FINAL REPORT

Demonstration of Helicopter Multi-Sensor Towed Array Detection System (MTADS) Magnetometry Technology at Victorville Precision Bombing Range, California

ESTCP Project MM-0535

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14. ABSTRACT

The former Victorville PBR is located in San Bernardino County, CA. This site is classified as a Formerly Used Defense Site, known to contain one precision bombing range target and one demolition bombing target area. This demonstration utilized Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry (HeliMag), a wide area assessment technology. Data collection was conducted in March-April 2006 resulting in the survey of 4,567 acres. The airborne MTADS platform was deployed at approximately 3 m AGL over the entire site, the system was also flown at 5 m and 10 m AGL over approximately 825 acres for each higher altitude. The purpose for these higher altitude flights was to assess whether the same information can be collected at a higher flight AGL. The background geologic signal complicated the use of automated target selection routines. After consideration of a number of candidate target selection/density estimate techniques it was determined that manual target selection provided the most realistic and defensible density distribution estimates; 6,319 anomalies were selected from the dataset.

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Helicopter magnetometry, airborne magnetometry, HeiMag, wide area assessment, Victorville Precision Bombing Range

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TABLE OF CONTENTS

TABLE OF CONTENTS ii
LIST OF FIGURES iii
LIST OF TABLES iv
ACRONYMS v
ACKNOWLEDGMENTS vi
1. INTRODUCTION 1
1.1. Background 1
1.2. Objectives of the Demonstration 2
1.3. Regulatory Drivers 2
1.4. Stakeholder/End-User Issues 2
2. TECHNOLOGY DESCRIPTION 3
2.1. Technology Development and Application 3
2.1.1. Helicopter Platform 3
2.1.2. Sensors and Boom 4
2.1.3. Positioning Technologies 5
2.1.4. Data Acquisition System 5
2.1.5. Data Processing 5
2.1.6. Data Analysis 6
2.2. Previous Testing of the Technology 7
2.3. Factors Affecting Cost and Performance 7
2.4. Advantages and Limitations of the Technology 7
3. DEMONSTRATION DESIGN 8
3.1. Performance Objectives 8
3.2. Test Site Selection 8
3.3. Test Site History/Characteristics 8
3.4. Present Operations 13
3.5. Pre-Demonstration Testing and Analysis 13
3.6. Testing and Evaluation Plan 13
3.6.1. Demonstration Set-Up and Start-Up 13
3.6.2. Period of Operation 14
3.6.3. Area Characterized 18
3.6.4. Operating Parameters for the Technology 18
3.6.5. Data Processing 18
3.6.6. Data Analysis 21
3.6.7. Demobilization 22
4. PERFORMANCE ASSESSMENT 23
4.1. Data Calibration Results 23
4.2. Anomaly Selection / Density Distribution Results 26
4.3. Results Discussion by Area 33
4.3.1. Demolition Bombing Target Y 33
4.3.2. Precision Bombing Range Target 15 33
4.3.3. All Other Lands 33
4.4. Performance Criteria 33
4.5. Performance Confirmation Methods 34

5. COST ASSESSMENT 38
5.1. Cost Reporting 38
5.2. Cost Analysis 38
6. IMPLEMENTATION ISSUES 40
6.1. Regulatory and End-User Issues 40
7. REFERENCES 41
8. POINTS OF CONTACT 42

LIST OF FIGURES

Figure 1. Helicopter MTADS technology as deployed on Bell Long Ranger helicopter. 4
Figure 2. The track guidance system provides flight traverse information to the pilot. 4
Figure 3. Helicopter MTADS processing flow chart. 6
Figure 4. Victorville PBR demonstration area and historical information. 11
Figure 5. Demonstration study site at Victorville PBR. 12
Figure 6. Victorville PBR site condition impacts to data collection included topography; tall vegetation; wind and dust; and ORV use. 16
Figure 7. Map of areas selected for higher altitude surveys (5 m and 10 m AGL) conducted at Victorville PBR. 17
Figure 8. Derived x and y coordinates for the calibration targets relative to the supplied ground truth. 24
Figure 9. Dipole depth estimates for calibration line targets. 25
Figure 10. Dipole fit size estimates for calibration line targets. 25
Figure 11. Dipole fit solid angle estimate for calibration line targets. 26
Figure 12. HeliMag total magnetic field data collected at the Victorville Precision Bombing Range. Insets show regions of high geologic response (top) and high density of ferrous objects typical of a high use bull's eye like target. 27
Figure 13. Density distribution images using four different target density derivation approaches. The manual target selection method (top left) provides superior mitigation of localized geologic response. This assertion is based upon the fact that the target density for the manual method shows the lowest correlation with the geologic response. 28
Figure 14. To test detection of bull's eye like targets in challenging geologic regimes the total magnetic field data collected over PBR 15 are added to a section of challenging geology. 29
Figure 15. Test results indicating that high anomaly density bombing targets such as PBR Target 15 are recognizable in challenging geologic regimes using manual target selection. The simulated bull's eye in the northwest section of the survey area is clearly identifiable in the even in the region that has challenging geology. 30
Figure 16. Target locations superimposed over the HeliMag total magnetic field data (top left) and hillshade LiDAR data (top right) and the final density distribution image (bottom). 31
Figure 17. High altitude (5 m) target locations superimposed over the HeliMag total magnetic field data (left) and hill shade LiDAR data (right). 32
Figure 18. Histogram of sensor altitude above ground level. 35
Figure 19. 20 second sample of high altitude data, 'final' filtered data. 36

LIST OF TABLES

Table 1. Sky Research HeliMag Technology Components 3
Table 2. Performance Objectives 10
Table 3 Calibration Items Seeded in the Calibration Lane 14
Table 4. Data Collection Issues 15
Table 5 HeliMag Data Collection at Victorville PBR 15
Table 6. Helicopter MTADS Raw Data Input Files 19
Table 7. Calibration Results for Calibration Lane Targets 23
Table 8. Performance Criteria for the Victorville PBR HeliMag Technology Demonstration 34
Table 9. Performance Metrics Confirmation Methods and Results 37
Table 10. Cost Tracking 39
Table 11. Points of Contact 42

ACRONYMS

AGL	Above Ground Level
ASR	Archive Search Report
AVR	Advanced Virtual RISC (Reduced Instruction Set Computer)
BLM	Bureau of Land Management
CRADA	Cooperative Research and Development Agreement
cm	centimeter(s)
Cs	Cesium
CSM	Conceptual Site Model
DAQ	Data Acquisition Computer
DBT	Demolition Bomb Target
DERP	Defense Environmental Restoration Program
DGM	Digital Geophysical Mapping
DoD	Department of Defense
DSB	Defense Science Board
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GIS	Geographic Information Systems
GPS	Global Positioning System
HE	High Explosive
HeliMag	Helicopter MTADS Magnetometry (see MTADS)
Hz	hertz
IMU	Inertial Measurement Unit
lb	pound
LiDAR	Light Detection and Ranging
m	meter(s)
m/s	meters per second
MTADS	Multi-Sensor Towed Array Detection System
NRL	Naval Research Laboratory
nT	nanotesla
OB/OD	Open Burn/Open Detonation
ORV	Off-Road Vehicle
PBR	Precision Bombing Range
PPS	Pulse Per Second
RISC	Reduced Instruction Set Computer
RTK GPS	Real-Time Kinematic Global Positioning System
TOA	Time of Applicability
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WAA	Wide Area Assessment

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Demonstration of Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry at Victorville Precision Bombing Range, California documents the acquisition, processing, analysis, and interpretation of Helicopter Multi-sensor Towed Array Detection System Magnetometry data for unexploded ordnance related sites at the former Victorville Precision Bombing Range. The work was performed by Sky Research, Inc. of Oregon, with Dr. John Foley serving as Principal Investigator and Mr. David Wright serving as co-Principal Investigator.

Funding for this project was provided by the Environmental Security Technology Certification Program Office. This project offered the opportunity to examine advanced airborne methods as part of the Department of Defense's efforts to evaluate wide area assessment technologies for the efficient characterization and investigation of large Department of Defense sites.

We wish to express our sincere appreciation to Dr. Jeffrey Marqusee, Dr. Anne Andrews, and Ms. Katherine Kaye of the ESTCP Office for providing support and funding for this project.

1. INTRODUCTION

1.1. Background

Unexploded Ordnance (UXO) contamination is a high priority problem for the Department of Defense (DoD). Recent DoD estimates of UXO contamination across approximately 1,400 DoD sites indicate that 10 million acres are suspected of containing UXO. Because many sites are large in size (greater than 10,000 acres), the investigation and remediation of these sites could cost billions of dollars. However, on many of these sites only a small percentage of the site may in fact contain UXO contamination. Therefore, determining applicable technologies to define the contaminated areas requiring further investigation and munitions response actions could provide significant cost savings. Therefore, the Defense Science Board (DSB) has recommended further investigation and use of Wide Area Assessment (WAA) technologies to address the potential these technologies offer in terms of determining the actual extent of UXO contamination on DoD sites (DSB, 2003).

In response to the DSB Task Force report and recent Congressional interest, the Environmental Security Technology Certification Program (ESTCP) designed a Wide Area Assessment pilot program that consists of demonstrations at multiple sites to validate the application of a number of recently developed and validated technologies as a comprehensive approach to WAA. These demonstrations of WAA technologies include deployment of high airborne sensors, helicopter-borne magnetometry arrays and ground surveys.

This report documents the demonstration of the Helicopter Multi-sensor Towed Array Detection System (MTADS) Magnetometry (HeliMag) technology for WAA of 4,567 acres at the former Victorville Precision Bombing Range (PBR). This demonstration was conducted as part of ESTCP project MM-0535.

HeliMag provides efficient low-altitude digital geophysical mapping (DGM) capabilities for metal detection and feature discrimination at a resolution approaching that of ground survey methods, limited primarily by terrain, vegetation, and structural inhibitions to safe low-altitude flight. The magnetometer data can be analyzed to extract either distributions of magnetic anomalies (which can be further used to locate and bound targets, aim points, and open burn/open detonation (OB/OD) sites), or individual anomaly parameters such as location, depth, and size estimate. The individual parameters can be used in conjunction with target remediation to validate the results of the magnetometer survey.

1.2. Objectives of the Demonstration

The purpose of this demonstration was to survey a subset of the WAA demonstration site in areas amenable to low-altitude helicopter surveys. Specific objectives of this demonstration included:

- Identify areas of concentrated munitions, including the known and suspected target areas;
- Bound the target areas;
- Estimate density and distribution of munitions types and sizes;
- Characterize site conditions to support future investigation, prioritization, remediation, and cost estimation tasks.

A determination of success for this demonstration was based on the performance of the system, as described in Section 4.

1.3. Regulatory Drivers

United States Army Corps of Engineers (USACE) is the lead federal agency under the Formerly Used Defense Site (FUDS) program. USACE administers the FUDS Military Munitions Response Program (MMRP) program using DoD investigation/cleanup methods based on the U.S. Environmental Protection Agency (USEPA) Comprehensive Environmental, Response, Compensation, and Liability Act (CERCLA) process.

1.4. Stakeholder/End-User Issues

ESTCP managed the stakeholder issues as part of the pilot program. ESTCP used a process to ensure that the information generated by the high-airborne, helicopter, airborne, ground validation surveys was useful to a broad stakeholder community (e.g., technical project managers and Federal, State, and local governments, as well as other stakeholders).

2. TECHNOLOGY DESCRIPTION

2.1. Technology Development and Application

The Naval Research Laboratory (NRL) developed the MTADS technology. Use of this technology was transferred to Sky Research for commercialization via a Cooperative Research and Development Agreement (CRADA). Prior to the transfer, this technology was fully evaluated for the DoD by ESTCP (Nelson et al. 2005; Tuley and Dieguez 2005).

The HeliMag system includes a helicopter-borne array of magnetometers and software designed specifically to process data collected with this system and perform physics-based analyses on identified targets (Table 1). These technologies are described in greater detail in the following subsections.

Table 1. Sky Research HeliMag Technology Components

Technology Component	Specifications
Geophysical Sensors	7 Geometrics 822 cesium vapor magnetometers, 0.001 nanotesla (nT) resolution
GPS Equipment	2 Trimble MS750 GPS receivers, 2-3 centimeter (cm) horizontal precision
Altimeters	1 Optech laser altimeter and 4 acoustic altimeters, 1 cm resolution
Inertial Measurement Unit	Crossbow AH400, 0.1 degree resolution
Data Acquisition Computer	NRL Data Acquisition Computer
Aircraft	Bell Long Ranger helicopter

2.1.1. Helicopter Platform

Sky Research used a Bell Helicopter Model 206 helicopter (Figure 1) for data collection at the former KPBR site. The helicopter platform was used to deploy the geophysical sensors, global positioning system (GPS) equipment, altimeters, inertial measurement unit (IMU), and data acquisition computer (DAQ) technologies listed in Table 1. Because the magnetic signal falls off quickly with distance, helicopters are typically flown at survey altitudes of 1-3 meters (m) above ground level (AGL).

Onboard navigation guidance displays (Figure 2) provide pilot guidance, with survey parameters established in a navigation computer that share the real-time kinematic GPS (RTK GPS) positioning data stream with the DAQ. The survey course is plotted for the pilot in real time on the display. The sensor operator monitors presentations showing the data quality for the altimeter and GPS and the GPS navigation fix quality; this allows the operator to respond to both visual cues on the ground and to the survey guidance display.

Following each survey, the operator has the ability to determine the need for surveys of any missed areas before leaving the site.

Figure 1. Helicopter MTADS technology as deployed on Bell Long Ranger helicopter.

2.1.2. Sensors and Boom

The MTADS magnetic sensors are Geometrics 822A Cesium (Cs) vapor full-field magnetometers (a variant of the Geometrics 822). The array of seven sensors is interfaced to NRL's DAQ and the sensors are evenly spaced at 1.5 m intervals on a 9 m Kevlar boom mounted on the helicopter. This NRL boom has been used in previous ESTCP demonstrations of the technology.

Figure 2. The track guidance system provides flight traverse information to the pilot.

2.1.3. Positioning Technologies

Two Trimble MS750 RTK GPS receivers are used to provide positions and platform attitude at 20 hertz (Hz), with four acoustic altimeters for recording the altitude of the platform. An IMU is used to correct for platform pitch. The DAQ is aligned with the GPS Universal Time Coordinated (UTC) time. The GPS time stamp is used as the basis for merging position data with sensor information.

RTK GPS is also used to generate positions for ground surveying. Sky Research utilizes an in-house professional land surveyor to ensure that geospatial data maintain accurate ties to the local coordinate system.

2.1.4. Data Acquisition System

Magnetometer, altimeter, and navigational instrumentation are streamed into a rack-mounted computer housed in the back seat of the helicopter. This computer runs a customized version of Geometrics MagLogNT data collection software. The equipment rack also contains the GPS receivers and Geometrics G-822AS super counters, which control the sampling rates for the seven individual sensors. The magnetometer data are typically logged at 100 Hz, which provides a nominal down-the-track sample interval of 0.15 m at a typical survey speed of 15 m/second (m/s).

2.1.5. Data Processing

Data are downloaded via computer disks and uploaded via the Internet after each survey mission. Data processing is performed using custom application software running under the Oasis Montaj (Geosoft Ltd., Toronto, Canada) geophysical data processing environment. An overview of this process is outlined in the flow diagram provided in Figure 3. The processing conducted as part of this demonstration is described in greater detail in Section 3.6.5.

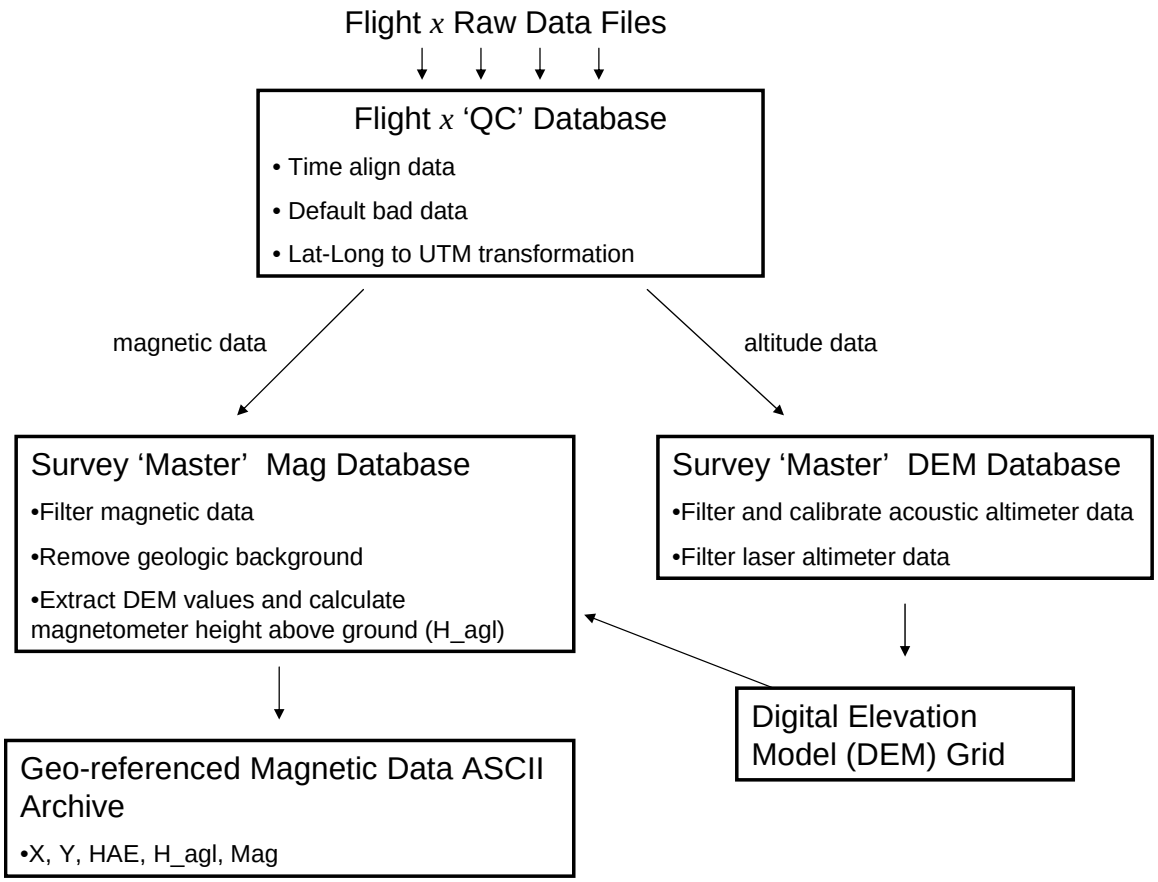

Figure 3. Helicopter MTADS processing flow chart.

2.1.6. Data Analysis

Once magnetic anomaly maps are created, anomalies are selected using an automated target selection methodology in Oasis Montaj. Automatic target selection for large-scale surveys such as this one has the advantage of being objective and repeatable as well as much faster than manual selection. However, automatic target pickers are not yet sophisticated enough to reliably detect closely spaced targets or targets that are at or below the same amplitude as local geologic signal and do not perform well in areas of high target density. To avoid selecting an excessive number of false targets, automatic target selection routines are only used to select targets with response amplitudes significantly above the background geologic noise.

The limitations of automatic target selection are not as detrimental for WAA purposes as they would be for individual target selection. The challenge is to calibrate the automatic target selection routine so that the number of valid targets of interest selected is maximized, while minimizing the number of targets selected due to geologic noise (or other noise sources). To achieve this, manual target selection results were compared with

those obtained using an automated target selection routine over a representative subset of each demonstration site. The results of the comparisons were used to fine-tune the parameters for automatic target selection.

2.2. Previous Testing of the Technology

Previous testing of the helicopter magnetometry technology in general was supported by ESTCP (Nelson et al. 2005). The primary development objective was to provide a site characterization capability for extended areas, while retaining substantial detection sensitivity for individual MEC. The system included data-collection hardware in the form of a helicopter-borne array of magnetometers, and software designed to process data collected with this system and to perform physics-based analyses on identified targets.

2.3. Factors Affecting Cost and Performance

For any airborne survey, the largest single factor affecting the survey cost is the operation of the survey aircraft and sensors at the site. These equipment costs are related to capital value, maintenance overhead, and direct operating costs. In addition, mobilization and demobilization costs can be substantial. These costs increase with distance; some cost savings can be achieved if flexibility of scheduling is possible to share costs across several projects running consecutively.

The primary factors affecting performance are limitations imposed by topography, vegetation, geology, and weather. Helicopter surveys should not be used in areas where topography and/or vegetation limit the ability to safely conduct low altitude flights. The efficacy of the system can be diminished in areas where the magnetic geologic signal is sufficient to mask signals from our targets of interest. Last, weather can delay helicopter surveys, decreasing the daily production rate average and increasing the survey costs through standby day charges.

2.4. Advantages and Limitations of the Technology

As with all characterization technologies, site-specific advantages and disadvantages exist that strongly influence the level of success of their application.

Advantages of HeliMag technologies include:

- the ability to characterize very large areas; and
- lower per survey acre cost than ground-based DGM methods.

Limitations of HeliMag technologies include:

- as a WAA tool, not intended to detect individual MEC; and
- constraints on use due to site physiography, such as terrain, soils, vegetation and geology.

3. DEMONSTRATION DESIGN

3.1. Performance Objectives

Performance objectives are a critical component of the demonstration plan because they provide the basis for evaluating the performance and costs of the technology. For the WAA projects, both primary and secondary performance objectives were established. Table 2 lists performance objectives, criteria and metrics used for evaluation.

3.2. Test Site Selection

In response to the DSB Task Force report and recent Congressional interest, ESTCP created the WAA pilot program to validate the application of a number of recently developed technologies as a comprehensive approach to WAA. The selection of the Victorville PBR demonstration site as one of several demonstration sites was based on criteria selected by the ESTCP Program Office in coordination with the WAA advisory group of state and federal regulators.

3.3. Test Site History/Characteristics

The former Victorville PBR is a 5,540 acre FUDS (Figure 4) used as a WWII-era military training facility, located approximately 100 miles northeast of the city of Los Angeles in San Bernardino County, California. The designated study site for this demonstration (Areas A, B and C) encompasses the 5,540 acre site. The WAA study area was known to contain one precision bombing range target (PBR 15), as well as one demolition bombing target "Y" (DBT Y) area (Figure 5).

The physiography and known munitions use history of the study area are discussed in some detail in the Conceptual Site Model (CSM) V0 (Versar, 2005). Physiographic and historic military use characteristics most relevant to the technology demonstration were topography, soils and vegetation, climate and hydrology, land use and former military use; each of these topics is briefly discussed below.

Topography. The site is centered on Means Lake, a dry lake bed located between small mountain masses in the eastern Mojave Desert. The elevation of the lake bed is 2,572 feet, with the surrounding mountain reaching heights in excess of 3,000 feet. The topographic complexity of the site posed constraints to accessibility for helicopter operations.

Soils and Vegetation. The soils are typical of arid regions and include shallow alluvial sediments usually less than 1,000 feet to bedrock. The soil surface increases in stoniness upslope. In places, gravely desert pavement occurs. The area is sparsely vegetated with desert brush and grasses; however, the heights of shrubs posed constraints to HeliMag

operations, requiring flight altitudes that were higher than those normally flown for HeliMag.

Climate and Hydrology. Rainfall is sparse in all months, with precipitation occurring mainly in the winter (late October to early April). The total annual precipitation is about five inches. Very small amounts of snow are recorded during the winter months. The average seasonal snow fall is about two inches. High winds are common in the area, which complicated the collection of HeliMag data.

Land Use. The majority of the site is controlled and managed by the Bureau of Land Management (BLM), with a small percentage of the site in the southern buffer zone area in private ownership with multiple owners. The site is used for recreation, including off-road vehicle recreation, camping, and target practice by the public and similar recreational use by the private owners on the privately owned areas. Data collection methods were altered to accommodate recreational use in the dry lake bed during helicopter operations.

Munitions. The Victorville PBR was used by the DoD as a Demolition Bombing Range for training pilots and bombardiers. Target Area A is approximately 2,240 acres and was used as the main demolition bombing range. Area B is approximately 2,560 acres and consists of the buffer area surrounding the original target areas. The South Buffer Zone, comprising approximately 320 acres, is adjacent to the main target area and forms part of the southern boundary. The potential ordnance items that could exist at surface or subsurface levels at the Victorville PBR include high explosive (HE) bombs, 100- pound (lb) demolition bombs (AN-M30 series), 100-lb practice bombs (M38A2), and 500-lb bombs, according to the Archive Search Report (ASR) for the installation. No chemical, toxic or radiological hazards were identified on site. The site includes two known target areas.

Table 2. Performance Objectives

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)
Primary/Qualitative	Ease of use and efficiency of operations for each sensor system	Efficiency and ease of use meets design specifications
Primary/Quantitative	Geo-reference position accuracy	Within 0.25 m
Secondary/Quantitative	Survey coverage	>0.95 of planned survey area
Secondary/Quantitative	Operating parameters (altitude, speed, overlap, production level)	1-3 m AGL; 15-20 m/s (30-40 knots); 10%; 300 acres/day
Primary/Quantitative	Noise level (combined sensor/platform sources, post-filtering)	<1 nT
Secondary/Quantitative	Data density/point spacing	0.5 m along-track 1.5 m cross track
Secondary/Quantitative	UXO parameter estimates	Size <0.02 m; Solid Angle < 10º

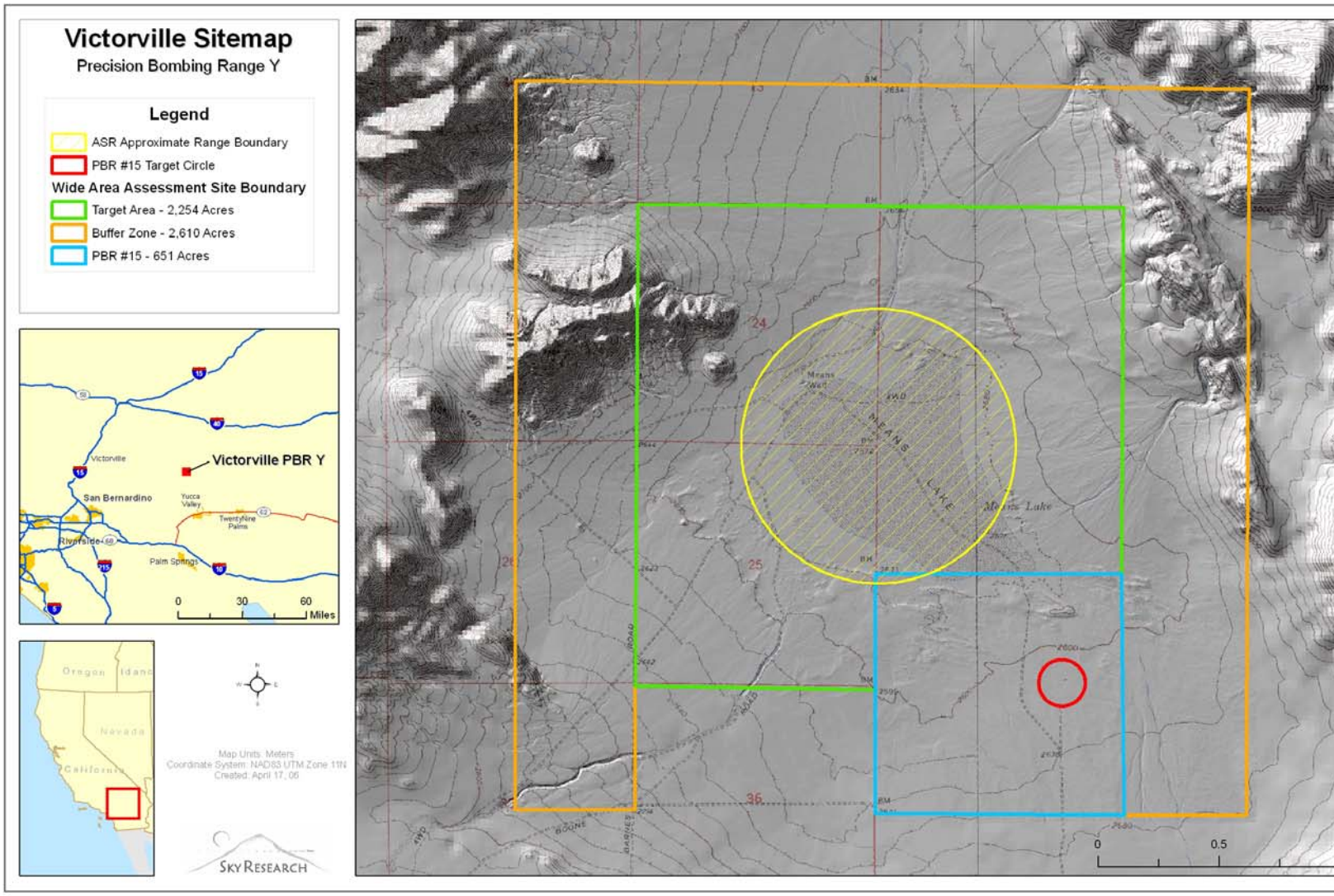

Figure 4. Victorville PBR demonstration area and historical information.

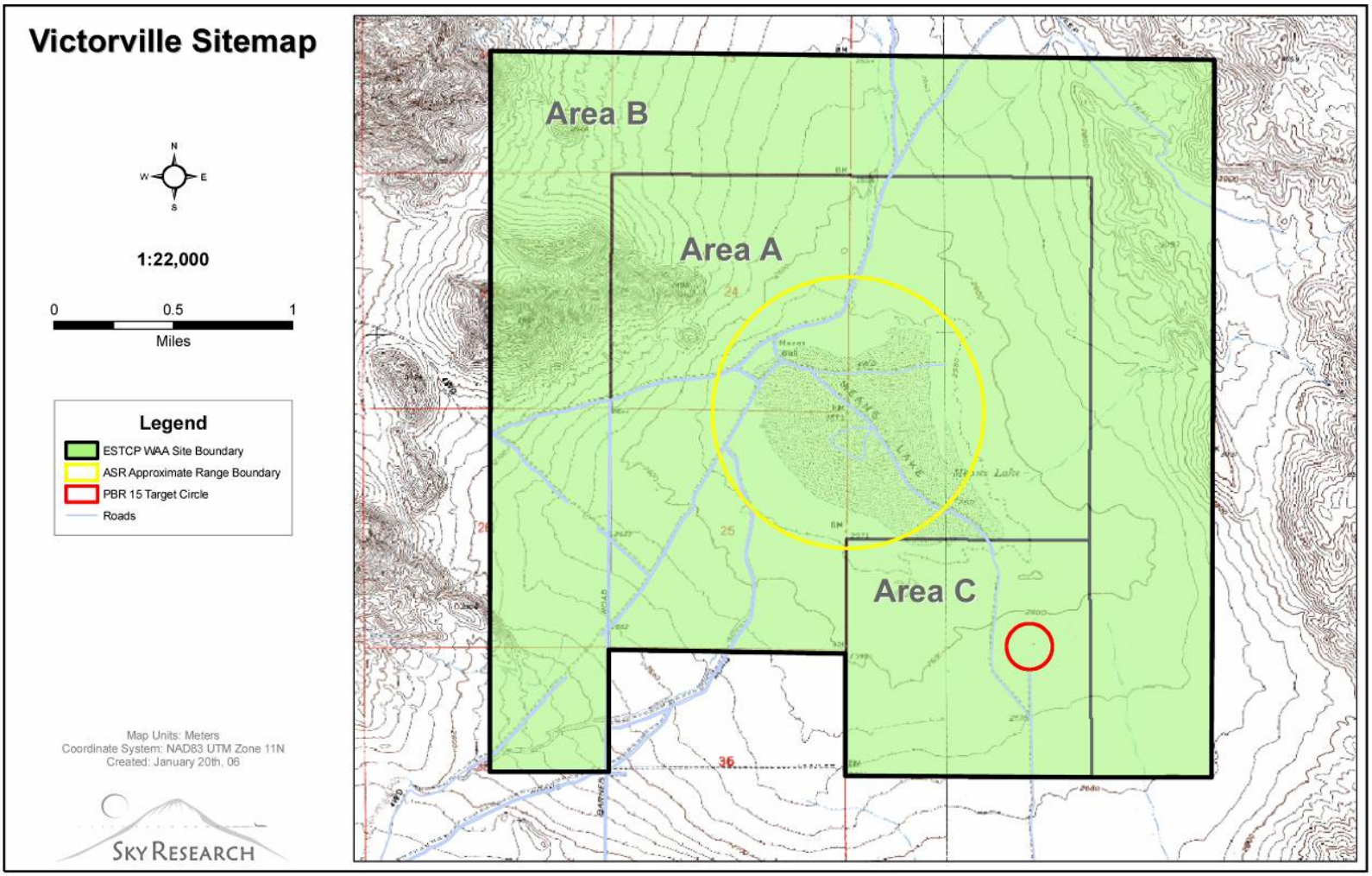

Figure 5. **Demonstration study site at Victorville PBR.**

3.4. Present Operations

There are no active military operations at Victorville PBR. Site characterization activities are currently underway and are being conducted under the FUDS program.

3.5. Pre-Demonstration Testing and Analysis

As discussed previously, the helicopter technology utilized for this demonstration is based on the NRL MTADS technology, transferred to Sky Research for commercialization via a CRADA. Prior to the transfer, this technology was fully evaluated by ESTCP (Nelson et al. 2005; Tuley and Dieguez 2005).

3.6. Testing and Evaluation Plan

3.6.1. Demonstration Set-Up and Start-Up

Mobilization for this project required:

1) Mobilization of the equipment, pilot, and sensor operators.
2) Deployment of ground-support personnel to establish ground fiducials, establish and operate GPS base stations, establish calibration line location and collect data on calibration location, and provide logistical support.
3) Establishment of calibration line and standard pre-collection maintenance and calibration procedures established during previous deployments.

A base of field operations was established at the Apple Valley Airport, providing fuel and temporary hanger/storage space during operations at the site.

Ground Control

RTK GPS provided centimeter-accuracy real time positioning and was used with the HeliMag system. It was also used to generate positions for ground fiducials and for positioning ground calibration data and field verifications. The Sky Research in-house professional land surveyor assured that geospatial data generated by the project maintain accurate ties to the local coordinate system and to oversee the accurate field emplacement of fiducials for data registration, and surrogate targets for sensor calibration and verification of classification and analysis algorithms.

Sensor Calibration Targets

A 350 m calibration lane, oriented north-south, was seeded with 8 targets comprising four unique types of items (Table 3). Calibration flights were flown at the start and end of each day of data collection, resulting in 34 datasets collected over 17 days over the calibration lane. No targets were buried and no attempt was made to measure a probability of detection.

Table 3 Calibration Items Seeded in the Calibration Lane

ID	X	Y	Azimuth	Description
1	534980.01	3809569.75	28	2.75 inch rocket
2	535030.18	3809569.81	17	Simulated 100-lb bomb
3	535079.53	3809569.47	9	155 mm projectile
4	535129.96	3809569.70	17	Metal cache box
5	535179.81	3809569.58	23	2.75 inch rocket
6	535229.91	3809569.66	13	Simulated 100-lb bomb
7	535279.69	3809569.48	16	155 mm projectile
8	535330.09	3809569.41	22	Metal cache box

3.6.2. Period of Operation

The Victorville PBR site encompasses approximately 5,400 acres; the HeliMag data collection area was reduced to 4,567 acres due to the presence of mountain slopes and other topographic features that impeded HeliMag data collection. Approximately 900 acres had to be re-flown due to data coverage gaps discovered during initial processing activities at the end of each survey day. Flight lines were spaced approximately 7 m apart.

The airborne survey crew consisted of one pilot and one system operator. Data collection required 17 days from March 25 to April 24, 2006. There were a number of challenges and delays associated with the data collection due to technical issues with the equipment and because of site characteristics such as wind, topography, vegetation, and use of the site by off-road vehicle (ORV) users. Table 4 briefly summarizes these issues. Figure 6 illustrates some of the site conditions encountered at Victorville PBR.

In addition to deploying the airborne MTADS platform at approximately 3 m AGL over the entire site, the system was also flown at 5 m and 10 m AGL over approximately 825 acres for each higher altitude (Figure 7). These flights covered the high target density bombing target with the flight lines extending out to lower target density areas. The line spacing was increased to 12 m for the 10 m AGL flights. The purpose for these higher altitude flights was to assess whether the same information can be collected at a higher flight AGL; if so, data could then be collected more quickly and safely. Table 5 summarizes the number of acres collected, including the 900 acres of recollected data and the 825 acres of higher altitude data collected.

Table 4. Data Collection Issues

Issue	Description	Summary of Impact
Equipment	Helicopter/boom: Faulty fuel gauge, boom vibration, possible faulty compressor. Computer hardware/software: sensor noise, DAQ computer booting issues, keyboard failure, GPS radio line issues.	Resulted in more time being required to accomplish surveys.
Topography	Boom strikes, hard to maintain survey speed in downhill areas.	More than 800 acres of the site could not be surveyed; some flight lines were shortened due to steep slopes.
Wind/Rain	Strong winds, blowing sand and rain presented dangerous flight conditions; difficult to maintain flight lines, flight speed and orientation.	Resulted in survey days being shortened or cancelled due to unsafe helicopter operating conditions.
Vegetation	Tall shrubs/bushes impeded the data collection activities at the normal flight height AGL.	Resulted in higher than normal flights AGL in some areas.
ORV Use	The presence of campers and ORV users impeded the collection of low airborne data; vehicles/campers parked on flight lines; spectators; and motorcycles racing with helicopter.	Resulted in more lines having to be flown and an increase in overall survey time.

Table 5 HeliMag Data Collection at Victorville PBR

Data Collection Day	Acres Surveyed
March 25, 2006	50
March 26, 2006	134
April 1, 2006	510
April 2, 2006	430
April 3, 2006	780
April 4, 2006	250
April 5, 2006	112
April 9, 2006	403
April 10, 2006	620
April 11, 2006	617
April 12, 2006	223
April 13, 2006	298

Data Collection Day	Acres Surveyed
April 14, 2006	293
April 20, 2006	108
April 21, 2006	659
April 22, 2006	536
April 24, 2006	107
Acres Collected	**6,130 (~ 900 acres recollected)**
Average Daily Productivity	**307 acres/day**

Figure 6. Victorville PBR site condition impacts to data collection included topography; tall vegetation; wind and dust; and ORV use.

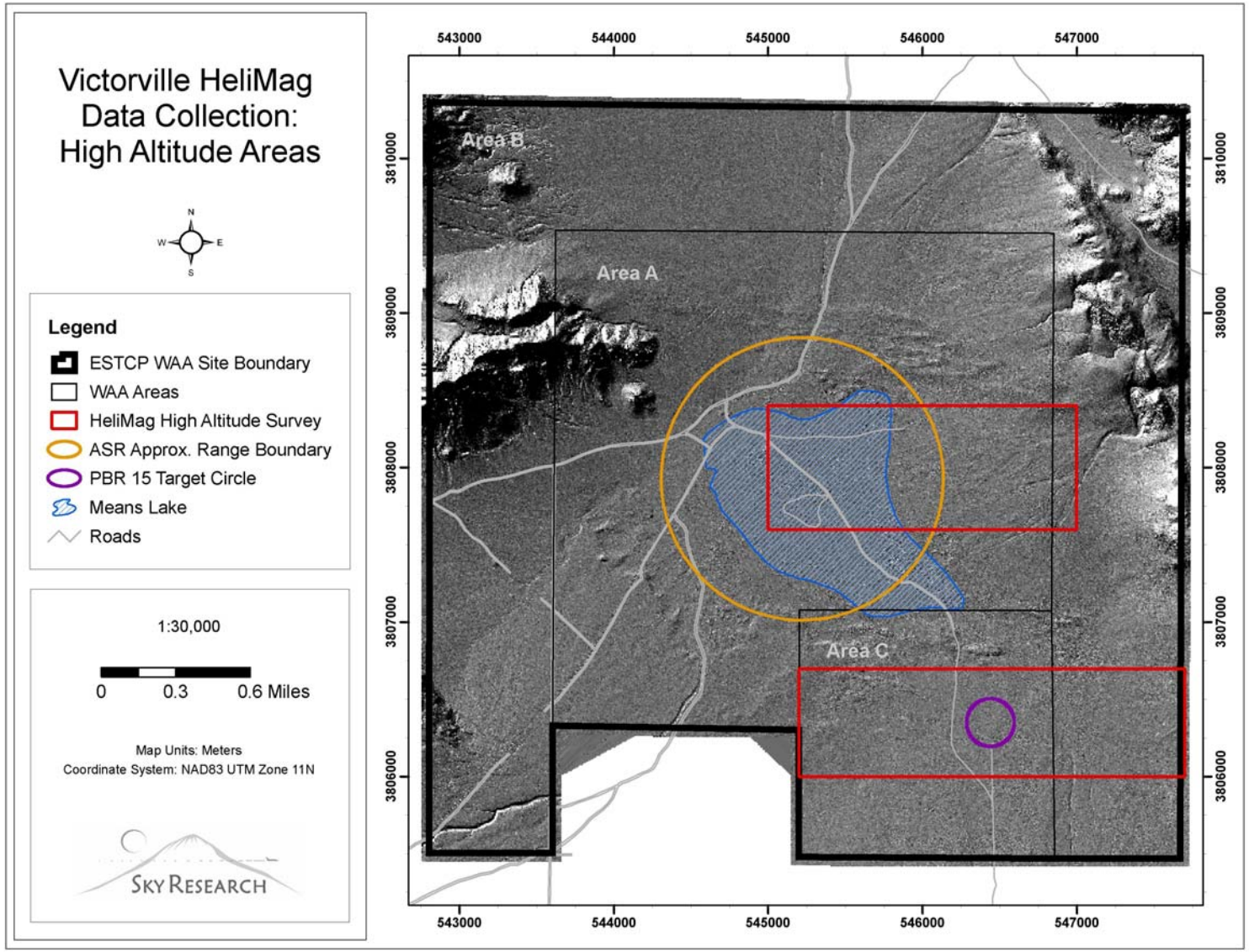

Figure 7. Map of areas selected for higher altitude surveys (5 m and 10 m AGL) conducted at Victorville PBR.

3.6.3. Area Characterized

HeliMag surveys were conducted within the ESTCP WAA demonstration site boundaries in areas amenable to low altitude flight. A total of 4,567 acres of the demonstration site were characterized.

3.6.4. Operating Parameters for the Technology

Sky Research deployed the airborne MTADS system on a Bell 206 Long Ranger helicopter platform, together with a pilot and system operator. A ground support team operated the RTK GPS base stations. The helicopter was flown at a low altitude (1-3 m), with a forward velocity of 10 - 20 m/s.

As described previously, seven full-field Cs vapor magnetometers were deployed on the 9 m boom mounted transversely on the front of the helicopter skids. The DAQ logged data at 100 Hz. With the sensor spacing of 1.5 m and a speed over ground of 15 m/s, the resulting data density provides a minimum of 50 data points on a typical target to fit the dipole signature. The aircraft flew traverse lines over the area evenly spaced at 7 m. This spacing provides considerable overlap (28%) but is necessary to ensure complete coverage because of the degree of difficulty involved in flying perfectly straight lines under real world conditions.

3.6.5. Data Processing

Data processing for this demonstration was performed by AETC. During the first data processing stage, the raw data for a given survey flight were time-aligned and transcribed from the various raw data files into a ‘flight’ database. Routines were run to automatically reject or ‘default’ invalid data. Data were rejected based upon status flags present in the raw data records or, in the case of the magnetometer data, a simple ‘in range’ test was used. The GPS geographic position coordinates were transformed to WGS84 Universal Transverse Mercator (UTM) coordinates. At this point the data were visually inspected to ensure both integrity and quality. This pre-processing stage is instrumentation-specific and the steps required to transcribe these data into a time-aligned database were dictated by the structure of the data outputs from each device and the manner in which they were logged. All data outputs were received by the on-board DAQ. A DAQ time stamp was appended to each sample data string and the sample was then stored in a separate data file for each device. Table 6 provides a list of the raw data input files generated during the demonstration.

Table 6. Helicopter MTADS Raw Data Input Files

Device	Sample Rate (Hz)	Data Type	Filename extension	Remarks
Geometrics custom DAQ computer system trigger	100	TTL pulse	TriggerDevice.trig	Generated and logged by the DAQ – initiates the magnetometer sampling
Geometrics Model 822A Cs Magnetometers	100	RS232-ASCII	822A.Mag_a / 822A_Mag_b	7 magnetometers are controlled by 2 consoles – Mag_A sensors 1-4, Mag_B sensors 5-7
Trimble Model MS750 GPS position/attitude data	20/10	RS232-ASCII	GPS.nmea	Position data are in Trimble GGK message format, azimuth and roll are in Trimble AVR message format
Trimble Model MS750 GPS PPS (pulse per second)	1	TTL pulse	PpsDevice.pps	Used to accurately align integer GPS time with DAQ time
Trimble Model MS750 GPS time tag	1	RS232-ASCII	SerialDevice.utc	Used to resolve the integer ambiguity of the GPS PPS signal
Optech Model 60 Laser Altimeter	10	RS232-ASCII	SerialDevice.laser	Measures helicopter height AGL
Crossbow Tilt meter	10	RS232-Binary	SerialBinDevice.tilt	Used primarily for aircraft pitch measurement
Fluxgate magnetometer	10	RS232-ASCII	SerialDevice.fluxgate	Provides redundant aircraft attitude measurement
Acoustic altimeters	10	Analog voltage	AnalogDevice.analog	Measures sensor array height above ground level at two points
Trimble Model MS750 GPS position/attitude data	20/10	RS232-ASCII	GPS.nmea	Position data are in Trimble GGK message format, azimuth and roll are in Trimble AVR message format
Trimble Model MS750 GPS PPS (pulse per second)	1	TTL pulse	PpsDevice.pps	Used to accurately align integer GPS time with DAQ time

An important consideration for integration of the positioning system with geophysical sensors is that of time alignment. For dynamic applications, the time of applicability (TOA) of the geophysical sensor data must be aligned with the TOA of the measured positioning data to within one millisecond. Any measurement will have some latency before the data are collected and stored, which may be static or variable in nature. In addition to this latency, conventional time stamping of RS232 data is not precise and can inject hundreds of milliseconds of additional delays. Thus, simply time stamping the positioning data as it is transmitted to the DAQ does not ensure that the TOA of the positions can be precisely aligned with that of the geophysical data. When the Geometrics magnetometer consoles are triggered externally, the time lag between this external trigger and the TOA of the magnetometer samples is constant. Thus, using a trigger pulse generated by the DAQ allows determination of the TOA of the magnetometer data relative to the DAQ system time.

GPS systems commonly have an internal latency that is variable (i.e., the time between the applicability of a given measurement and the transmission of the derived position will vary) in addition to the serial port variability. To allow users to know precisely when a measurement applies, the data message is time stamped (i.e., the position solution is given in 4 dimensions; time, x, y, and z) to a very high degree of precision. In addition, GPS receivers also output a pulse per second (PPS) trigger at every precise integer second to provide a means to synchronize the DAQ time with GPS time. The integer ambiguity of the PPS trigger is resolved by sending the data acquisition system a message (via RS232) that is simply used to assign the precise GPS integer time to the incoming PPS trigger. In this manner, GPS time may be precisely aligned with the DAQ system time.

The steps used to transcribe and time-align the raw data into a single flight database were as follows:

1) For each DAQ trigger event, the corresponding magnetometer data were read from the Mag_A and Mag_B files and stored as a database record. This record has seven magnetometer channels and a DAQ time channel.
2) The Coordinated Universal Time (UTC) time stamp was used to assign integer times to the GPS PPS data and these data were interpolated into a GPS time channel. This interpolation is based upon alignment of the DAQ time stamp assigned to each PPS with the existing DAQ time channel. This results in each sample of seven magnetometer readings having a corresponding DAQ time and GPS time record.
3) The GPS time channel and GPS time field in the raw data files were used to interpolate the GPS position and attitude data for each magnetometer sample. This results in the creation of the following channels in the database: Latitude, Longitude, Height above ellipsoid, GPS status, Advanced Virtual RISC (Reduced Instruction Set Computer) (AVR) yaw (angle of the sensor boom relative to true north), AVR roll (angle of the sensor boom relative to the horizontal plane), and AVR status. The geographic positions represent the positions of the master GPS

antenna relative to the WGS84 ellipsoid. The GPS status and AVR status provide a quality of fit indication for the position and attitude data respectively.

4) The DAQ time channel and the DAQ time field in the raw data files were used to interpolate the ancillary data for each magnetometer record. The ancillary data channels include the following: laser, four acoustic altimeter channels (two for each acoustic altimeter station to provide redundancy), tilt meter pitch and roll, and fluxgate x, y, and z components.

After the data were transcribed, invalid data were defaulted to 'dummy' values. The magnetometer data were defaulted outside of a reasonable range and the GPS data were defaulted based upon the values of the two status flags. A four-point average filter was applied to the magnetometer data to remove the 25 Hz noise assumed to be vortex shedding. This noise is relatively small in amplitude (less than 0.5 nT) and, as a result, this filter has very little effect on the data.

Data processing with the use of Geosoft Oasis Montaj MTADS Processing Toolbox greatly speeds up the merging and data interpolating process due to the large database functionality and optimized merging algorithms. Typical production processing for 300-500 acres takes approximately eight hours of data processing to produce a raw data plot image.

During each day of the demonstration, the project data processor conducted an initial review of the geophysical data to ensure that the data were within a reasonable range, free from dropouts/spikes and timing errors, and otherwise apparently valid. Oasis Montaj software performs the review and provides the mean, maximum, minimum, and standard deviation for each data file. The summary was reviewed and the data visually inspected. If any problems existed, the project geophysicist assessed the problem(s) and made adjustments to the field operations as needed to ensure quality data collection. Additional processing steps after the raw data processing step include filtering, geologic trend removal, and smoothing if needed.

3.6.6. Data Analysis

At Victorville PBR, the background geologic signal was a complicating factor that affected the utility of automated target selection routines. After consideration of a number of candidate target selection/density estimate techniques it was determined that manual target selection by an experienced analyst provided the most realistic and defensible density distribution estimates. Manual target selection was performed by AETC. As described above, manual picking is a subjective process. Any recognizable dipole-like anomaly was picked by the analyst and was assumed to have a metallic source. The background noise level was dominated by geology and varied throughout the survey area. Thus the "effective" target picking threshold also varied across the site. In areas with little geologic signal, anomalies as small as several nT in amplitude were regularly picked by the analyst. In the more geologically challenging areas the probability of detecting an anomaly of given amplitude was strongly dependant on its position in relation to the

background geology. If a several nT anomaly was in a "favorable" position (e.g., in a low amplitude, long-wavelength trough) there was a strong chance it would be picked by the interpreter. On the other hand, it is likely that larger amplitude anomalies in "unfavorable" locations (e.g., spanning a linear trending geological feature) went undetected by the analyst. A detailed analysis of the candidate target picking methodologies and the results obtained with each methodology is presented in section 4.2.

3.6.7. Demobilization

At the conclusion of the surveys, the helicopter, associated equipment, and field crews were demobilized from the site. Targets were investigated at a later date by a different contractor on behalf of ESTCP as part of the WAA validation surveys.

4. PERFORMANCE ASSESSMENT

4.1. Data Calibration Results

The data collected over each target from the calibration line passes that are assumed to be valid (i.e., target positions are stable and data positioning quality is good) were analyzed with the MTADS dipole fit algorithm (using the UX Analyze environment). This analysis derives the parameters for a model dipole that best fits the observed data. These parameters include horizontal position, depth, size, and solid angle (i.e., the angle between the Earth's magnetic field vector and that of the dipole model). The derived parameters were examined for accuracy (determined as the average error where relevant) and repeatability (indicated by the standard deviation), as presented in Table 7.

Table 7. Calibration Results for Calibration Lane Targets

Dipole Fit Parameter	Bias	Standard Deviation
Easting	0.05 m	0.17 m
Northing	0.09 m	0.17 m
Depth	0.19 m	0.29
Size	n/a	0.017 m
Solid Angle	n/a	4.4°

Figure 8 shows the derived positions for each target relative to the ground truth supplied. The accuracy of these positions relative to the ground truth is well within the range expected for the MTADS system. The greater variability in the position of Item 304 (a simulated 100 lb bomb) was due to the item moving North-West during the course of the deployment.

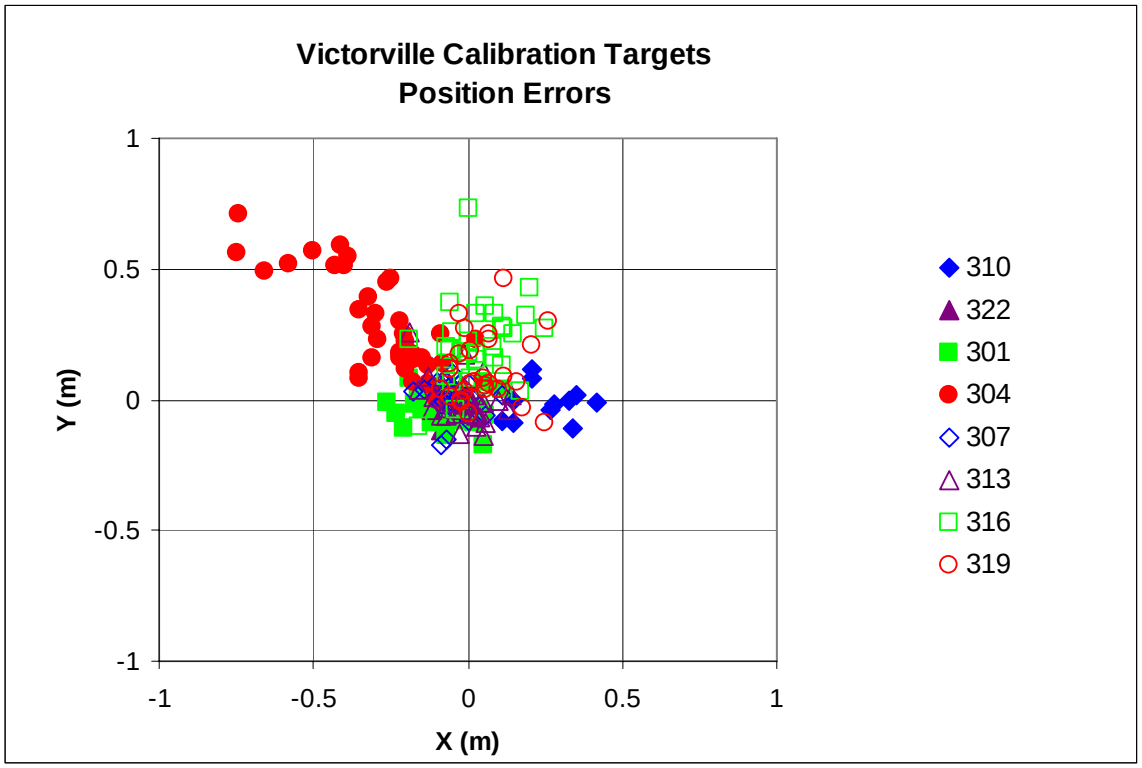

Figure 8. Derived x and y coordinates for the calibration targets relative to the supplied ground truth.

The dipole fit size estimate for any given munition will vary considerably depending upon the alignment of the object with the Earth's magnetic field. Therefore, the size can only be used as a coarse estimate of the object size. For this reason, the accuracy of the size estimate of the calibration items is not of particular import when discussing the system performance, other than simply verifying that the estimate falls within the expected range for a given target (which they do, as shown in Figure 9). Because the calibration data consists of repeated flights over the same stationary targets, the repeatability of the derived size estimates can be used as an indication of consistent system performance (Figure 10). The average size for each specific target was removed from the target size estimates before the standard deviation for the entire set of size estimates was calculated.

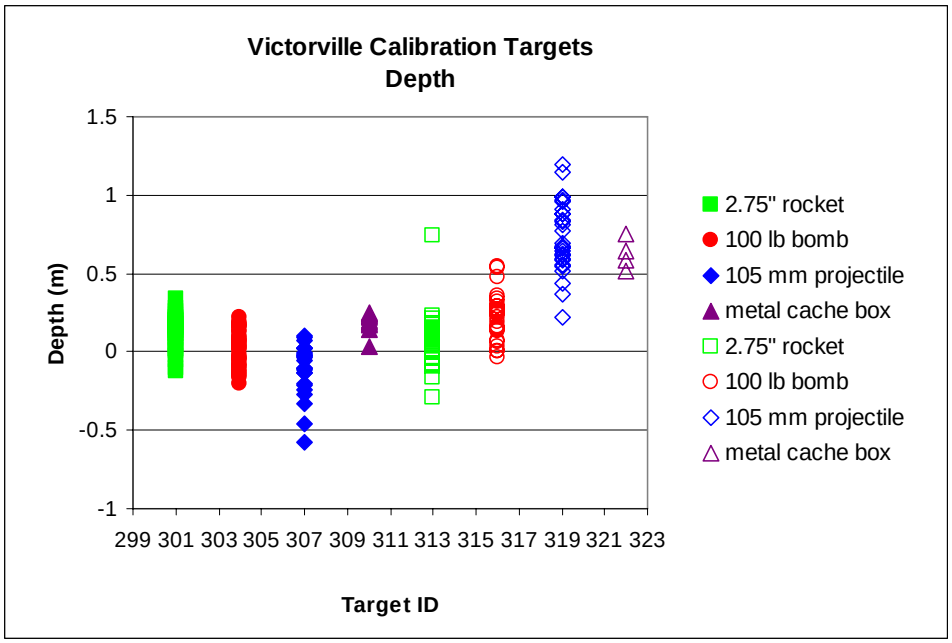

Figure 9. Dipole depth estimates for calibration line targets.

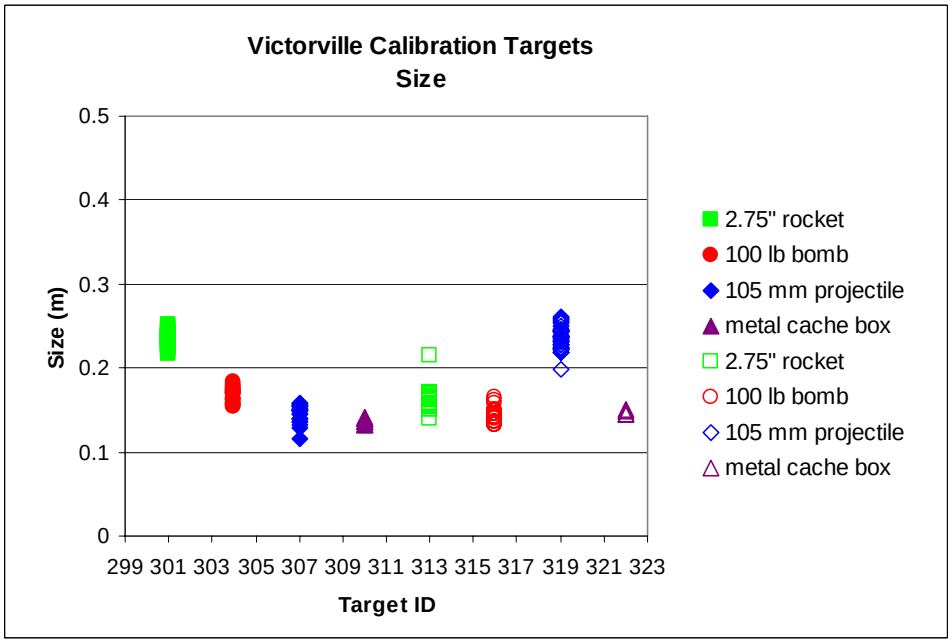

Figure 10. Dipole fit size estimates for calibration line targets.

In a manner similar to the size estimates discussed above, the dipole fit solid angle estimates depend heavily on the orientation of the target relative to the Earth's magnetic field. In the case of the calibration line test targets, the 'ground truth' is unknown and not really important. However the stability of this prediction for repeated flights over the calibration line is indicative of the performance of the airborne system (Figure 11).

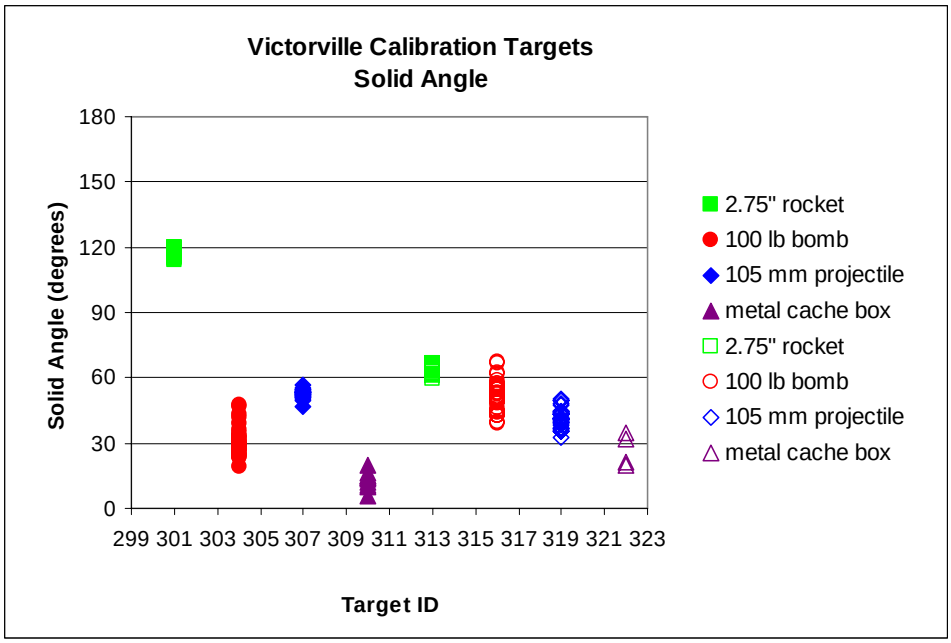

Figure 11. Dipole fit solid angle estimate for calibration line targets.

In addition to determining the repeatability of analyses performed on the calibration targets, the data collected over the targets can also be used to confirm the utility of the automatic target picking routine that is employed on the data sets to derive target density maps. The automatic target picker performs peak detection on a Geosoft style grid of the magnetic analytic signal that is in turn derived from a grid of the total magnetic field data. Prior to producing the analytic signal grid, the total magnetic field data were upward continued by 0.75 m to simulate burial of the targets by the same amount. The peak detection algorithm first applies a 3 x 3 Hanning filter to the analytic signal grid to remove very high spatial frequency features (local noise) so that multiple peaks are not detected in the vicinity of a true peak. The number of applications of this filter is optional. A second parameter used is the minimum threshold for peak detection. Testing of this peak detection routine (described in section 4.2) has shown that the optimal number of filter passes is two and the nominal threshold value should be around 5 nT/m. Figure 14 shows the peak amplitudes for multiple passes over the calibration targets.

4.2. Anomaly Selection / Density Distribution Results

As alluded to above, portions of the site were characterized by magnetically active geology. In Figure 12 we can clearly see the effect of the geology on the measured total magnetic field. In addition to manual target selection, three separate techniques were used to automatically derive ferrous metal density distribution images to assist in identifying and delineating areas of likely UXO contamination.

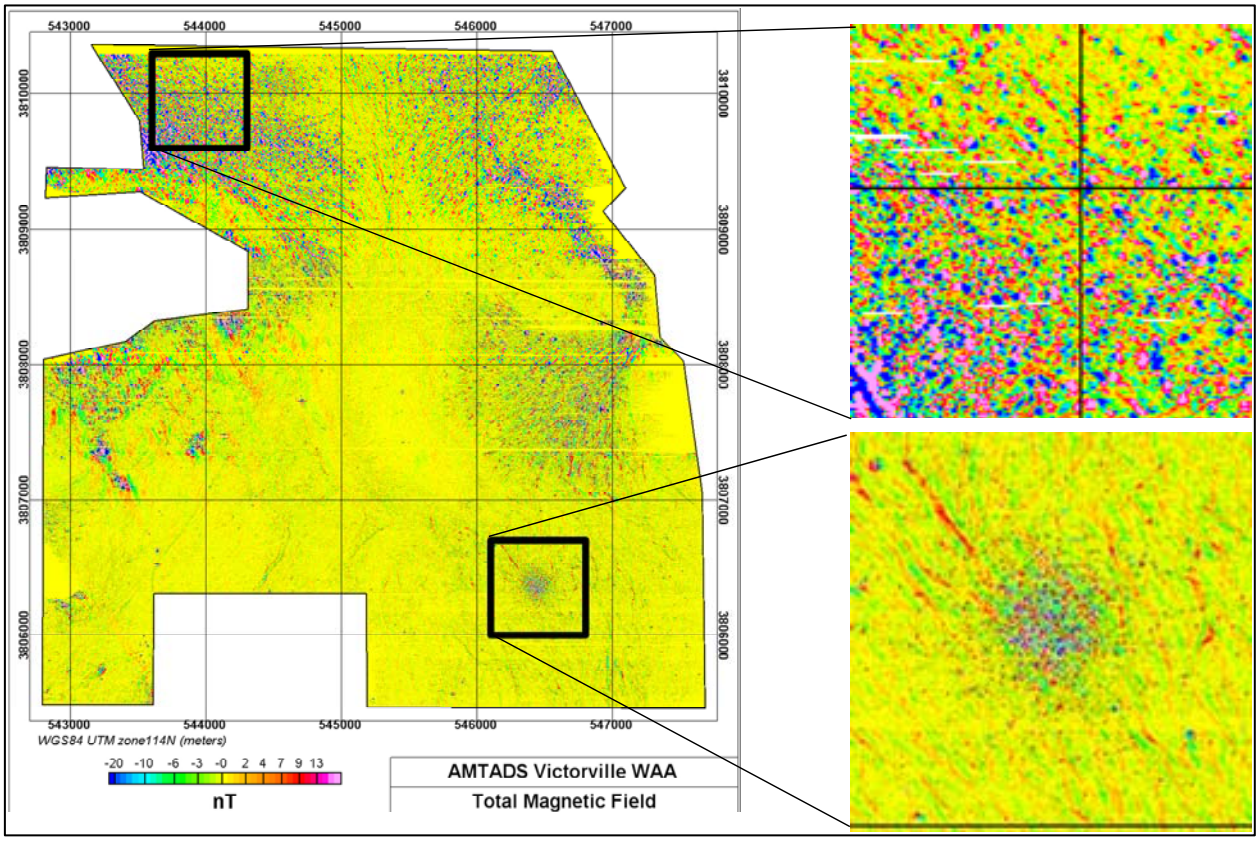

Figure 12. HeliMag total magnetic field data collected at the Victorville Precision Bombing Range. Insets show regions of high geologic response (top) and high density of ferrous objects typical of a high use bull's eye like target.

The Geosoft™ peak detection routine and an experimental wavelet-based dipole detection routine are two of the methods used to derive the density distribution of ferrous material. Both of these methods automatically generate a list of anomalies that are then used to generate the density estimates in the form of a density raster (the manual target selection method also derives a target list). The density raster is computed to visualize the distribution of metal objects across the study area using a 76.2 m (250 ft) radius neighborhood kernel that assigned anomaly densities in anomalies per hectare to each cell in the raster. Simply described, at grid nodes of every two meters the number of targets that appear within a 76.2 m search radius were counted. This search radius provides the density in targets per 18,241 m^2. These values were then 'normalized' by diving by 1.8241 to provide density estimates in targets/hectare. The resulting data were gridded to provide anomaly density images. The remaining method attempts to estimate the anomaly density as a function of the standard deviation of the observed magnetic field.

In the absence of independent ground truth, we cannot quantitatively determine the best method. However, we can qualitatively assess the relative performance of each of these approaches by noting the degree to which we are able to de-correlate regions of elevated target density from regions of elevated geologic response. Using this measure, it was determined that the manual target selection provided the results that best mitigated the

effect of geologic magnetic signals. The assertion that de-correlation with geologic response is a valid indicator of performance is strengthened if we can show that this method will detect high anomaly density targets within geologically active areas. In Figure 13 we show the density images derived using the various methods.

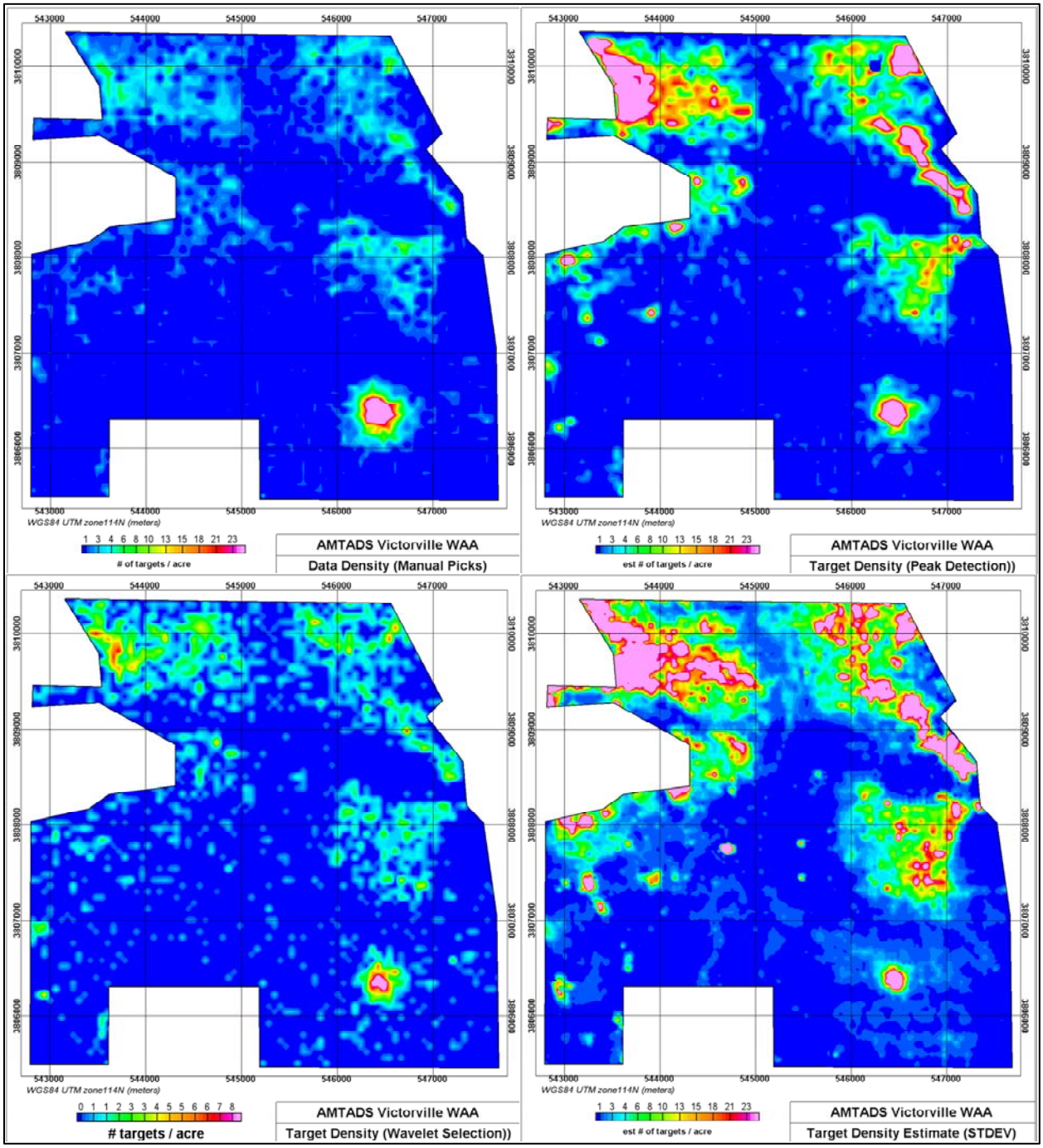

Figure 13. Density distribution images using four different target density derivation approaches. The manual target selection method (top left) provides superior mitigation of localized geologic response. This assertion is based upon the fact that the target density for the manual method shows the lowest correlation with the geologic response.

In an effort to assess our ability to detect regions of high metal densities in areas with challenging geology, a test was performed whereby we simulate a high anomaly density bombing target in a region of active geology. We perform this simulation by adding the gridded magnetic response of PBR Target 15 to a grid of a section of the geologically active region. The respective regions used for this analysis are shown as insets in Figure 12. In Figure 14 we show the original gridded responses for each of these areas, and the sum of these responses that we assume are indicative of a bombing target in a geologically active environment. Manual target selection was performed over the resultant grid. We replaced the original selections in this region with the new selections and these results were used to derive the test density raster shown in Figure 15. The results of this test indicate that high density, bull's eye features are detectable in the presence of the elevated geologic regions at Victorville.

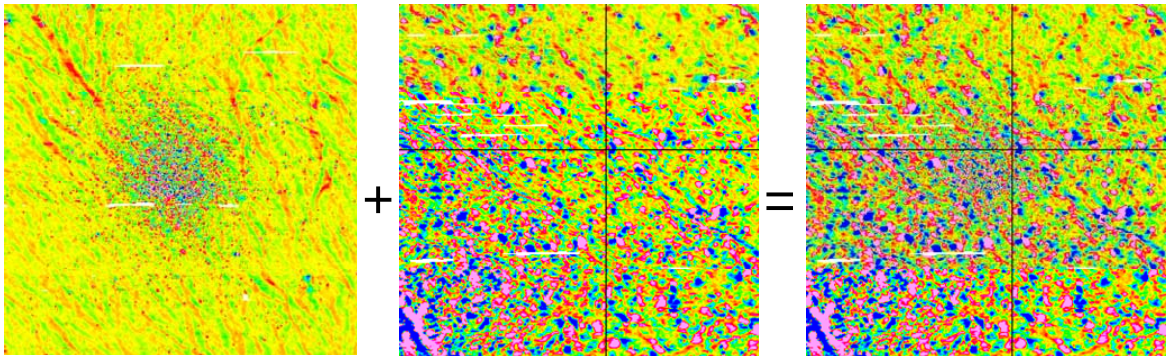

Figure 14. To test detection of bull's eye like targets in challenging geologic regimes the total magnetic field data collected over PBR 15 are added to a section of challenging geology.

Using manual picking procedures, 6,319 anomalies were selected from the data to assess the distribution of metal objects across the study area. Figure 16 illustrates the locations of these anomalies over the WAA study area and the final density distribution image.

In an effort to determine the limitations imposed by survey altitude on detection/delineation of high anomaly density bull's eye features, PBR 15 and the Means Lake area were covered at 5 m and 10 m survey altitudes.

At the 5 m AGL survey altitude, a cluster of 62 anomalies were selected in the PBR Target 15 circle and no anomalies selected in the lake bed (Figure 17). At 10 m AGL, no anomalies were selected. It was concluded that at 10 m AGL the sensors readings were not sufficient to allow for target selection. A detailed description of each area of interest for both surveys is provided in section 4.3.

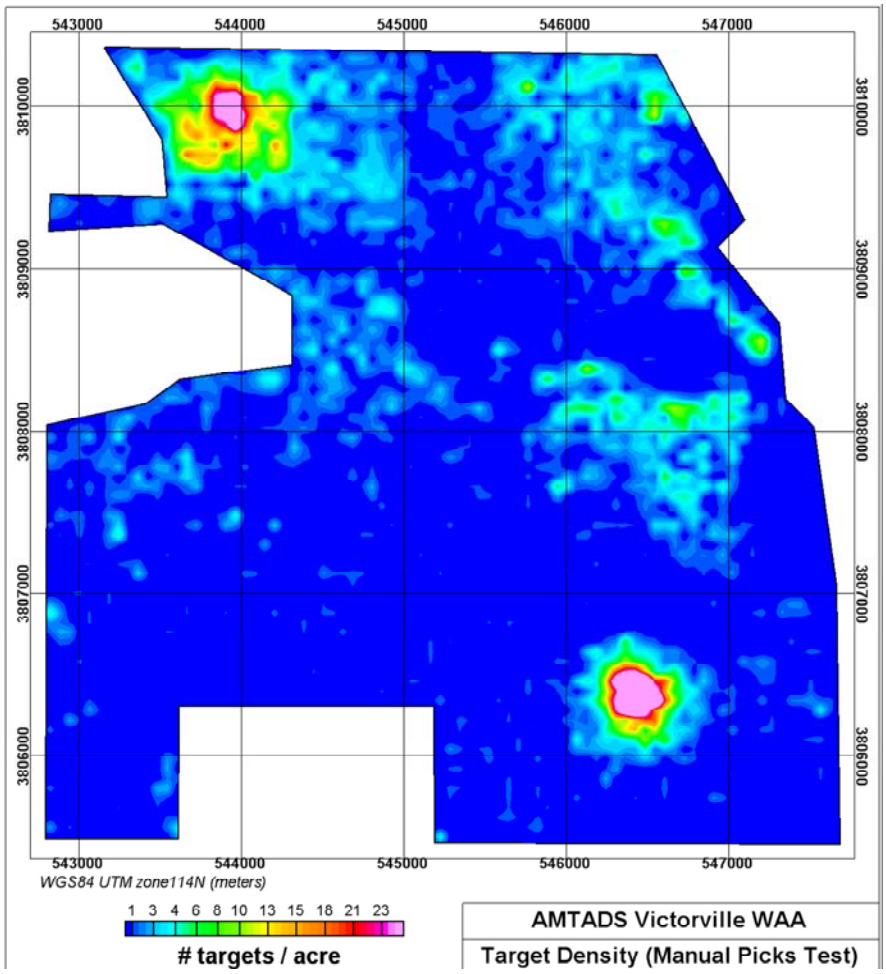

Figure 15. Test results indicating that high anomaly density bombing targets such as PBR Target 15 are recognizable in challenging geologic regimes using manual target selection. The simulated bull's eye in the northwest section of the survey area is clearly identifiable in the even in the region that has challenging geology.

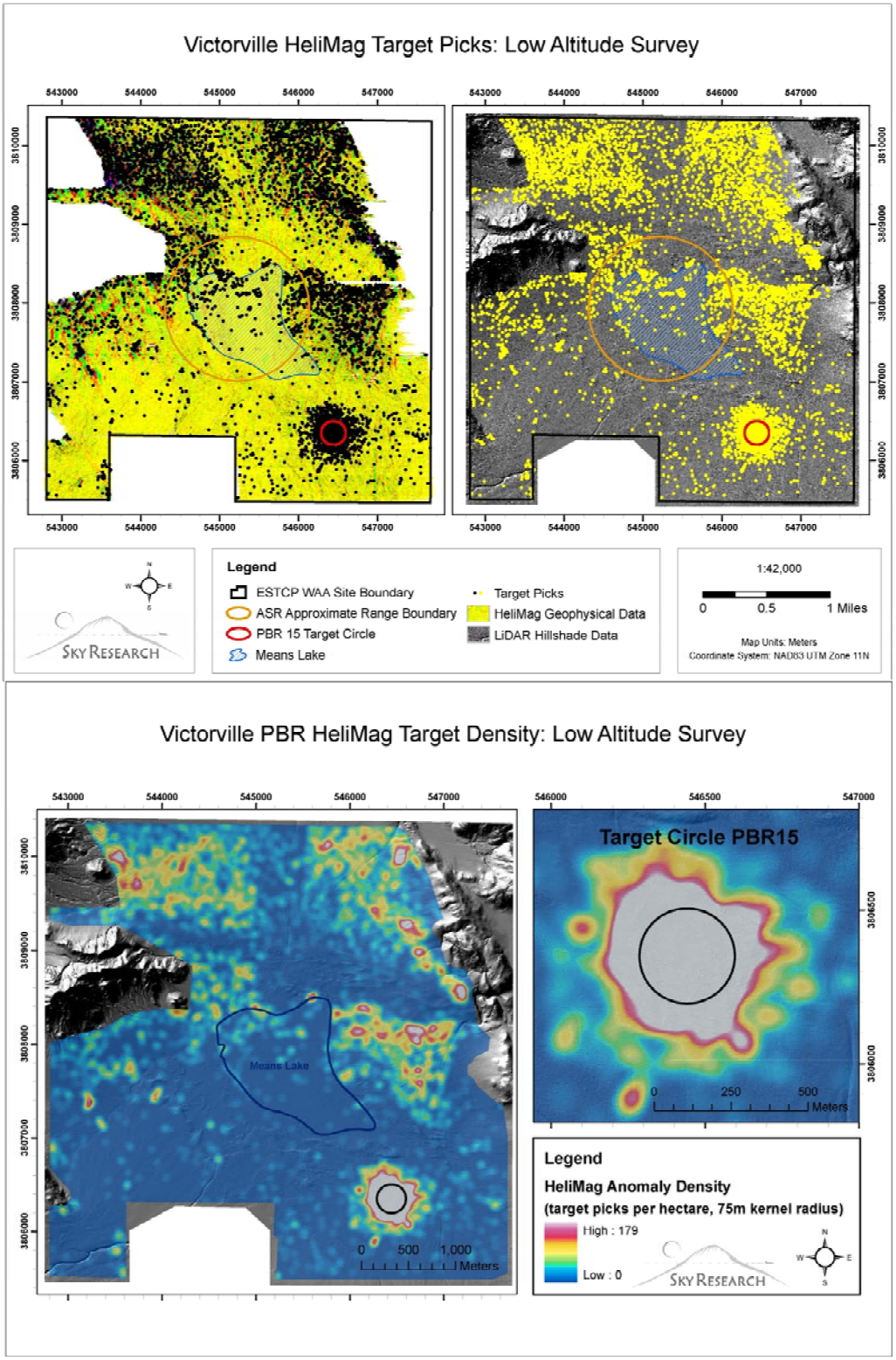

Figure 16. Target locations superimposed over the HeliMag total magnetic field data (top left) and hillshade LiDAR data (top right) and the final density distribution image (bottom).

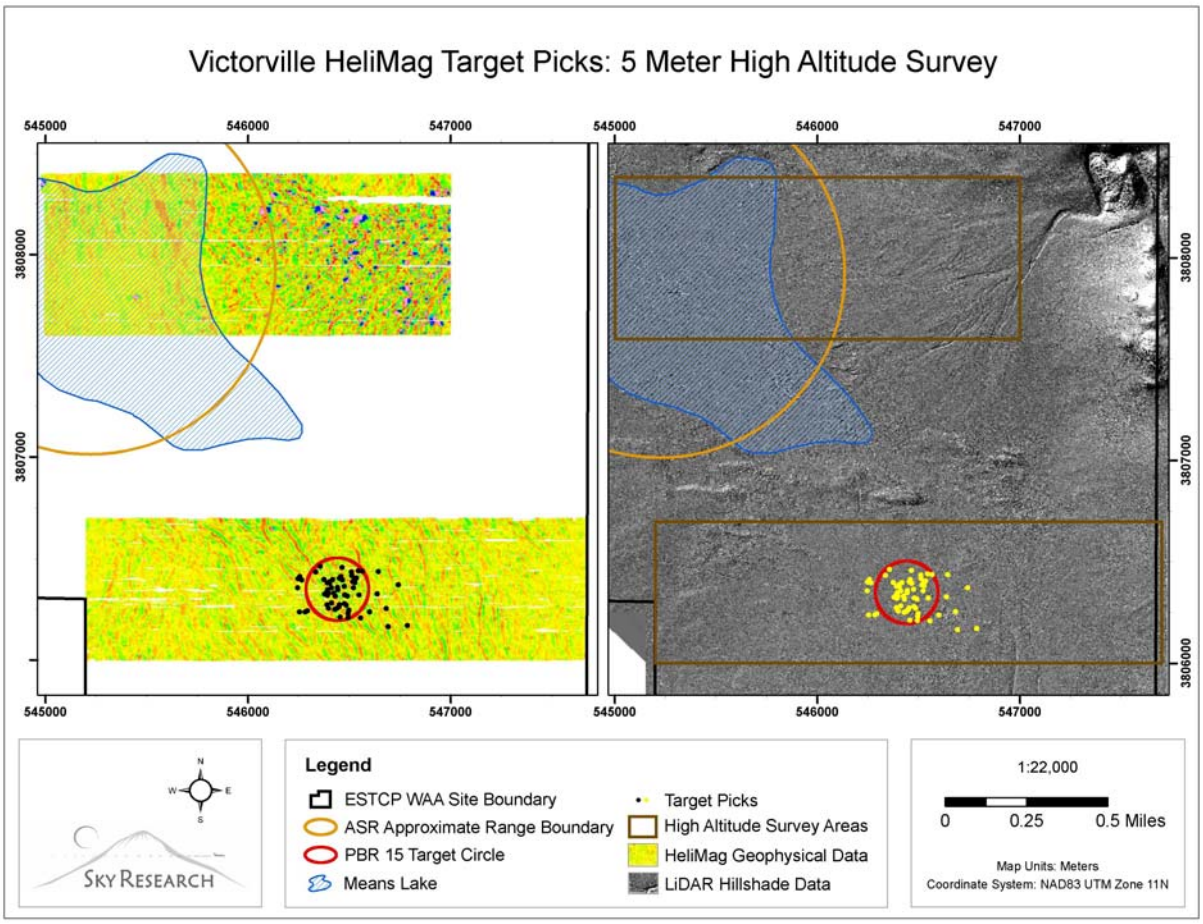

Figure 17. High altitude (5 m) target locations superimposed over the HeliMag total magnetic field data (left) and hill shade LiDAR data (right).

4.3. Results Discussion by Area

4.3.1. Demolition Bombing Target Y

The Demolition Bombing Target Y (DBT Y) area is shown in Figure 16. This target area was shown to have an elevated anomaly density based on the ground transects. The Helimag data showed some isolated pockets of elevated density, (e.g., there is a small area of elevated target density on the western edge of the lake bed) but no obvious high target density bull's eye features are identified by the Helimag data in this area. These findings do not support the CSM V0 evidence of extensive munitions use in this area. It is possible that the high proportion of explosives used in the demolition bombs resulted in smaller fragments that are essentially undetectable with airborne technologies.

4.3.2. Precision Bombing Range Target 15

The results obtained over the PBR Target 15 area are shown in Figure 16. The location of this area identified in CSM V0 is confirmed by the HeliMag density results. These results indicate that the target area is roughly circular with an approximate diameter of 500 m. Because there were no advanced analyses performed on the targets, size and depth estimates are not available for this site.

4.3.3. All Other Lands

The remainder of the area covered by the HeliMag system is characterized by regions of variable geologic magnetic regimes. Areas associated with rocky outcropping and their associated erosion depositions are generally much more magnetically active than the low lying areas. Isolated regions of elevated anomaly densities coinciding with regions of geologic activity are considered to be geologic artifacts and are not likely to be indicative of munitions use. The results from the test described in section 4.2 provide reasonable assurance that no large bull's eye like targets exist other than the one identified in PBR Target 15. Although there were some areas of increased anomaly densities identified in the ground-based transects, these were not detected or confirmed by the Helimag data and analysis performed.

4.4. Performance Criteria

The performance of the helicopter magnetometry technology was measured against the criteria listed in Table 8.

Table 8. Performance Criteria for the Victorville PBR HeliMag Technology Demonstration

Performance Criteria	Description	Type of Performance Objective
Technology Usage	Ease of use and efficiency of operations.	Primary/ Qualitative
Geo-reference position accuracy	Comparison of calibration target dipole fit analysis position estimates (in 3 dimensions) to ground truth	Primary/ Quantitative
HeliMag survey area coverage	Actual # acres surveyed/Planned # of survey acres.	Secondary/ Quantitative
Operating parameters (altitude, speed, overlap, production level)	Valued calculated using average and mean statistical methods to compute each parameter	Secondary/ Quantitative
System Noise	Accumulation of noise from sensors and sensor platforms, including GPS, rotor noise, radio frequencies, etc. calculated as the standard deviation of a 20 sec window of processed data collected out of ground effect.	Primary/ Quantitative
Data density/point spacing.	(# of sensor readings/sec)/ airspeed	Secondary/ Quantitative
UXO parameter estimates	The size and dipole angle estimates of the calibration items are consistent.	Secondary/ Quantitative

4.5. Performance Confirmation Methods

Table 9 details the confirmation methods that were used for each criterion, the expected performance, and the performance achieved.

Position accuracy on a dynamic platform is very difficult to measure precisely. We are able to infer the position accuracy of the sensor data by using the position estimates derived from dipole fit analysis of data collected over known targets. Although there are additional error sources (other than just those due to the data positioning) in the dipole fit results, they are almost negligible due to the stability of the magnetometer calibration and the robustness of the dipole fit process. Because reciprocal passes will tend to hide along-track position errors (due to the robustness of the dipole fit process), the dipole fit analyses were performed on each a single pass over the targets.

The spatial extent of a magnetic anomaly (from our targets of interest) is a factor of two times greater than the sensor offset distance. Based upon our minimum survey height of 1.5 m, we can conservatively define gaps in survey coverage as areas where the distance to the nearest sensor reading is greater than 2 m. Gaps in survey coverage are generally related to navigation (a combination of pilot skill, topography/vegetation, and wind

conditions) or data integrity (primarily GPS fix quality). As a general practice, images representing the data from each day of survey flying are created to identify areas requiring fill-in flying to cover significant gaps in coverage. Invariably there will be a number of gaps in survey coverage that cannot be practically filled. To estimate the survey coverage performance, at every 0.25 m interval (grid node) we search through a 1 m radius for a valid data point. The number of grid nodes where valid data are found is divided by the total number of grid nodes to derive the percentage of survey coverage. Based upon these factors and acreages, the final coverage was 98.6%.

The assessment of the survey altitude and speed was performed by extracting statistics for these parameters from the survey databases. Survey speed was consistently maintained between 20 and 50 knots (10 – 25 m/s), with some insignificant variation at the beginning or end of the survey lines. Survey altitude is a critical parameter for this type of investigation and is expected to be a little more variable than survey speed. In Figure 18, we present a histogram of the survey altitude performance. As with presentation/analysis of the results, prior to deriving these statistics, all altitudes above 5 m were rejected. These altitudes generally occur at the end of survey lines or during times when the helicopter has broken off a survey line and is circling back to reacquire it. The mean survey altitude was 2.1 m and the standard deviation was 0.44 m.

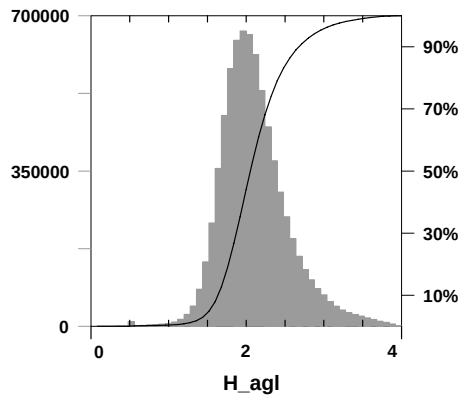

Figure 18. Histogram of sensor altitude above ground level.

HeliMag system noise levels were determined by calculating the standard deviation of the final filtered magnetic data flown at high altitude out of ground effect. The noise varied by sensor/orientation with the Earth's field. Typical results varied from 0.09 to 0.17 nT. Figure 19 depicts a typical 20 second stretch of high altitude data.

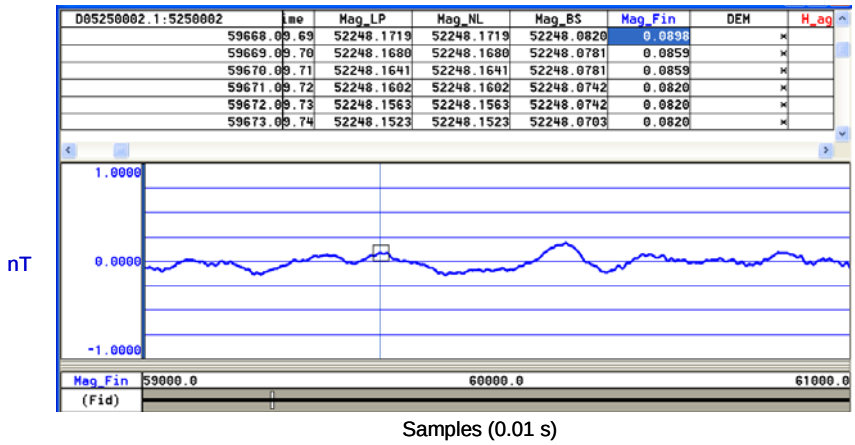

Figure 19. 20 second sample of high altitude data, 'final' filtered data.

The cross-track data density is essentially static and is a function of the system geometry.

With the exception of isolated data gaps (addressed above) the 'worst case' spacing is our sensor spacing of 1.5 m. The effective density is much higher than this due to the significant overlap required to ensure (or at least minimize) data gaps due to the inevitable cross-track variation of the helicopter flight path. However, because the density is not uniform, we quote the 'worst case' as the data density achieved. Down-track data density is much higher than the cross-track density and is a function of survey speed. At our final sample rate of 100 Hz, the survey speeds of 10 – 25 m/s (20 – 50 knots) resulted in down-line data spacing of 0.10 - 0.25 m.

Table 9. Performance Metrics Confirmation Methods and Results

Performance Metric	Confirmation Method	Expected Performance	Performance Achieved
Technology Usage	Field experience using technology during demonstration	Relative ease of use	Pass
Geo-reference position accuracy	Infer sensor position accuracy from position estimates of calibration targets derived using dipole analysis of repeated data collection over calibration targets	Horizontal < 0.25m Vertical <0.5m	Horizontal: 0.19 Vertical: 0.29
HeliMag survey area coverage	The sum of actual areas surveyed calculated in a geographic information system (GIS) and compared to the final survey area.	95%	98.6%
Operating parameters (altitude, speed, overlap, production level)	Field data logs and/or final survey databases used to calculate the operating parameters	Altitude: 1-3 m AGL Speed: 10-20 m/s (20-40 knots) Production 300 acres/day	Altitude: 2.1 m AGL Speed: mean 15.1 m/s, Production:307 acres/day
System Noise	The system noise was calculated as the standard deviation of a 20 sec window of processed high-altitude data.	<1 nT	0.24 nT
Data density/point spacing.	Calculated based upon system sample rate and survey speed (along track) and system geometry and survey line spacing (cross-track track).	0.5 m along-track 1.5 m cross-track	Along-track: Mean 0.15 m max 0.30 m Cross-track: Max: 1.5 m
UXO parameter estimates	Comparison of analysis results of repeated data collected over calibration targets.	Size: <.02 m Solid Angle: < 10 º	Size: 0.17 m Solid Angle 4.4 º

5. COST ASSESSMENT

5.1. Cost Reporting

Cost information associated with the demonstration of all airborne technology, as well as associated activities, was tracked and documented before, during, and after the demonstration to provide a basis for determining the operational costs associated with this technology. For this demonstration, Table 10 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 airborne services, support personnel, and leased equipment; and costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration. The magnetometers used for the HeliMag technology were provided through a CRADA with NRL; as such, the actual cost of using the technology was not captured in this demonstration. However, we will estimate the true cost of using this technology, in addition to the cost and performance of all technologies demonstrated, in the ESTCP Cost and Performance Report to be submitted following this demonstration.

5.2. Cost Analysis

The single largest cost element for an airborne survey is the cost of aircraft airtime. In addition, mobilization costs for the helicopter can be significant. Generally, mobilization cost is a function of distance from the home base for the aircraft, equipment, and personnel. For this demonstration, two mobilizations were conducted. The first mobilization for demonstration, in February 2006, encountered equipment issues that resulted in a failed mobilization for the data collection. These issues included vibration issues with the rental helicopter; altimeter calibration; and data acquisition computer issues. The costs for the mobilization therefore include the first mobilization, the time on site spent addressing each issue, and a second successful mobilization to the site. Planning and data processing and analysis functions made up the bulk of the remaining costs.

Project management and reporting were a significant cost for this demonstration, as the project was conducted under the WAA pilot program and required more meetings, travel, and reporting than would generally be expected for a production level survey.

Costs associated with validation were not considered in the cost analysis, as the validation was conducted as part of the WAA pilot program.

Table 10. Cost Tracking

COST CATEGORY	SUB CATEGORY	DETAILS	COSTS ($)
START-UP COSTS	Pre-Deployment and Planning	Includes planning, contracting, site visit, and site inspection	$26,390
	Mobilization	Personnel mobilization, equipment mobilization, and transportation	$79,700
OPERATING COSTS	Helicopter Survey	Data acquisition and associated tasks, including helicopter operation time	$326,446
DEMOBILIZATION	Demobilization	Demobilization, packing, calibration line removal	$5,855
DATA PROCESSING AND ANALYSIS	Data Processing	Initial and secondary processing of data	$30,503
	Data Analysis	Analysis of airborne magnetometry datasets	$23,151
MANAGEMENT	Management and Reporting	Project related management, reporting and contracting	$39,318
TOTAL COSTS			
		Total Technology Cost	$531,363
		Acres Characterized	4,567
		Unit Cost	$116/acre

6. IMPLEMENTATION ISSUES

6.1. Regulatory and End-User Issues

The ESTCP Program Office has established a WAA pilot program Advisory Group to facilitate interactions with the regulatory community and potential end-users of this technology. Members of the Advisory Group include representatives of the US EPA, State regulators, Corps of Engineers officials, and representatives from the services. ESTCP staff has worked with the Advisory Group to define goals for the WAA pilot program and develop Project Quality Objectives.

There will be a number of issues to be overcome to allow implementation of WAA beyond the pilot program. Most central is the change in mindset that will be required if the goals of WAA extend from delineating target areas to collecting data that are useful in making decisions about areas where there is not indication of munitions use. A main challenge of the WAA pilot program is to collect sufficient data and perform sufficient evaluation that the applicability of these technologies to uncontaminated land and their limitations are well understood and documents. Similarly, demonstrating that WAA data can be used to provide information on target areas regarding boundaries, density and types of munitions to be used for prioritization, cost estimation and planning will require that the error and uncertainties in these parameters are well documented in the program.

7. REFERENCES

Billings, S.D., and F. Hermann, 2003. "Automatic detection of position and depth of potential UXO using a continuous wavelet transform", in Proceedings of SPIE Vol. 5089*, Detection and Remediation Technologies for Mines and Minelike Targets VII,* pp 1012-1022, 2003.

Blakely, R.J. and R. W. Simpson, 1986, "Approximating edges of source bodies from magnetic or gravity anomalies," *Geophysics*, v.51, p.1494-1498.

Nelson, H., J. McDonald and D. Wright, April 2005, "Airborne UXO Surveys Using the MTADS," Naval Research Laboratory NRL/MR/6110--05-8874.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, December 2003, "Report of the Defense Science Board Task Force on Unexploded Ordnance," 20301-3140.

McDonald, J.R., David Wright, Nagi Khadr, and H.H. Nelson, "Airborne MTADS Demonstration at the Aberdeen Proving Ground, July 2002," NRL/PU/6110--02-xxx, April 2003.

Nelson, H.H., T.W. Altshuler, E.M. Rosen, J.R. McDonald, B. Barrow, and N. Khadr, "Magnetic Modeling of UXO and UXO-like Targets and Comparison with Signatures Measured by MTADS", in Proceedings from the UXO/Countermine Forum 1998.

Tuley, M. and E. Dieguez, July 2005, "Analysis of Airborne Magnetometer Data from Tests at Isleta Pueblo, New Mexico," IDA Document D-3035.

Versar, 2005, "Former Victorville Precision Bombing Range, Conceptual Site Model, V0".

8. POINTS OF CONTACT

Table 11. Points of Contact

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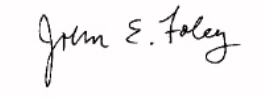
Mr. Hollis (Jay) Bennett	US Army R&D Center (CEERD-EE-C) 3909 Halls Ferry Road Vicksburg, MS 39180-6199	(Tel) 601.634.3924	DoD Service Liaison

Project Lead Signature: