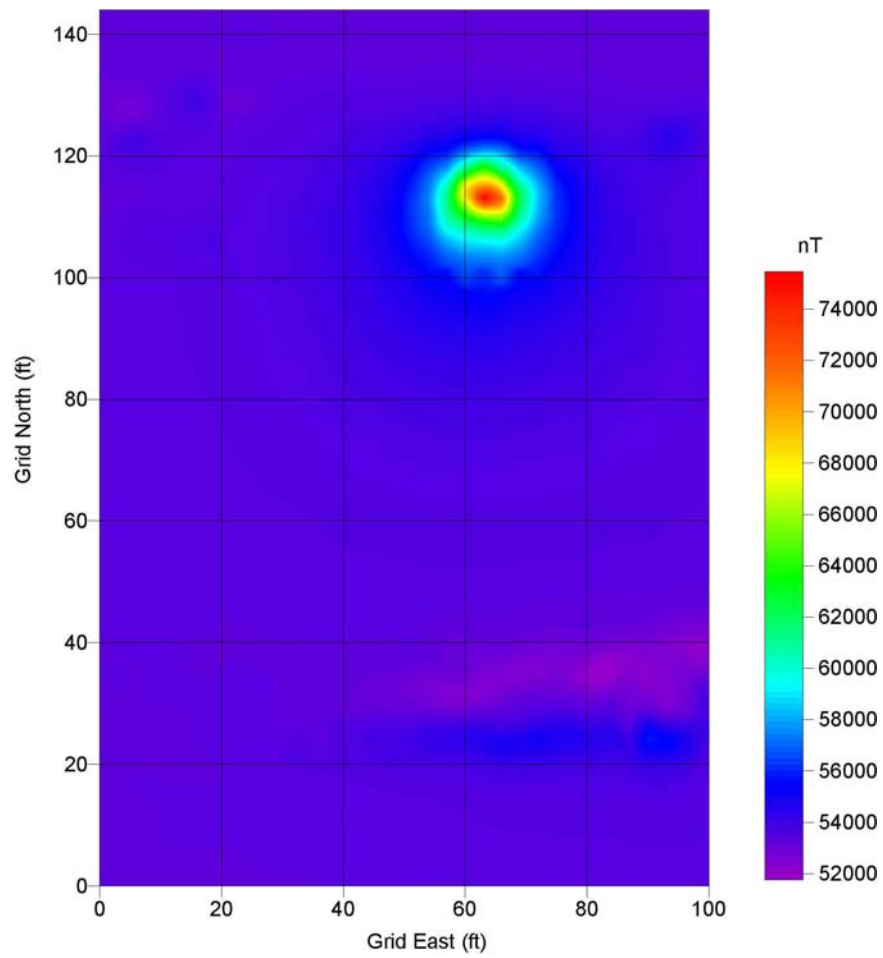


Total Field Component of Magnetic Anomaly at Grid I8



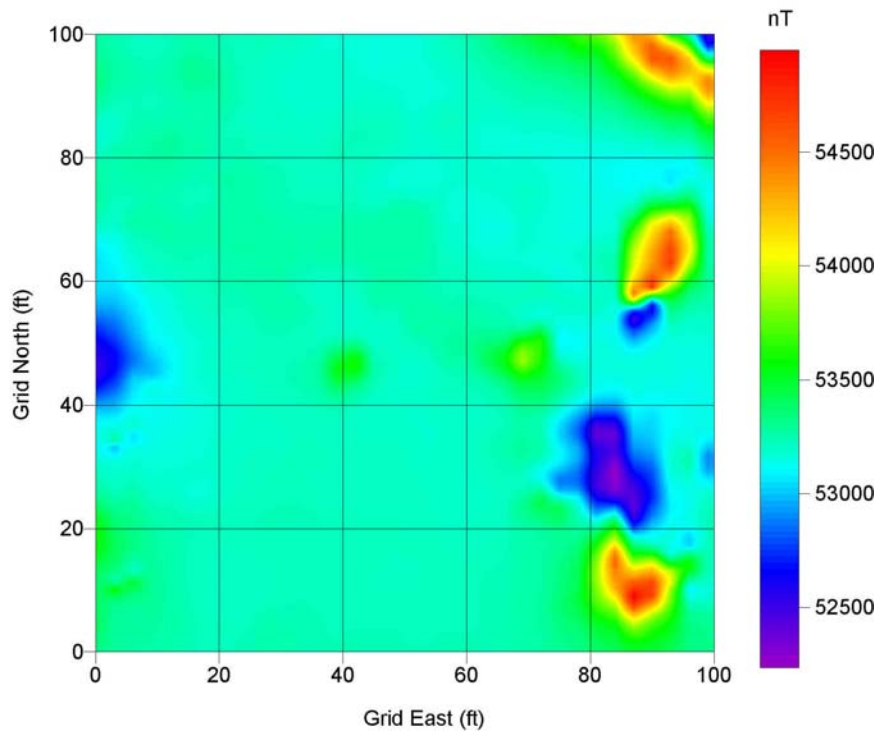


Total Field Component of Magnetic Anomaly at Grid I9 & I11

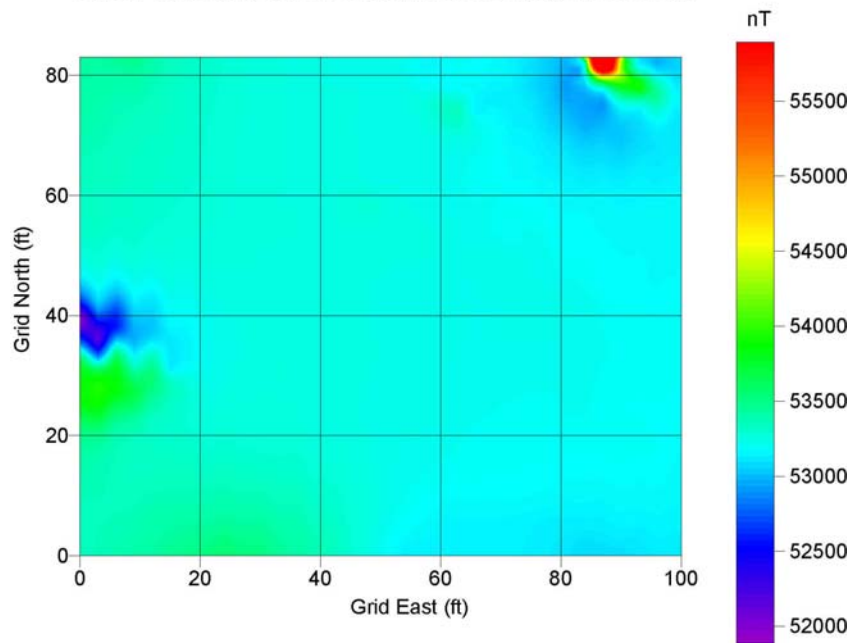




Total Field Component of Magnetic Anomaly at Grid I10

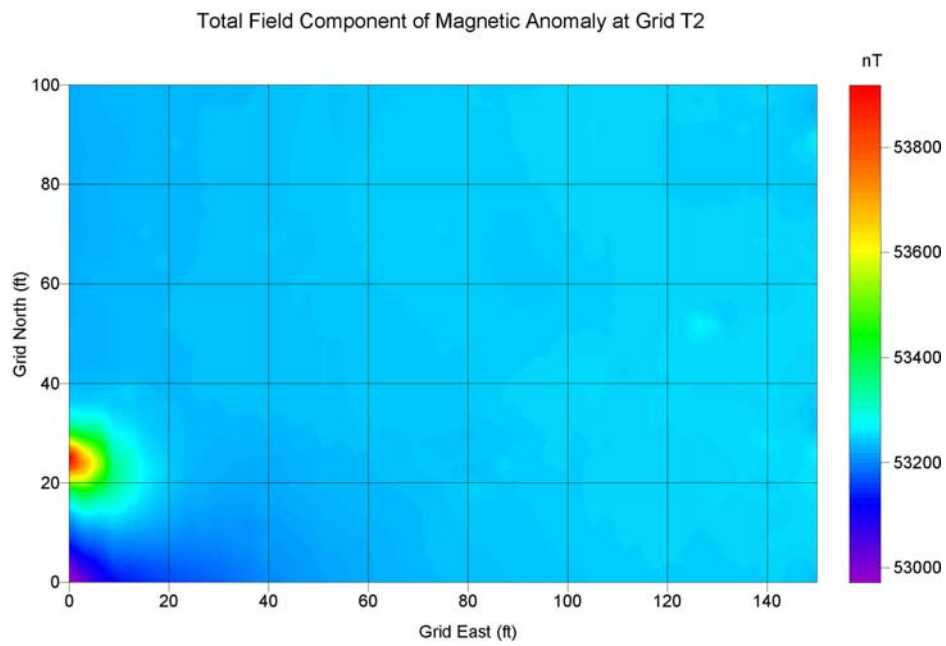
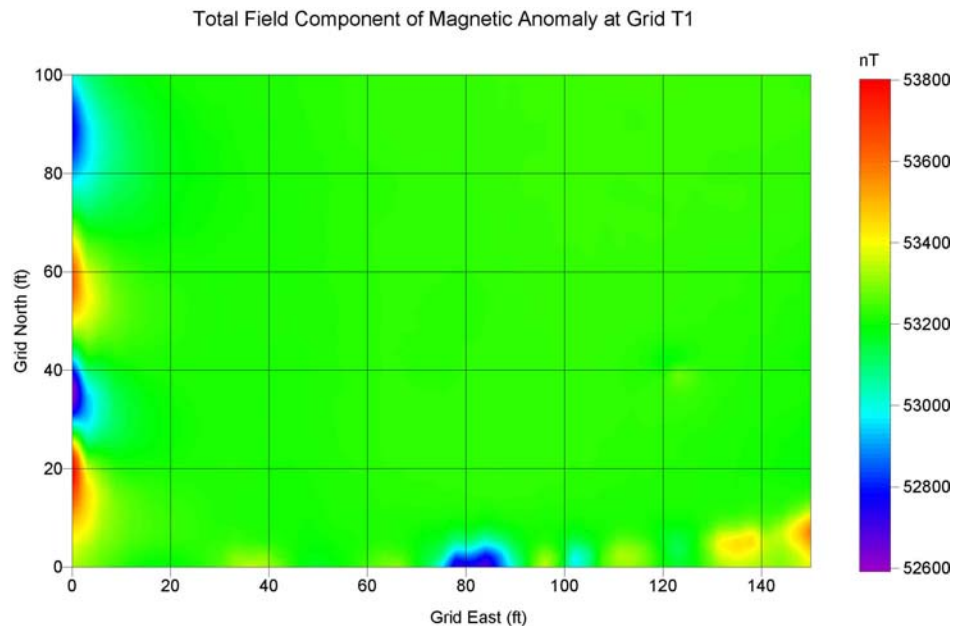


Total Field Component of Magnetic Anomaly at Grid I12



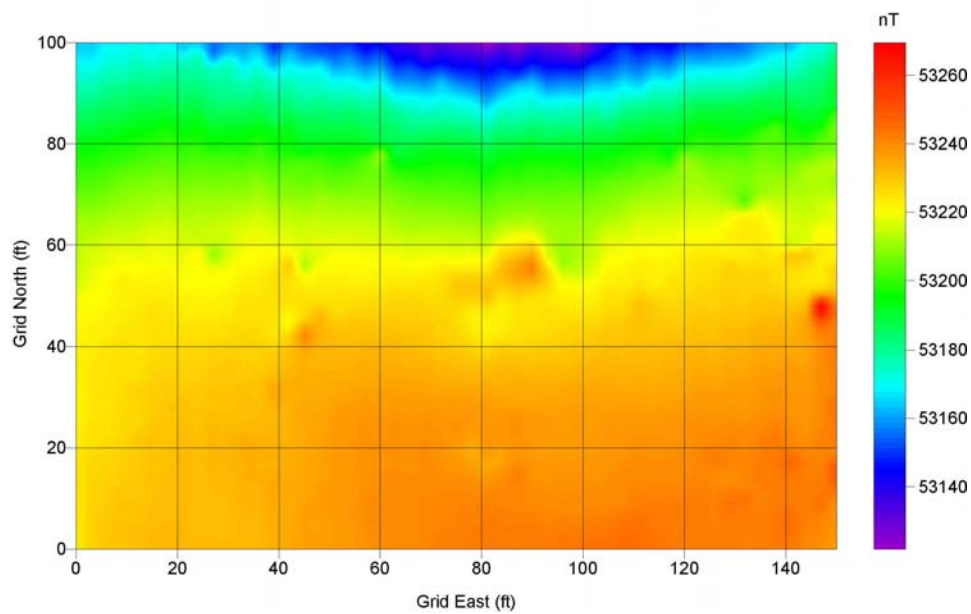


#### 4. Grids T1 - T10 at Trailer Park

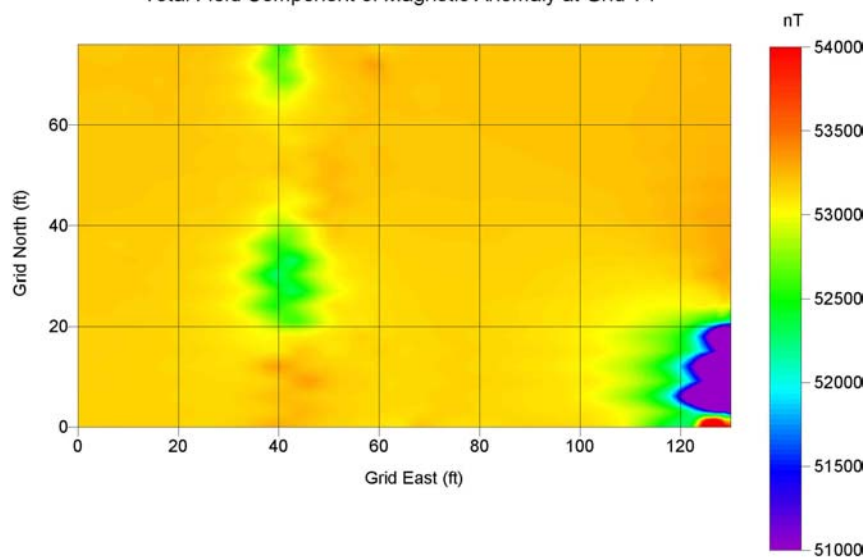




Total Field Component of Magnetic Anomaly at Grid T3

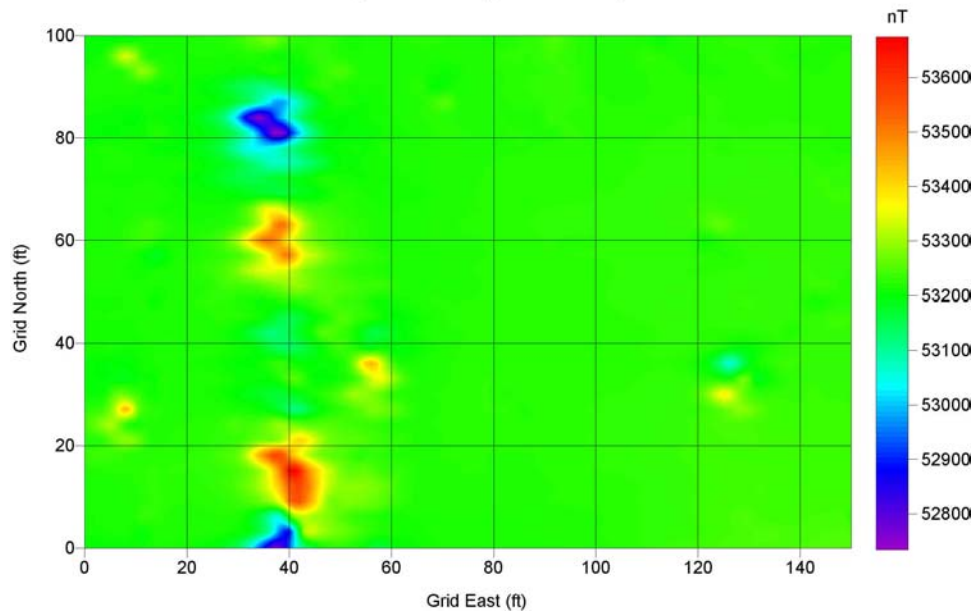


Total Field Component of Magnetic Anomaly at Grid T4

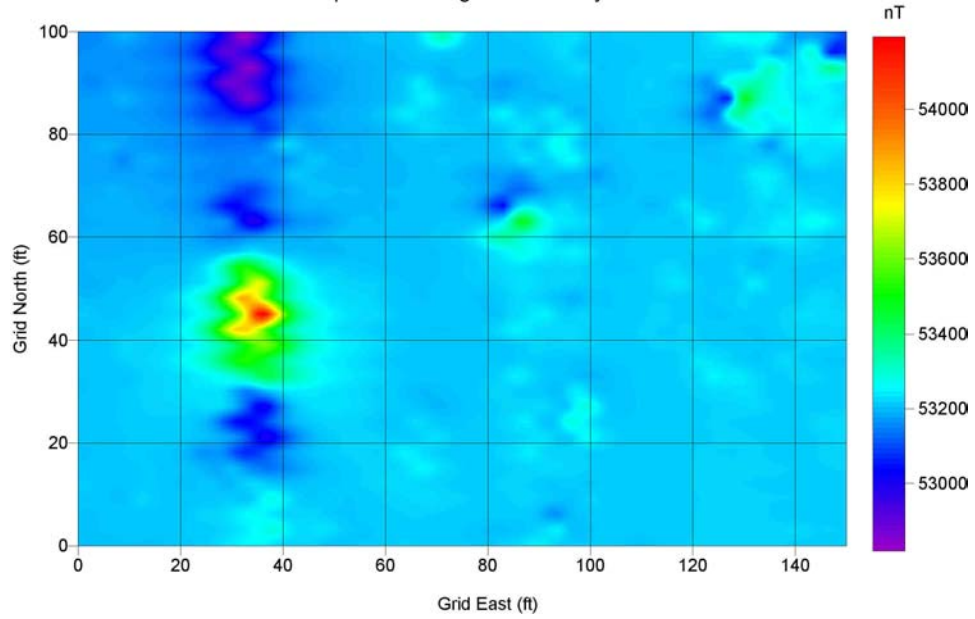




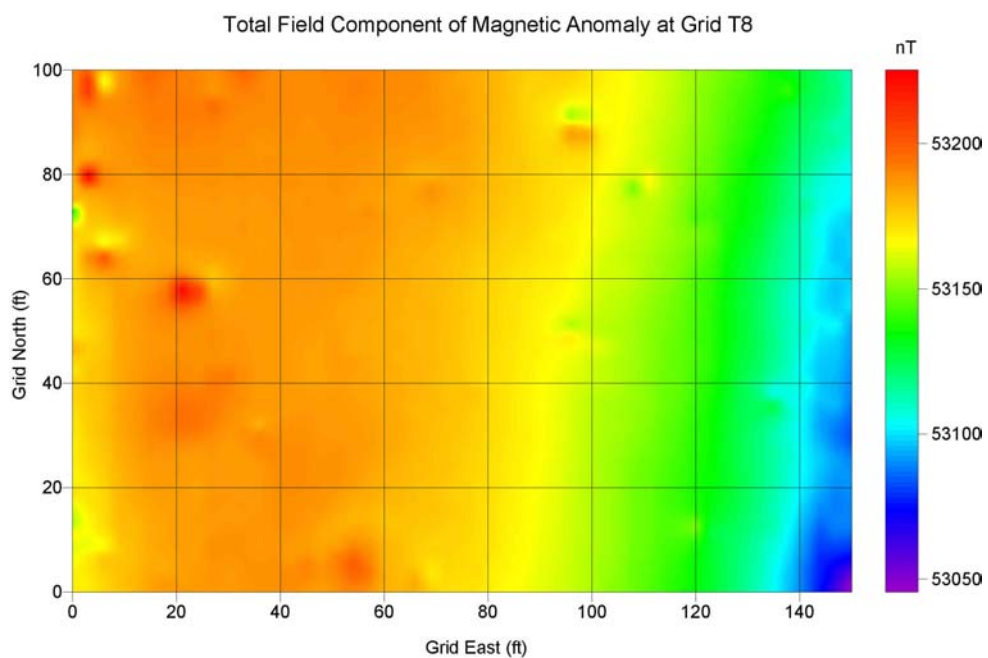
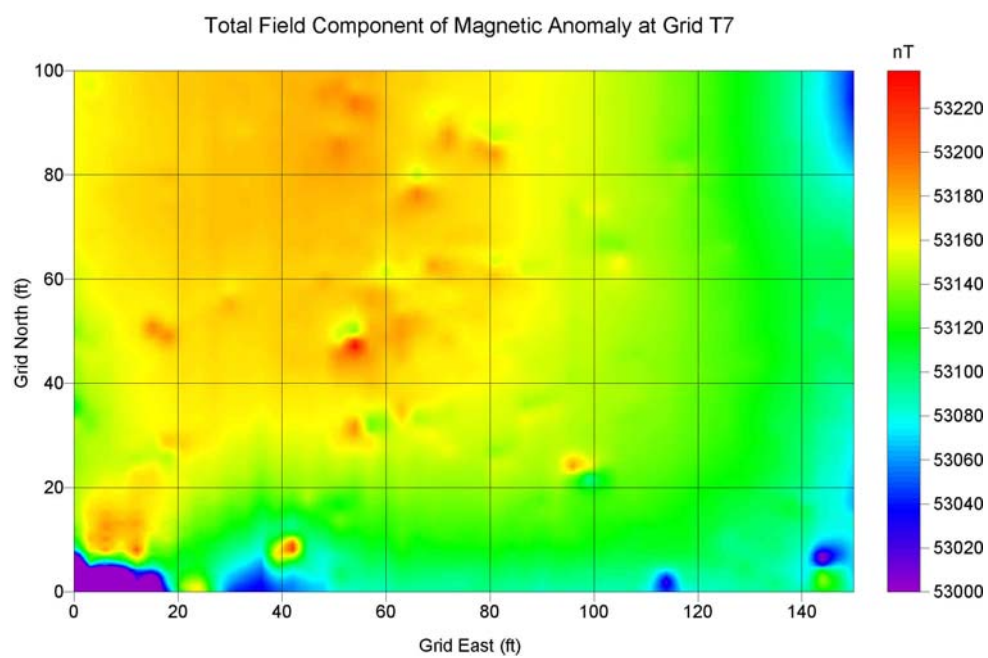
Total Field Component of Magnetic Anomaly at Grid T5



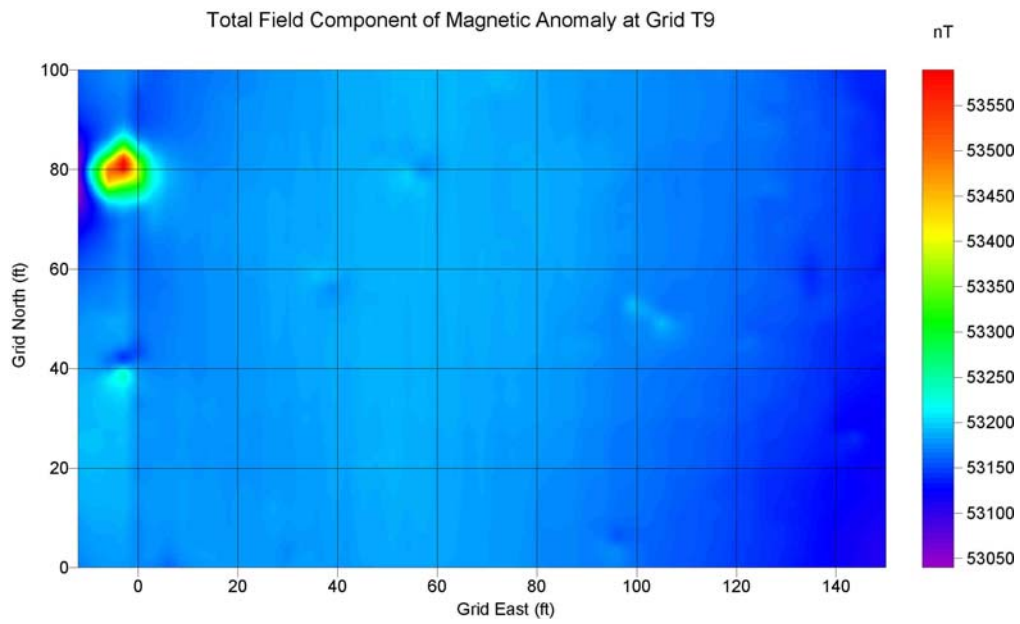
Total Field Component of Magnetic Anomaly at Grid T6



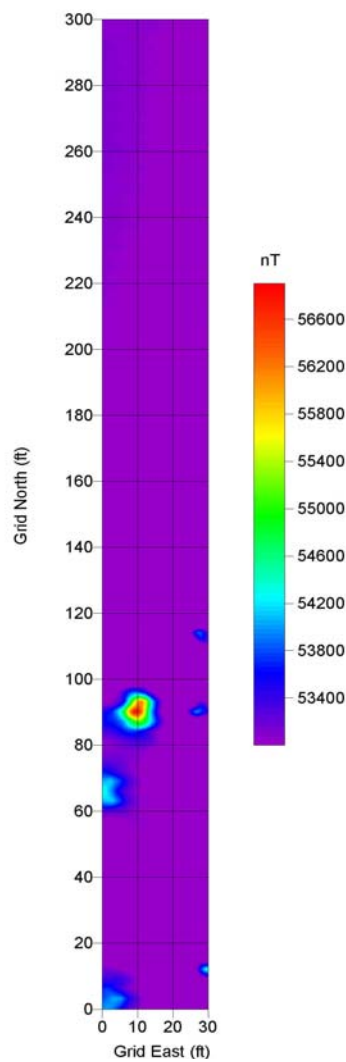






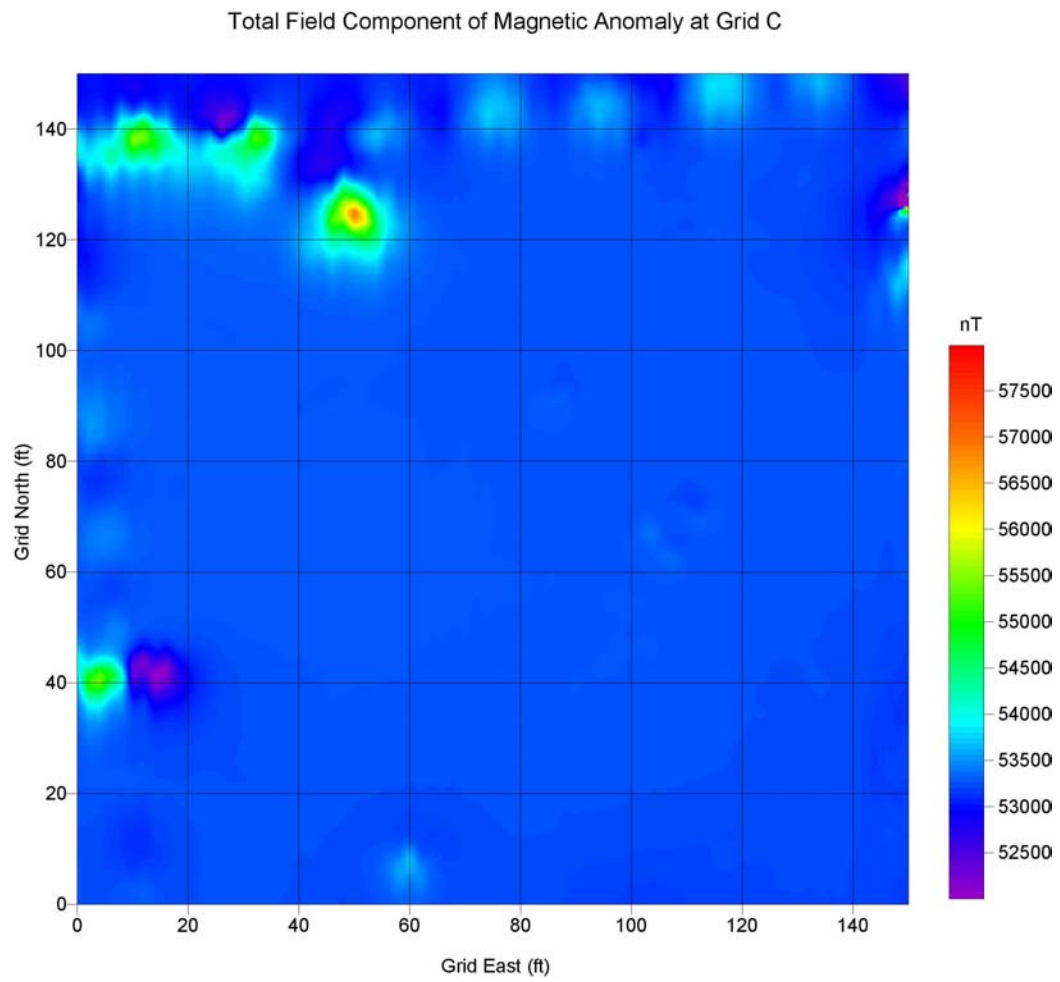


Total Field Component of Magnetic Anomaly at Grid T10



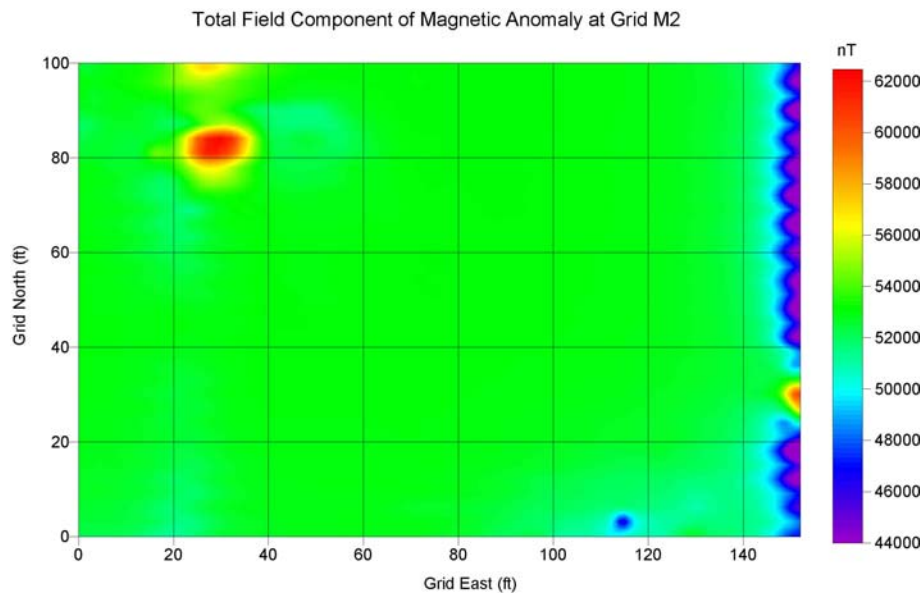
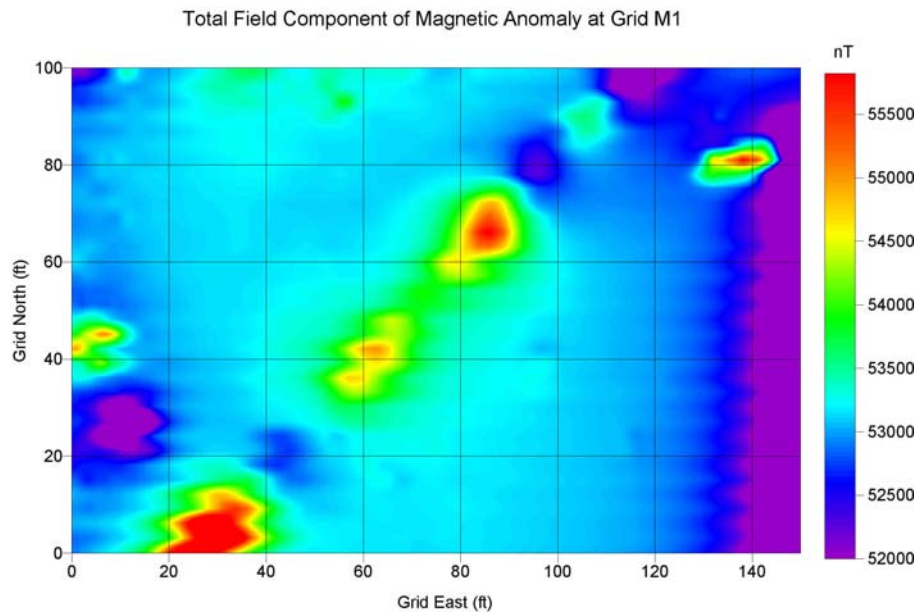


## 5. Grid C at Chemical & 8<sup>th</sup> Street



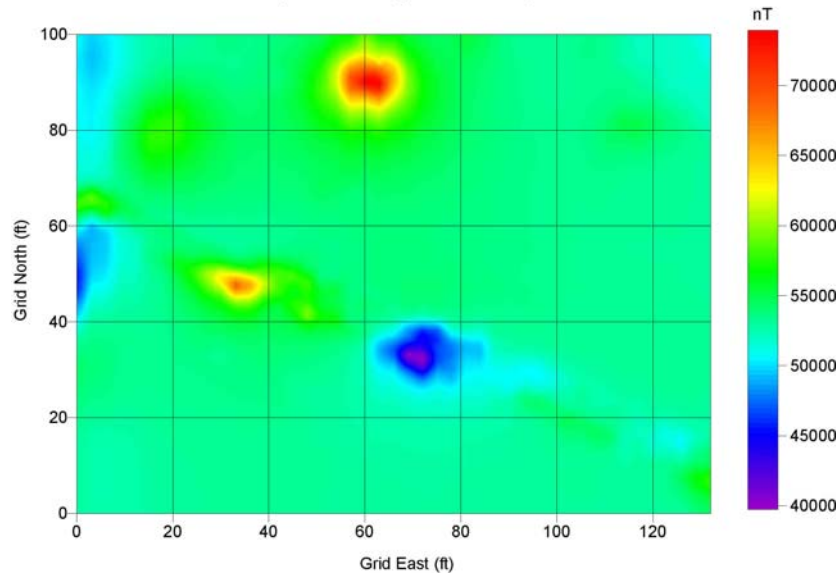


## 6. Grids M1 - M8 at Monroe Street & Avenues E and F

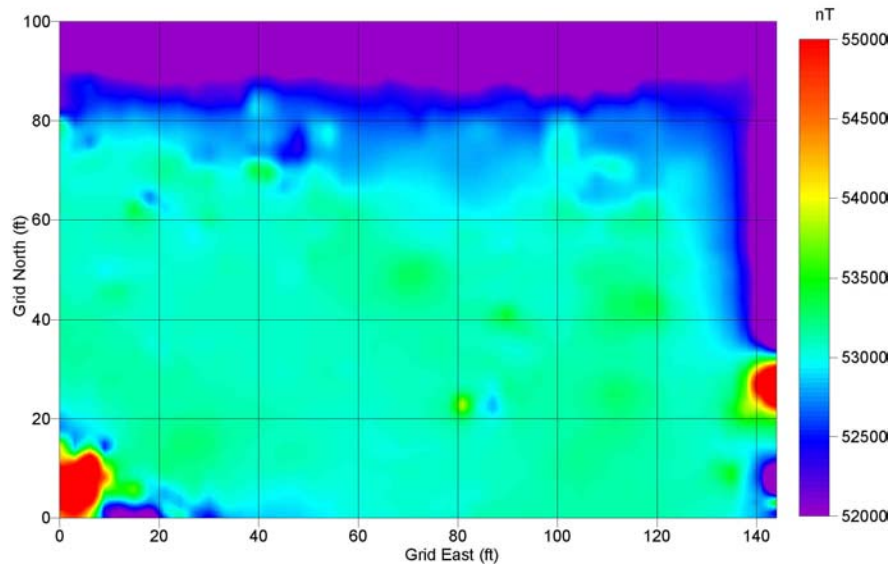




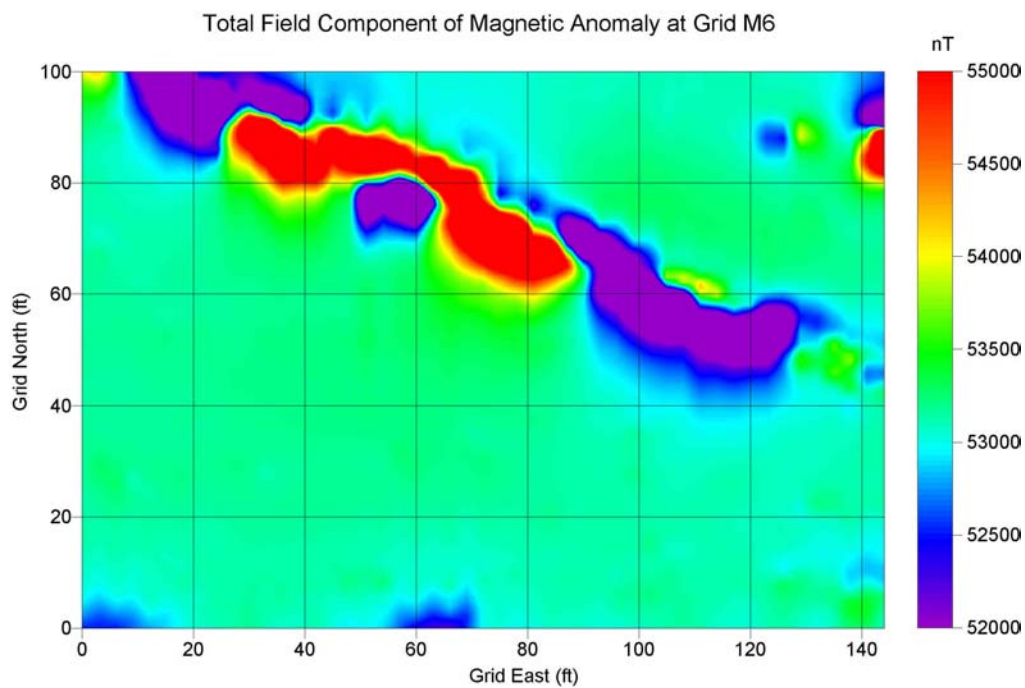
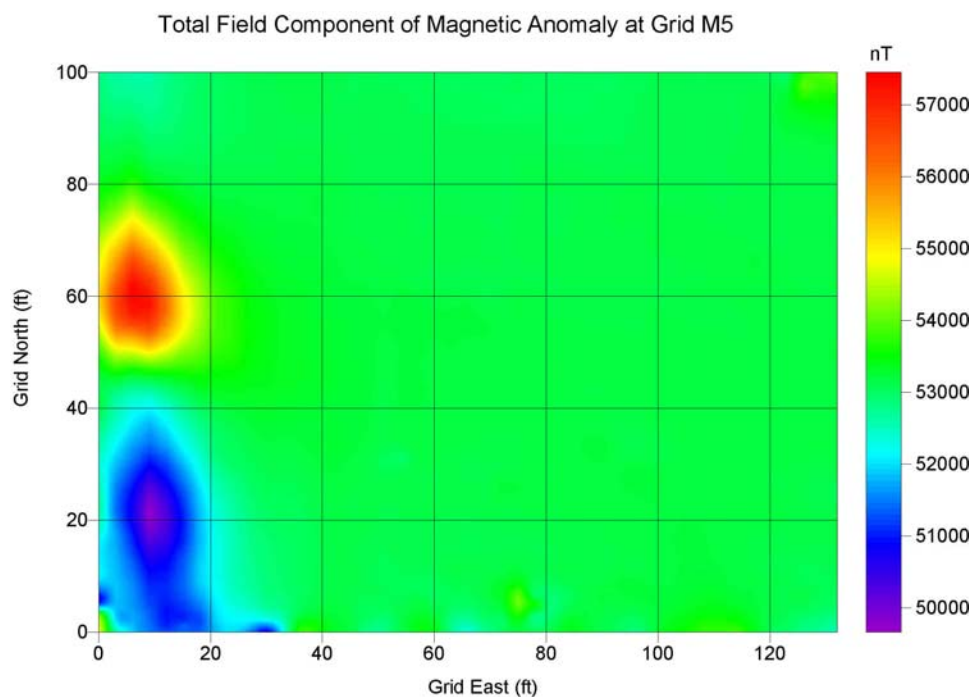
Total Field Component of Magnetic Anomaly at Grid M3



Total Field Component of Magnetic Anomaly at Grid M4

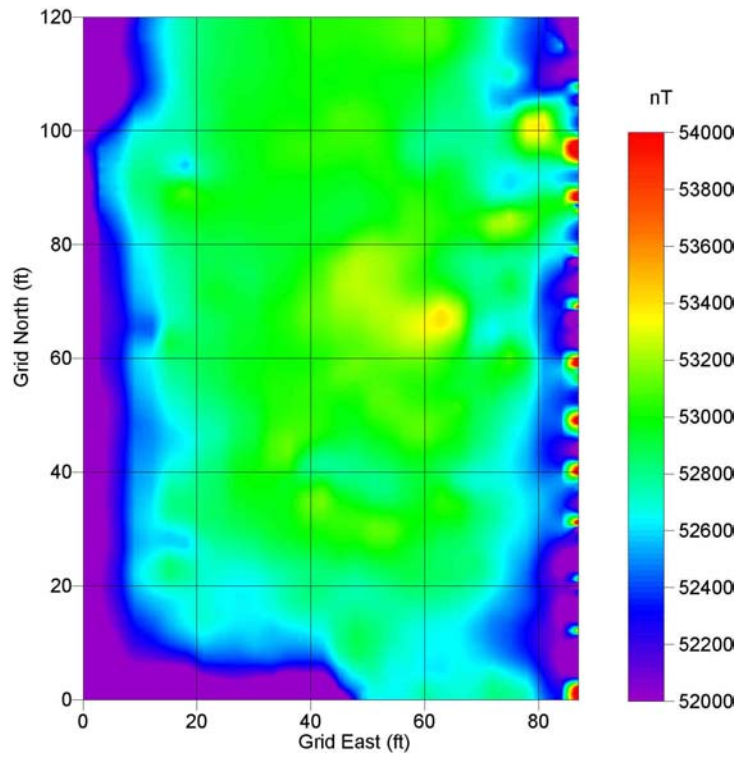




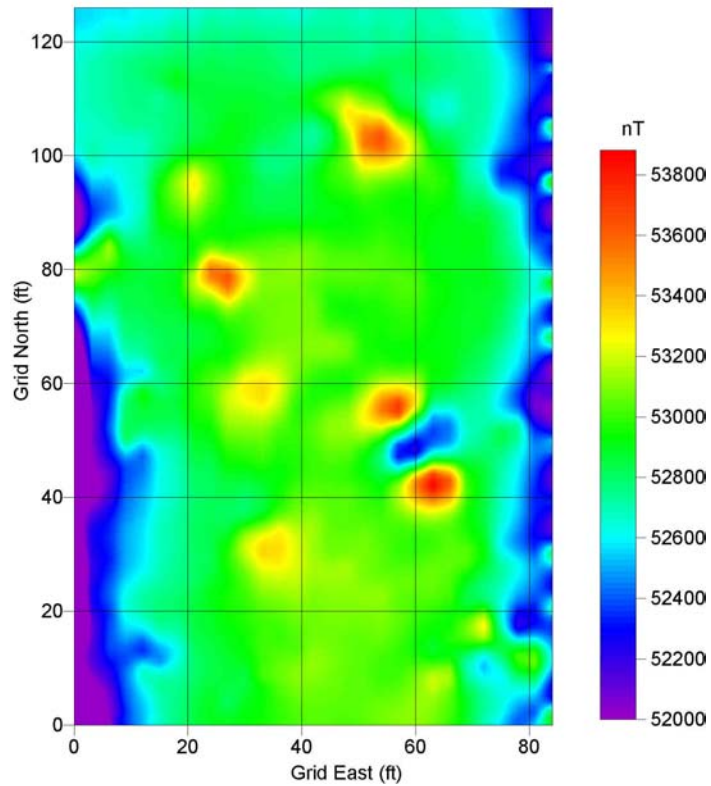




Total Field Component of Magnetic Anomaly at Grid M7



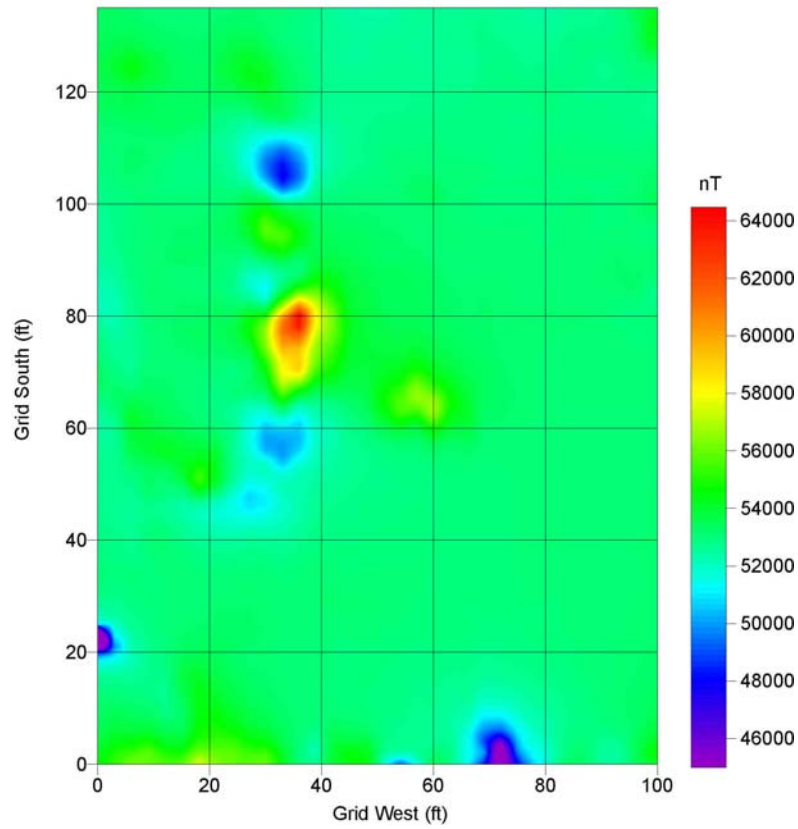
Total Field Component of Magnetic Anomaly at Grid M8



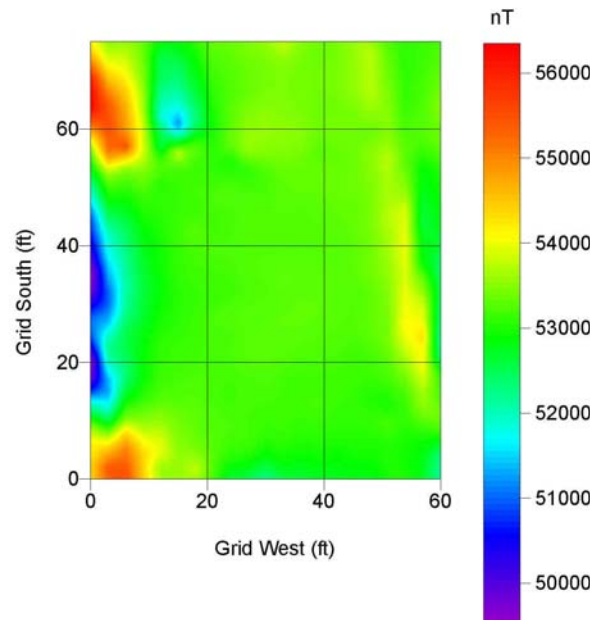


## 7. Grids L1 - L3 at Stuckey Lumber

Total Field Component of Magnetic Anomaly at Grid L1



Total Field Component of Magnetic Anomaly at Grid L2





Total Field Component of Magnetic Anomaly at Grid L3

