Final Report on 2002 Airborne Geophysical Survey at Badlands Bombing Range, South Dakota

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14. ABSTRACT
This report describes the results of a low altitude helicopter geophysical survey performed by Oak Ridge National Laboratory (ORNL) and the U.S. Army Engineering Support Center, Huntsville (USAESCH) over areas contaminated by unexploded ordnance at the Badlands Bombing Range on tribal lands of the Oglala Sioux Nation in September/October, 2002. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometry system for ordnance detection. Surveys were carried out at at five sites designated Test Grid (2 ha), Parsons A (25 ha), Parsons B (23 ha), Bombing Target 1 (22 ha), and Bouquet Table (40 ha). The latter four sites were areas where the Department of Defense was suspected or known to previously have conducted weapons tests or bombing exercises. The average rate of coverage for the three suspected target sites ranged between 13 ha/hr to 25 ha/hr. The average along line survey speed was between 6 m/s and 13 m/s. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies was about 1 m.

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Table of Contents

Acronym List

ADU	Attitude determination unit
AGL	Above ground level
ALASA	As low as safely allowable
AS	Analytic signal
ASCII	American Standard Code for Information Interchange
BBR	Badlands Bombing Range
BQ	Bouquet Table at Badlands Bombing Range
BT-1	Bombing Target 1 at Badlands Bombing Range
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAS	Data analysis system
DoD	Department of Defense
DQO	Data Quality Objective
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FOM	Figure of merit
FUDS	Formerly Used Defense Site
GIS	Geographic Information System
GPS, DGPS	(Differential) Global Positioning System
HAZWOPR	Hazardous Waste Operations and Emergency Response
INS	U.S. Immigration and Naturalization Service
MTADS	Multi-Sensor Towed Array Detection System
NAD	North American Datum
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
SERDP	Strategic Environmental Research & Development Program
TIF, GeoTIF	(Geographically referenced) Tagged Information File
TF	Total (magnetic) field
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

List of Figures

List of Tables

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Abstract

This report describes the results of a low altitude helicopter geophysical survey performed by Oak Ridge National Laboratory (ORNL) and the U.S. Army Engineering Support Center, Huntsville (USAESCH) over areas contaminated by unexploded ordnance at the Badlands Bombing Range on tribal lands of the Oglala Sioux Nation in September/October, 2002. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometry system for ordnance detection. Surveys were carried out at at five sites designated Test Grid (2 ha), Parsons A (25 ha), Parsons B (23 ha), Bombing Target 1 (22 ha), and Bouquet Table (40 ha). The latter four sites were areas where the Department of Defense was suspected or known to previously have conducted weapons tests or bombing exercises. The average rate of coverage for the three suspected target sites ranged between 13 ha/hr to 25 ha/hr. The average along line survey speed was between 6 m/s and 13 m/s. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies was about 1 m. Net noise levels of the Arrowhead system magnetometers were lower than that of the previously used Hammerhead system. At the 61 m x 61 m excavation area in Parsons Area A, 100% of all ordnance items were detected. Ordnance consisted of eighteen M-38 practice bombs with spotting charges and a single live 100 pound bomb which was later detonated in place. No smaller ordnance items were found in the dig area by the Parsons during their follow-up ground magnetic survey and excavations. Ferrous items not detected in the helicopter survey but which were detected in the subsequent ground magnetometry survey all proved to be exploded ordnance fragments or metallic non-UXO items.

1.0 Introduction

1.1 Background

Portions of lands belonging to the Lakota Nation, known as the Badlands Bombing Range (BBR), in South Dakota have been contaminated with unexploded ordnance (UXO) through Department of Defense (DoD) training exercises or during weapons tests. Several sites in the BBR have been surveyed as part of ESTCP projects, including three previous airborne surveys conducted by Oak Ridge National Laboratory (ORNL). The airborne technology offers an approach for rapid reconnaissance of large UXO-contaminated sites which are common at DoD sites, particularly in the western United States.

This report describes the results of a low altitude helicopter geophysical survey performed by Oak Ridge National Laboratory (ORNL) and the U.S. Army Engineering Support Center, Huntsville (USAESCH) over UXO-contaminated areas on the former Badlands Bombing Range. The areas, located in the region known as the on the Pine Ridge Reservation in South Dakota, were flown in four survey blocks designated Bombing Target 1 (BT-1), Bouquet Table (BQ), Parsons Area A (Parsons A), and Parsons Area B (Parsons B). Supplemental data were also acquired over a test grid where known UXO and non-UXO items were emplaced.

The entire set of surveys was carried out from September 8 to October 6, 2002. Mobilization of U.S. and Canadian-based crews began on September 9. Upon arrival of the Canadian aircraft and crew, equipment installation and calibration flights were conducted. Total magnetic field data were collected on September 30 and October 2. Before September 30, surveys using an experimental electromagnetic survey system were conducted over portions of target areas for the Environmental Security Technology Certification Program (ESTCP) and the Strategic Environmental Research and Development Program (SERDP). After October 3, tests with a vertical gradient system were carried out. This report addresses only the performance of the total magnetic field system. Treatment and discussion of the vertical magnetic gradient system and the electromagnetic system are covered in separate reports.

1.2 Objectives of the Demonstration

The objectives of the demonstration survey are:

- To provide a means of determining the improvement resulting from recent modification in the Oak Ridge Airborne Geophysical System (ORAGS) total field magnetometry system;
- To assess the capabilities of the system at a site representing conditions and ordnance types typically found on former DoD ranges;
- To detect and map UXO and UXO-related items for subsequent clearance actions.

The survey was carried out using the ORAGS Arrowhead magnetometer array.

1.3 Regulatory Drivers

UXO clearance is generally conducted under CERCLA authority. No "Range Rule" has been established. Irrespective of lack of specific regulatory drivers, many DoD sites and installations are pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g. buried waste sites or ordnance caches) that resulted from weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for the application of technologies in advance of future regulatory drivers and mandates.

1.4 Stakeholder/End-User Issues

The BBR sites are formerly used defense sites and as such it is important that concentrations of ordnance and locations of possibly live ordnance be mapped so that actions can be taken toward removal of UXO or safeguards can be established where there is the possibility that live ordnance is still in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology is expected to contribute to the performance of these activities in terms of efficiency as well as cost.

2.0 Technology Description

2.1 Technology Development and Application

The total field system is a fourth-generation airborne magnetometer array (Figures 2.1 and 2.2) that we have designated as the ORAGS-Arrowhead system. Changes from the previous ORNL airborne magnetometer array, the ORAGS-Hammerhead, include a new boom architecture designed to position sensors at low-noise locations, and a new aircraft orientation system. The new attitude determination system is based on four Global Positioning System (GPS) antennas rather than fluxgate magnetometer measurement as in previous generations. For the ORAGS-Arrowhead system, four magnetometers at 1.7-meter spacing are located in a forward V-shaped boom, and two magnetometers with equivalent spacing are located in each of the lateral booms. Although the spacing is similar to that of the predecessor ORAGS-Hammerhead system, the forward positioning of two magnetometers that were previously the innermost rear boom magnetometers on the Hammerhead system improves noise conditions over those of the Hammerhead system.

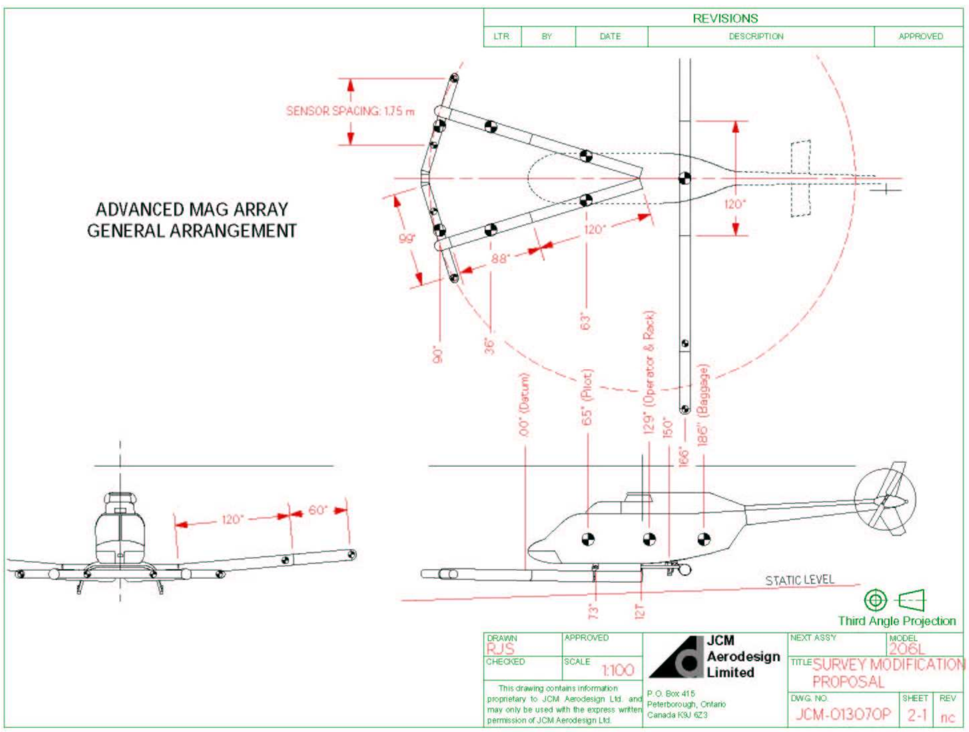

Figure 2.1 Schematic for the ORAGS-Arrowhead airborne total field magnetometer system that has been constructed to evaluate the improvements over previous generations of total field systems.

Figure 2.2 ORAGS-Arrowhead helicopter total field magnetometry system.

2.2 Previous Testing of the Technology

ORNL has previously tested two generations of boom-mounted airborne magnetometer systems for UXO detection and mapping. The first system tested was the HM-3 system, depicted in Figure 2.3, developed by Aerodat, Ltd., under the direction of J.S. Holladay and T. J. Gamey. The 1999 airborne magnetometer tests at BBR deployed this system, operated by High Sense Geophysics, and was modified to meet ORNL requirements (Gamey et al., 2000).

In September 2000, ORNL deployed a more advanced helicopter system at BBR, the ORAGS-Hammerhead system, in cooperation with Dr. Holladay (now at Geosensors Inc., a teaming partner with ORNL) and Mr. Gamey (now at ORNL). While somewhat similar in appearance to the HM-3 system, this system, illustrated in Figure 2.4, is significantly improved in terms of the number of magnetometers, magnetometer spacing, system positioning, navigation, and data acquisition parameters (Doll et al., 2001; Gamey et al., 2001). Additionally, a dihedral in the boom tubes improved system safety by raising the boom tips.

In April/May 2002, Arrowhead surveys were conducted at sites on the Pueblos of Laguna and Isleta, near Albuquerque, New Mexico. In July 2002, a survey was carried out at Aberdeen Proving Ground, near Baltimore, Maryland.

Figure 2.3 The HM-3 helicopter magnetometry system used by ORNL in 1999 for surveys at Badlands Bombing Range.

Figure 2.4 ORAGS-Hammerhead airborne magnetometer system used at Badlands Bombing Range in FY2000.

2.3 Factors Affecting Cost and Performance

The cost of an airborne survey depends on several factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site and fuel costs, among other factors.
- The total size of the blocks to be surveyed
- The length of flight lines
- The extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives which dictate survey altitude and number of flight lines
- The temperature and season, which control the number of hours that can be flown each day
- The location of the site, which can influence the cost of logistics
- The number of sensors and their spacing; systems with too few sensors may require more flying, particularly if they require interleaving of flight lines
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction

2.4 Advantages and Limitations of the Technology

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at a site at considerably lower cost than ground-based systems. Current indications are that the survey cost may approach $70.00 per acre under optimal conditions. Furthermore, the data may be acquired and processed in a shorter period of time, thereby reducing the time required for reviewing large areas. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush or mud makes it difficult to conduct ground-based surveys.

Both airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation limits the utility of helicopter systems, necessitating survey heights too high to resolve individual UXO items.

3.0 Demonstration Design

3.1 Performance Objectives

Shown in Table 3.1 is a listing of the various performance objectives for this survey.

Table 3.1 – Performance Objectives of Arrowhead Airborne Magnetic System

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Qualitative	Total Field (TF) system aerodynamically stable	Pilot report	Yes
Quantitative	TF system has lower noise than predecessors	Comparison of data sets at test site and elsewhere	Yes
Qualitative/Quantitative	Improved aircraft compensation over previous systems	Comparison of Figure of Merit (FOM) and compensated profiles with those from Hammerhead system data	Arrowhead FOM improved ~30% over Hammerhead FOM
Quantitative	Probability of detection	>90%	Yes,100% in excavated sub-area, consisting of M-38 and larger ordnance
Quantitative	False alarm rate	6%	No, 9.5%
Quantitative	Location accuracy	<60 cm	No, ~100 cm
Quantitative	Survey rate	>40 acres/hr	Yes
Quantitative	Percent site coverage	100%	Yes

3.2 Selecting Test Sites

The airborne survey sites were chosen to enable, where possible, direct comparison of results from the new generation airborne systems with results of ground-based geophysical systems for UXO detection and mapping. Airborne data were acquired at five sites at BBR denoted: Test Grid, Parsons A, Parsons B, Bombing Target 1, and Bouquet Table. All sites were remote, but accessible by both road and air, and were found to contain significant M38 ordnance debris at the surface.

3.3 Test Site History/Characteristics

The former Badlands Bombing Range, also known as the Pine Ridge Gunnery Range, is a formerly used defense site (FUDS) located within the Pine Ridge Indian Reservation in Shannon and Jackson counties, South Dakota. Totaling more than 339 000 acres, portions of the site are flat and devoted to farming and ranching. The remaining portions are badlands that are gently rolling to nearly vertical in appearance that have been formed due to the extensive rapid erosion of the soft fine-grained underlying sediments. The Badlands are primarily devoted to grazing. A portion of the site is now part of the Badlands National Park.

The geology of the area is dominated by both consolidated and unconsolidated units and includes bentonite and siltstone with discontinuous limestone and sandstone beds. There are also wind-blown sand deposits that consist of fine to medium grained quartz sand. These deposits can include clay, in addition to the silt and fine sand. Soil characteristics on the site include intermingled clays and loamy soils on mesas, escarpments, buttes, and tablelands.

The area also contains numerous archeological, cultural, and historical sites. Most of these sites are related to the presence of Native Americans over the last 10,000 years, and include Indian mounds (burial sites), ceremonial sites, and home sites.

With regard to historical ordnance, numerous sites exist across the entire area that were utilized for aerial gunnery, aerial bombardment, and surface-based gunnery activity. From historical records, use of the range began in the early 1940's and terminated in the mid-1970's. Groups that utilized the range include Rapid City Air Force Base (now Ellsworth AFB), the U.S. Army, and the South Dakota Army National Guard. Ordnance types found at the former Badlands Bombing Range include 75-mm high explosive (HE) projectiles; 105-mm and 155-mm HE and Illumination projectiles; 8-inch HE projectiles; M38 practice bombs; M50 and M54 incendiary bombs; and 2.75-inch and 2.25-inch rockets.

Located in the northwestern-most portion of the Pine Ridge Indian Reservation is a large plateau known as Cuny Table. This area is approximately 10,000 acres in size and is characterized as having relatively flat topography. This area has been used and is currently being used for farming and grazing of livestock. Cuny Table is known to contain a number of aerial gunnery targets, aerial bombardment targets, and waste burial pits associated with the presence of ordnance and explosives.

3.4 Present Operations

The U.S. Army Engineering and Support Center – Huntsville (USAESCH) contracted Parsons Engineering Science to conduct an Environmental Evaluation / Cost Analysis (EE/CA) at BBR, which includes Cuny Table where the 2002 airborne tests were conducted. The Parsons work is part of a multi-year project, with most of the mapping conducted with surface- based walkover magnetometer surveys. The 200 ft. x 200 ft. grid blocks are selected using a modified SiteStats / GridStats procedure. Parsons has previously used the ORAGS-Hammerhead airborne system to support their EE/CA work at BBR. Surveys conducted by ORNL were a combination of high-density surveys over bombing targets and transects over areas suspected of being impact areas or target areas.

3.5 Pre-Demonstration Testing and Analysis

Shakedown testing of the assembled airborne system and associated components was conducted in Toronto, Ontario, Canada during December 10-21, 2001. These tests were used to determine whether the completed system and its components were performing as designed.

The airborne magnetic system was flight tested by an aeronautical engineer and determined to be completely flightworthy. The testing validated both the aerodynamic stability and performance of the system. Magnetic noise levels for the system were measured both on the ground and during flight. Total magnetic field data were collected at low altitude over known targets in a seeded test area.

One of the main design changes made in moving from the ORAGS-Hammerhead design to the ORAGS-Arrowhead design was to shift the positions of sensors 3 and 6—the innermost magnetometers on the aft booms of the Hammerhead system, located 2.6 m from the helicopter centerline. On the Arrowhead system, sensors 3 and 6 were re-positioned to the outer parts of the foreboom. This effectively cut in half the noise levels of sensors 3 and 6 without compromising the efficiency of the aerodynamics or the quality of the data from the other sensors.

In summary, all system components in both airborne systems performed as anticipated. The noise levels at the aft inboard magnetometer positions 4.3 meters from the centerline of the helicopter is somewhat higher than the noise levels of the other magnetometers, but is reduced over inboard magnetometers from the ORAGS-Hammerhead system, which were located only 2.6 m from the helicopter centerline. Flight performance and maneuverability were excellent with no ballast required.

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3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

Mobilization involved packing and transporting all system components by trailer to Rapid City, South Dakota and installing them on a Bell 206L Long Ranger helicopter. Calibration and compensation flights were conducted and results evaluated. The eight cesium magnetometers, GPS systems (positioning and attitude), fluxgate magnetometers, data recording console, and laser altimeter were tested to ensure proper operation and performance. The Mission Plan was read and signed by all project participants to assure safe operation of all systems.

3.6.2 Period of Operation

Mobilization of the geophysical crew from Oak Ridge, Tennessee began on September 8, 2002. Two days travel was required to transport geophysical equipment from Oak Ridge to Rapid City, South Dakota. The helicopter crew mobilized from Toronto, Canada on September 9 and arrived on September 10. Installation of the ORAGS electromagnetic system began the morning of September 11. No calibration site set-up was necessary, as ordnance and non-ordnance items had already been emplaced at the Test Grid, and ground-based surveys had been carried out. Most of the survey time allotted at BBR was spent testing the ORAGS electromagnetic system and the ORAGS vertical gradient system. A damaged rotor mast on the helicopter combined with a delay getting a replacement mast resulted in down time during September 17-24. EM tests resumed September 25. The ORAGS Arrowhead total magnetic field system was installed after the EM tests, on September 29. On September 30, the total field system was flown over Parsons Area A and B. Rain on October 1 grounded the helicopter, but flights resumed on October 2 over Bombing Target 1, Bouquet Table, and the Test Grid. The total field system was uninstalled on October 3 and replaced by the vertical gradient system. De-installation of the vertical gradient system took place on October 7. On October 8, the geophysical and air crews departed for Flagstaff, Arizona for a survey at Camp Navajo.

3.6.3 Area Characterized

A total of four sites were surveyed, along with a 2 ha test area seeded with buried UXO and non-UXO items. All four sites encompassed known or suspected bombing targets. The areas surveyed at these sites are: Parsons A (25 ha), Parsons B (23 ha), Bombing Target 1 (22 ha) and Bouquet Table (40 ha). The total area surveyed by the total field system is thus 110 ha. At each site, 100 percent coverage of the target area was attained using 12-m flight line spacing.

3.6.4 Residuals Handling

This section does not apply to this report.

3.6.5 Operating Parameters for the Technology

The ORAGS Arrowhead system is designed for daylight operations only. Lines were flown in a generally east-west or north-south pattern depending on local logistics and weather conditions with a nominal 12m flight line spacing for the high density survey coverage and 48m flight line spacing for the statistical sampling coverage. Binary data from the eight magnetometers was recorded on the console at a rate of 1200 samples per second. A typical survey speed for the system was 100 km/hr. Survey height was 1-3 m above ground level. In areas where background magnetic susceptibility is small and its variation limited, where vegetation height is low, and topographic change gradual, the system can be expected to detect anomalies as small as 2 nT.

3.6.6 Experimental Design

The test conducted with the ORAGS-Arrowhead total magnetic field system are summarized in Table 3.2.

Table 3.2 - Field Tests with Arrowhead Total magnetic field System

Test ID	Description	Parameters	Sites
Standard configuration	Test overall system performance (aerodynamics, noise, compensation, positioning, orientation, detection)	Alt = ALASA at each of the four larger BBR sites. Alt = 1m, 10 m at Test Grid.	Dense coverage of five BBR sites: Test Grid, Bouquet Table, Parsons A, Parsons B, Bombing Target 1.

Data quality objectives (DQOs) to be used for this technology demonstration focused on prior-generation airborne results as the baseline performance condition, as well as previous MTADS demonstration data. Analysis of HM-3 data by the Institute for Defense Analyses (Andrews et al., 2001) yielded the following results: 78% to 83% ordnance, 17% to 24% false positives. A subsequent analysis by Scott Holladay of Geosensors confirmed these figures. Holladay's calculations yielded 83% ordnance, 17% false positives (ORNL, 2002). Subsequent ORAGS-Hammerhead airborne surveys at BBR, Shumaker Naval Ammunition Depot and Rocket Test Range, Nomans Land Island, and New Boston Air Force Station yielded results consistent with the previous surveys at BBR. One difference is that positional accuracy of the data has improved from approximately 2m in Hammerhead tests to about 1m with the Arrowhead system. This we attribute to the fact that by moving sensors 3 and 6 to the forward boom, they were closer to the GPS sensor than in the Hammerhead assembly, and less susceptible to mispositioning caused by helicopter yaw.

Given the various considerations associated with both the interpretation of airborne geophysical survey data and the calculations of the various performance parameters, DQOs for the demonstration of the fourth-generation total field system approached or met the current performance parameters. The methodology used to acquire the airborne data are as described in previous sections of this document with a variety of altitudes flown. All surveys conducted with the Arrowhead total field system were performed as high-density surveys with line spacing established to account for sensor positions such that no gaps or voids exist in any data set, except where planned. The mean value for positioning accuracy, estimated from the average of the distances between the position where items were excavated and where they were predicted based on analytic signal peaks, was just under 100 cm.

Data Processing Procedures
The 1200 Hz raw data were desampled in the signal processing stage to a 120 Hz recording rate. All other raw data were recorded at a 120 Hz sample rate. Data were converted to an ASCII format and imported into a Geosoft format database for processing. With the exception of the differential GPS post-processing, all data processing was conducted using the Geosoft software suite and proprietary ORNL algorithms and filters. The quality control, positioning, and magnetic data processing procedures (steps a-i) are described below.

Quality Control
All data were examined in the field to ensure sufficient data quality for final processing. The adequacy of the compensation data, heading corrections, time lags, orientation calibration, overall performance and noise levels, and data format compatibility were all confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines or areas where data were not captured were reacquired. Data were also examined for high noise levels, data drop outs, significant diurnal activity, or other unacceptable conditions. Lines flown, but deemed to be unacceptable for quality reasons, were re-flown.

Positioning
During flight, the pilot was guided by an on-board navigation system that used real-time satellite-based DGPS positions. This provided sufficient accuracy for data collection (approximately 1m), but was inadequate for final data positioning. To increase the accuracy of the final data positioning, a base station GPS was established at geodetic survey marker CT-1 on Cuny Table (NAD83 43° 31’ 13.58701” N 102° 41’ 53.89149” W NAVD88 1008.237m). Raw data in the aircraft and on the ground were collected. Differential corrections were post-processed to provide increased accuracy in the final data positioning. The final latitude and longitude data were projected onto an orthogonal grid using the North American Datum 1983 (NAD 83) UTM Zone 13N. Vertical positioning was monitored by laser altimeter with an accuracy of 2 cm. No filtering was required of these data, although occasional drop-outs were removed.

Magnetic data processing procedure
The magnetic data were subjected to several stages of geophysical processing. These stages included correction for time lags, removal of sensor dropouts, compensation for dynamic helicopter effects, removal of diurnal variation, correction for sensor heading error, array balancing, and removal of helicopter rotor noise. The calculation of the magnetic analytic signal was derived from the corrected residual magnetic total field data.

(a) Time Lag Correction
There is a lag between the time the sensor makes a measurement and the time it is time stamped and recorded. This applies to both the magnetometer and the GPS. Accurate positioning requires a correction for this lag. Time lags between the magnetometers, fluxgate magnetometer, and GPS signals were measured by a proprietary ORAGS firmware utility. This utility sends a single pulse that is visible in the data streams of all three instruments. This lag was corrected in all data streams before processing.

(b) Sensor Dropouts
Cesium vapor magnetometers have a preferred orientation to the Earth's magnetic field. As a result of the motion of the aircraft, the sensor dead zones can occasionally align with the Earth's field. In this event, the readings drop out, usually from an average of 53,000 nT to 0 nT. This usually only occurs during turn-around between lines, and rarely during actual data acquisition. All dropouts were removed manually before processing.

(c) Aircraft Compensation
The presence of the helicopter in close proximity to the magnetic sensors results in considerable deviation in the readings, and generally requires some form of compensation. The orientation of the aircraft with respect to the sensors and the motion of the aircraft through the earth's magnetic field are also contributing factors. A special calibration flight is performed to record the information necessary to remove these effects. The maneuver consisted of a square or rectangular-shaped flight path at high altitude to gain information in each of the cardinal directions. During this procedure, the pitch, roll and yaw of the aircraft were varied. This provided a complete picture of the effects of the aircraft at all headings in all orientations. The entire maneuver was conducted twice for comparison. The information was used to calculate coefficients for a 19-term polynomial for each sensor. The fluxgate data were used as the baseline reference channel for orientation. The polynomial is applied post flight to the raw data, and the results are generally referred to as the compensated data. This data is used in the development of the analytic signal maps presented in this report.

(d) Magnetic Diurnal Variations
The earth's magnetic field changes constantly over the course of the day. This means that magnetic measurements include a randomly drifting background level. A base station sensor was established near the GPS base station monument at Albuquerque International Sunport to monitor and record this variation every five seconds. The recorded data are normally subtracted directly from the airborne data. The time stamps on the airborne and ground units were synchronized to GPS time. The diurnal activity recorded at the base station was extremely quiet. In general, the low frequency diurnal variations were less than 5nT per survey line. Processing included defaulting repeated values and linearly interpolating between the remaining points.

(e) Heading Corrections
Cesium vapor magnetometers are susceptible to heading errors. The result is that one sensor will give different readings when rotated about a stationary point. This error is usually less than 0.2 nT. Heading corrections were applied to adjust readings for this effect.

(f) Array Balancing
These magnetic sensors also provide a lower degree of absolute accuracy than relative accuracy. Different sensors in identical situations will measure the same relative change of 1 nT, but they may differ in their actual measured value, such as whether the change was from 50,000 to 50,001 nT or from 50,100 to 50,101 nT. After individual sensors were heading-

corrected to a uniform background reading, the background level of each sensor was corrected or balanced to match the others across the entire airborne array.

(g) Regional Removal
Deep-seated, large scale background geology and some cultural features which contribute to the local regional magnetic field were removed using a combination of filtering and splining techniques. The output is a residual magnetic total field. This process also removed all diurnal, heading and balancing effects.

(h) Rotor Noise
The aircraft rotor spins at a constant rate of approximately 400 rpm. This introduces noise to the magnetic readings at a frequency of approximately 6.6 Hz. Harmonics at multiples of this base are also observable, but are much smaller. This frequency is usually higher than the spatial frequency created by near surface metallic objects. This effect has been removed with a low-pass frequency filter.

(i) Analytic Signal
The data resulting from this survey are presented in the form of analytic signal. The square root of the sum of the squares of the three orthogonal magnetic gradients is the total gradient or analytic signal. It represents the maximum rate of change of the magnetic field in any direction (i.e. a measure of how much the readings would change by moving a small amount in any direction such as left-right, forward-backward, or up-down). This parameter was calculated from the gridded residual total field data.

There are some advantages to using the analytic signal. For small objects, it is somewhat more straightforward to interpret visually than total field data. Total field measurements typically display a dipolar response signature to small, compact sources, having both a positive and negative deviation from the background. The actual source location is a point between the two peaks, as determined by the magnetic latitude of the site and the properties of the source itself. Analytic signal is more symmetric about the target, is always a positive value and has less dependence on magnetic latitude. Analytic signal maps present anomalies as low intensity to high intensity shapes.

3.6.7 Sampling Plan

This section does not apply to this report.

3.6.8 Demobilization

De-installation was carried out on October 7. Booms were dismounted from the helicopter frame and the magnetometers and GPS instrumentation were disconnected and packed in shipping containers. The containers were placed in a trailer for transport to Flagstaff, Arizona. The helicopter crew demobilized and departed for Flagstaff, Arizona on October 8, 2002 for a subsequent survey at Camp Navajo.

4.0 Performance Assessment

4.1 Performance Criteria

Demonstration effectiveness is determined directly from comparisons of the processed/analyzed results from the demonstration surveys and the results of previous airborne and ground-based surveys. These comparisons include both the quantitative and qualitative items described in this section. Demonstration success is determined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established previously in this document (Section 3.1). Methods utilized by ORNL on both current and past airborne acquisitions to ensure airborne survey success include daily QA/QC checks on all system parameters (e.g. GPS, magnetometer operation, data recording, system compensation measurements, etc.) in the acquired data sets, a series of compensation flights at the beginning of each survey, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase.

Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Altitude can be recorded and will enter into the data analysis and comparisons with previous results. The aircraft attitude measuring system provides a documented database that cannot be directly compared with previous surveys when this system was not available. The consistent and scientific evaluation of performance is accomplished by using identical or parallel (where parameters are dataset dependent) processing methods with identical software to produce a final map, and following consistent procedures in interpretation when comparing new and existing datasets from the test sites.

Data processing involves several steps, including GPS post-processing, compensation, spike removal, removal of magnetic diurnal variations, time lag correction, heading correction, filtering, gradient calculations, and gridding. Each step is performed in the same manner on data acquired with sequential generations of system at the same sites, to provide a basis for comparing the performance of the systems. The processing procedures have been selected and developed from experience with similar data over a span of more than five years for optimal sensitivity to UXO.

Data quality objectives, as described in Section 3.6.6 (Experimental Design), were used for this demonstration. Surveys over the previously described test areas were conducted as described in Section 3.6. Data collection occurred at flight altitudes over the various test areas and configurations as described in Section 3.6.6. Data confirmation was in accordance with the processes previously described in this section.

Table 4.1 identifies the expected performance criteria for this demonstration, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative). This table also identifies expected performance for each of the technologies present in this demonstration.

Table 4.1: Performance Criteria

Performance Criteria	Expected Performance Metric (Pre-demo)	Performance Confirmation Method	Actual Performance (Post-demo)
Primary Criteria (Performance Objectives) – Quantitative			
System Performance (total field system)	Ordnance detection – greater than 90%	Comparison to prior collected airborne and ground-based data	100% (site contained M-38 and larger ordnance)
System Performance (total field system)	False positives – less than or equal to 6%	Comparison with actual dig results	9.5%
System Performance (total field system)	Data acquisition rate – greater than or equal to 40 acres per hour	Comparison to prior ORNL-conducted airborne surveys	Up to 62 acres/hour, including turnaround time
System Performance (total field system)	Detection threshold (5 nT sensitivity)	Comparison to prior collected ground-based geophysical data	~3 nT for reliable detection
System Performance (total field system)	Anomaly positional accuracy (60 cm)	Comparison to known benchmarks and known (documented) anomalies at the test site locations	<1.0m (~96 cm)
Primary Criteria (Performance Objectives) – Qualitative			
Process Waste	None	Observations	No process waste.
Factors Affecting Technology	Helicopter geophysical noise	Comparison to expected noise levels based on prior geophysical measurements around the helicopter	Noise lower than in previous surveys.
Factors Affecting Technology	Helicopter geophysical noise	Comparison of sensor compensation measurements against prior compensation values	Lower noise for sensors 3 and 6, by factor of ~2.
Factors Affecting Technology	Helicopter movement	Record constellation changes and use during positioning accuracy determination	Recorded.

Secondary Criteria (Performance Objectives) – Quantitative			
Hazardous Materials	None expected, other than spotting charges in M38 practice ordnance	Observations and documentation during excavations	All UXO-related materials excavated were labeled UXO-fragments
Secondary Criteria (Performance Objectives) – Qualitative			
Reliability	No system or component failures	Observations and documentation	No Arrowhead system components failed during the total field surveys
Ease of Use	Pilot "comfort" when flying with the system installed	Observations and documentation	Pilot states that he feels at ease flying the system under normal wind conditions
Ease of Use	No ballast required	Observations and documentation	Engineer declared the system balanced without need for ballast
Safety	Conformance with all FAA requirements and requirements as documented in the Mission Plan	Observations and documentation	System met all FAA flightworthiness requirements
Versatility	Cultural feature detection and mapping	Observations and documentation	Fence clearly discernable from ordnance targets at BT-1.
Maintenance	System mount points, hardware, and component inspection	Observations and documentation	Minimal wear and tear.

4.2 Performance Confirmation Methods

Accurate estimation of two of the system performance criteria, i.e. ordnance detection and false positives, are dependent largely on the method of post-survey excavation used. For the BBR survey, Parsons performed 95 excavations ORAGS anomalies in a 61 m x 61 m subsection of the area denoted Parsons A. For the purposes of this survey, we define ordnance detection as a prediction of UXO based on a measured magnetic anomaly. The "ordnance" need not be live UXO to be considered a successful detection, but could be live or inert UXO, or significant UXO fragments. We define false positives as clearly incorrect predictions of UXO, i.e. predictions in classes 1 and 2, based on magnetic anomalies, the sources of which turned out to be non-UXO related. Such non-UXO sources could be barbed wire, ferrous farm implements, localized zones of magnetized earth, or declared "no contacts."

4.3 Data Analysis, Interpretation, and Evaluation

The ORAGS-Arrowhead magnetometer system does not distinguish within the numerous features mapped between UXO and ferrous scrap without interpretation. The total field and analytic signal maps provided in this report depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of ferrous debris associated with human activity), and potential UXO items (discrete sources). Those responses, interpreted as potential UXO, will likely also include smaller pieces of ferrous debris. Additional analysis and interpretation of the survey results are included in this final project report.

Positional accuracy

We estimated positional accuracy by comparison of predicted dig locations, chosen from the peak value of the analytic signal anomaly, with actual position of items emplaced in the Test Grid area. Items were emplaced in two different years. Items labeled between 6601 and 6625 were emplaced one year before items numbered in the 7000s. Analytic signal anomalies from the items with an ID of 7001 or greater show a consistent shift between the alleged locations of the emplaced items and the analytic signal peaks to the east of the item. The items with ID numbers 6601-6625 show no consistent offset direction between emplaced position and anomaly peak. We therefore believe that these latter items have less systematic measurement error associated with the emplaced item location. The distance from the positions of the buried test grid items to each item's associated analytic signal peak (the miss distance) is shown in Table 4.2. Using the sampling of 20 items from the earliest emplacement, shown in the table with an asterisk, the average miss distance is 96 cm.

Table 4.2 Distance between analytic signal peak value and emplaced item

Item	Description	Miss Distance (m)
6601	2" Galvanized pipe w/end cap	0.19 *
6602	3 ea. Rebar/rod sections	0.64 *
6603	2" Galvanized pipe elbow	0.88 *
6604	Steel channel	0.74 *
6605	2" Galvanized pipe w/end cap	1.13 *
6606	2" Galvanized pipe with two cast floor flanges	0.99 *
6608	I-beam section	0.33 *
6610	4 ea. Rebar/rod sections	1.12 *
6611	I-beam section	0.34 *
6613	100-lb. Bomb fragments	0.88 *
6614	100-lb. Bomb fragments	2.15 *
6615	250-lb. Bomb Simulant	1.67 *
6616	250-lb. Bomb Simulant	0.99 *
6617	100-lb. Bomb (intact)	2.14 *
6618	100-lb. Bomb fragments	1.21 *
6619	2.75" Rocket (nose section)	0.92 *
6620	100-lb. Bomb fragments	0.77 *
6621	100-lb. Bomb fragments	0.31 *
6622	2.75" Rocket (cylinder)	0.93 *
6625	2 ea. 2.75" Rocket Simulants	0.95 *
7001	Galvanized stove pipe	0.19
7002	Box beam	0.59
7003	250# bomb	2.08
7004	105mm round	1.59
7005	155mm round	0.99
7008	105mm round	1.80
7009	2.75” rocket	2.11
7010	105mm round	2.53
7012	81mm mortar	2.16
7013	Aluminum rod	2.13
7016	81mm mortar	2.04
7018	60mm illumination round	1.27
7020	60mm illumination round	1.38
7022	81mm mortar	1.76
7023	Steel pipe	1.97

7024	2.25” rocket	1.61
7026	155mm round	2.15
7027	155mm round	1.97
7028	155mm round	1.70
7029	100# bomb	1.20
7030	2.75” rocket	1.97
7031	81mm mortar	1.31

Note: Items marked with the ‘*’ symbol were buried at an earlier date than the other items.

Sensitivity

In the excavation area of Parsons A, the practical limit at which the ORAGS-Arrowhead system was able to consistently detect UXO fragments is at a peak-to-peak total field anomaly amplitude of about 3 nT. Above these limits, most excavated anomalies containing intact UXO or UXO fragments were detected by the Arrowhead system. Below 3 nT, considerably fewer excavated anomalies were detected by the Arrowhead system, or conversely, fewer Arrowhead anomalies less than 3 nT peak-to-peak were associated with ordnance fragments.

Test Grid

A 105 m x 160 m (~2 ha) test grid was established on a topographically flat area of Cuny Table to verify the system response to expected UXO items under local geologic conditions. The location of the test grid was chosen based not only on the suitability of the topography, but also on the absence of significant vegetation and metallic debris. The dimensions of the grid were such that the ORAGS-Arrowhead array could completely survey it in as few as 9 passes. Iron stakes were placed at the southwest and northeast corners of the grid, and plastic highway placards were positioned for the pilot’s visual reference.

Results of the test grid survey carried out at a nominal flight height of 1 m AGL are shown in Figures 4.1 and 4.2. The source of the large anomaly at site 6607 in the figures is unknown. It appeared in earlier pre-seed ground surveys. The list of seeded items is presented in Table 4.3. At the 1 m survey height, virtually every ferrous item was cleanly detected. Anomalies were weak, if present from anomalies 7009, 7021, and 7025, corresponding to a 2.75” rocket, several 20mm projectiles, and a vertical 60mm mortar. Beyond these, the only items that did not show in the data were non-magnetic: three aluminum plates and a coil of copper wire. Figures 4.3 and 4.4 show the total magnetic field anomaly map and the analytic signal map from an airborne passes at a height of 10 m AGL. At this height, only the larger items—bombs or large fragments from bombs—are clearly discernable in the gridded data.

Table 4.3 Description of emplaced items at BBR Test Grid

Item	Description	Weight (in lbs)	Length (in ft)	Width or Diameter (in ft)	Azimuth	Depth to Top of Item (in ft)
6601	2" Galvanized pipe w/end cap	6	1.1	0.2	East-West	1.6
6602	3 ea. Rebar/rod sections	12	2.5	-	Random	1.85
6603	2" Galvanized pipe elbow	10	2.0	0.2	-	2.3
6604	Steel channel	15	1.75	0.25 x 0.25	-	2.1
6605	2" Galvanized pipe w/end cap	6	1.1	0.2	East-West	1.0
6606	2" Galvanized pipe with two cast floor flanges	10	1.2	0.2	East-West	1.3
6607	Empty	-	-	-	-	-
6608	I-beam section	29	1.2	0.35	East-West	1.4
6609	Cast cylinder	25	0.85	0.4	-	1
6610	4 ea. Rebar/rod sections	9	2.5	-	Random	1.5
6611	I-beam section	10	0.3	0.67	-	2.1
6612	Rod	9	1.7	0.12	North-South	1.6
6613	100-lb. Bomb fragments	unknown	-	-	-	0.3-0.5
6614	100-lb. Bomb fragments	19	-	-	-	1.0-1.6
6615	250-lb. Bomb Simulant	50	5.3	1.2	North-South	4.4
6616	250-lb. Bomb Simulant	65	5.3	1.2	East-West	2.4
6617	100-lb. Bomb (intact)	50	4.0	0.65	North-South	3.1
6618	100-lb. Bomb fragments	32	2.2	0.8	North-South	1.3
6619	2.75" Rocket (nose section)	9	0.9	0.25	East-West	1.5
6620	100-lb. Bomb fragments	unknown	-	-	-	0.3-0.5
6621	100-lb. Bomb fragments	unknown	-	-	-	0.3-0.5
6622	2.75" Rocket (cylinder)	9	0.75	0.25	East-West	2
6623	Steel T-Section Channel	9	1.05	0.25	-	2.4
6624	Cast Square Plate	55	1.1	1.4	-	3
6625	2 ea. 2.75" Rocket Simulants	12	0.75	0.25	N-S,E-W	1.3
7001	Galvanized stove pipe	4	2.50	0.58	East-West	3.17
7002	Box beam	10	2.17	0.41x0.17	East-West	2.00
7003	250# bomb	115	2.13	0.79	Vertical	3.25
7004	105mm round	19	1.25	0.33	Vertical	2.17
7005	155mm round	53	1.96	0.50	Vertical	2.25
7006	105mm round	18	1.25	0.33	North-South	2.42

7007	61mm mortar	2	0.71	0.21	Vertical	1.17
7008	105mm round	19	1.25	0.33	Vertical	2.58
7009	2.75” rocket	5	2.17	0.23	North-South	2.00
7010	105mm round	18	1.25	0.33	East-West	2.42
7011	81mm mortar	8	1.42	0.27	North-South	2.58
7012	81mm mortar	8	1.42	0.27	North-South	1.08
7013	Aluminum rod	1	3.00	0.08	East-West	2.67
7014	Aluminum rod	1	3.00	0.08	East-West	1.58
7015	Aluminum rod	1	3.00	0.08	East-West	1.00
7016	81mm mortar	9	1.42	0.27	Vertical	1.42
7017	Coiled wire	1	0.00	1.33 loop	Horizontal	0.00
7018	60mm illumination round	2	1.27	0.21	Vertical	0.25
7019	60mm illumination round	4	1.27	0.21	North-South	0.42
7020	60mm illumination round	4	1.27	0.21	East-West	0.42
7021	20mm rounds (x24)	2	0.27	0.04	Scattered	0.00
7022	81mm mortar	7	1.42	0.27	North-South	1.83
7023	Steel pipe	9	1.58	0.25	East-West	2.00
7024	2.25” rocket	10	2.40	0.19	North-South	1.75
7025	60mm mortar	3	0.63	0.25	Vertical	1.33
7026	155mm round	56	2.00	0.50	Vertical	1.83
7027	155mm round	56	1.96	0.50	North-South	2.42
7028	155mm round	56	1.67	0.50	East-West	2.83
7029	100# bomb	6	2.50	0.75	Vertical	1.67
7030	2.75” rocket	7	0.92	0.23	North-South	3.00
7031	81mm mortar	7	1.42	0.27	East-West	1.58
7032	8” nail (corner)	0	0.67	0.02	Vertical	0
7033	8” nail (corner)	0	0.67	0.02	Vertical	0
7034	8” nail (corner)	0	0.67	0.02	Vertical	0
7035	8” nail (corner)	0	0.67	0.02	Vertical	0

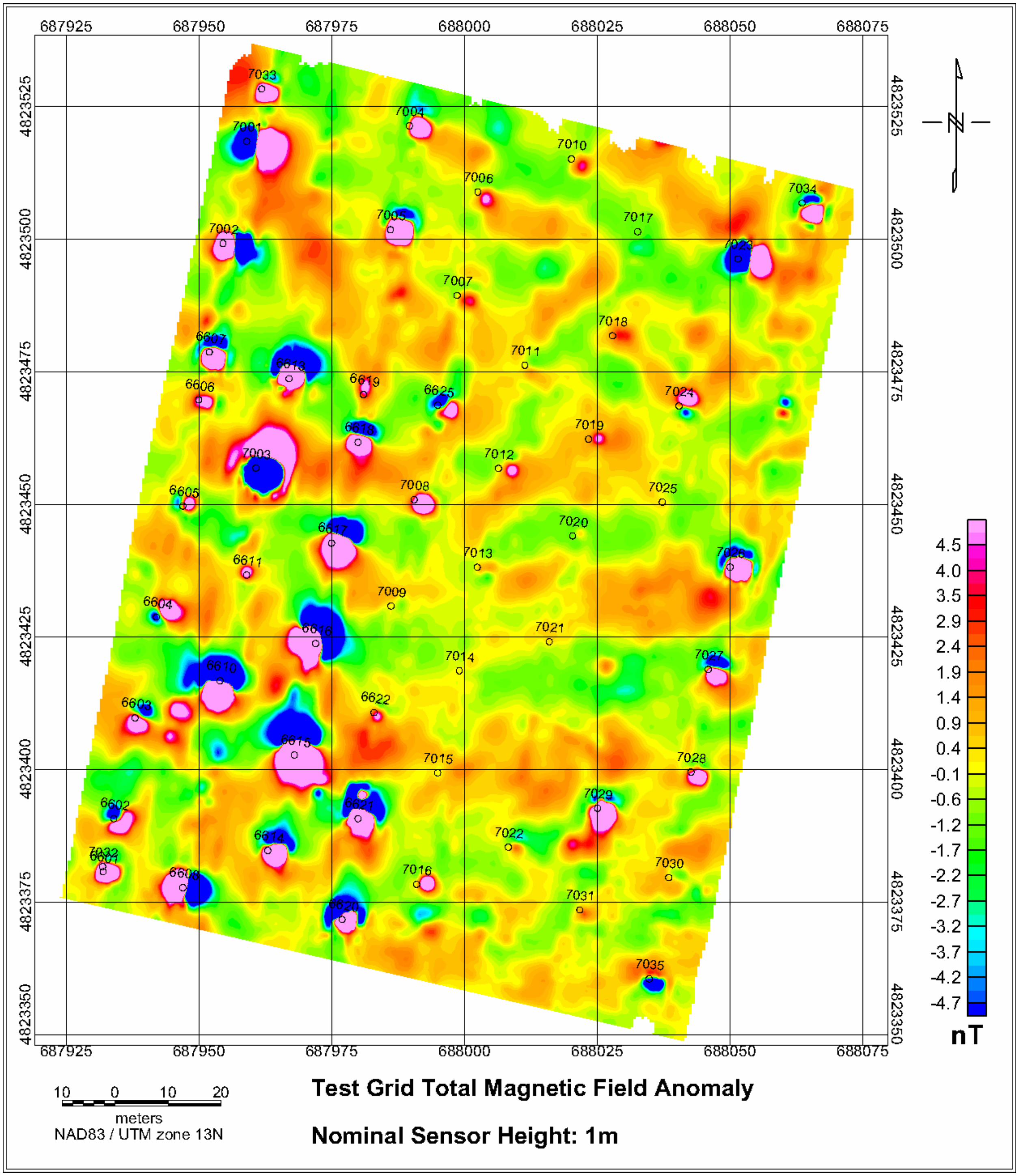

Figure 4.1 ORAGS-Arrowhead total magnetic field data over BBR Test Grid. Nominal survey height: 1m.

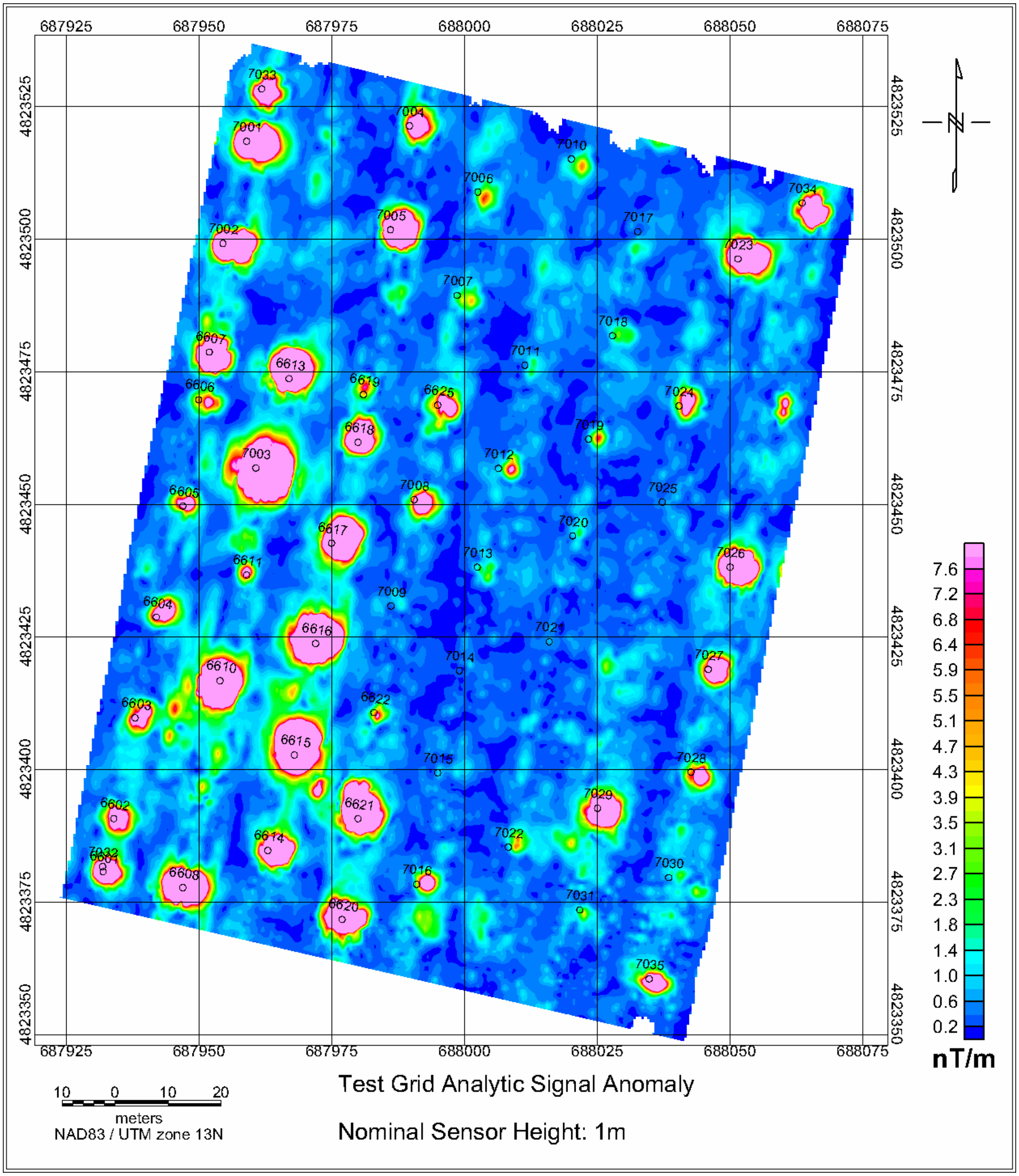

Figure 4.2 ORAGS-Arrowhead analytic signal map for BBR Test Grid. Nominal survey height: 1m.

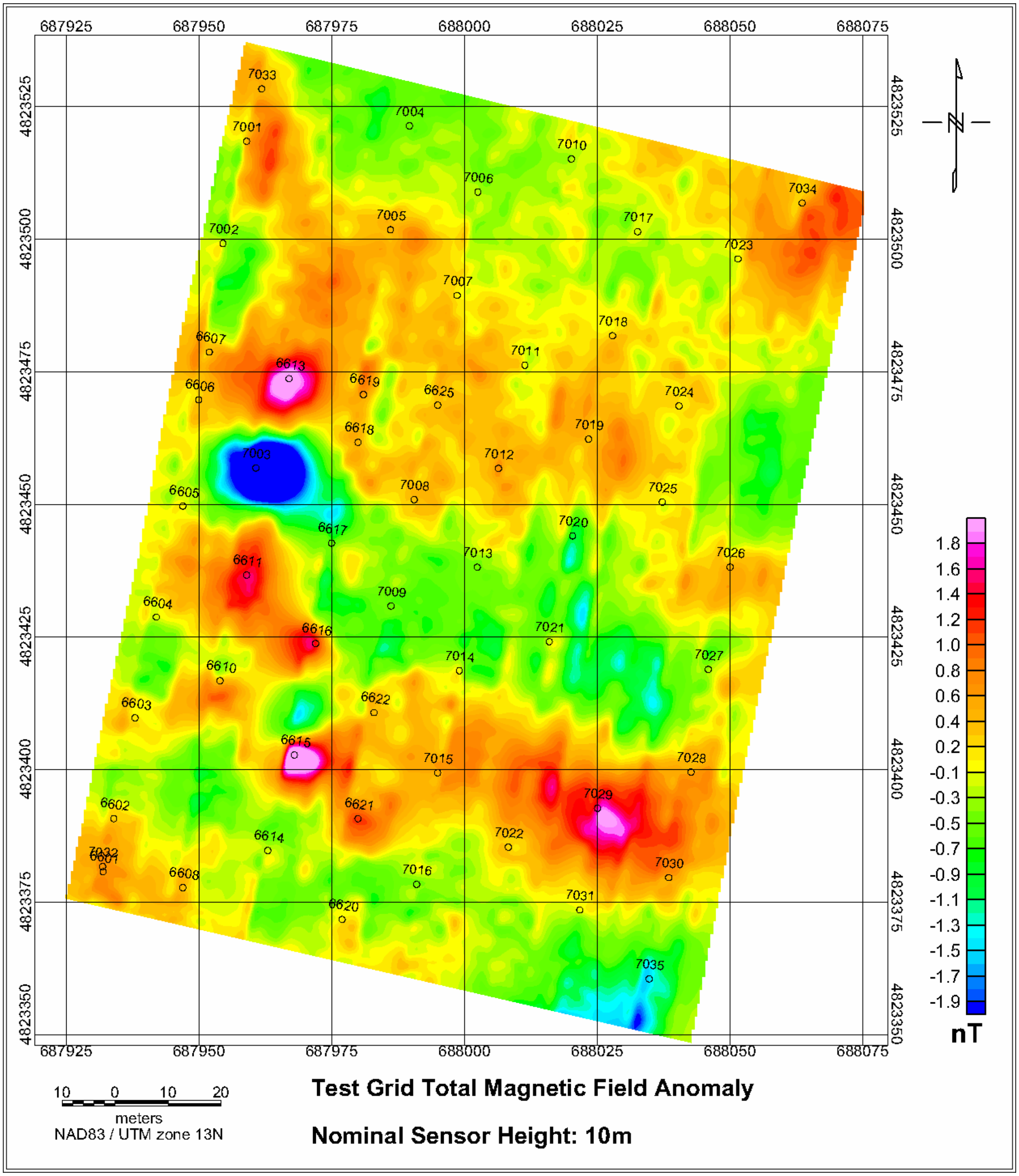

Figure 4.3 ORAGS-Arrowhead total magnetic field data over BBR Test Grid. Nominal survey height: 10 m.

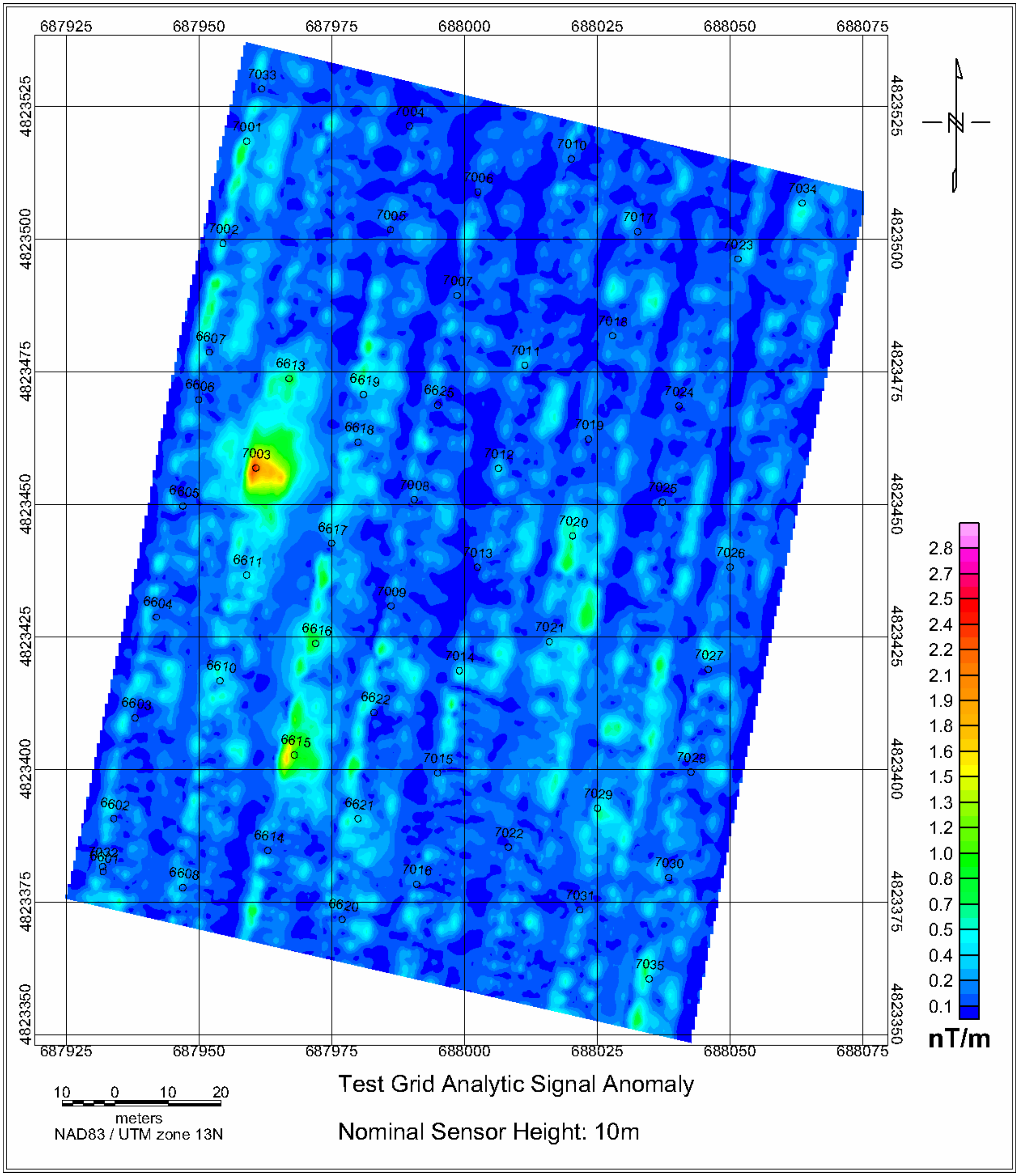

Figure 4.4 ORAGS-Arrowhead analytic signal map for BBR Test Grid. Nominal survey height: 10 m.

Parsons Area A

Parsons Area A is a 400 m x 625m rectangle comprising about 25 ha where previous bombing activity was suspected to have taken place. Most of the area is topographically flat with low vegetation, and thus well-suited for low-flying helicopter surveys. Lines were flown in an east-west direction with a 12m flight line separation. Survey heights over the entire area ranged from 0.5 m to 3.3 m and averaged 1.35 m. The survey heights in the 61 m x 61 m area, indicated in Figures 4.5 and 4.6, that was excavated by Parsons subsequent to the survey ranged from 1.1 m to 2.1 m. Surface fragments indicated that the most likely type of ordnance to be encountered were M-38 practice bombs. Figures 4.5 and 4.6 show anomaly maps of the total magnetic field and analytic signal for a nominal 2 m survey height. The average survey speed along line in Area A was 11.4 m/s (41 km/hr), and the average coverage rate, including turnaround time, was 15 ha/hr.

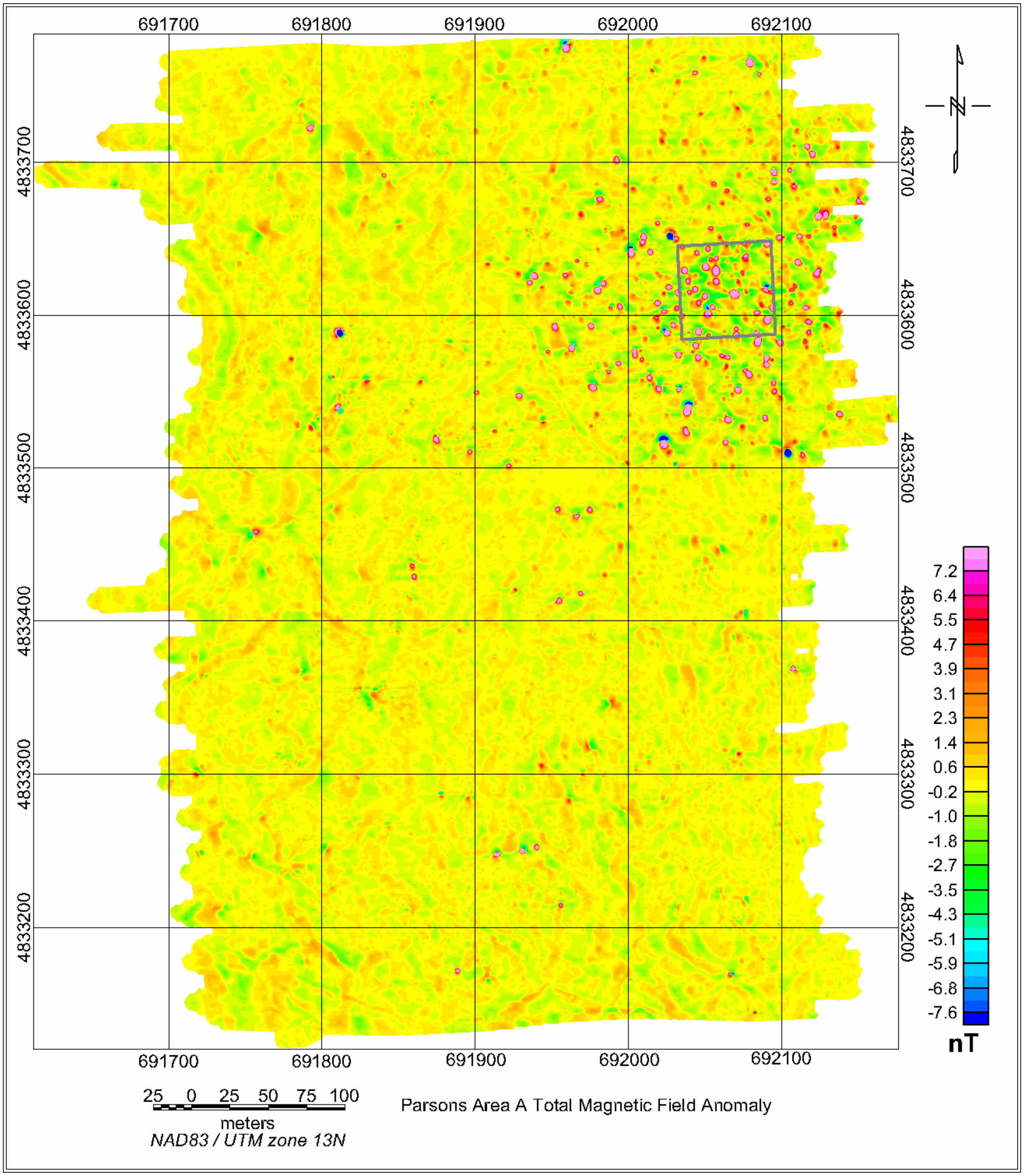

Figure 4.5 Total magnetic field residual anomaly map for Parsons Area A. Survey height: ALASA (mean: 1.3 m). Grey rectangle in upper right represents 61m x 61m square where excavations were conducted.

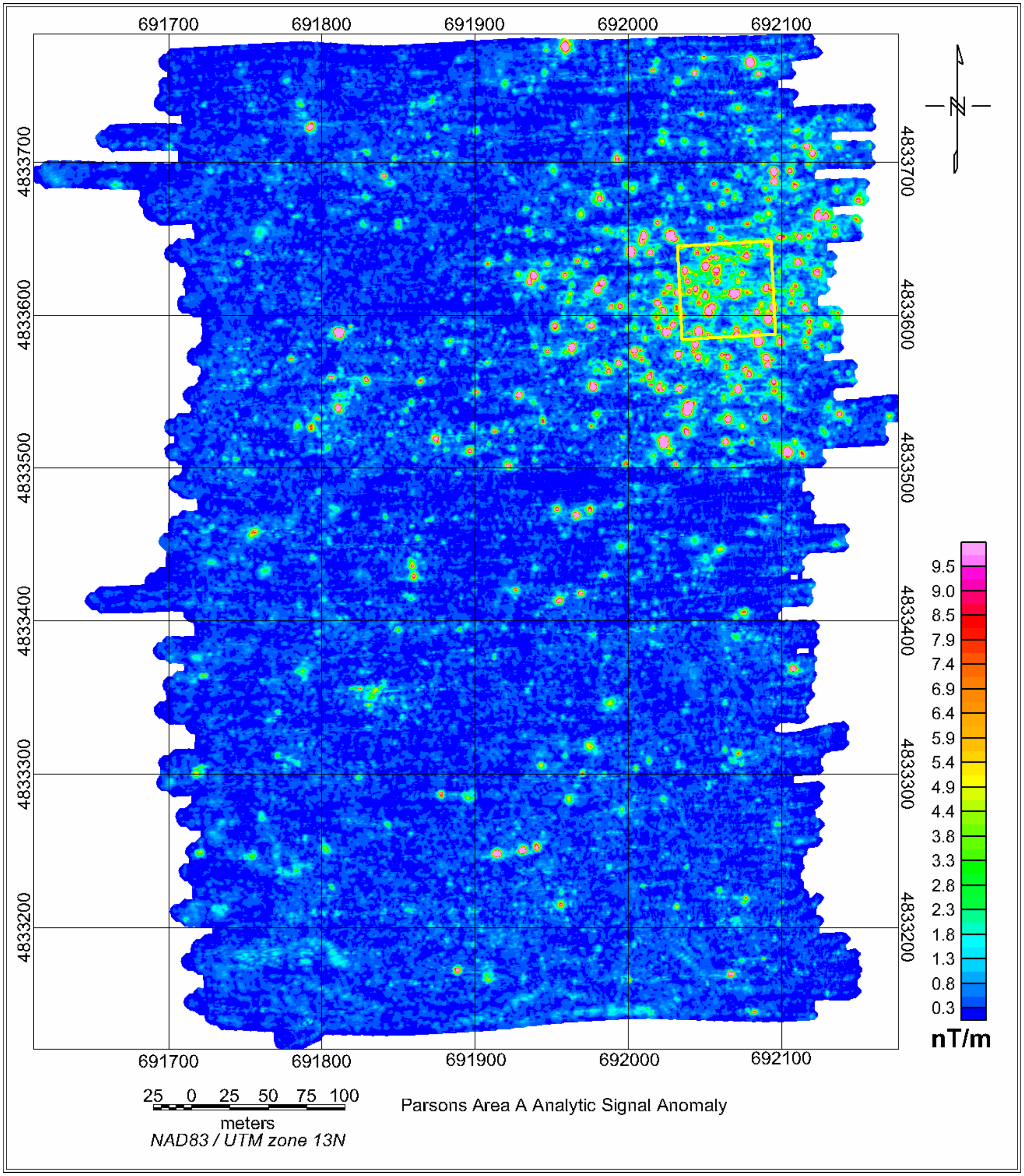

Figure 4.6 Analytic signal anomaly map for Parsons Area A. Survey height: ALASA (mean: 1.3 m). Grey rectangle in upper right represents 61m x 61m square where excavations were conducted.

Parsons Area B

Parsons Area B, comprises a 430 m x 530 m (23 ha) rectangular area in a zone where practice bombing activities were suspected to have taken place. Most of the area is topographically flat with low vegetation, and thus well-suited for low-flying helicopter surveys. Lines were flown in an east-west direction. Total magnetic field and analytic signal anomaly maps are shown in Figures 4.7 and 4.8, respectively, for a nominal survey height of 2m. Lines were flown in an east-west direction with a 12m flight line separation. Average survey height over the area was 2.07 m. Average survey speed along line in Area B was 5.9 m/s (21 km/h), and the average coverage rate, including turnaround time, was 12.5 ha/hr. Only a few magnetic anomalies appear in the maps, indicating the area was not a target area. No excavations were performed at this site.

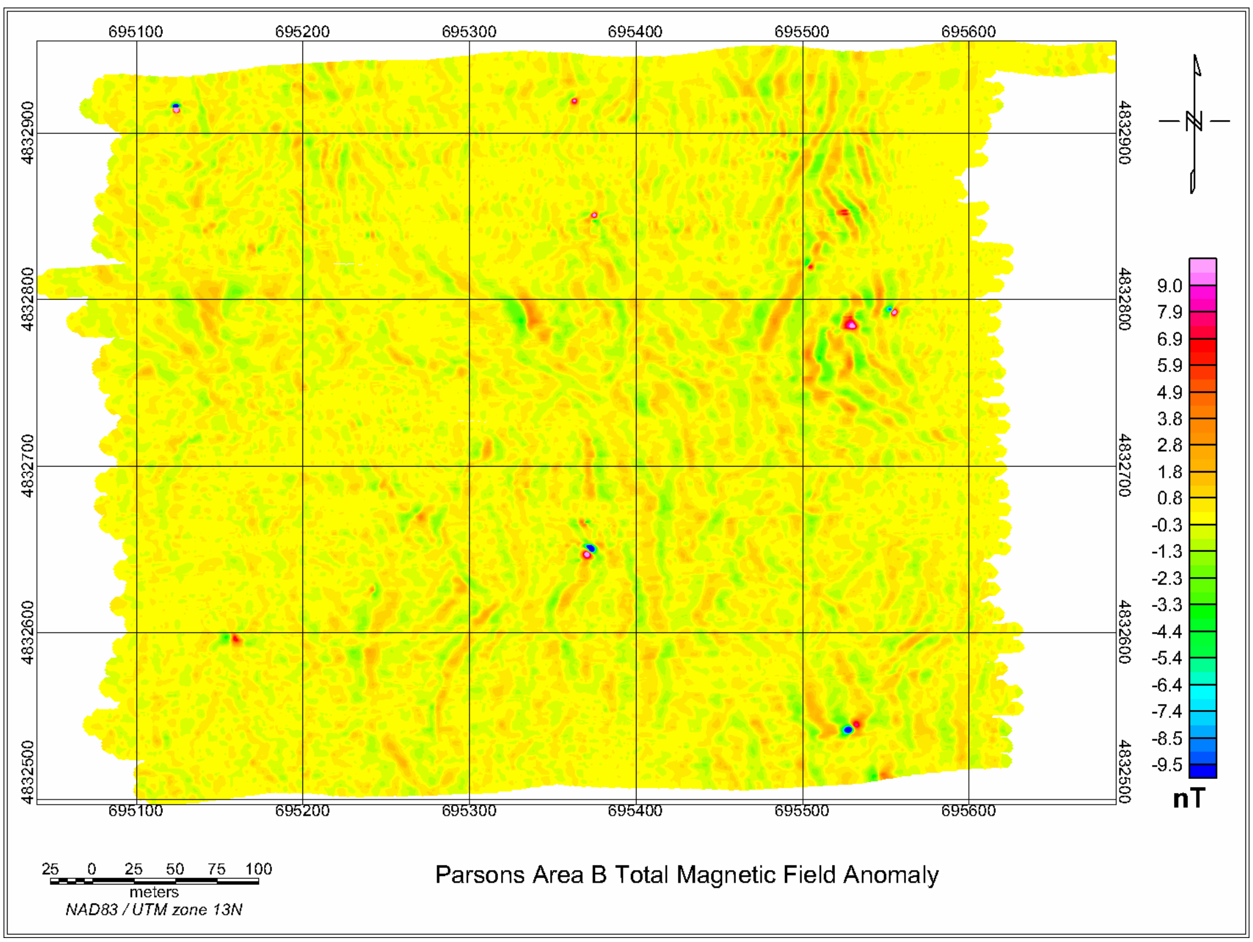

Figure 4.7 Total magnetic field residual anomaly map of Parsons Area B for a nominal 2m survey height.

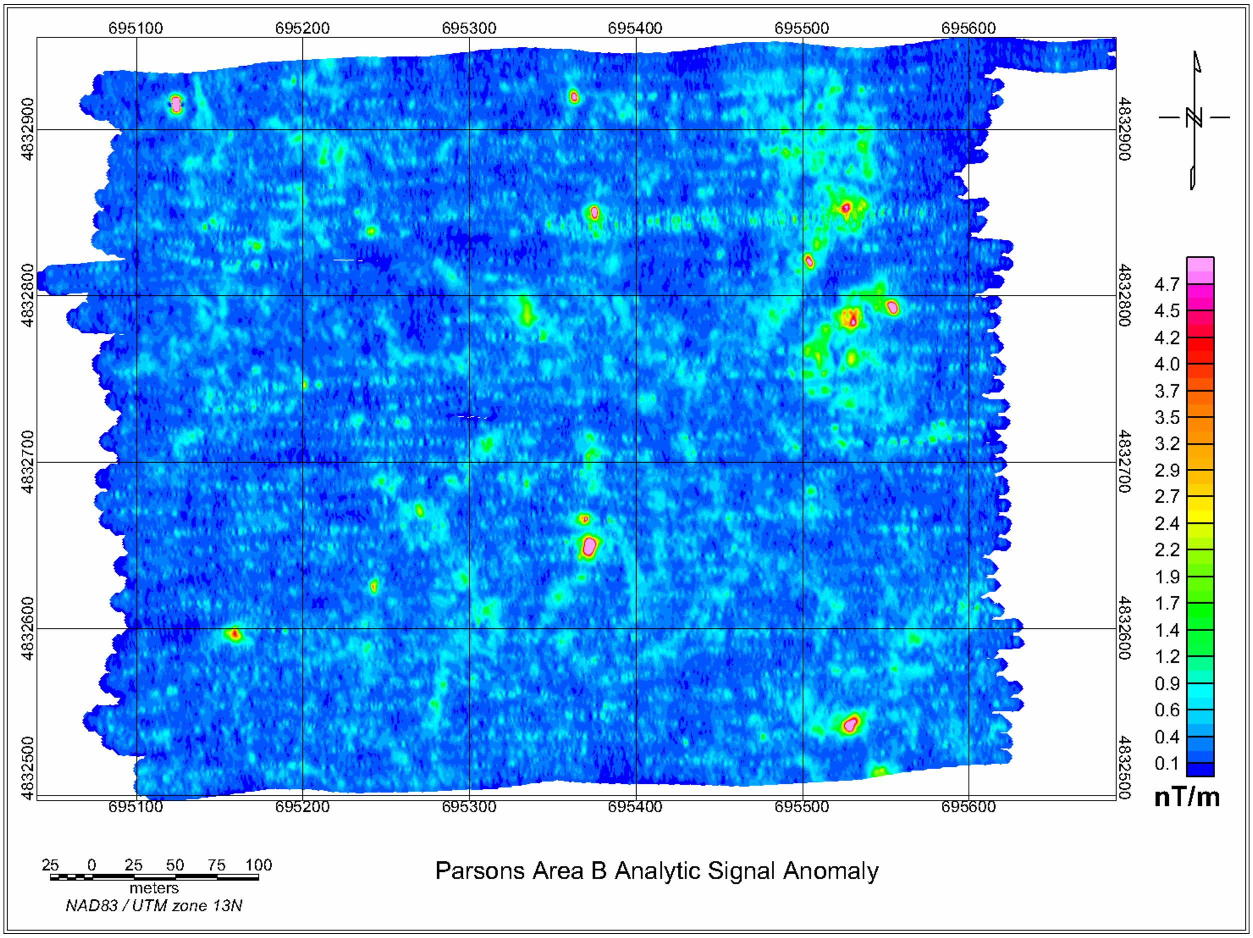

Figure 4.8 Analytic signal anomaly map of Parsons Area B for a nominal 2m survey height.

Bombing Target 1

Bombing Target 1 (BT-1) is defined by a roughly 0.33 km x 0.66 km (22 ha) rectangle centered over a bombing target. Lines were flown north-south, and covered the central portion of the target completely, using 12m flight line spacing. Total magnetic field and analytic signal maps are shown in Figures 4.9 and 4.10, respectively. The along line survey height ranged from 0.7 m to 4.3 m and averaged 1.7 m. The average survey speed along line at BT-1 was 9.5 m/s, and the average coverage rate, including turnarounds, was 24.6 ha/hr. No excavations were performed at this site.

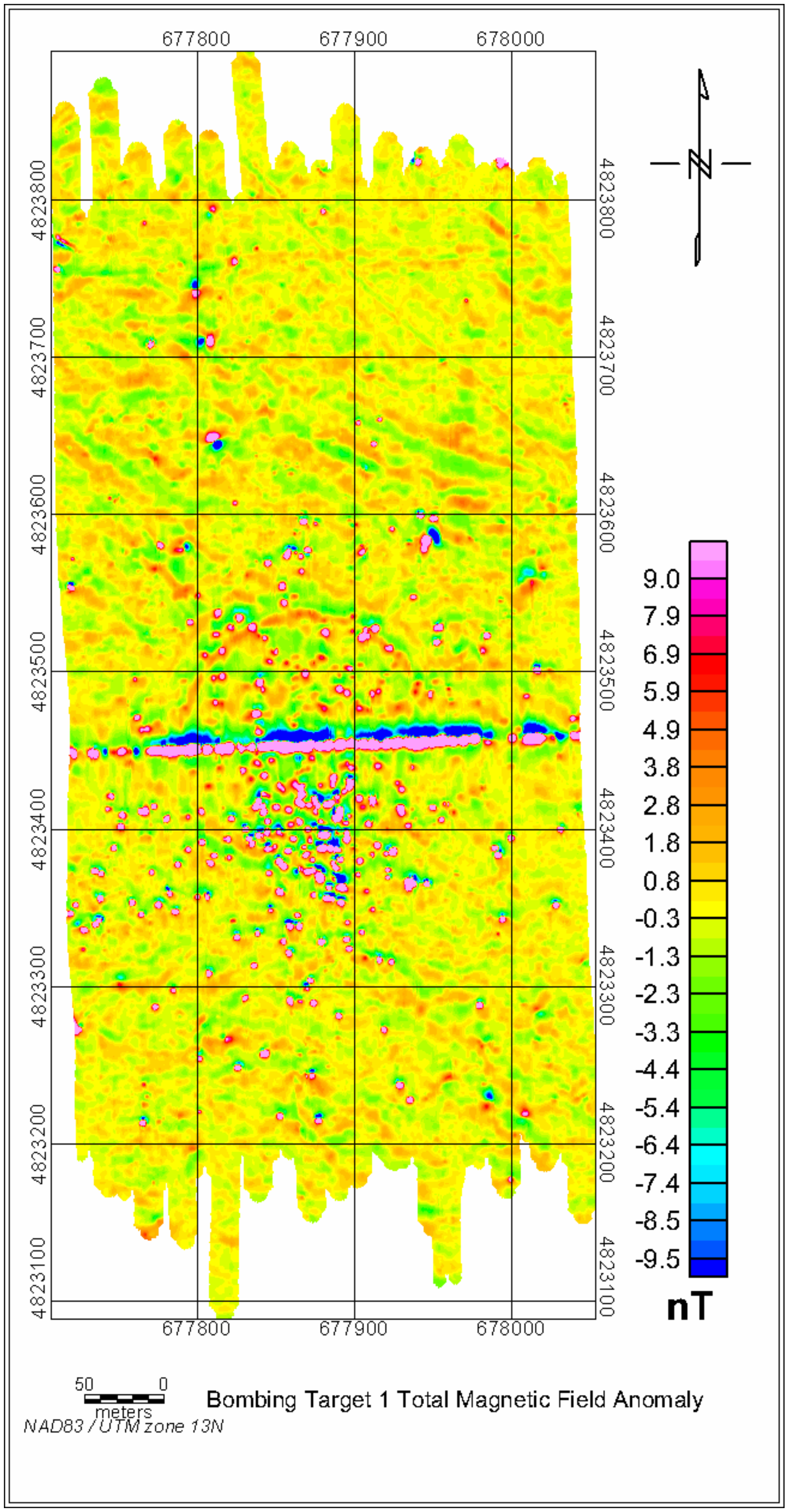

Figure 4.9 Total field anomaly map,Bombing Target 1, ALASA (mean: 1.7 m).

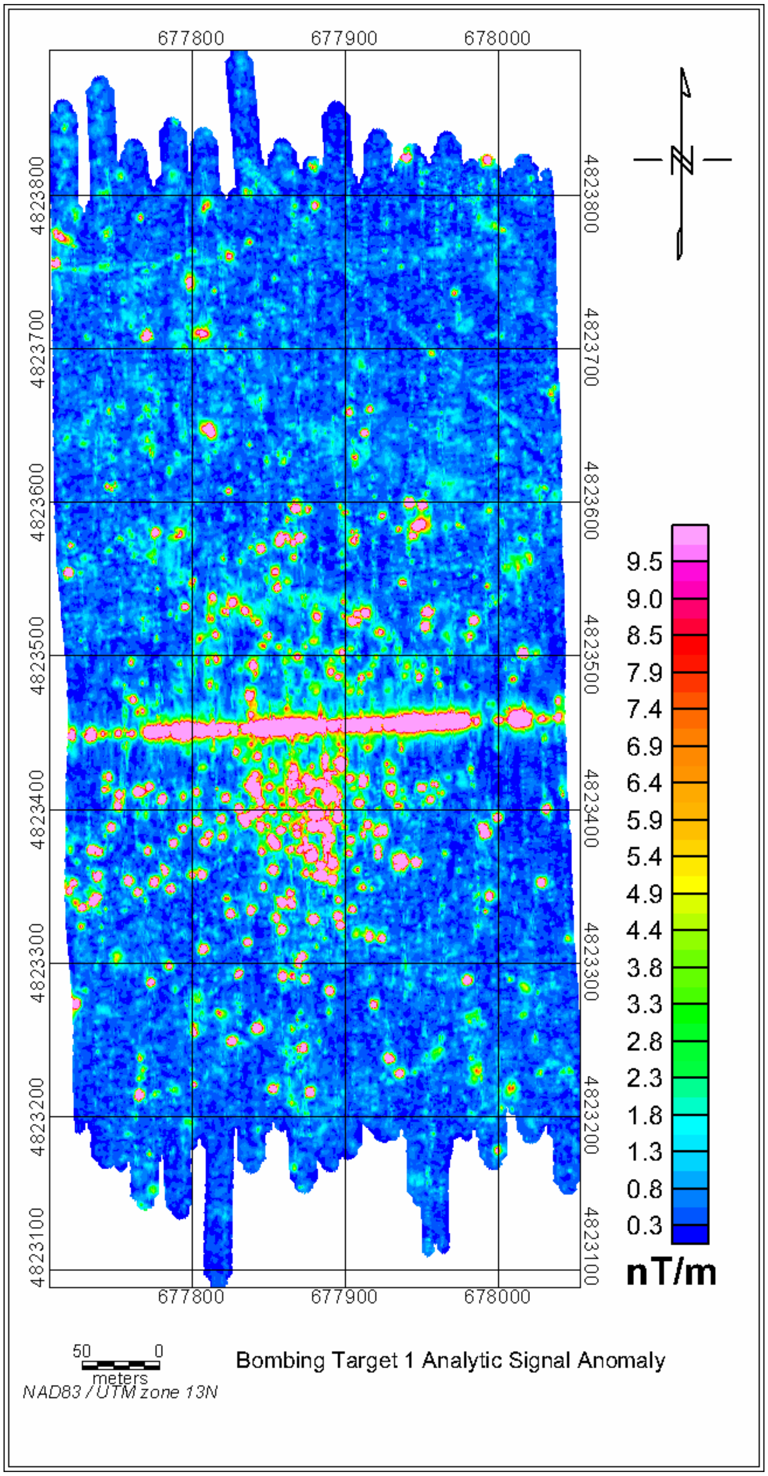

Figure 4.10 Analytic signal anomaly map, Bombing Target 1, ALASA (mean: 1.7 m).

Bouquet Table

Bouquet Table (BQ) is a 40 ha area centered over a known bombing target. Lines were flown north-south, and covered the central portion of the target completely with 12m flight line spacing. Total magnetic field and analytic signal maps are shown in Figures 4.11 and 4.12, respectively. The along line survey height ranged from 0.7 m to 7.6 m and averaged 1.7 m. The average survey speed along line at BQ was 13.0 m/s, and the average coverage rate, including turnarounds, was 23.6 ha/hr. No excavations were performed at Bouquet Table.

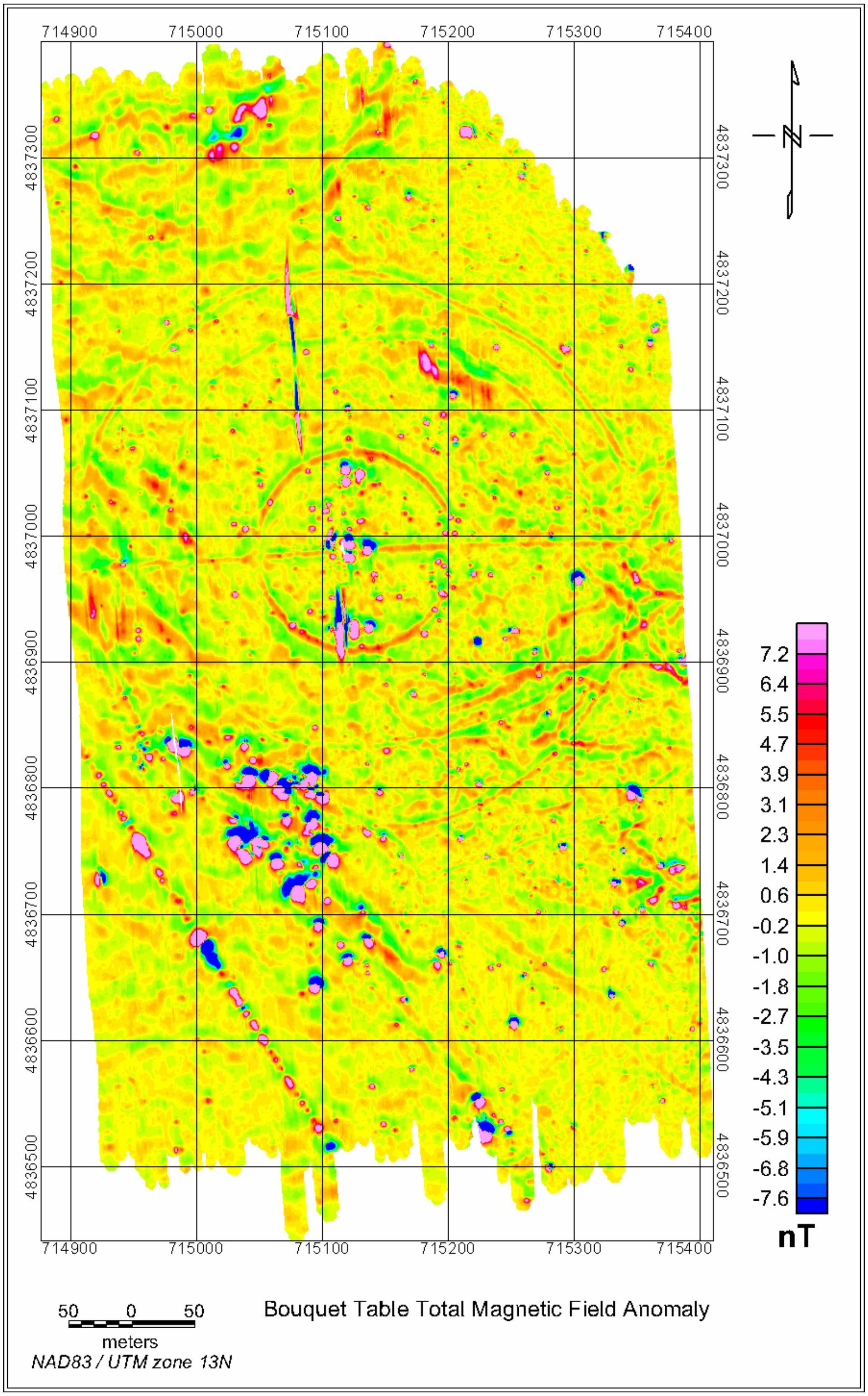

Figure 4.11 Total magnetic field anomaly map of Bouquet Table, ALASA (mean: 1.7 m).

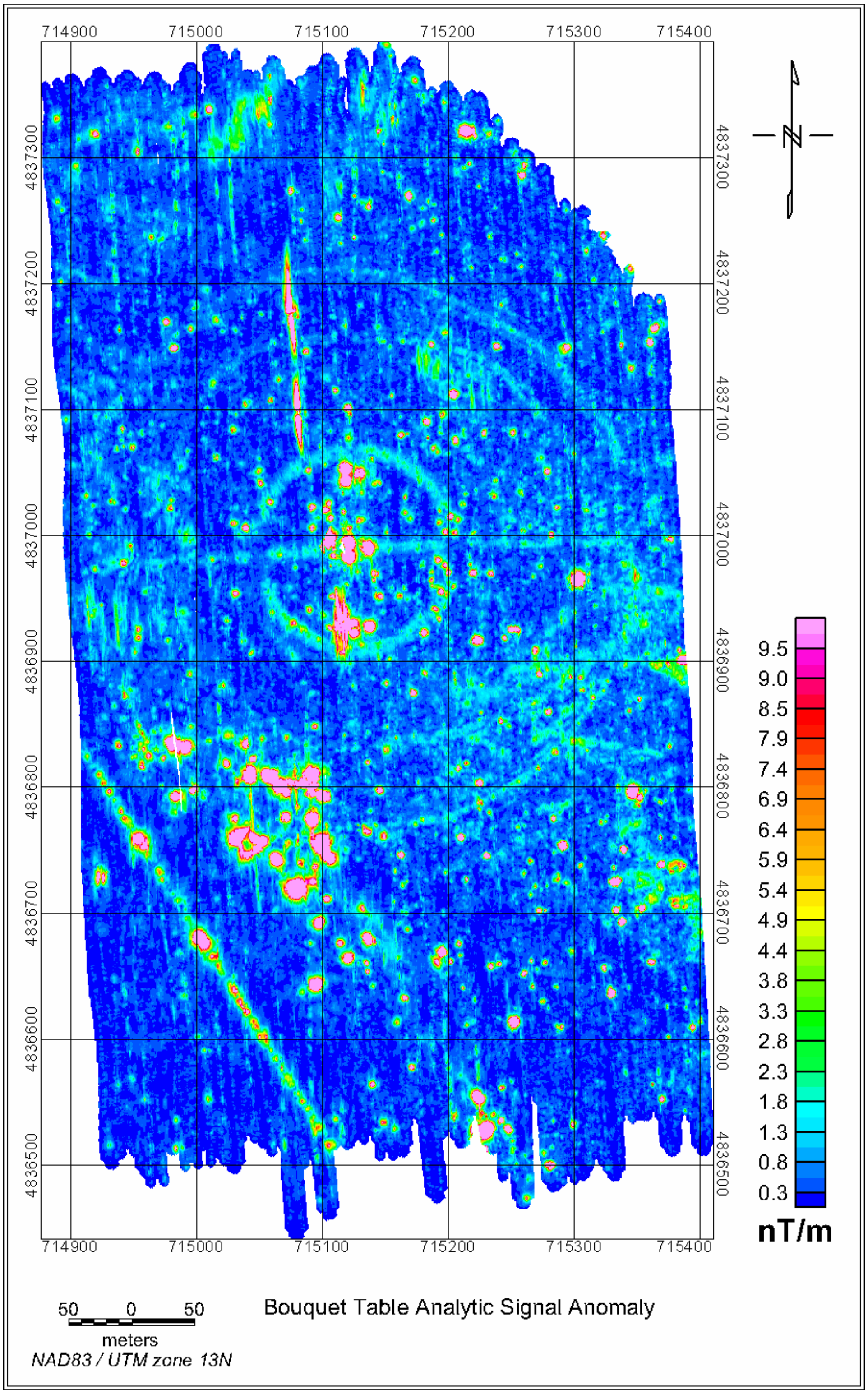

Figure 4.12 Analytic signal map of Bouquet Table Area, ALASA (mean: 1.7 m).

Sensor noise levels

Sensors behaved as expected during the demonstration, and sensor noise levels were at or below levels measured in previous surveys. Figure 4.13 shows total magnetic field data for a 10 second portion of a relatively quiet part of a line at Bouquet Table. The effect of the rotor and blades have not been removed from the data. The sensor response has been offset by 5 nT from the response of the previous sensor. Sensors 2 and 7, the two inboard sensors on the rear booms, appear to have higher noise levels than either the outer rear sensors or the four forward sensors. The noise envelope ranges from less than 1 nT peak-to-peak for the most quiet sensor (sensor 4) to about 6 nT peak-to-peak for the noisiest sensor (sensor 2). The effects of the blades and rotor can be almost completely removed from the data, to as low as 0.1-0.2 nT peak-to-peak without undue anomaly degradation through the application of frequency filters.

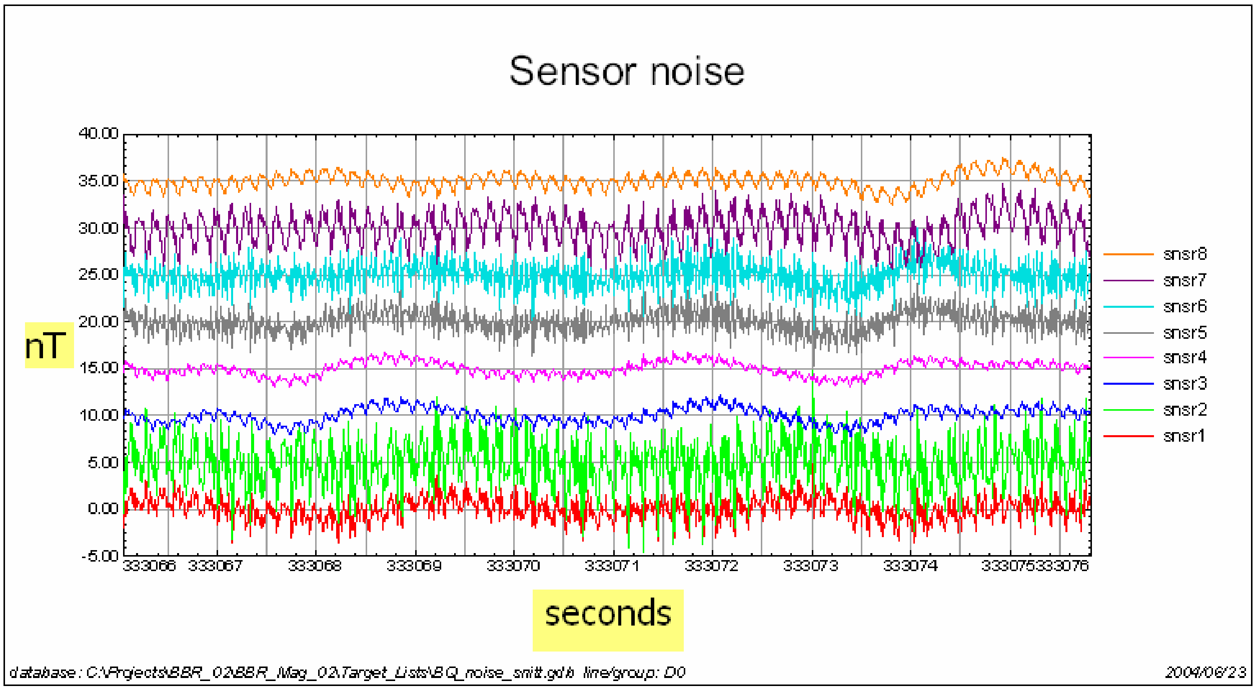

Figure 4.13 Total magnetic field data from each of the eight magnetometers over a quiet portion of Bouquet Table. The effects of the helicopter blade and rotor have not been removed from these data.

The figure of merit (FOM) is a measure of the total noise of a multiple sensor system. It is computed by examining the noise during roll, pitch, and yaw maneuvers while the helicopter is flying in each of the four cardinal directions. It is therefore the sum of these twelve noise components, and an FOM is derived for each of the eight sensors. As can be seen in Table 4.3, the average FOM for the Hammerhead system (computed from data at Nomans Island, Massachusetts) is more than 30% higher than for the Arrowhead. This is mainly because the two inboard rear-boom sensors on the Hammerhead system (sensors m3 and m6) have been moved to a less noisy position on the forward boom of the Arrowhead system. The noise levels of all other sensors are essentially unchanged, given that wind conditions can have a significant effect on sensor noise levels. Sensors 1 and 2, located on the aft port boom show modestly increased noise levels, but these amounts are easily within the range caused by wind-induced vibration. Thus, the net sensitivity of the Arrowhead system can be considered greater, and the likelihood of detecting smaller objects with the Arrowhead is somewhat greater than with the Hammerhead.

Table 4.4: FOM comparison between Hammerhead and Arrowhead.

Sensor	m1	m2	m3	m4	m5	m6	m7	m8	ave
Hammerhead	1.7	2.9	7.6	2.4	2.1	8.5	3.2	1.6	3.8nT
Arrowhead	2.3	3.7	3.0	2.3	2.4	2.4	2.7	1.7	2.6nT

Anomaly evaluation

Following the ORAGS-Arrowhead survey of Parsons Area A, anomaly picks were made from the Area A analytic signal map. A 61 m x 61 m plot in Area A was designated for sample excavations. The excavation plot is outlined in the northeast quadrant of Parsons Area A in Figures 4.5 and 4.6. In this plot, the most conspicuous of these anomalies were evaluated using MTADS-DAS magnetic dipole inversion software (Nelson and McDonald, 1999), and prioritized based on the inversion results. In addition, Area A anomalies were prioritized using multivariate analysis (Appendix A of this report; Beard et al., 2003). In the excavation plot, multivariate analysis prioritized 66 additional anomalies, not coincident with the 29 anomalies evaluated using MTADS-DAS. A dig list of the positions of these 95 anomalies was provided to Parsons for excavation (see file labeled 'AirborneAnomalyResults.xls' on accompanying CD). In the summer of 2003, a team from Parsons reacquired these 95 positions using GPS, searched a 1 meter radius around the positions using a ground magnetometer, and dug on the strongest signal. Of the 95 ORAGS-Arrowhead anomalies, 83 were ordnance related, either major portions of M-38 practice bombs, or in a single case, a live 100 pound bomb. Nine of the 95 anomalies proved to be non-UXO metallic debris. Three of the 95 anomalies proved to be no-finds (false positives).

The Parsons team also performed a full ground magnetometry survey of the 61 m x 61 m excavation plot, and dug an additional 62 anomalies detected by the ground system and not by the ORAGS-Arrowhead system. Figure 4.14 shows airborne and ground anomalies chosen for excavation. None of the items associated with the 62 ground anomaly digs proved to be UXO or major UXO fragments. The airborne anomalies produced by these fragments were mostly under 2 nT. A few exceeded 3 nT but were near larger items detected by the airborne survey. Parsons concluded that in the 61 m x 61 m excavation zone all the UXO items were detected by the ORAGS Arrowhead system (Van et al., 2004). The 100% detection rate is in large part a result of the size of the UXO ordnance type: all UXO found in the excavation area were M-38 practice bombs, or in a single case, a live 100 pound bomb, previously unknown at this site.

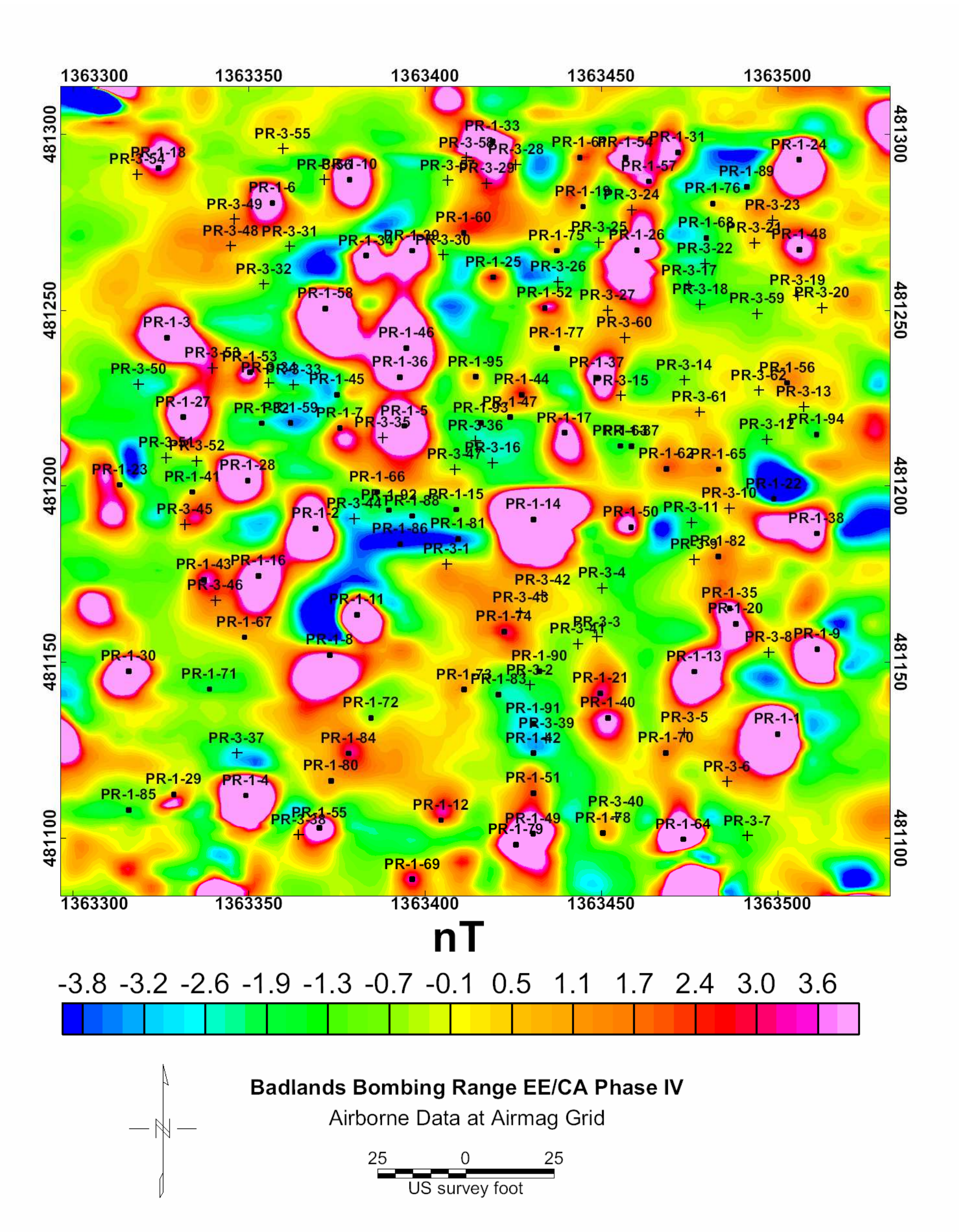

Figure 4.14 Magnetic anomalies at Area A excavation site selected from ORAGS airborne data (labeled PR-1-*) and additional anomalies selected from Parsons ground magnetic data (labeled PR-3-*).

The single ordnance type also made classification more straightforward. We sent to Parsons a list of 95 anomaly positions located in the 61 m x 61 m excavation zone. Twenty-nine of the more prominent anomalies were evaluated with the MTADS-DAS magnetic dipole inversion software (Nelson and McDonald, 1999). The anomalies were assigned a classification of 1 through 6 according to the following general categories: 1, most likely UXO; 2, probably UXO; 3, possibly UXO; 4, possibly scrap; 5, probably scrap; and 6, most likely scrap. Table 4.5 shows that each of the 29 prominent anomalies were categorized in classes 1, 2, 3, or 4. Eight of the 29 anomalies proved to be bombs, and these eight anomalies were all correctly placed in classes 1-3. Two anomalies classed as probably UXO (class 2) proved to be non-UXO (a steel spike and chicken coop wire), and at the site of a third anomaly classed as 2 nothing was found, although this does not rule out the possibility of magnetic soil. These three anomalies were the only anomalies that were poorly classified using the DAS software, amounting to 10% misclassification. 100% of all UXO, i.e. M38 practice bombs or intact ordnance, classified with the DAS software were placed in categories 1-3. Of all the anomalies classed as 1, 2, or 3, 42% proved to be UXO, 42% were UXO fragments, 11% were metallic non-UXO items, and 5% were no finds, possibly anomalies produced by magnetic soil.

The Parsons excavation team did not necessarily dig at the precise locations given by ORNL for the 95 anomalies, but instead used standard industry practice. They searched a radius around the specified location with a Schonstadt metal detector for a high signal level, and used this to more precisely locate the item. Most digs were within a meter of the stated ORAGS-derived dig list location (Van et al., 2004). The actual location of the dig was not recorded by the team, so we were unable to give a precise value for the offset between the actual and predicted locations of the excavated UXO items. However, the search radius was typically less than 1 m from the ORAGS dig list location.

Table 4.5 - Classification of 29 ORAGS anomalies at Parsons Area A with MTADS-DAS

Priority	**1**	**2**	**3**	**4**	**5**	**6**
100 # bomb	1	0	0	0	0	0
M38 practice bomb	2	1	4	0	0	0
Bomb Fragments	3	3	2	1	0	0
Non-UXO	0	2	0	0	0	0
No contact	0	1	0	0	0	0

Sixty-six of the less prominent anomalies were classified using a multivariate statistical approach developed at ORNL (Appendix A; Beard et al., 2003). This approach simultaneously weighs several factors that our data have shown are correlated, albeit weakly, to UXO. Results from the multivriate method of analysis are summarized in Table 4.6. Using the multivariate approach, we find that 10 of 11 intact UXO are placed in categories 1, 2, or 3 (91%), and that 33% of all items classed as 1 or 2 proved to be UXO (M38 practice bombs or intact ordnance). Of the 66 anomalies classified with the multivariate method, only 5 were poorly classed (7.5% misclassification). The term "poorly classed" in this report means that a non-UXO or no contact was placed in classes 1 or 2 (high probability UXO classes), or that a UXO item was placed in classed 5 or 6 (high probability non-UXO classes). Non-UXO items placed in class 3 (possibly UXO) are not considered as poorly classed, nor are UXO items placed in class 4 (possibly scrap).

In total, 8 anomalies—of a total of 95—were placed in classes 1 or 2, indicating a high likelihood of being UXO, that proved to be non-UXO (6) or no contacts (2). A ninth item that proved to be non-UXO was given the classification 3 (possibly UXO). These nine items yield a false alarm rate of 9.5%.

Table 4.6 – Statistical classification of 66 ORAGS anomalies at Parsons Area A

Priority	**1**	**2**	**3**	**4**	**5**	**6**
100 # bomb	0	0	0	0	0	0
M38 practice bomb	1	8	1	1	0	0
Bomb Fragments	3	10	6	7	15	6
Non-UXO	1	3	1	0	0	2
No contact	1	0	0	0	0	1

4.4 Technical Conclusions

The ORAGS-Arrowhead total field magnetometry system provided data adequate to the task of defining zones in former test ranges where bombing activities have occurred. The total magnetic field data were precise enough that positions of individual pieces of UXO scrap could usually be identified to within a radius of about 1 meter (Van et al., 2004). Once on site, the ORAGS-Arrowhead system was able to collect data at rates of 12-25 ha/hr (30-60 acres/hr), figures that include turn around times at the ends of lines. The rate of coverage was dependent upon the size of the area, with higher rates of coverage in areas where longer flight lines were possible. Peak-to-peak noise levels in the raw magnetic data, including blade and rotor noise, ranged from 1-6 nT. Once filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors. In a 61m m x 61 m excavation plot in Parsons Area A, the locations of 100% of all ordnance (M-38 practice bombs and a live 100-pound bomb) were accurately delimited by the ORAGS-Arrowhead system (Van et al, 2004). A subsequent ground magnetic survey of the area turned up some additional UXO fragments, but no additional intact ordnance. Nine false positives (non-UXO or no finds) occurred in 95 samples, for a false positive rate of 9.5%.

5.0 Cost Reporting

Cost information associated with the demonstration of all airborne technology, as well as associated activities, were closely tracked and documented before, during, and after the demonstration to provide a basis for determination of the operational costs associated with this technology. It is important to note that the costs for airborne surveys are very much dependent upon the character, size, and conditions at each site; ordnance objectives of the survey (e.g. flight altitude); type of survey conducted (e.g. high-density or transects); and technology employed for the survey (e.g. total field magnetic) so that a universal formula cannot be fully developed. For this demonstration, the Table 5.1 contains the cost elements that were tracked and documented for this demonstration. These costs include both operational and capital costs associated with system design and construction; salary and travel costs for support staff; subcontract costs associated with helicopter services, support personnel, and leased equipment; costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration.

Table 5.1: Demonstration Costs

Cost Category	Sub Category	Details	Quantity	Cost[1] (in dollars)
Pre-Survey (Start-up)	Site Characterization	Site inspection (includes hotel and per diem)	1 day	$1,869
	Mobilization	Mission Plan preparation & logistics (a portion of the effort is covered under the corresponding EM project)	5 days	$8,845
		Calibration Site development (includes pre-seed and post-seed ground-based surveys)	0 days	$0
		Equipment/personnel transport	2-1/2 days	$9,622
		Helicopter/personnel transport	2 days (15 hours airtime)	$12,193
		Unpacking and system installation	1 day	$4,559
		System testing & calibration	1 day	$6,309
Pre-survey subtotal				$43,397
	Cesium-vapor magnetometers	$122,200 total cost	8 each	$12,220

Capital Equipment[2]	GPS	$15,500 total cost	1 each	$1,550
	Booms and mounting hardware	$36,500 total cost	1 set	$3,650
	Orientation system	$16,600 total cost	1 each	$1,660
	Fluxgate magnetometer	$5,300 total cost	1 each	$530
	Navigation system	$5,200 total cost	1 each	$520
	Laser Altimeter	$7,300 total cost	1 each	$730
	Data management console	$31,200 total cost	1 each	$3,120
	Magnetic base station	$15,100 total cost	1 each	$1,510
	GPS base station	$15,600 total cost	1 each	$1,560
	PCs for data processing & analysis	$3,450 total cost	2 each	$345
	Shipping Cases	$4,750 total cost	6 each	$475
	Trailer	$3,600 total cost	1 each	$360
Capital subtotal				$28,230

Operating Costs	Equipment Rental	Spare magnetometers	2 each	$840
		GPS equipment	1 each	$950
	Data acquisition	Helicopter time, including pilot and engineer labor	2 days (13 hours airtime)	$10,400
	Operator labor		2 days	$350
	Data processing	Geophysicist	3 days (24 hours labor)	$4,620
	Field support/management	Engineer	3 days (24 hours labor)	$4,620
	Maintenance	Geosoft software maintenance[3]	1 each	$1,243
	Hotel and per diem	Survey team in South Dakota	8 days	$4,016
	Fuel Truck	Remote re-fueling[4]	-	$0
	Airport Landing Fees		3 days	$75
	Data analysis and interpretation	Geophysicist	5 days	$7,723
	Project management		4 days	$6,164
	Reporting and documentation		10 days	$15,460
Operating cost subtotal				$56,461
	Demobilization[4]	Disassembly from helicopter, packing, and loading for	1 day	$4,559

Post-Survey		transport Equipment/personnel transport (includes travel) Helicopter/personnel transport (includes travel)	2-1/2 days 2 days (15 hours airtime)	$9,622 $12,193
Post-survey Subtotal				$26,374
Indirect Environmental Activity Costs	Environmental and Safety Training[4]	8-hour HAZWOPR (includes the course cost)	-	$0
Miscellaneous	Department of Energy Federal Acquisition Cost (FAC)	3% of project total; Congressionally-mandated charge for administering the Work-for-Others (WFO) program		$4,634
Total Costs				$159,096

[1]Includes all overhead and organization burden, fees, and associated taxes
[2]Capital costs are apportioned at 10% of the original equipment cost for this project; all capital equipment was used for several projects during the course of the year in which this project occurred
[3]Geosoft software costs include the cost of 1 license and the UX-Detect module. The license cost is apportioned at 10% of the total cost for this project in a similar fashion to the capital equipment costs
[4]Costs associated with this sub-category item are included in other airborne survey projects

6.0 Implementation Issues

6.1 Environmental Checklist

In order to operate, each system must have Federal Aviation Administration approval (STC certificate). The required testing and evaluation performed in Toronto before mobilization to South Dakota has been completed. In addition, ground crews are required to complete the 40-hour HAZWOPR course and to maintain their annual 8-hour refreshers for operation at most UXO sites.

6.2 Other Regulatory Issues

There are no additional regulatory requirements for operation at BBR sites.

6.3 End-User Issues

The primary stakeholders for UXO issues at the BBR site in South Dakota are the members of the Lakota Tribe, other residents of the Pine Ridge Reservation, and State of South Dakota regulatory authorities. The airborne UXO survey was designed to accommodate the limitations and needs of the site. Larger scale surveys have been proposed and discussed with several sites. USAESCH has assisted in efforts to commercialize the existing technology and this has led to shared operation with one contractor for engineering evaluation/cost analysis (EE/CA) activities. As new systems are developed and proven, they will enter into the same cycle of application and commercialization.

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8.0 Points of Contact

Points of contact are given below in Table 8.1.

Table 8.1: Points of Contact

NAME	ORGANIZATION	PHONE	Role in Project
Gary Jacobs	ORNL	865-576-0567	Division Director
David T. Bell	ORNL	865-574-2855, 865-250-0578 (cellular)	Project Manager
Dr. Bill Doll	ORNL	865-576-9930	Technical Manager
Jeff Gamey	ORNL	865-574-6316 865-599-0820 (cellular)	Operations Manager
Dr. Les Beard	ORNL	865-576-4646	Geophysicist
D. Scott Millhouse	USAESCH	256-895-1607	Project Lead
Emma Featherman-Sam	Oglala Sioux Tribe	605-867-1271	Director, Badlands Bombing Range Project
Dan Munro	National Helicopters	416-990-2727	Helicopter Contractor President

Appendix A: Analytical Methods Supporting the Experimental Design

A.1 Statistically based UXO discrimination

We began investigating statistically-based discrimination methods after an analysis of dig results based on data collected at the former Badlands Bombing Range (BBR) in South Dakota showed statistical differences between ordnance and non-ordnance. In no instance was the statistical difference so strong that a single parameter could predict whether the source of an anomaly was UXO or not, but the possibility for discrimination increased as more parameters were considered. We used a routine developed to our specifications by Geosoft to rapidly identify and characterize anomalies above a given threshold from an analytical signal map. From these peaks we identified the associated magnetic field anomaly and sensor altitude, and computed a number of parameters that could be used directly or otherwise combined as statistically relevant predictors. From this point we used two different approaches for discrimination—a univariate and a multivariate methods.

A.1.1 Univariate method (not used with BBR data)

The univariate method relies on correlations from dig results based on airborne magnetic data collected at two different sites: an East Coast site and BBR. Both sites were geologically 'clean' in that neither contained basaltic rock or magnetic soils that could complicate any interpretations. We chose six parameters showing correlation with known UXO, and at each anomaly location evaluated whether the parameters fell within the range of the majority of known measured UXO. Each of the six parameters was scored zero if the parameter fell outside a specified range, and one if it fell within the range. For example, almost all ordnance in our known sample pool yielded peak-to-peak magnetic anomalies between 1.0 and 80 nT. Any anomaly falling outside this range was scored zero, as non-UXO. The six characteristics were scored and summed, so that items could have a value ranging from 6 (all characteristics in the range of UXO) to zero (all characteristics outside the range for UXO). The six parameters used in the univariate analysis were analytic signal amplitude, magnetic anomaly peak-to-peak magnitude, the distance between the magnetic anomaly peak and low, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the estimated source depth, and the angle between magnetic north and the line connecting the positive and negative lobes of the magnetic anomaly (denoted theta).

A.1.2 Multivariate method

Multivariate analysis should provide more information than the univariate approach described above as long as some or all of the variables are correlated, and if the number of known samples is large enough to obtain reliable statistics. The parameters must also be appropriately normalized to remove the effects of different magnitudes for the given parameters. We derived a vector of standard mean parameters $\boldsymbol{\mu}_0$ from a set of measurements over known ordnance items, and compute the symmetric covariance matrix $\mathbf{S}$ from the covariances computed for the different variable combinations. The statistical similarity between the known ordnance and the parameter vector **x** associated with an unknown is given by the Mahalanobis distance (Swan and Sandilands, 1995)

$$D = \{(\mathbf{x} - \boldsymbol{\mu}_0)^T \mathbf{S}^{-1} (\mathbf{x} - \boldsymbol{\mu}_0)\}^{1/2}. \quad (1)$$

The smaller the Mahalanobis distance the more closely the unknown resembles ordnance from the known pool of items. The vectors **x** and $\boldsymbol{\mu}_0$ each have five entries: analytic signal peak, the magnitude of the negative lobe of the magnetic anomaly, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the ratio of the distance between the magnetic anomaly positive peak and the analytic signal peak to the instrument height added to the estimated source depth, and theta, as described in the univariate section. The differences in the variables used in the two methods of analysis occurred because the univariate analysis was done prior to a more complete statistical review of the data, which led to the multivariate approach.

A.2 Model-based inversion of magnetic data as an aid to discrimination

Magnetic fields in the vicinity of UXO can often be reliably estimated using a model based on a magnetic dipole. The MTADS-DAS software (McDonald and Nelson, 1999) is based on this model. MTADS-DAS does not perform discrimination, but rather is an aid to the interpreter, who subjectively performs the discrimination task. MTADS-DAS requires as input a set of coordinates (x,y,z) and a magnetic total field measurement at each coordinate. The software constructs a grid of the total field data from which the interpreter can select individual anomalies as likely UXO targets. The user selects a boundary around the anomaly that includes some area outside the main anomaly, and the MTADS-DAS code searches for a dipole model that best fits the selected data. Estimates of the moment of the magnetic dipole, its length, orientation, burial depth, and goodness of fit are output. From the returned parameters, an experienced interpreter can make a reasonably well-informed judgment as to whether or not the source of the anomaly is intact ordnance, scrap, or non-UXO related.

Appendix B: Quality Assurance Project Plan (QAPP)

At the time of this survey, we were not required to have a QAPP in place, nor had ESTCP published the current guidelines for QAPP documentation (ESTCP Final Report Guidance for UXO Projects, Revision 2, April 2002). We nevertheless developed our own QA/QC procedures that were followed through this and other projects. These fall into three main categories: operational QA/QC, system QA/QC, and data QA/QC.

Under the category of operational QA/QC:

- Site visit preliminary to survey to assess appropriateness of site for helicopter geophysical surveying;
- De-gaussing of helicopter rotor to decrease magnetic noise produced by this component;
- Review of GPS almanac to assess best times of the day for surveying;
- Emplacement of a calibration grid for daily system checks;
- A morning meeting to coordinate each day’s activities;
- An evening meeting to review activities and safety issues.

Under the category of system QA/QC:

- Installation of booms under the supervision of the pilot and engineer, and subsequent double-checking of all mounts and bolts;
- Daily helicopter inspection and maintenance by pilot and engineer;
- Ground tests of system after installation (checks to determine if all magnetometers are operating and have been connected in the correct order, and an impulse test to determine the lag between magnetometers and fluxgate);
- An initial check flight after installation.

Under the category of data QA/QC:

- An extensive test flight to evaluate the effects of pitch, roll, and yaw on the magnetometers, from which we can calculate compensation coefficients, and to examine the high altitude noise levels of the magnetometers.
- Daily inspection of diurnal magnetic activity at a base station magnetometer;
- Visual inspection of all data;
- Daily plots of flight path and laser altitude;
- Adherence to the data processing flow, described in section 3.6.6;
- Daily production of digital magnetic maps;
- Archiving of all materials: flight logs, digital materials, and report.

Appendix C: Health and Safety Plan

This document represents the health and safety plan applied to field operations at the Badlands Bombing Range, South Dakota.

C.1 Aircraft Base of Operations

Rapid City Regional Airport
4550 Terminal Road, Suite 102
Rapid City, SD 57703
Phone: 605-394-4195
Fax: 605-394-6190

The base of operations for all aircraft activities was the Rapid City Regional Airport. The aircraft were stored and some refueling activities will occur at this location. Other refueling activities will occur remotely through use of a fuel truck provided by National Helicopters, Inc. No direct aircraft support (e.g., housing, fuelling, etc.) is requested from the Department of Defense.

C.2 Communications

Air-to-ground and ground-to-ground communications occurred using two-way VHF radios provided by ORNL and National Helicopters. Radios broadcasted at 118 - 135 MHz. All other communications were via cellular telephones.

C.3 Schedule Constraints and Crew Rest

C.3.1 Schedule Constraints

During aviation missions, activities can occur that are uncontrollable by the survey team and cause a delay of data acquisition. These activities may result in missed data acquisition windows or the loss of entire days of data acquisition.

C.3.2 Crew Rest

Crew rest will follow the guidelines prescribed by FAA regulations. Restrictions are placed on both the pilot's in-air flight-time and duty-time.

C.4 Aircraft

Bell 206L Long Ranger III Helicopter
Color scheme: White with midnight blue and light blue accents
Serial Number: 45784
Tail Number: C-CFLYC

National Helicopters, Inc.
11339 Albion Vaughn Road
Kleinburg, Ontario, Canada
Phone: 905-893-2727

C.5 Statement of Risks

Airborne geophysical surveys are designed to be conducted with minimal risk to personnel. Safe operation of the aircraft is the ***direct responsibility*** of the pilot, who will determine the minimum safe flight altitude and local weather conditions for safe flying on an ongoing basis. The mission was flown under all applicable Federal Regulations.

Most ground activities were limited to routine working conditions; however certain field activities will expose personnel to summer heat and prairie wildlife. Precautions against the heat include drinking plenty of water, using sunscreen, and taking breaks as needed. Precautions against the wildlife include wearing hiking (or similar) boots and minimization of exposure to that environment. In addition, the two-man rule was in effect for all on-site field activities.

For additional risk-related information, consult the Operational Emergency Response Plan contained in Appendix B of this document.

C.6 Emergency Notification

Emergency action plans are included in the Appendix of this document. In the event of an emergency, staff will first request assistance, then provide appropriate first aid measures until emergency assistance arrives. As soon as emergency assistance has been obtained, the following people were to be notified in sequence based on availability:

Mr. David Bell, ORNL Project Manager
Cellular: 865-250-0578
Office: 865-574-2855
Dr. Bill Doll, ORNL Technical Manager
Cellular: 865-599-0820
Office: 865-576-9930
Mr. Jeff Gamey, ORNL Operations Manager

Cellular: 865-599-0820
Office: 865-574-6316

Mr. Scott Millhouse, USAESCH Program Manager
Office: 256-895-1607

Mr. Dan Munro, National Helicopter, President
Office: 905-893-2727

Dr. Steve Hildebrand, ORNL Environmental Sciences Division Director
Office: 865-574-7374
Home: 865-966-6333

Each organizational member of the project team is responsible for flow-down of communications within the respective organization in the event of an incident or emergency (e.g. notification of next-of-kin by ORNL Environmental Sciences Division Director if ORNL staff is involved in an emergency situation, etc.). Any member of the project team, in the event of an emergency situation, shall **not** contact persons other than those designated in the above listing.

C.7 On-Site Ground Emergencies

In the event of an emergency that occurs on-site:

1) Telephone local emergency response organizations via 911, if needed.
2) Conduct appropriate first aid.
3) Notify managers, as listed above in sequence. **The ORNL Project Manager has jurisdiction for all on-site emergency activities.** If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.
4) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.
5) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.8 Off-Site Ground Emergencies

In the event of an emergency that occurs off-site:

1) Assess the urgency of the emergency.
2) Telephone local emergency response organizations via 911, if needed.
3) Conduct appropriate first aid while awaiting professional assistance.

4) Notify managers, as listed above in sequence. **<u>The ORNL Project Manager has jurisdiction for all off-site emergency activities.</u>** If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.
5) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.
6) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.9 In-Air Emergencies

In-air emergencies were to be handled via standard aircraft emergency protocol, including radio contact with the Rapid City Regional Airport. **<u>The pilot has jurisdiction for all emergency response activities and requirements when the aircraft is airborne.</u>** Follow-up telephone/radio notification to the emergency response personnel listed in Section 11.0 were to be made as soon as possible.

Appendix D: Data Storage and Archiving Procedures

General

Digital data are on the CD accompanying this report. Included are: (1) readme files, (2) a copy of the final report in *.DOC format, (3) digital copies of the total field and analytic signal maps from each area flown in TIF format, (4) dig lists in ASCII format, (5) geophysical data files in ASCII format, (6) ORNL analysis files, and (8) excavation and remediation results.

Geophysical Data

The data included with this report is ASCII text and conforms to the format described in the "Area_Data_Readme.txt" file on the CD-ROM provided. Files are named according to area surveyed: BT1_MAG.XYZ, TG_1M_MAG.XYZ, TG_10M_MAG.XYZ, BQ_MAG.XYZ, BQ_REFLY_MAG.XYZ, PARSONS_A_MAG.XYZ, PARSONS_B_MAG.XYZ.

ASCII text file format is comma delimited in the following order:

Column 1: x, Easting coordinate (m), UTM Zone 13 N, NAD83 (Continental US).
Column 2: y, Northing coordinate (m), UTM Zone 13 N, NAD83 (Continental US).
Column 3: line3, Line ID (one for each sensor, last digit of each line represents sensor 0-7.
Column 4: alt, laser altimeter (m)
Column 5: rawmag, raw magnetic signal (nT)
Column 6: mag, residual total magnetic field (nT)

Dig Lists

The dig list information is saved in an ASCII text format file. Coordinates are given in UTM Zone 13 N (meters) using a NAD83 (Continental US) datum, as well as in geographical latitude/longitude. File format is:

Anomaly ID, X, Y, Latitude, Longitude, Estimated Depth to Target, Priority

Parsons_A_1_29.XYZ— Targets generated using MTADS-DAS software and prioritized 1-6 according to likelihood of being UXO (1= highest likelihood UXO, 6=lowest).

Parsons_A_30_95.XYZ— Targets generated using multivariate analysis and ranked according to statistical semblance to UXO.

Images

Geophysical anomaly maps--total field residual and analytic signal—for each area are provided as image files in TIF formats. The TIF images have been saved at 200dpi at the scale labeled on each map.

Remediation Results

Excavation results by Parsons from the 61 m x 61 m grid in area A are provided in Excel files labeled: ‘AirborneAnomalyResults.xls.’