ESTCP
Cost and Performance Report

(MM-0743)

Demonstration and Validation of an Improved Airborne Electromagnetic System for UXO Detection and Mapping

May 2010

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: MM-0743

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

Page

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE	U.S. Air Force Center for Engineering and the Environment
AGL	above ground level
ALASA	as low as safely achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DoD	Department of Defense
DSP	digital signal processor
EM	electromagnetic
EM-61	Geonics EM61 MK2
ESTCP	Environmental Security Technology Certification Program
FKPBR	Former Kirtland Precision Bombing Range
FP	false positive
FUDS	formerly used defense site
GPS	Global Positioning System
HAZWOPR	Hazardous Waste Operations and Emergency Response
HEAT	high explosive anti-tank warhead
Hz	Hertz
IDA	Institute for Defense Analyses
kHz	kilohertz
MCAGCC	Marine Corps Air Ground Combat Center
MEC	munitions and explosives of concern
MTADS	Multisensor Towed Array Detection System
NRL	Naval Research Laboratory
nT/m	nanoteslas per meter
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
PBR	Precision Bombing Range
Pd	probability of detection
ppm	parts per million
QA	quality assurance
QC	quality control

ACRONYMS AND ABBREVIATIONS (continued)

RAAF	Royal Australian Air Force
RMS	root mean square
ROC	receiver operating characteristic
S12	S12 Target
SORT	simulated oil refinery target
SNR	signal-to-noise ratio
STC	Supplemental Type Certificate
TEM	Time-Domain Electromagnetic
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	unexploded ordnance
VG	vertical (magnetic) gradient
VSEMS	Vehicular Simultaneous Electromagnetic Induction and Magnetometer System
WAA	wide area assessment

ACKNOWLEDGEMENTS

This work was funded by the Environmental Security Technology Certification Program (ESTCP) under the direction of Dr. Herbert Nelson, Dr. Jeffrey Marqusee, and Dr. Anne Andrews. Mr. Jon Haliscak at the U. S. Air Force Center for Engineering and the Environment (AFCEE) at Brooks Air Force Base (AFB), Texas, served as the contracting officer's representative for this project. The report was prepared by employees of AMEC Earth and Environmental and Battelle – Oak Ridge Operations.

This page left blank intentionally.

1.0 EXECUTIVE SUMMARY

In September 2008, Battelle completed construction of a new airborne, time-domain electromagnetic system for mapping and detecting unexploded ordnance (UXO). This system was developed with corporate funds on the basis of successful evaluation of a prototype system under Environmental Security Technology Certification Program (ESTCP) Project 200101. This system has been developed to address shortcomings of magnetometer-based systems where the presence of basalt flows or other iron-bearing soils and rocks impede the performance of magnetometer systems. Although this is not a universal problem, it occurs with varying degrees of severity at many sites, in particular, in the western continental United States as well as portions of Hawaii and Alaska.

The Battelle Time-Domain Electromagnetic (TEM)-8 system is contained within a 12 by 3 meters (m) rectangular boom structure with a two-lobed transmitter loop composed of two 3 by 4 m rectangles. There are four receivers on each side of the aircraft, located within 4 m tube segments that are oriented parallel to the long axis of the boom structure. As with most transient electromagnetic (EM) systems, a current is established in the transmitter loop, then rapidly switched off, inducing a secondary magnetic field in the earth. The decay of the secondary magnetic field is measured in the receiver coils. The central third of the boom structure is directly under the helicopter and is inactive requiring interleave flight lines to achieve full coverage of the underlying subsurface.

Two sites near Albuquerque, NM, were selected for a February 2009 demonstration—a 617-acre portion of the Former Kirtland Precision Bombing Range (FKPBR), and the Kirtland Precision Bombing Range (PBR)-S12 Target (S12). The FKPBR area was chosen to enable comparison with previous ESTCP demonstrations of wide area assessment (WAA) technologies and because moderate basaltic interference has been recognized in previous WAA demonstrations. A 100-acre area within the FKPBR area was specified for emplacement of seed items. The seed items were emplaced under the direction of the ESTCP Program Office without involvement from AMEC or Battelle. Validation of data from this area was made by the Institute for Defense Analyses (IDA) by comparing dig lists to a master list of seeded items. A total of 110 seed items were emplaced, including 81-millimeter (mm) and 4.2-inch mortars, 105 mm projectiles and high explosive anti-tank warhead (HEAT) rounds, and 155 m projectiles. IDA determined that TEM-8 detected 109 of the 110 seed items, missing one 4.2-inch mortar by only 1 centimeter (cm) outside the 150 cm halo. The mean miss distance was 0.34 m with a standard deviation of 0.23 m.

The PBR-S12 site was chosen as being representative of sites where ground-based and airborne magnetometer data are ineffective for UXO mapping and detection due to interference from a basalt flow that is exposed across the entire site. Airborne magnetometer data that were acquired in 2002 with the Oak Ridge Airborne Geophysical System (ORAGS)-Arrowhead system at PBR-S12 indicated no distinguishable response to ordnance at the target, even though a concentration of M38 scrap was observed at the surface near the center of the target. The ordnance at the site consists almost exclusively of M38 fragments, with occasional M38s that are largely intact. From the airborne data, two 100 by 100 m grids were selected for validation. Ground-based geophysical data were collected in these grids with a Geonics EM61 MK2 (EM61) time domain metal detection system. A total of 327 anomalies detected by the TEM-8 and EM61 were evaluated by excavation. The validation indicated that all but two of the excavated items over 5 lb were detected by TEM-8, and 78% of the excavated items weighing between 1 and 5 lb were detected. The TEM-8 detected 31% of the M38 fragments that weighed less than 1 lb.

The TEM-8 demonstration exceeded all performance objectives established in advance of the test. The results indicate that TEM-8 fills an important niche in WAA assessments by enabling the use of lower-cost airborne detection systems in areas where moderate to severe basaltic interference causes magnetometer systems to encounter many false positive anomalies or to miss ordnance altogether. The TEM-8 may also prove beneficial as a primary or supplemental system in areas where magnetometer system performance is acceptable.

2.0 INTRODUCTION

2.1 BACKGROUND

It is estimated that UXO may contaminate 15 million acres or more within the United States alone. A need for improved technologies for mapping and detecting UXO has led to development of a sequence of airborne reconnaissance systems, using electromagnetic (Beard et al., 2004; Doll et al., 2003; Holladay et al., 2006) and magnetic (Gamey et al., 2004) sensors.

2.2 OBJECTIVES OF THE DEMONSTRATION

There are two distinct objectives for this demonstration. First and foremost, the demonstration provides a means of assessing the effectiveness of the new TEM-8 airborne TEM system and comparing this technology with airborne magnetometer systems for mapping and detecting ordnance. The assessment is performed from data collected in two distinct geologic areas in New Mexico. One area contains mild geologic interference, and the other contains basaltic terrain that poses severe geologic interference associated with the magnetite content of the basalt.

A second objective of the demonstration is to assess the effectiveness of the TEM-8 system for WAA applications. The Demonstration Site for this project has been used for previous WAA demonstrations and therefore allows a basis for achieving this second objective.

2.3 REGULATORY DRIVERS

No specific regulatory drivers influenced this technology demonstration. UXO-related activity is generally conducted under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority. Regardless of a lack of specific regulatory drivers, many Department of Defense (DoD) sites and installations are aggressively pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g. burial sites) that resulted from weapons testing or training activities. These issues include munitions footprint reduction and site characterization that are areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at military munitions sites can lead to airborne surveying to assess the extent of munitions impacted areas and remediation efforts despite the absence of relevant regulatory drivers and mandates.

This page left blank intentionally.

3.0 TECHNOLOGY

3.1 TECHNOLOGY DESCRIPTION

The Battelle TEM-8 system is a helicopter-mounted time-domain electromagnetic metal detection system that was designed for mapping UXO in areas where geologic conditions cause magnetometer-based systems to be ineffective. Figure 1 depicts the system during aerial maneuvers. First and foremost, it has been anticipated that the TEM-8 system will prove superior to magnetometer systems where the presence of basalt flows impedes the performance of the magnetometer systems. Although this is not a universal problem, it occurs with varying degrees of severity at many sites throughout the United States and, in particular, in the western continental United States as well as portions of Hawaii and Alaska. Secondarily, an electromagnetic system would prove beneficial at sites where nonferrous ordnance might occur, or where more attributes derivable from TEM-8 data could provide a cost-effective reduction in the number of targets requiring further ground-based evaluation.

Figure 1. TEM-8 airborne electromagnetic system.

In 2002, under ESTCP Project 200101, Battelle staff (then at Oak Ridge National Laboratory [ORNL]) evaluated a prototype TEM system for mapping and detecting UXO (ORNL, 2004a). This study demonstrated excellent sensitivity to ordnance when the system (ORAGS-TEM) was flown at sufficiently low altitudes. The system, however, lacked the necessary efficiency for production-scale operations as it contained only two receiver channels.

Battelle committed corporate funds to design and construct a new TEM system as a result of successful testing conducted in 2002. This system is similar to the ORAGS-TEM system in many regards but contains eight receiver coils instead of two. The Battelle TEM-8 system is housed within a 3 m by 12 m rectangular boom structure with a two-lobed transmitter loop composed of two 3 m by 4 m rectangles. There are four receivers on each side of the aircraft, located within 4 m tube segments that are oriented parallel to the long axis of the boom structure (as presented in Figure 1). As with other transient EM systems, a current is established in the transmitter loop. This current is then rapidly switched off, inducing a secondary magnetic field in the earth and any metallic objects present including target ordnance. The decay of this secondary magnetic field is measured in the receiver coils as a voltage response. The central third of the boom structure directly under the helicopter is inactive, thus making it is necessary to interleave flight lines in order to achieve full coverage of the underlying subsurface. The Battelle TEM-8 system was first deployed in a shakedown test at Battelle's West Jefferson Ohio UXO Airborne System Test Site in November 2007 as part of this ESTCP project. The TEM-8 system was subsequently deployed at Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, CA, and at Royal Australian Air Force (RAAF) Amberley, Australia, during calendar year 2008.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at a site with a considerably lower cost per acre than ground-based systems. Furthermore, the airborne data is acquired in a shorter period of time. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush, wetland, mud, or rocky terrain makes it difficult to conduct ground-based surveys. Sensitivity of airborne systems is clearly lower than that of ground-based systems (e.g., towed array surveys using the Vehicular Simultaneous Electromagnetic Induction and Magnetometer System [VSEMS]), which can operate with sensors at less than 0.5 m above ground level (AGL).

Airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation can limit the utility of helicopter systems, necessitating survey heights that are too high for resolution of individual UXO items. The performance of ground-based electromagnetic systems has been proven superior to magnetometer systems where magnetite bearing basaltic rocks are problematic. The airborne TEM-8 system demonstrates a similar advantage over airborne magnetometer systems under the same geologic conditions. Where magnetic geology is not problematic, TEM-8 does not perform as well as magnetometer systems at altitudes 2 m and higher.

The primary advantage of the airborne technology is the capability to survey large areas more quickly and less expensively than conventional ground-based surveys. Ground-based EM systems are preferred over ground-based magnetometer systems, even when geology is not magnetic when the target ordnance are at shallow depths. Ground-based magnetometer systems are usually preferred over ground-based EM systems for deep ordnance items. Similarly, airborne EM systems are less sensitive to deep ordnance than airborne magnetometer systems. The primary advantage of airborne EM systems over airborne magnetometer systems is the ability to collect meaningful data within sites containing significant magnetic geologic interference, or where UXO targets may be largely non-magnetic. Airborne systems also have an advantage in areas where ground access is limited or difficult due to surface conditions (swamp or marsh) or inherent danger (exposure to UXO or other contaminants). Areas with a sensitive ecological environment may also benefit from the less intrusive airborne technologies.

4.0 PERFORMANCE OBJECTIVES

Demonstration performance is generally assessed by comparison of the processed/analyzed results from the demonstration survey with established baselines from previous assessments or demonstrations. In this case, however, there are no previous airborne EM surveys that can be used in comparison (other than the informal results from the ORAGS-TEM system at the Badlands Bombing Range [ORNL, 2004a]), so the assessment must be done by comparison with airborne magnetometer results, ground-based EM results, or projected performance metrics. Evaluation of seeded items provides a basis for assessing the detection of ordnance items. Demonstration success is defined 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 and presented in Table 1. Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Therefore, it is difficult to obtain as much precision and repeatability as one might want for comparing system performance. Depth estimates are not made from the TEM-8 data, but the depths of emplaced and excavated targets will be recorded as a parameter for characterizing the depth sensitivity of the system. Items that are detected as well as those that are missed have been reviewed to assess any role that their depth may have played. Data were acquired at two sites, FKPBR and PBR-S12, described in greater detail in Section 5. Figure 2 depicts the two areas adjacent to Double Eagle Airport that were surveyed in previous ESTCP WAA projects. Figure 3 shows total field magnetic anomaly map of the area at FKPBR that was surveyed by Sky Research in an earlier 2005-6 ESTCP WAA project. Both figures are discussed in more detail in Section 5.

Table 1. Performance objectives of TEM-8 system.

Performance Objective	Metric	Data Required	Success Criteria	Results
Quantitative Performance Objectives				
Detection[1] of all munitions of interest (moderate geologic interference)	Percent detected of seeded items (FKPBR)	Location of seeded items Prioritized dig list	Probability of detection (Pd) per item as summarized in Table 2	Detected 99.1% of seeded items at FKPBR, exceeding success criteria for all ordnance types per Table 2
Detection[1] of all munitions of interest (extreme geologic interference)	Percent detected of items identified in EM61 survey (PBR-S12)	Dig list from EM61 survey Prioritized dig list from TEM-8 Locations from validation survey	Detect 90% of M38 at PBR-S12	Detected 95% of largely intact M38s at PBR-S12
Reduction of false alarms relative to magnetometer measurements (PBR-S12)	Percent of False positives[2] at PBR-S12	Dig list from EM61 survey Prioritized dig list from TEM-8 Locations from validation survey	Equal numbers of false positives and successful detections at SNR of 2:1 for M38s or other ordnance types at PBR-S12	81.3% of digs from TEM-8 list were successful in finding M38s or M38 frag (157 of 193 digs). False positives constituted 18.7%

Table 1. Performance objectives of TEM-8 system (continued)**.**

Performance Objective	Metric	Data Required	Success Criteria	Results
Improved signal-to-noise ratio (SNR) of EMI over magnetics in adverse geologic settings (PBR-S12)	SNR[3] at PBR-S12.	Amplitude of TEM-8 detections Amplitudes of previous magnetic detections Gridded TEM and magnetic data sets	TEM SNR > mag SNR	At PBR-S12, the TEM-8 SNR is estimated to be more than 1200 times as large as the magnetometer SNR. At FKPBR, where geology is less severe, a representative quiet area had similar SNRs, while in a noisier background; the TEM-8 SNR was about four times that of the magnetometer system.
Location accuracy	Average error and standard deviation for seed (FKPBR) and excavated (PBR-S12) items	Location of seed items surveyed to accuracy of 1 cm (FKPBR) Locations of excavated items to accuracy of 2 cm (PBR-S12) Estimated locations from analysis of TEM-8 data	90% of estimated locations for detected ordnance within 1.50 m of actual; ΔN and ΔE <0.5 m σN and σE <0.5 m	99% were within 1.5 m at FKPBR, with mean miss distance of 0.34, and s.d. of 0.23. At PBR-S12, all but three of 157 detected items were within 1.5 m, and the mean miss distance was 0.58 m with 0.31 m s.d.
Production rate	Number of acres of data collection per day	Log of field work	Survey: 125 acres per day	22.35 acres/hr or 106.2 acres/day Afternoon winds caused short days
Qualitative Performance Objectives				
Ease of use		Pilot approval		Flight performance is acceptable.
Terrain/vegetation restrictions		Acceptable for targets of interest		Sensitivity falls off markedly above about 3.5-4.0 m altitude, where higher altitude was caused by vegetation.
Aerodynamic stability		Safety, certification, no restrictions		Airspeed limited to 70 knots
Detection capabilities		Superior delineation of ordnance compared to magnetometer systems in the presence of magnetic background		TEM-8 was unaffected by magnetic background. Performance relative to magnetometer systems depends on degree of magnetic interference.

[1]We define the term "ordnance detection" to mean the percentage of ordnance items that produced electromagnetic anomalies discernable above the noise floor and within a defined search radius. The term does not imply that the anomalies were or were not correctly classified.
[2]By the term "false positive" we refer to an EM anomaly for which no metallic conductor can be associated.
[3]SNR for both EM and magnetic systems is to be calculated as the average peak amplitude of positive M38 detections divided by the root mean squared (RMS) noise over the entire target area.

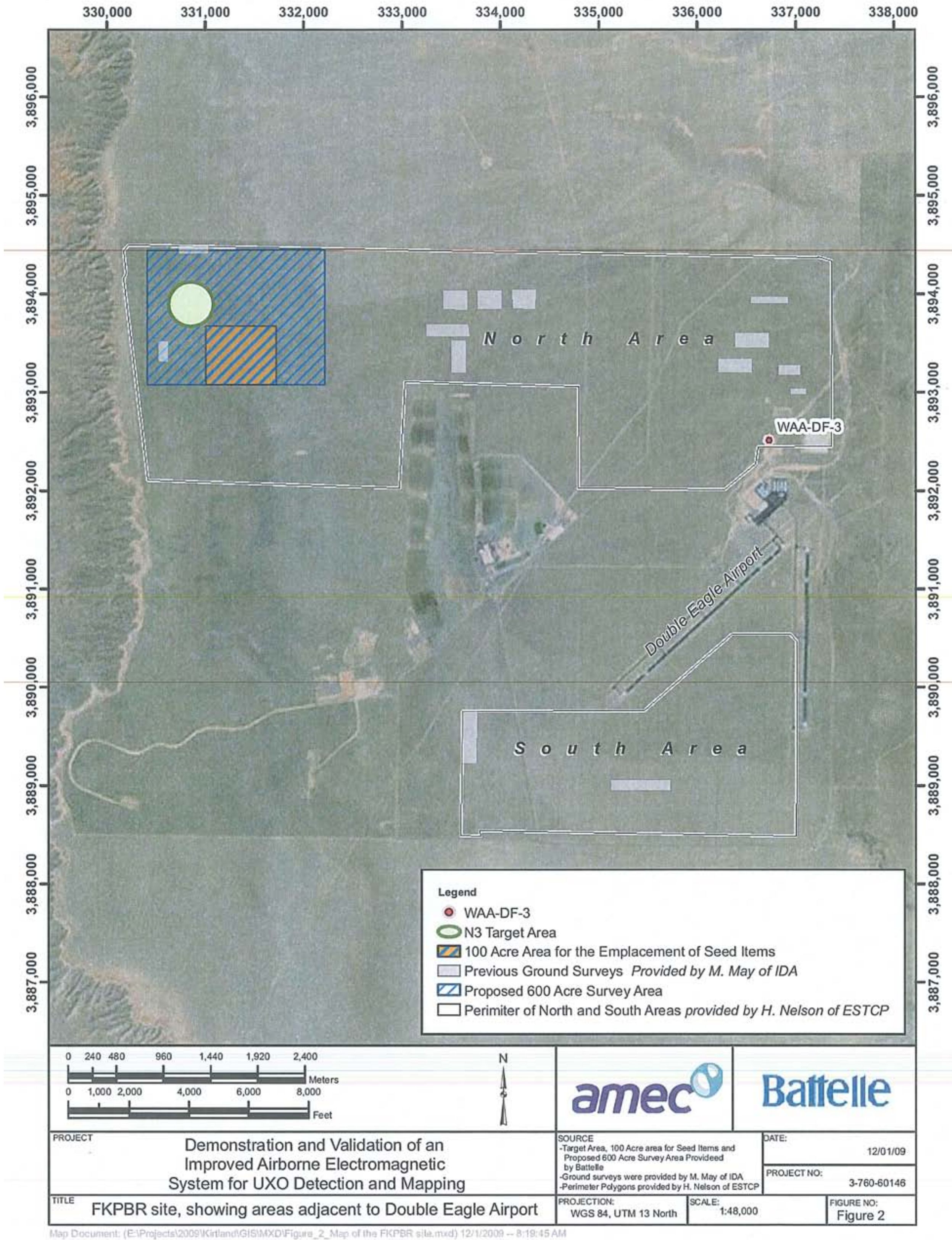

Figure 2. Map of the FKPBR site showing areas adjacent to Double Eagle Airport.

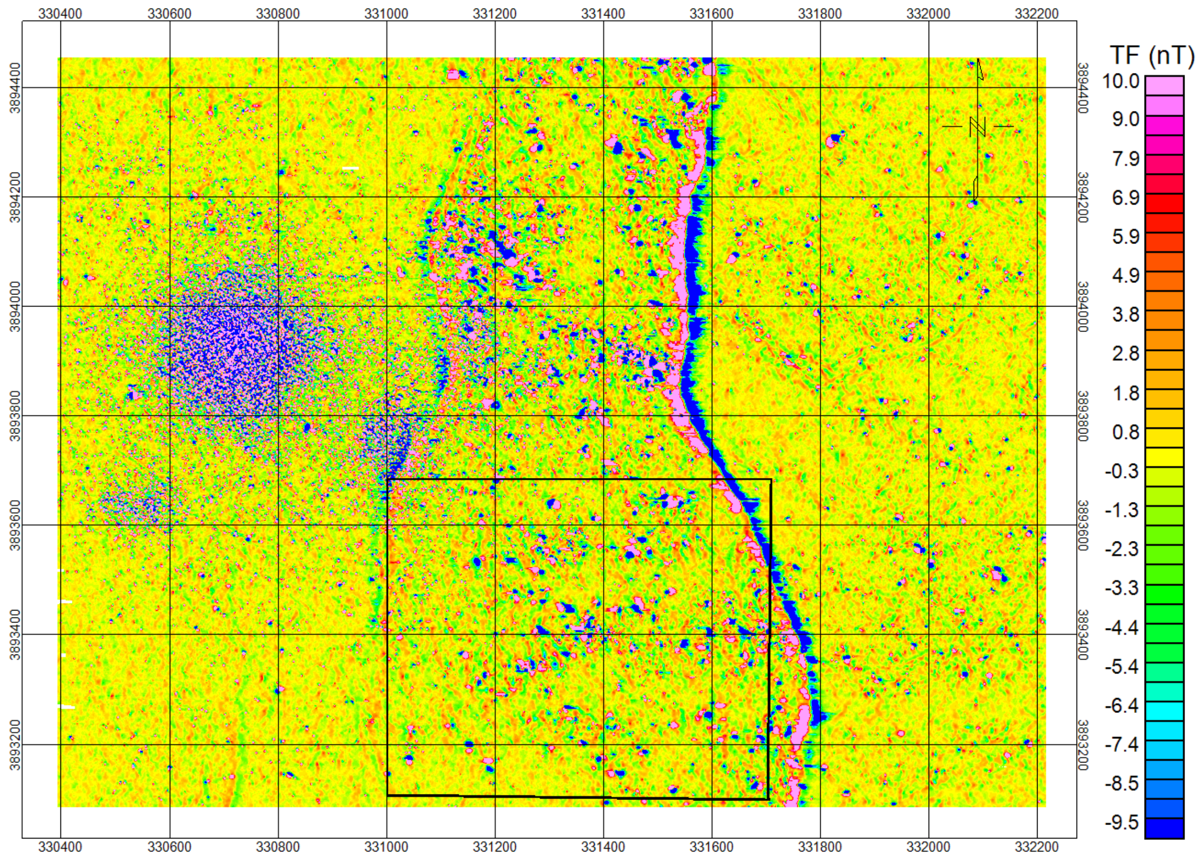

Figure 3. Total field magnetic anomaly surveyed by Sky Research.

Airborne geophysical systems do not distinguish between UXO and metallic scrap. Map products depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of metallic debris associated with human activity), and potential UXO items (discrete sources). It is not the purpose of this test to discriminate between UXO and non-UXO items. Here the detection capability is assessed over a large area with 110 blind-seeded items. The predicted and resultant detection rates are listed in Table 2.

Table 2. Anticipated detection rates for FKPBR seeded grid.

Ordnance Type	Predicted Detection	# of Seeds	Achieved Detection
81 mm	40%	12	100%
105 mm projectile	65%	8	100%
105 mm HEAT	60%	14	100%
4.2-inch mortar	60%	52	98%
155 mm	80%	24	100%

At PBR-S12, the objective was to assess the TEM-8 performance at a site that is not artificially seeded and where in situ M38 ordnance (or at least M38 fragments) are visible at the surface. It is also a site where previous airborne magnetometer surveys have been completely ineffective. The detection of M38s at PBR-S12 was assessed by direct comparison with EM61 survey results and validation digs, which are compared against the anomaly list provided from the TEM-8 survey. The expected Pd was 90% for mostly intact M38s at PBR-S12. For detection purposes, a “largely intact-M38” is defined as any M38 related ordnance or frag larger than 50 x 24 cm, or any intact tail-fin. Actual performance is summarized in Table 3.

Table 3. Summary of targets detected by EM61 and TEM-8.

Item	Excavated	Detected by EM61	Detected by TEM-8
Mostly intact M38	38	37	36
Nose cone	46	45	34
Initiator	42	41	6
2" band	22	21	4
Wire	6	6	0

At PBR-S12, an approximation to false alarms can be made from the validation areas. Results from a 2002 ORAGS-Arrowhead magnetometer survey provide a comparable magnetic database. Validation areas were selected from areas that show concentrations of discrete anomalies in the TEM-8 data. Within these areas, EM61 data were acquired and anomalies from the EM61 data were subsequently validated by excavation. False positives (FP), defined as anomalies produced by non-metallic sources, are documented. As indicated in Table 1, only 18.7% of the digs at PBR-S12 were airborne FPs.

A quantitative measure of the improvement in SNR is a key metric in terms of defining the benefit of TEM over magnetic data obtained in areas where geologic formations or material contain magnetic minerals that influence background measurements, in this case basalt. Measurements were made over PBR-S12 where both magnetic and electromagnetic data have been collected. SNR is described in greater detail in Section 7.2. The TEM-8 had significantly better SNR in areas where moderate to severe basalt-generated noise occurred, four times that of the magnetometer system in the moderately basaltic FKPBR, and 1300 times better than the magnetometer system at the more severely basaltic PBR-S12. Where there is less basalt, the SNR of the TEM-8 was similar to that of the magnetometer system.

The positional accuracy is an important constraint for enabling satisfactory ground follow-up of anomalies and can be measured from both the FKPBR and PBR-S12 datasets. Positional accuracy within PBR-S12 was determined by comparing the positions of detected and reported anomalies in the PBR-S12 validation areas with the validation results. Positional accuracy within the FKPBR seeded area is determined by positions of seed items provided by the ESTCP Program Office after the “dig lists” were provided to ESTCP by Battelle. At FKPBR, the mean miss distance was 0.34 m with a standard deviation of 0.23 m. At PBR-S-12 the mean miss distance for successful digs associated with TEM-8 anomalies was 0.58 m with a standard deviation of 0.34 m. The objective was met at both sites.

This page left blank intentionally.

5.0 SITE DESCRIPTION

The two areas that were selected for this demonstration are a 617-acre portion of the FKPBR (Figure 3) and a 444-acre area surrounding the center of PBR-S12 (Table 4). A 100-acre area within the FKPBR area was specified for emplacement of seed items, to be emplaced under the direction of the ESTCP Program Office without involvement from AMEC or Battelle.

Table 4. Breakdown of proposed survey blocks for Battelle TEM-8 system at FKPBR.

Area	Altitude	Purpose
FKPBR-600	ALASA*	To allow comparison of TEM-8 survey noise and ordnance detection to airborne magnetic data previously acquired by another contractor
FKPBR-100	ALASA	To assess TEM-8 sensitivity to seeded items, emplaced under the direction of the ESTCP Program Office
PBR-S12	ALASA	To assess TEM-8 performance of detection of M38 practice bombs in an area where basaltic contamination is severe

*ALASA – as low as safely achievable

5.1 SITE LOCATION AND HISTORY

Two sites were selected for this project. The ESTCP Program Office had requested that survey data be acquired at the FKPBR in New Mexico, where previous WAA surveys had been conducted (see Figure 2).It was thought that a demonstration in this area would provide valuable comparisons with other WAA survey tools while reducing overall cost of the demonstration to ESTCP.

Figure 2 depicts the two areas adjacent to Double Eagle Airport that were surveyed in previous ESTCP WAA projects. The proposed 600-acre survey area is shown in red. The blue box within the proposed survey area represents the 100-acre area for emplacement of seed items. The green circle is approximately where the N-3 target area is located. Locations of previous ground surveys provided by M. May of IDA are included as smaller rectangles. The perimeter polygons for the north and south areas were provided by H. Nelson of ESTCP.

Figure 3 shows total field magnetic anomaly map of the area at FKPBR that was surveyed by Sky Research in an earlier 2005-6 ESTCP WAA project. The selected area in Figure 3 clearly shows the geologic interference caused by basalt formations and float rocks. The inset shows the location of the 100-acrea area selected for blind-seeding. The area of interest shows generally moderate, and locally severe, geologic interference as a result of basalt bedrock and float materials. The 100-acre area was also surveyed by Sky Research in 2009 with a newer airborne magnetometer system for ESTCP. None of the seed items were in place when the magnetometer data shown in Figure 2 were acquired.

Survey data were also acquired at the Kirtland PBR-S12 target (S12, Figure 4). This site was chosen as being representative of sites where ground-based and airborne magnetometer data are ineffective for UXO mapping and detection due to interference from basalt bedrock and float materials. Airborne magnetometer data were acquired with the ORAGS-Arrowhead system at PBR-S12 and show no distinguishable response to ordnance at the bombing target, even though a concentration of M38 scrap can be observed at the surface near the center of the target (Figure 5).

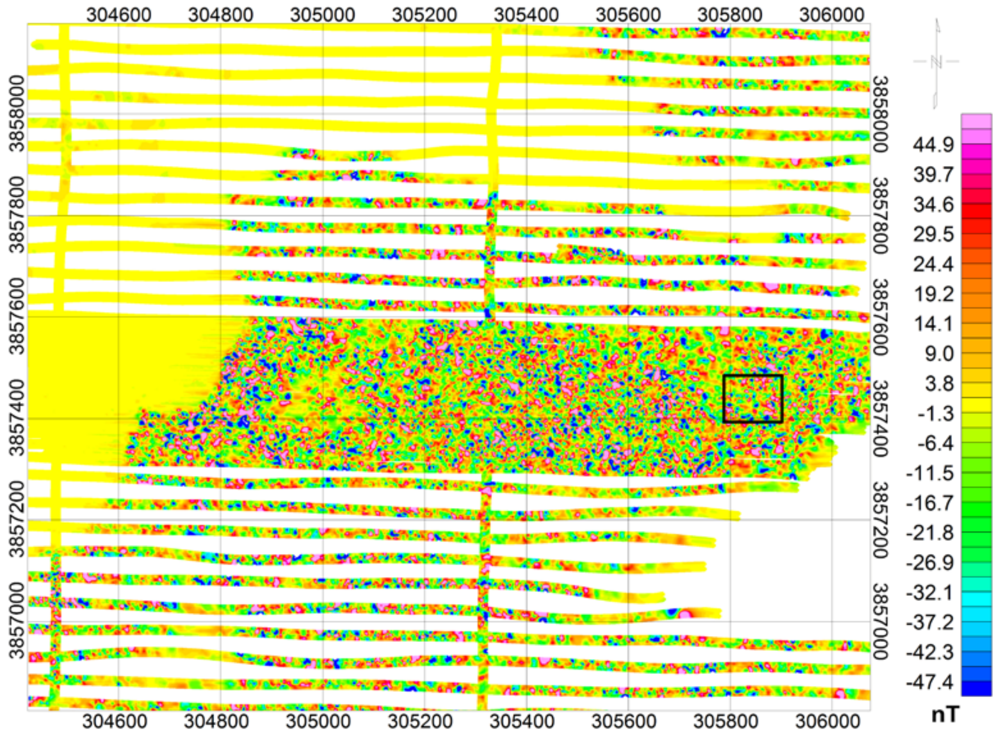

Figure 4. The 400-acre TEM-8 survey area at the Kirtland PBR-S12 target (blue box) superimposed on the Arrowhead magnetic map of the site, acquired in 2002.
The area was selected to allow comparison of magnetic and TEM-8 data and to encompass both basaltic and non-basaltic areas at PBR-S12. The area selected is centered on the target.

Figure 5. Photograph, looking north across the center of the PBR S-12 target.
The pile of M38 scrap in the center of the photograph was not detected by the airborne magnetometer survey.

The FKPBR site is a 38,000-acre formerly used defense site (FUDS). It has been subject to previous geophysical surveys and partial excavation, primarily under the guidance of the ESTCP Program Office. It is currently undeveloped open rangeland. It was used in World War II as a training area for Kirtland AFB. The ESTCP WAA pilot study area consists of 5000-6500 acres of land adjacent to Double Eagle Airport, near Albuquerque, NM. There are at least three bombing targets and a simulated oil refinery target (SORT) within this study area. Known or suspected ordnance types at the site are M38 practice bombs and 250-lb high explosive bombs. The portion of the FKPBR that was surveyed by the TEM-8 includes the N-3 target area that is just northwest of the seeded area and two smaller targets adjacent to N-3 (see Figure 3).

The Kirtland PBR-S12 target is located within land owned by the Pueblo of Laguna Native American tribe and is a FUDS about 35 miles west of Albuquerque, NM. The predominant ordnance type at the site is World War II vintage M38 practice bombs. The Pueblo of Laguna land totals more than half a million acres, and large portions of this typically western desert environment are flat and devoted to ranching. The remaining portions of land are gently rolling to nearly vertical in relief and were formed by extensive erosion of the soft, fine-grained underlying sediments creating canyons, washes, gullies, and arroyos.

5.2 SITE GEOLOGY

The sites are situated on the eastern edge of the New Mexico portion of the Colorado Plateau, east of the Albuquerque-Belen Basin. A series of strong north-south trending, high-angle faults separate the geologic provinces, stepping downward from the plateau into the basin. The geology of the area is dominated by both consolidated and unconsolidated units and includes sandstone, mudstone, claystone, and shale. Igneous basalt formations cap the mesas in the area (e.g., Mesa Lucero, where the PBR-S12 target is located). In other locations, basalts have emanated from fissures or vents, providing sources for mafic alluvium on a more moderate scale (e.g., FKPBR). The typical altitude is 5000-6000 ft above sea level.

5.3 MUNITIONS CONTAMINATION

With regard to historical ordnance, numerous sites across the entire area were utilized for aerial bombardment training activity. From both visual inspection and previous Naval Research Laboratory (NRL) Multisensor Towed Array Detection System (MTADS) surveys, the principal ordnance type present at these sites is the M38 practice bomb. Evidence of these ordnance items is present on the surface at all sites used for this demonstration, with several hundred M38s excavated during the MTADS demonstration (McDonald and Nelson, 1999).

This page left blank intentionally.

6.0 TEST DESIGN

6.1 CONCEPTUAL EXPERIMENTAL DESIGN

The demonstration has been designed to address the most common situation where an airborne EM capability would be beneficial; that is where background geology causes moderate to severe performance issues for airborne magnetometer systems. Airborne systems are viewed primarily as tools for WAA and as such are not required to achieve a high Pd. However, where geologic interference is severe, most frequently due to basalt, the magnetic response from ordnance may be orders of magnitude smaller than the local geologic response. In this project, we assess the performance of the TEM-8 system at one site where basalt causes severe problems for magnetometer systems and where M38s are the predominant ordnance type, and at a second site where geologic interference is less severe and where a suite of more challenging seed items were emplaced.

6.2 SITE PREPARATION

The ESTCP Program Office arranged for burial of 110 seed items within the 100-acre FKPBR survey area. This was conducted several months in advance of the TEM-8 survey without involvement from the TEM-8 survey team.

6.3 SYSTEM SPECIFICATIONS

The Battelle TEM-8 system was described in Section 3.1.

6.4 DATA COLLECTION

6.4.1 Scale

As discussed in Section 5.1, data were acquired over a total of 1062 acres at the two sites. This is a sufficient area for the demonstration of the technology for WAA purposes and for allowing distribution of seed items within an area of sufficient size to be representative of WAA applications.

6.4.2 Sample Density

The TEM-8 system acquires data at a line separation of 0.75 m and a down-line sample interval of a few centimeters, depending upon the system base frequency and helicopter flight speed. Once the data are fully processed, a sample spacing of about 10 cm is typical. The diameter of the anomalies (1.5-2.5 m or larger) collected at acceptable altitudes results in several measurements per anomalous response.

6.4.3 Quality Checks

Methods utilized by Battelle to ensure airborne survey success on both current and past airborne data acquisition surveys include daily quality assurance (QA)/quality control (QC) checks on all system parameters (e.g., Global Positioning System [GPS], sensor operation, data recording) in the acquired data sets. In addition, 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 was completed. Data are processed, gridded, and reviewed daily to assure ongoing performance. Lines were re-flown when the daily QC checks showed gaps between lines, unacceptable altitude perturbations, or localized noise.

6.4.4 Data Summary

Data were stored on the recording console and transferred at least daily to the desktop processing computer. Backups of data at selected levels of processing were stored on external hard drives or DVDs. The data were then stored on a large hard drive in the Battelle Oak Ridge offices. Upon completion of processing, all data including raw and processed products were archived and retained for future reference.

6.5 VALIDATION

Validation of survey results was conducted on both the FKPBR and PBR-S12 survey sites. Seed items at FKPBR (Table 2) were selected based upon items that were shown to be detectable at Battelle's Ohio UXO test grid under controlled conditions. Without complete excavation of an area, the actual Pd and FP ratio cannot be calculated. For FKPBR, a Pd can be calculated for seed items. The FP ratio cannot be calculated because the non-seed items were not excavated. Dig lists from the airborne data were derived as described later in Section 7. A search radius of 1.50 m was used to determine whether each anomaly constituted a positive hit corresponding to one of the seed items. This search radius and seed item knowledge provided the basis for calculating the Pd and location accuracy of the system.

Five validation grids were selected within the bounds of the PBR-S12 demonstration area. The grids were located in areas that contain a reasonable number of discrete anomalies that could be surveyed and excavated with the allotted budget. EM61 ground surveys were conducted over two of these grids, and a dig list was generated based upon those data. The EM61 anomaly list was edited to remove all hits below a threshold equivalent to the TEM-8 picking threshold. The remaining anomalies were excavated and the Pd, FP ratio, and location accuracy statistics were compiled. A search radius of 1.50 m was used.

7.0 DATA ANALYSIS AND PRODUCTS

7.1 PREPROCESSING

A digital signal processor (DSP) in the console conducts initial data reduction tasks prior to data storage. Data responses are acquired at 10.8 kilohertz (kHz) sample rate and binned into time gates. The DSP also calculates the response values in each of the selected time gates, inverts the responses from the negative transmission pulses, and stacks between two and six sets of values before storage. At 270 hertz (Hz) base frequency, three time gates are available. Maps were produced from a single time gate based on initial assessment of noise properties for each individual time gate. Typically, Bin 2 is selected because it maximizes the spatial resolution of the data and the helicopter noise rejection capabilities. Additional processing steps are conducted subsequently to filter helicopter noise, remove instrument drift, minimize effects of ground conductivity, integrate base station corrected positioning data, and grid the data.

The quantity measured at the receiver is the temporal rate of change in the magnetic field as the field decays from its initial value after the transmitting coil is turned off. Data are sampled at the same frequency that the transmitter coil is driven (270 Hz, 225 Hz, or 90 Hz). All data processing is done using Geosoft Oasis montaj, with the exception of the GPS orientation and positioning data.

The position of each receiver is calculated based on the locations of two GPS antennae, one on the starboard side and the other on the port side of the helicopter. Data streams from both GPS antennae are post-processed using the base station data to provide improved positioning and orientation accuracy. The orientation of the aircraft is calculated from the relative GPS locations of the two antennae. The sensor locations are calculated based on this aircraft orientation and the GPS location of the antennae on the same side of the aircraft.

After converting the raw data to ASCII and importing it into Geosoft, a low-pass filter is applied to remove helicopter rotor noise. A high-pass filter is subsequently applied to remove effects of aircraft motion, vibrations, and ground conductivity.

7.2 TARGET SELECTION FOR DETECTION

Anomalies were picked from the peaks of the gridded data using a threshold based on the background noise levels for that particular data set. The target list was edited to remove obvious artifacts and cultural sources (fences, etc). The final list was sorted based on target amplitude.

Background noise is calculated as the standard deviation of the gridded data. In data sets such as EM and magnetic analytic signal that ideally have a zero-minimum value, the background noise is the value that responses must rise above to be considered anomalous. The background noise is an aggregate of all noise measured by the TEM-8 sensors at the site, incorporating random and systematic sources such as the electronics, platform, local geology, and altitude attenuation. This background value is unbiased by the number and amplitude of anomalies unless the area is so contaminated that there is little or no background to be measured. The amplitude threshold used in anomaly selection is some multiple of this value and represents the minimum SNR of the anomaly list. The optimal threshold may vary depending on the size of the sample set (grid) and the distribution about the mode (geologic noise level). In benign geologies, an SNR of 2 may be acceptable. In other environments an SNR of 10 may be preferred. The area chosen to calculate the noise should be as large as possible, as long as background conditions (geology, altitude, equipment) remain consistent. The threshold for picking anomalies at PBR-S12 was deliberately set low so that performance of low amplitude anomalies could be tested.

7.3 PARAMETER ESTIMATES

This demonstration is centered on detection capabilities of the airborne system. The target location is the only parameter being estimated from this data set. The target location is determined directly from the peak amplitude of the anomaly in the gridded data set. As such, the target location resolution is limited to the grid cell size. No inversion has been performed to estimate other target parameters.

7.4 CLASSIFIER AND TRAINING

The calibration line results were used to establish thresholds for anomaly selection and data filtering. EM anomalies were classified strictly by response amplitude, with anomalies thought to be caused by cultural features excluded. To study the relationship of EM and magnetic anomalies, areas where both types of data occur were evaluated. A determination was performed selecting the closest magnetic anomaly to a particular EM anomaly. If the EM and magnetic anomalies were spatially close enough to one another it was assumed that they were likely to be produced by the same body. A scatter plot was then produced showing the amplitude of the magnetic anomalies plotted against the EM anomalies. There is currently no reliable method for discriminating fragments from intact ordnance using TEM-8 data.

7.5 DATA PRODUCTS

This section provides the summary data products for the report. High resolution maps have been provided to the ESTCP Program Office along with anomaly lists and Geosoft databases.

7.5.1 Test Grid Results

A test grid consisting of two parallel lines was established near the Double Eagle General Aviation Airport located near Albuquerque, NM, in an area that was within a few meters of the 2007 demonstration test grid of the Battelle vertical (magnetic) gradient (VG)-16 and VG-22 systems (Battelle, 2008a). Ordnance that were emplaced on the grid were provided by Battelle, Kirtland AFB, and the U.S. Army Engineering Support Center, Huntsville (USAESCH). USAESCH provided two 4.2-inch mortars, a 105-HEAT round with tail, and a 105 mm projectile. Battelle provided two 81 mm mortars, a 105-HEAT without tail, a 105 mm projectile, two 155 mm projectiles, two 60 mm mortars with tails, and M38s (one largely intact, one intact but without fins, a tail section, and a pair of primer caps). Four test items, unrelated to the ESTCP demonstration were provided by Kirtland AFB and emplaced in the grid. They included an 82 mm Russian projectile with tail, a 120G round, an MK35, and a 155 FWD mortar. The test grid was flown daily, typically at the beginning of the survey day, and additionally was flown at a suite of altitudes. A representative map of the Test Grid results is shown on Figure 6.

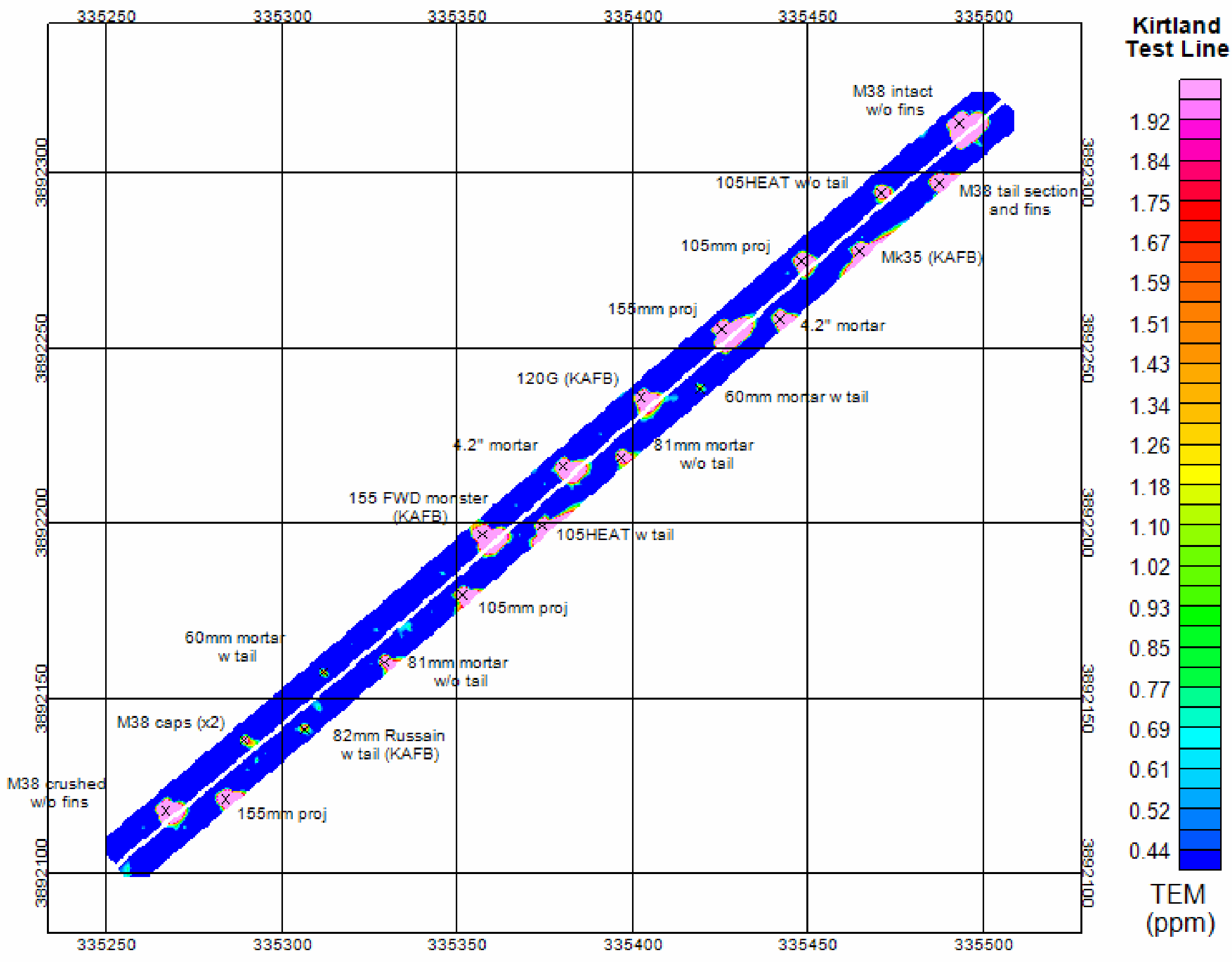

Figure 6. Representative example of FKPBR TEM-8 test grid.

Amplitudes of the anomalies associated with each of the test items for every test flight were compiled and plotted. These were used to assess representative amplitudes for each type of test item as a function of altitude. In turn, these amplitudes were used to select anomaly thresholds for data from the FKPBR and PBR-S12 sites. A summary plot of these data is provided in Figure 7.

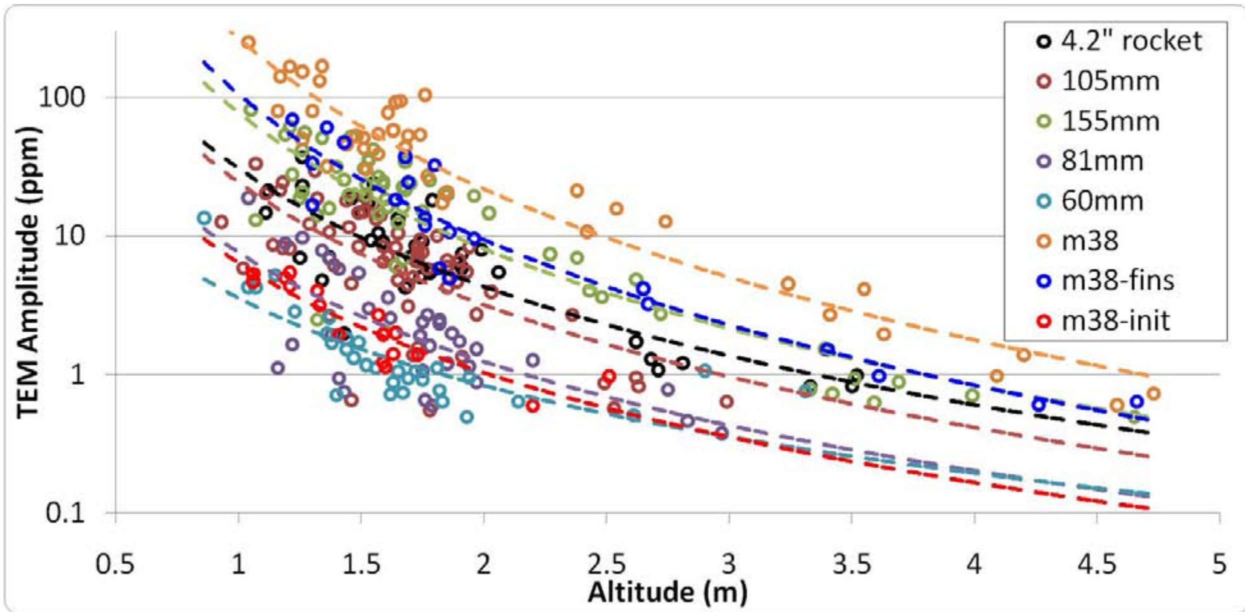

Figure 7. TEM-8 amplitude as a function of altitude for items in the test grid.

Each point represents a measurement from a separate pass over each of the items, including the daily flyovers and a set of flights at selected altitudes that were conducted early in the field deployment.

7.5.2 FKPBR Results

The TEM-8 results of the FKPBR survey area are depicted in Figure 8. The area surveyed encompassed a total of 617 acres. The N-3 target area (located at 330750 mE, 3893900 mN, Universal Transverse Mercator [UTM] Zone 13N) and several of the nearby secondary targets are apparent to the northwest of the blind-seeded area in Figure 8. The density of anomalies falls off to the east and southeast of the N-3 target. Power line interference can be seen along the northern boundary. The mean laser altimeter altitude from the entire 617-acre area was 1.23 m. Average altitude from the laser altimeter within the 100-acre seeded test grid at FKPBR was 0.97 m. The mean sensor altitude within the same area was 1.3 m.

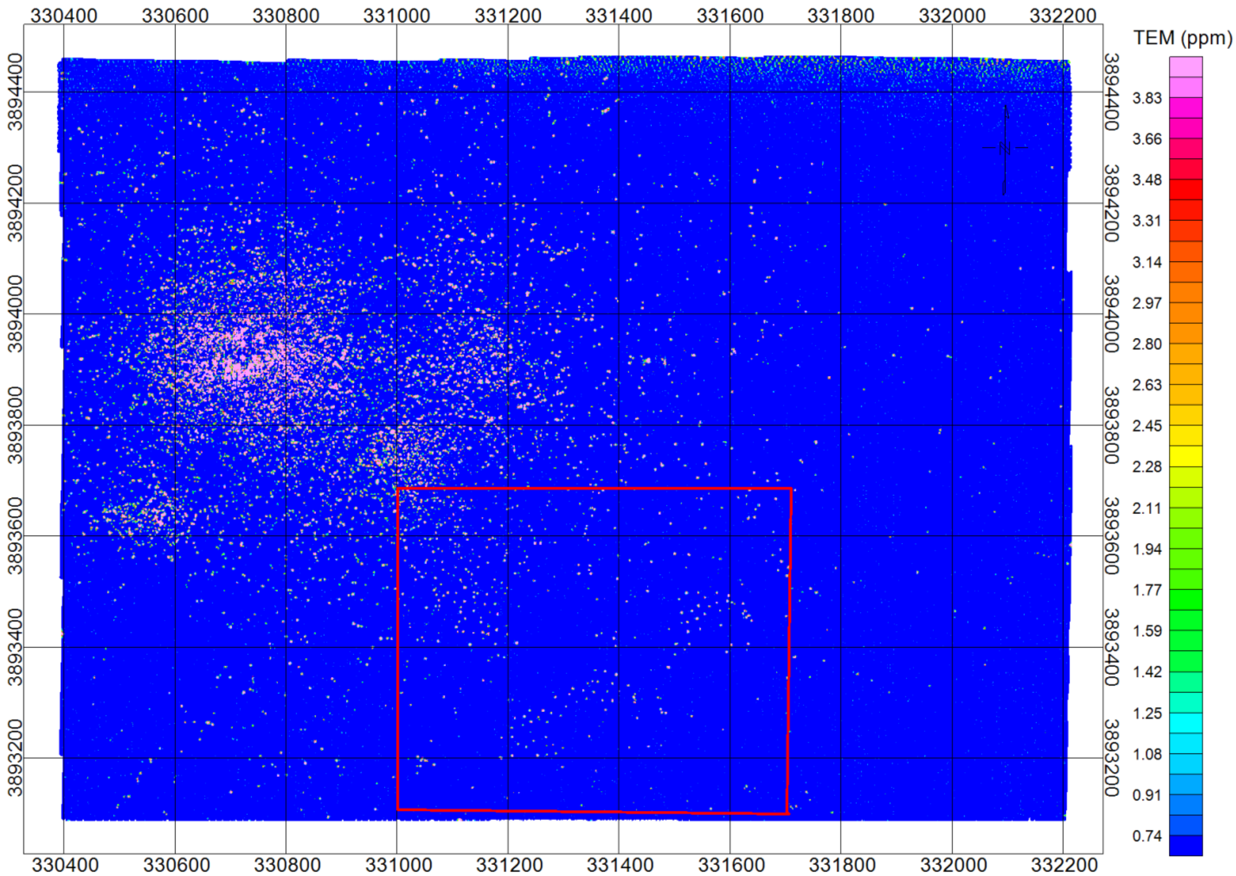

Figure 8. TEM-8 survey results from the FKPBR area.
N-3 target area and two smaller target areas are located
northwest of the seeded area (red box).

An expanded view of the blind-seeded area at FKPBR is depicted in Figure 9. A general southeastward decay in anomaly density is observed in Figure 10 and is presumably associated with the N3 target, along with some concentration of anomalies associated with the blind-seeded items.

Based on the anomaly amplitudes for the four types of items emplaced in the blind-seeded grid, the anomalies were divided into three categories: A, B, and C. Types of ordnance that might cause anomalies in each amplitude category were projected based on these amplitude results. A total of 1292 picks were submitted with 477 in the "A" category, 344 in the "B" category, and 471 in the "C" category. Depth of burial is assumed to be less than 0.3 m and, if deeper, could affect the breakdown of anomalies in the three categories described.

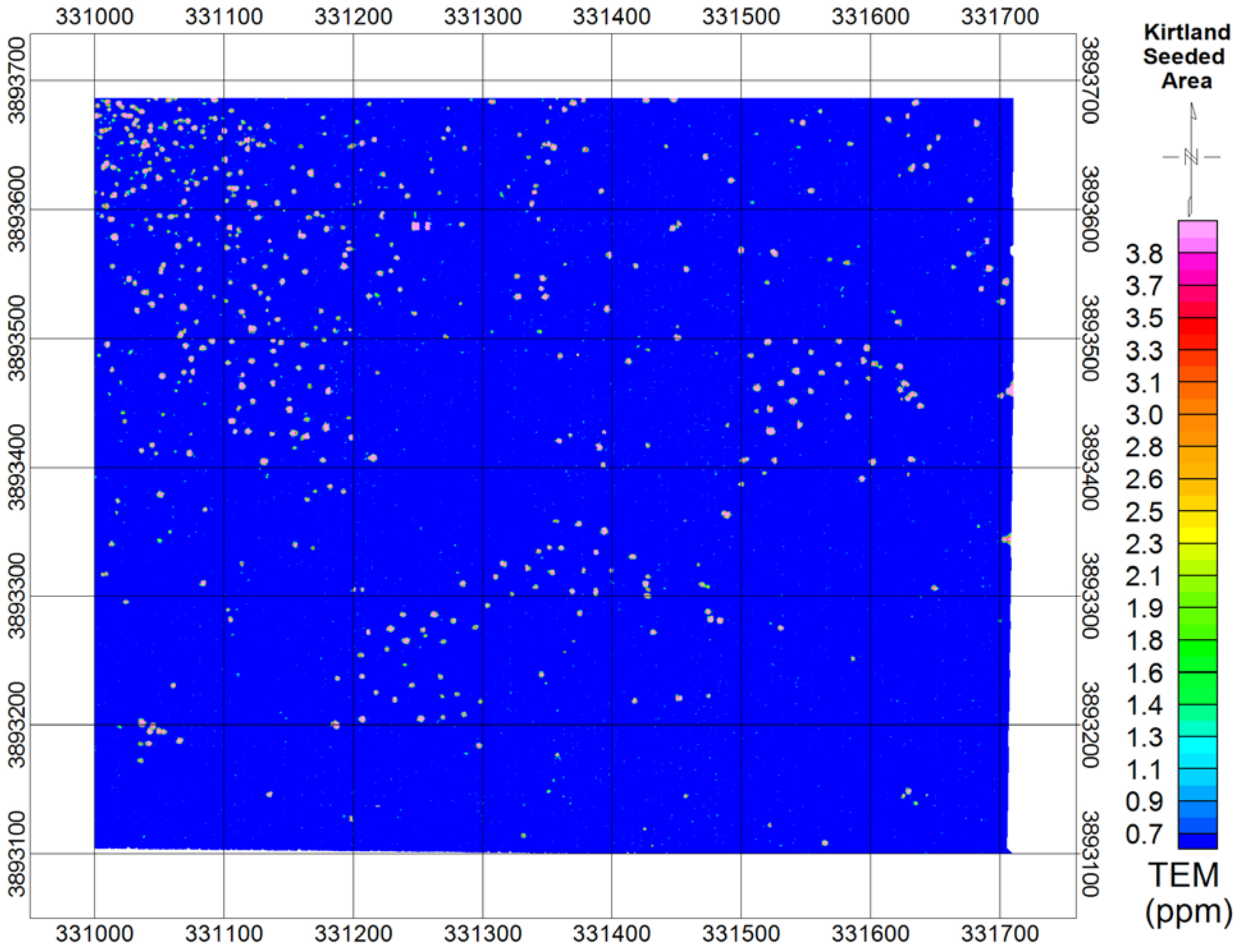

Figure 9. TEM-8 map of the blind-seeded area at FKPBR.

Targets labeled as high priority on the map and "A" on the target list are represented by a large circle and are 4.3 parts per million (ppm) and higher. Targets labeled as medium priority on the map and "B" on the target list are represented by a medium-sized circle and are between 1.3 ppm and 4.3 ppm. Targets labeled as low priority on the map and "C" on the target list are represented by a small circle and are below 1.3 ppm and above 0.9 ppm. However, visual inspection was done resulting in ranking of some higher and some lower on the basis of the profile and map character.

7.5.3 PBR S12 Results

The total area flown at PBR S12 was 444 acres. Before the survey began, it was noted that the study area extended beyond the edge of Mesa Lucero. This resulted in a small portion of the proposed area that could not be surveyed. To compensate for this, additional lines were flown along the northern boundary of the proposed area, ultimately leading to an 11% increase in the total survey area. The plan view of the survey area is shown in Figure 10. The edge of the mesa is apparent in the southeast quadrant of the map where data were not taken.

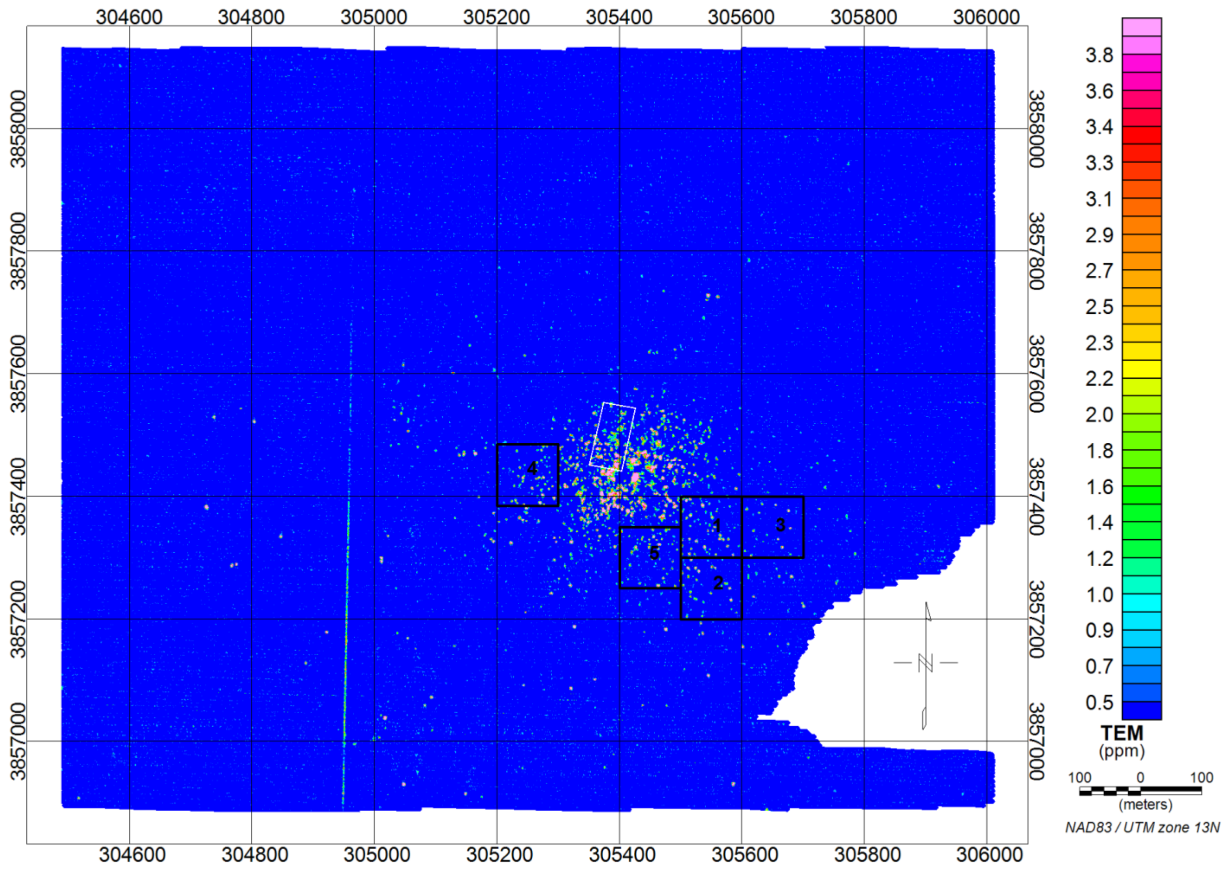

Figure 10. TEM-8 survey area at PBR S12.

Five areas were selected for possible ground-based mapping and validation, based on the airborne survey results. These five areas (numbered 1 through 5 on Figure 10) were chosen due to the modest number of large anomalies and because the overall density of anomalies was lower than in the central target area, indicating that there were few overlapping anomalies in the data. From these five areas, AMEC selected two, Areas 1 and 4, for validation. Figure 11 depicts the TEM-8 maps for Area 1 at PBR-S12.

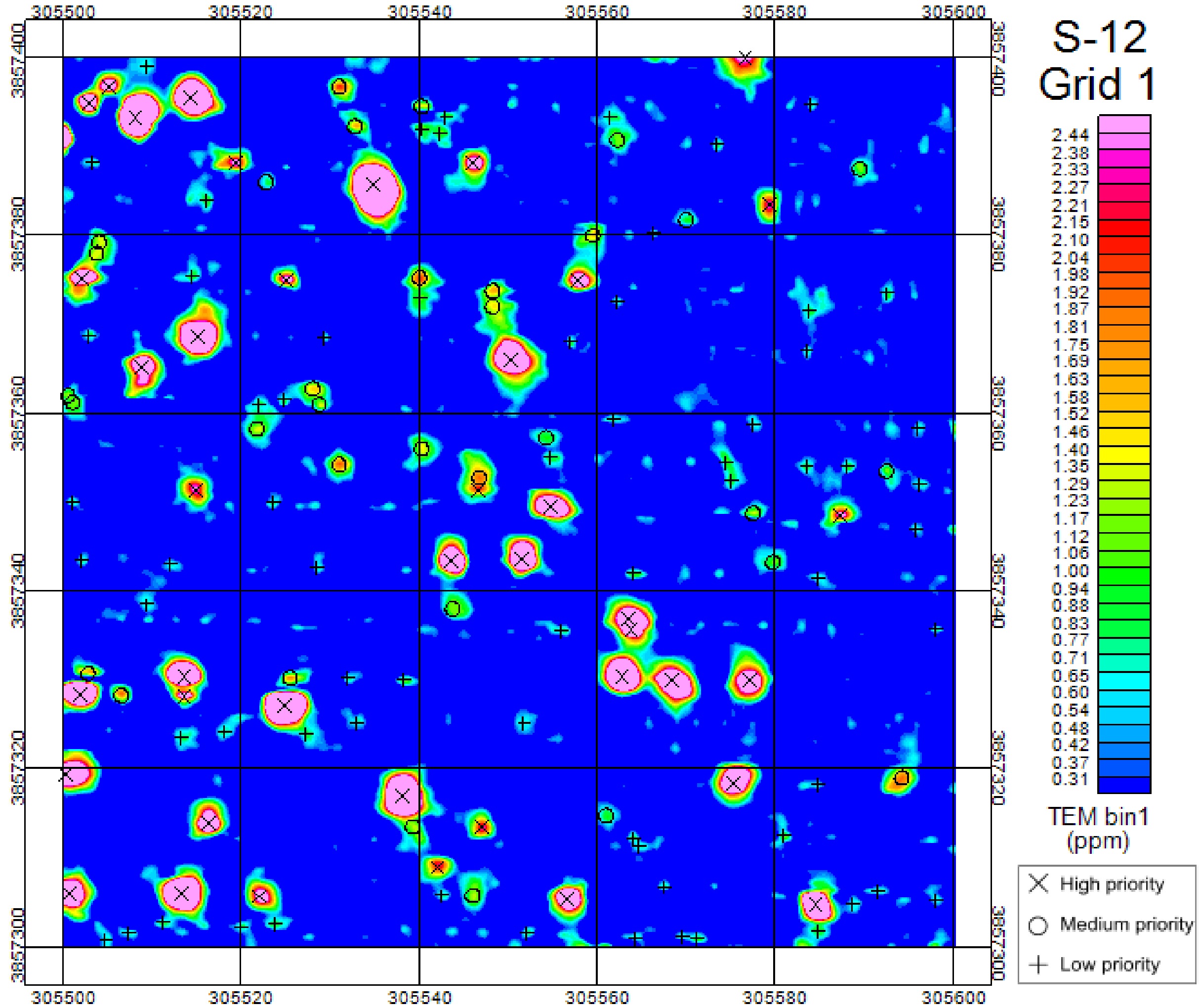

Figure 11. TEM-8 map for Area 1 at PBR-S12.
Symbols on the maps are associated with anomalies picked for three different ranges of amplitudes.

Dig lists were prepared and are listed by dig priority. The dig priority is represented by different symbols in Figure 11. Thresholds for Grids 1 and 4 were selected on the basis of measurements of M38s and M38 scrap at the Kirtland Test Grid (Section 7.5.1). The priority “A” anomalies are considered high priority and are represented on the map with an “X”. Circles are used to represent medium priority targets, which are also likely UXO fragments or munitions and explosives of concern (MEC), and are appropriate for investigation. The “C” anomalies, represented by a “+” are thought to be predominantly noise. The thresholds between the A, B, and C categories are generally 2.15 and 1.08 ppm respectively, but after reviewing each anomaly, some have been ranked higher and some lower on the basis of their profile and map character. A lower bound of 0.65 ppm was placed on the “C” anomalies. The total number of anomalies selected in each of the three categories is listed in Table 5.

Table 5. Numbers of anomalies picked for each of the five validation areas at PBR S12.

Area	Priority A	Priority B	Priority C	Total
1	**41**	**33**	**62**	**136**
2	24	22	60	106
3	13	18	70	101
4	**34**	**40**	**52**	**126**
5	36	44	55	135

An altitude map for the study area at S-12 is shown in Figure 12. The mean altitude at the S-12 survey site as a whole was 3.73 m. In the north, altitudes tended to be higher due to vegetation (Figure 12). Mean altitudes from the laser altimeter for Area 1 was 2.016 m, and for Area 4 was 2.094 m. Mean sensor altitudes are generally about 0.3 m higher than the laser altitudes.

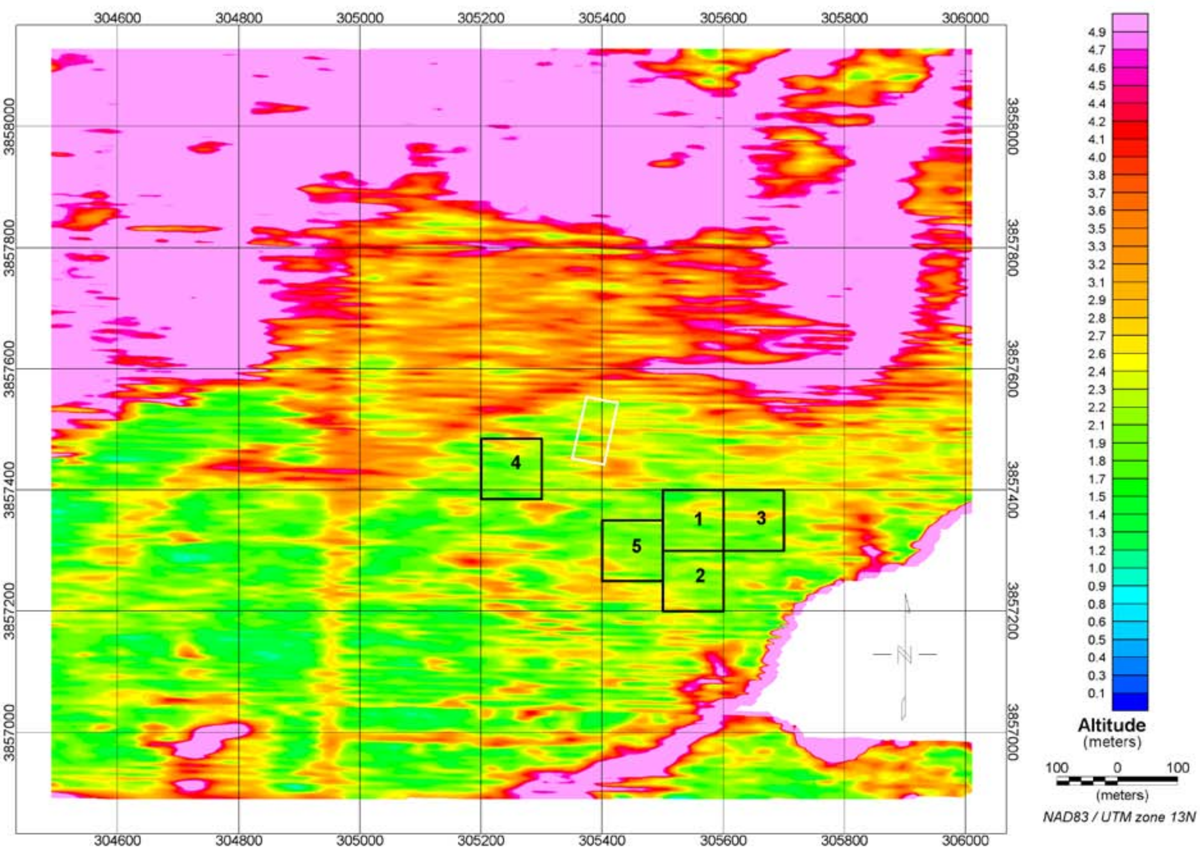

Figure 12. Altitude map of the entire S-12 study area.
Note higher altitudes in tree-covered areas in the north and a linear north trending feature associated with a fence in the western half of the study area.

8.0 PERFORMANCE ASSESSMENT

Effectiveness of the demonstration is determined from comparisons of the processed and analyzed results from the demonstration survey and the established ground truth. Some qualitative parameters may be judged against results of previous airborne and ground-based surveys at FKPBR and elsewhere. Evaluation of seeded items provides a basis for assessing detection of small ordnance items. These comparisons include both the quantitative and qualitative items described in this section that are documented fully in project reports available from ESTCP. Demonstration success is defined 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 Section 4.1. Methods utilized by Battelle 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) 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.

Data collection occurred at the specified flight altitudes over the various test areas. Table 1 identified the expected performance criteria for this project, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative).

8.1 FKPBR SEEDED AREA

After the AMEC/Battelle team submitted the target list to ESTCP for the FKPBR seeded area, the IDA conducted a comparison of the lists with the actual locations of seed items. In all, 110 items were emplaced in the 100-acre grid. Validation results compiled by IDA are listed in Table 6.

8.1.1 Detection

The performance results demonstrate that the TEM-8 system was successful in detecting 109 out of the 110 seed items for a 1.5 m search radius and 108 out of 110 for a 1 m search radius. The one missed item was a 4.2-inch mortar, which was 1.51 m from the nearest item on the dig list. The amplitude response of the seed items was larger than anticipated from the test grid. All but four of the seeded items had amplitudes in the “A” category, exceeding 4.3 ppm. The other four items were all in the “B” category, and all had amplitudes exceeding 1.3 ppm. The amplitude variance is thought to be related to the nature of flights over the test grid. Although test items were detected in flights over the test grid, there was often a lateral offset (greater than the 0.375 m maximum offset if ordnance is within the receiver array) between sensors and targets, resulting in lower measured amplitudes. Such offsets do not generally occur when the system is conducting a full density survey.

Table 6. Dig results for the blind-seeded area at FKPBR. (Mean and standard deviation of miss distances in meters)

Halo Radius	UXO Type	Total # Seeds	# Seeds Detected	Pd	Mean *(Xi)*	Mean *(Yi)*	Std Dev *(Xi)*	Std Dev *(Yi)*	Mean *(miss dist)*	Std Dev *(miss dist)*
0.5 m	All UXO	110	87	0.79	0.02	0.00	0.22	0.16	0.24	0.13
0.5 m	105 mm P	8	5	0.63	-0.14	0.03	0.18	0.06	0.18	0.14
0.5 m	4.2 inches	52	38	0.73	0.03	0.02	0.21	0.19	0.25	0.12
0.5 m	155 mm P	24	22	0.92	0.07	-0.02	0.22	0.11	0.22	0.11
0.5 m	81 mm M	12	9	0.75	0.06	0.03	0.29	0.19	0.29	0.19
0.5 m	105H	14	13	0.93	-0.06	-0.04	0.19	0.19	0.25	0.10
1 m	All UXO	110	108	0.98	0.09	-0.02	0.35	0.17	0.33	0.22
1 m	105 mm P	8	8	1.00	0.22	-0.04	0.52	0.11	0.42	0.37
1 m	4.2 inches	52	50	0.96	0.14	-0.01	0.34	0.20	0.35	0.21
1 m	155 mm P	24	24	1.00	0.02	-0.01	0.28	0.11	0.25	0.15
1 m	81 mm M	12	12	1.00	-0.02	0.01	0.43	0.18	0.38	0.24
1 m	105H	14	14	1.00	0.01	-0.04	0.33	0.18	0.30	0.22
1.5 m	All UXO	110	109	0.99	0.09	-0.02	0.36	0.17	0.34	0.23
1.5 m	105 mm P	8	8	1.00	0.22	-0.04	0.52	0.11	0.42	0.37
1.5 m	4.2 inches	52	51	0.98	0.16	-0.02	0.36	0.20	0.37	0.23
1.5 m	155 mm P	24	24	1.00	0.02	-0.01	0.28	0.11	0.25	0.15
1.5 m	81 mm M	12	12	1.00	-0.02	0.01	0.43	0.18	0.38	0.24
1.5 m	105H	14	14	1.00	0.01	-0.04	0.33	0.18	0.30	0.22

M = mortar, P=projectile, h=howitzer, Std Dev = standard deviation, miss dist = miss distances in meters, Xi = easting offset in meters, Yi = northing offset in meters, m = meters, mm=millimeters, Pd = probability of detection

All 109 detected test items were among the first 565 listed on the prioritized dig list. The remaining 727 anomalies on the dig list, categorized as false positives on the pseudo-receiver operating characteristic (ROC) curve, are of unknown origin. Because the 100-acre blind-seeded area lies within 300 m of the center of the N3 target and overlaps some of the previously identified ancillary targets, it is probable that a large portion of these 727 anomalies are also ordnance related. This cannot be determined without intrusive validation. A pseudo-ROC curve for the FKPBR is provided in Figure 13.

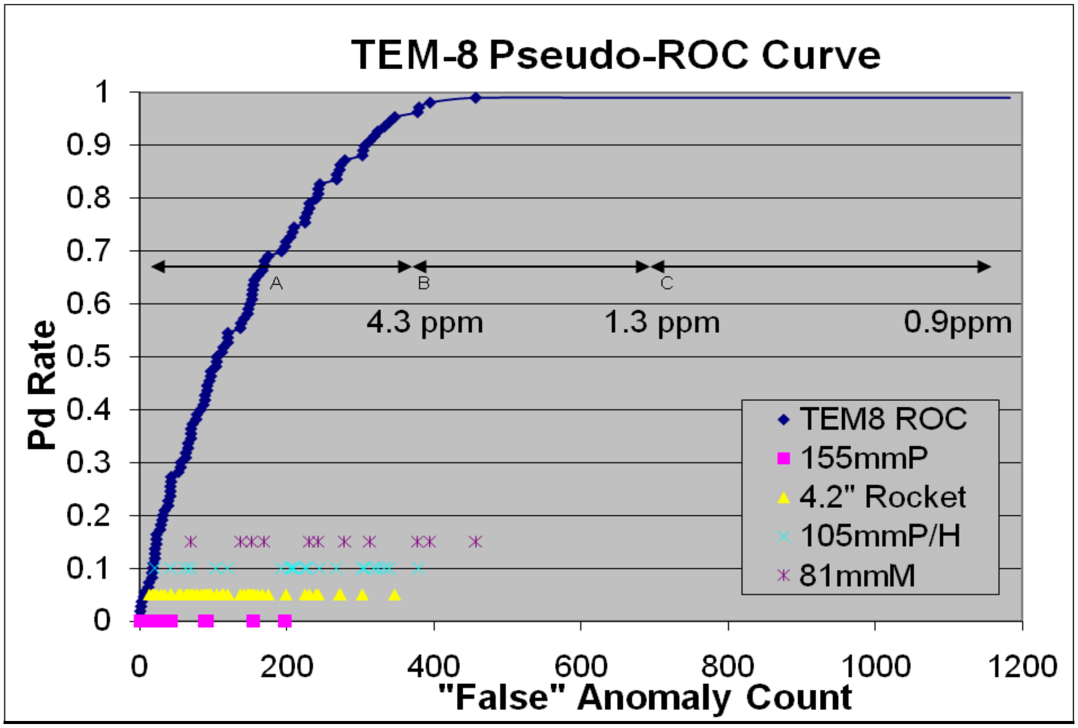

Figure 13. Pseudo-ROC curve for the FKPBR blind-seeded area.
The false anomalies are of unknown origin, and given site conditions, it is very likely that many of them are ordnance-related.

8.1.2 Positional Accuracy

Positional accuracy for the FKPBR site was much better than required, based on the guidelines established in advance of the survey (Figure 14). The mean miss distance was 0.34 m with a standard deviation of 0.23 m. The missed 4.2-inch mortar is included in this figure for completeness, near the eastern axis of the plot at 1.51 m offset, 1 cm from inclusion as a “hit.” The positioning errors are clearly skewed in an east-west direction, perpendicular to the flight path. This may be attributed to the larger sample interval in that direction, determined by the receiver coil spacing, whereas the on-line measurements occur at intervals of approximately 0.1 m.

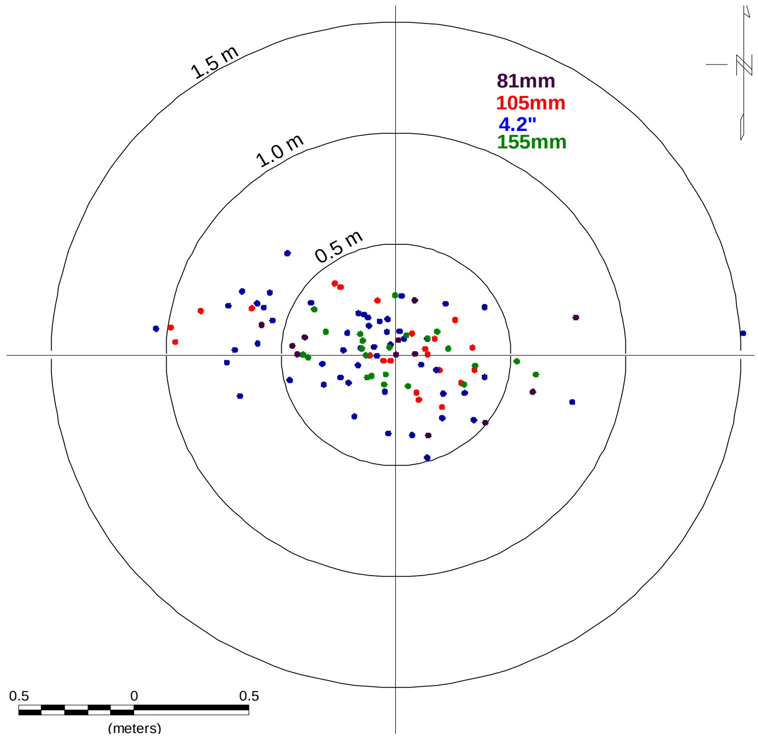

Figure 14. Positional accuracy for the FKPBR blind-seeded targets.

8.1.3 Noise Assessment at FKPBR

A comparison of TEM-8 and airborne magnetometer SNR was performed, using grids from the TEM-8 data and 2005 Sky Research "Helimag" data provided by ESTCP. For both the TEM-8 and Helimag data sets, two areas were chosen for assessment. The western area was selected as representative of a quiet magnetic environment, while the eastern block was representative of a noisier magnetic environment. There are no blind-seeded anomalies within either block. The average signal in the entire 600-acre area was estimated by taking the average of the peak of 770 coincident anomalies (within 1 m) picked from the Helimag and TEM-8 gridded data. The standard deviation of the profile data was calculated within each of the blocks for both data sets to provide a measure of noise. Noise measures were similar for the TEM-8 data in the two blocks but varied by a factor of about 5 for the magnetometer data (Table 7). Overall, the TEM-8 exhibited an SNR of 0.81 times that of Helimag in the quiet area and 4.0 times that of Helimag in the noisy area.

Table 7. SNR estimates for the FKPBR study area.

	TEM-8-West	TEM-8 East	Helimag West	Helimag East
Estimated noise	0.26 ppm	0.29 ppm	1.27 nT/m	6.78 nT/m
Estimated signal	11.27 ppm	11.27 ppm	66.81 nT/m	66.81 nT/m
SNR	42.67	39.31	52.48	9.86

ppm = parts per million, nT/m = nanoteslas per meter

Magnetometer data were also acquired in 2009 with the seed items present at the FKPBR site for ESTCP by Sky Research (Wright and Fonda, 2009). The results of that survey are not presented here, but should be available in other ESTCP reports and in UXO Forum online presentations.

8.2 PBR S12 VALIDATION

8.2.1 EM61 Data and Selection of Anomalies for Validation

EM61 data were acquired in Grids 1 and 4 at PBR-S12 for validation of the TEM-8 data. Results for Grid 1 are shown in Figure 10. EM61 anomalies were picked in three groups, selected to correlate with the three TEM-8 categories. The three groups were based on measured TEM-8 and EM61 results from the calibration grid. The EM61 results represent a standard EM61-MK2, bottom coil, gate 1. The resulting threshold conversions, based on these measurements, are provided in Table 8.

Table 8. Threshold values for TEM-8 and equivalent thresholds for EM61.

Anomaly Group	TEM-8 Amplitude Range	EM61 Equivalent Range
A	> 2.16 ppm	>100 mV
B	1.08-2.16 ppm	40-100 mV
C	< 1.08 ppm	<40 mV

ppm = parts per million, mV = millivolts

8.2.2 Detection Results

From the EM61 surveys, 222 anomalies were picked in Grid 1 (Figure 15) and 180 anomalies in Grid 4 (Table 9). From the two lists, all of the TEM-8 Category "A", most of the "B" anomalies and half or more of the "C" anomalies were selected for excavation. Total number of digs in Grid 1 was 168 (EM61 Digs + TEM-8 Digs – Overlap), and in Grid 4 was 157. These are tabulated in Table 9. All EM61 anomalies in both grids yielded detections; 14 of the TEM-8 digs in Grid 1 and 22 in Grid 4 yielded false positives. Figure 16 shows the breakdown of TEM-8 performance for all excavated anomalies (whether selected from TEM-8 or EM61 dig lists) by weight. All but two of the excavated items over 5 lb were detected by TEM-8, and 78% of the excavated items weighing between 1 and 5 lb were detected. TEM-8 detected 31% of the M38 frag that weighed less than 1 lb.

Table 9. Dig results for PBR S12 grids.
TEM-8 picks are further divided into the A, B, and C categories.
Numbers of anomalies picked by both EM61 and TEM-8 are listed as "overlap."

Grid 1

Source	Picks	Digs	Detects
EM61	**222**	**143**	**143**
TEM-8	**136**	**100**	**86**
TEM-8 A	41	41	39
TEM-8 B	32	32	28
TEM-8 C	63	27	19
Overlap	77	75	75

Grid 4

Source	Picks	Digs	Detects
EM61	**180**	**129**	**129**
TEM-8	**126**	**93**	**71**
TEM-8 A	34	34	34
TEM-8 B	39	39	31
TEM-8 C	52	20	6
Overlap	69	66	66

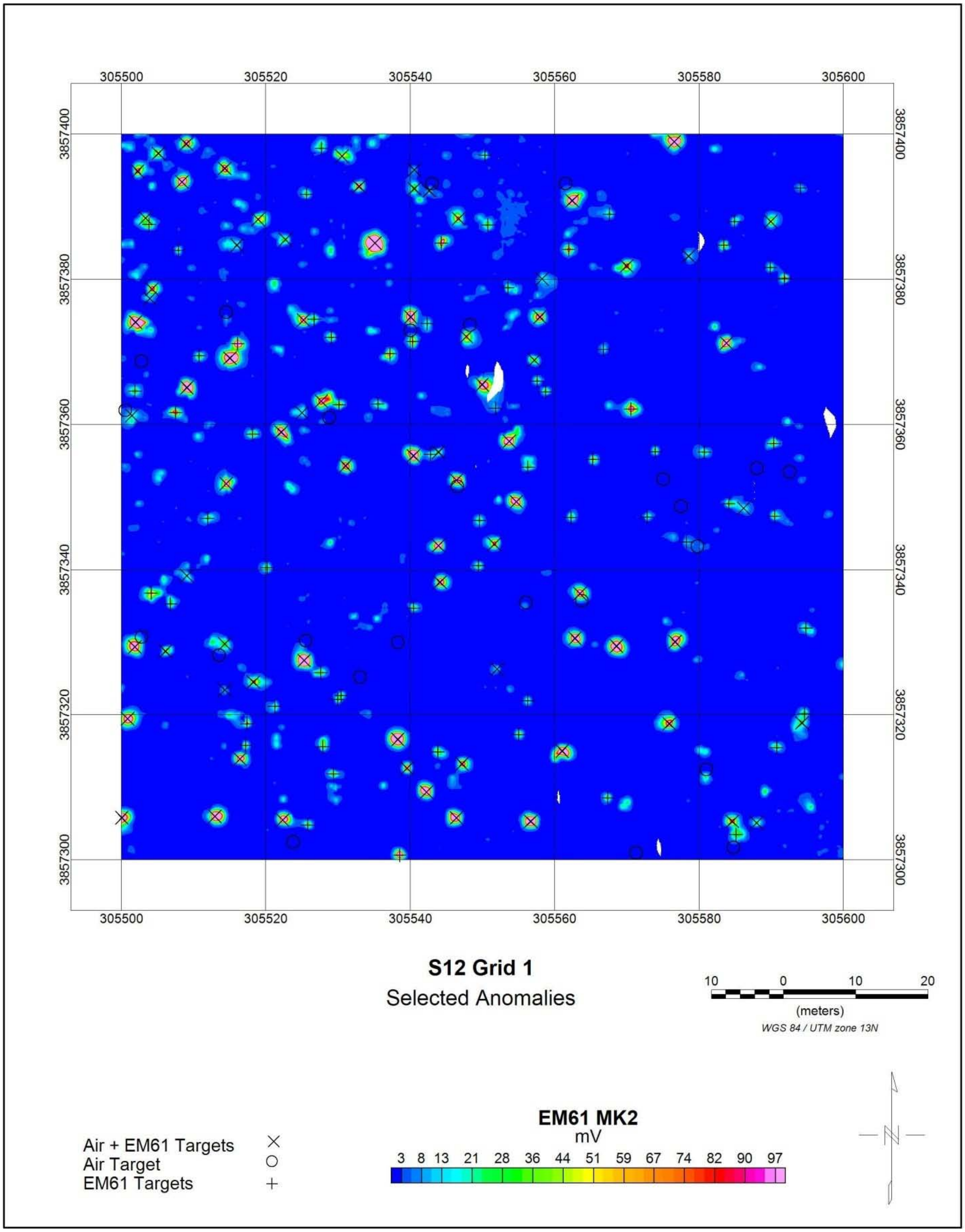

Figure 15. EM61 map of Grid 1 at PBR-S12.

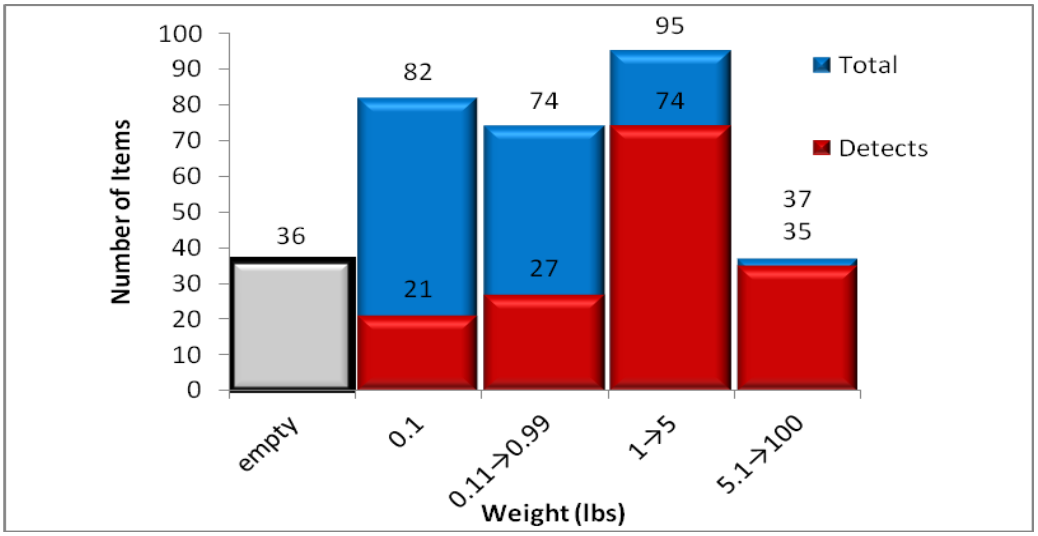

Figure 16. Graphical representation of the distribution of detects to total picks as a function of weight.

Four weight ranges are shown, and these are clearly not linear in the range of weights. Detection falls off sharply for items smaller than one pound, but it is noteworthy that some of the low mass items are even detected.

Table 10. Summary of targets detected by EM61 and TEM-8.

	Excavated	Detected by EM61	Detected by TEM-8
Mostly intact M38	38	37	36
Nose cone	46	45	34
Initiator	42	41	6
2-inch band	22	21	4
Wire	6	6	0

8.2.3 Positional Accuracy

The positional accuracy of the TEM-8 system at PBR-S-12 is shown in Figure 17. The mean miss distance for successful digs associated with TEM-8 anomalies was 0.58 m with a standard deviation of 0.34 m. There were two digs outside the 1.5 m search radius. The distribution of positioning errors for PBR-S12 is larger N-S than E-W and skewed opposite to the direction that it was skewed for FKPBR (Figure 17) because the flight direction was shifted about 90 degrees. This larger standard deviation is not fully understood but could be related to the way that the locations of excavated targets were measured, the accuracy of positioning for those items, or other factors.

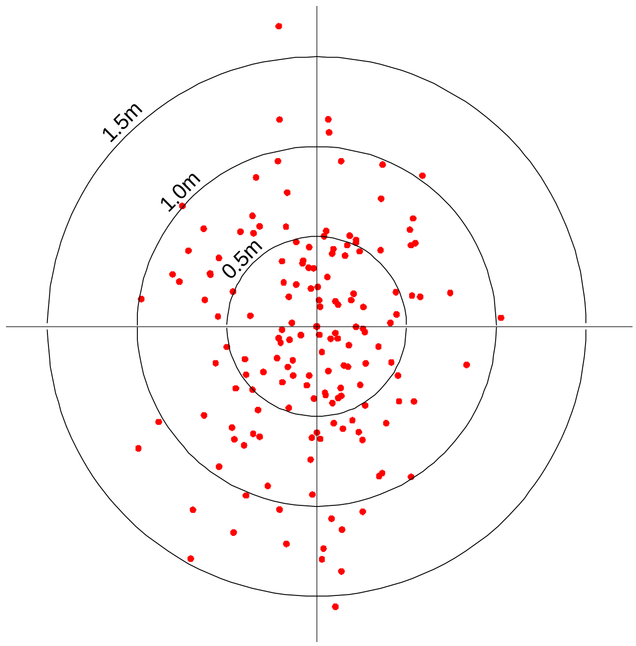

Figure 17. Positional errors for PBR-S12 validations.

8.2.4 Noise Assessment at PBR-S12

A comparison of TEM-8 SNR with ORAGS-Arrowhead airborne magnetometer SNR was performed, using data acquired in 2002 by the Battelle team while they were employed at Oak Ridge National Laboratory. Because no anomalies could be recognized in the total field magnetometer data from the PBR-S12 target, the value for signal was established from measurements of a largely intact M38. We used the same M38 as a test item for the TEM-8 test grid at FKPBR and for the VG system at Twentynine Palms, CA, in January 2008. The TEM-8 response to this M38 was 67.3 ppm, and the analytic response (taken from the gridded analytic signal data from the Twentynine Palms test grid) was 46.6 nanoteslas per meter (nT/m).

At PBR-S12, a 2.6-acre area was selected for noise assessment based on the sparseness of TEM-8 anomalies in that area and distance from the target center. As before, the standard deviation of the profile data was calculated within each of the blocks for both data sets to provide a measure of noise. Based on these estimations, the SNR for TEM-8 and ORAGS-Arrowhead systems at S-12 were determined, as summarized in Table 11.

Table 11. SNR comparison for an M38 at PBR-S12.

	TEM-8	ORAGS-Arrowhead
Estimated noise	0.23 ppm	204.5 nT/m
Estimated signal	67.3 ppm	46.6 nT/m
SNR	292.7	0.23

nT/m = nanoteslas per meter , ppm = parts per million

The TEM-8 SNRs for M38s at PBR-S12 are larger than those reported at FKPBR because of the large response generated by M38s in both magnetic and electromagnetic systems. The extreme improvement in SNR for TEM-8 over the magnetometer system is due primarily to the very large noise levels that occur with magnetometers over basalts. The important result here is the ratio of TEM-8 SNR to Arrowhead SNR, nearly 1300 times better, which is representative of the improvement that can be expected when using electromagnetic systems rather than magnetometer systems in severe basaltic environments.

8.3 DISCUSSION

By all measures, the performance of the TEM-8 at FKPBR and PBR-S12 exceeded expectations, as indicated by the performance metrics. Nearly all blind-seeded items were detected with amplitudes that were well above the noise floor, suggesting that, in hindsight, it would have been better to have emplaced smaller items, such as 60 mm mortars in addition to the ones that were seeded. Test grid results (Figure 8), which included TEM-8 measurements of 60 mm, support a view that some portion of these would have been detected had they been included. The PBR-S12 results demonstrated the ability of the system to detect a portion of the frag smaller than 1 lb.

In both areas, the system also appears to indicate lower numbers of false positives than typically seen with magnetometer systems. At the FKPBR blind-seeded grid, 109 seeded items were detected within the first 565 prioritized digs. In this case, many, if not most of the unknown anomalies are likely associated with ordnance or frag associated with the periphery of the N-3 target or its satellite targets. Figure 9, which shows the TEM-8 map of the 617-acre area at FKPBR, shows concentrations of anomalies that appear to be like those of bombing targets, which seem to continue into the 100-acre blind-seeded area. Similarly, approximately 81% of the TEM-8 anomalies that were excavated in Grids 1 and 4 at PBR-S12 were shown to be associated with ordnance or frag.

In determining the suitability of an area for TEM-8 operation, one of the most critical factors is the altitude above ground surface that the site may be flown. Figure 12 provides a basis for estimating the sensitivity of the system to various types of ordnance as a function of altitude. The results of this study indicate that TEM-8 should be a valuable tool for WAA surveys, particularly in those areas where geologic interference is problematic for magnetometer systems.

This page left blank intentionally.

9.0 COST ASSESSMENT

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

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site, fuel costs, terrain, and vegetation conditions impacting flight line configuration, turnaround, etc.
- Total size of the blocks to be surveyed
- Length of flight lines
- Extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives, which dictate survey altitude and number of flight lines
- Temperature and season, which control the number of hours that can be flown each day
- Location of the site, which can influence the cost of logistics
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction
- Swath width and continuity—some systems require interleaving for full coverage, and hence can require more flying than others.

The difference in cost for the TEM-8 electromagnetic and VG-16 vertical magnetic gradient systems lies largely in their swath. The VG-16 system acquires data along an entire 12 m swath with each pass, while the TEM-8 requires twice as many flight passes to cover the same area. This causes the acquisition cost to be nearly double for the TEM-8.

9.1 COST MODEL

Cost information associated with the demonstration of the TEM-8 airborne technology was 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 demonstrations and surveys are very much dependent on 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, vertical magnetic gradient, time domain electromagnetic induction) so that a universal formula cannot be fully developed. These costs include both operational and equipment costs associated with system application; mobilization and demobilization of equipment and personnel; salary and travel costs for project staff; subcontract costs associated with helicopter services, support personnel, and leased equipment; and costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration.

Table 12. Cost elements for TEM-8 survey demonstration at FKPBR and PBR-S12.

Cost Category	Sub Category	Details	Quantity	Battelle Cost[1] ($)	AMEC Costs ($)
Pre-survey (Start-up)	Site characterization	Site inspection	4 days		$14,859
		Mission plan preparation & logistics	18 days	$31,434	$33,615
		Calibration site preparation	2 days	$8555	$5,822
	Mobilization	Equipment/personnel transport (includes travel)	3 days	$9641	
		Helicopter/personnel transport (includes travel)	4 days	$24,331	
		Unpacking and system installation	1 day	$7073	
		System testing & calibration	1 day	$2796	
			Pre-survey subtotal	**$83,830**	**$54,296**
Capital equipment	System use rate ($700/day)		25 days	$17,500	
			Capital subtotal	**$17,500**	
Operating costs	Data acquisition	Helicopter time, including pilot and engineer labor	18 days (74 hours airtime)	$100,664	
	Operator labor		14 days	$8100	
	Field data processing	Geophysicist	18 days	$39,442	
	Field support/management	Geophysicist/manager	18 days	$24,256	$17,544
	Maintenance	Geosoft software maintenance		$0	
	Hotel, air fares, and per diem	Survey team	18 days	$7267	$4,687
	Fuel truck	Remote refueling[2]	4 days	$800	
	Airport landing fees and FBO fees		18 days	$1170	
	Project management		4 days	$6930	$38,032
			Operating cost subtotal	**$188,629**	**$60,263**
Post-survey	Demobilization	Disassembly from helicopter, packing, and loading for transport:	1 day	$6391	
		Equipment/personnel transport (includes travel)	3 days	$9821	
		Helicopter/personnel transport (includes travel)	3 days	$18,364	
	Additional data processing, analysis, interpretation, and reporting (Oak Ridge)			$119,703	
	Geophysical investigation	Mobilization, validation, demobilization			$106,719
	Reporting (AMEC)				$20,636
			Post-survey subtotal	**$154,279**	**$127,355**
			Total cost	**$444,238**	**$241,914**
			Total costs combined	**$686,152**	

[1] Includes all overhead and organization burden, fees, and associated taxes
[2] Remote refueling was required only at the PBR-S12 site.
*All costs reported are preliminary estimated costs through October 2009.

9.2 COST DRIVERS

The major cost drivers for an airborne survey are the cost of helicopter services and the data processing and analysis associated with the acquired data. In terms of tasks, these constitute the majority of the field-related costs (i.e., mobilization, data acquisition, and demobilization costs), which represent the single largest cost item for an airborne survey project.

As mentioned, helicopter services are a significant component of the costs associated with the airborne survey project. This cost element is included in the mobilization, data acquisition, and demobilization tasks. The costs include helicopter airtime, fuel, pilot, aircraft engineer (mechanic), airport landing and hanger fees (if applicable), and per diem for the flight crew. Depending on the survey location (distance from home base), mobilization and demobilization costs can be significant when compared to the overall data acquisition cost. Additionally, the type of survey, weather conditions, length of survey day, terrain, vegetation, and cultural features will greatly influence this cost element.

Data processing and analysis functions constitute the majority of the remaining costs associated with the field-related costs for a survey. As with helicopter services, mobilization and demobilization of the airborne survey equipment and the geophysical survey team is also a major task in terms of cost. This is typically a function of distance from the home base or previous survey location (i.e., if shared mobilization/demobilization is involved) to the intended survey project site. Peripheral costs associated with this demonstration-validation project, such as ground truth and excavations, are not part of the cost analysis in this section and the following section (Sections 9.2 and 9.3).

The sensitivity of the overall cost to these drivers can be modeled under several different scenarios. Helicopter time on site is a factor of several variables. The first is the number and dimensions of the survey blocks. The greatest amount of non-survey time is spent in turns at the end of each line in preparation and alignment for the next line. As such, fewer and longer survey lines are more efficient than numerous shorter ones. Typically, lines longer than approximately 3-5 km do not gain additional efficiencies. One mitigating factor to this limit is a pilot performance issue. Longer lines typically require more frequent re-flights since it is more difficult to maintain precision flying over such long lines. In practice, a maximum line length of 5 km is recommended.

As discussed above, other major cost drivers are mobilization, data processing, and demobilization. These costs are a function of project size and transportation distance. Processing costs and data delivery times typically decrease with experience at multiple sites.

9.3 COST BENEFIT

This section compares costs of three different survey technologies. These include man-portable, the ground-based MTADS system, and the TEM-8 airborne electromagnetic system. Operational costs for the TEM-8 system are equivalent to those of the Battelle VG-22 system because of their similar swath width. The difference in swath width for both systems results in higher cost than for the VG-16 vertical magnetic gradient system, which has a 12 m swath width. However, as noted throughout this report, the TEM-8 system was designed for use in areas where magnetometer systems are inappropriate.

Based on several sources of information regarding the deployment of ground-based towed array systems on a UXO contaminated site, five scenarios are presented for the purpose of comparing airborne surveys to ground-based surveys. These sources of information are generally informal and include discussions both with industry and USAESCH staff experienced in the application of ground-based towed array surveying equipment and projects.

Following Harbaugh et al. (2007), we assume that the two ground-based technologies might survey only 2% of the total area of concern, while the airborne systems would survey between 2% and 100%. This level of ground surveying has been used in ESTCP's WAA Pilot Program. We also include higher proportions of ground surveying for comparison purposes. Harbaugh et al. (2007) have proposed fixed costs of $75,000 (mobilization, demobilization, reporting) and acreage costs of $500/acre for use of MTADS at two sites. We assume that costs for a towed EM61 array would be roughly equivalent to those for the MTADS towed array. Similarly, Harbaugh et al. submit fixed costs of $45,000 plus acreage rates of $1540/acre for man-portable EM surveys at these sites.

Comparisons between airborne, vehicle, and man-portable magnetometer surveys are summarized in Table 13. These scenarios address sites of 1000 to 50,000 acres of geographic extent, with varying rates of coverage from 100% to 2%. TEM-8 airborne costs range from $136 to $291 per acre for a 100% coverage survey using the TEM-8 WAA system. These costs include a nominal $50,000 mobilization cost from our bases of operation in Tennessee and Ontario, Canada. Airborne costs are corroborated by recent work with magnetometer systems for non-ESTCP sponsors, e.g., the surveys at Kirtland AFB, Fort McCoy, Camp Lejeune, Pinecastle Range Complex, and Fort Ord.

Man-portable systems generally have significantly higher acquisition costs than airborne systems (ranging from $500 to $3000 per acre, depending on site conditions); are extremely time-consuming; and may present risks to personnel, equipment, and the environment. Neither the airborne nor the ground-based survey costs include the cost of excavation. Comparison of the airborne array to a ground-based towed array similar to MTADS maybe more representative.

The extent of coverage possible with an airborne system renders comparisons to handheld man-portable systems somewhat inappropriate. It is readily apparent that the advantage of airborne surveys over ground-based surveys becomes greater as the area of concern becomes larger. These figures illustrate that for EM surveys, man-portable platforms are most cost effective for sites requiring less than 30 acres of actual coverage; vehicular systems are most effective for 30-400 acres; and airborne systems are most effective for sites larger than 400 acres.

Table 13. Costs per acre for airborne, ground vehicle, and man-portable survey platforms for varying WAA survey densities.

Shaded cells are minimum cost. Man-portable are most cost effective for 0-30 acres actual coverage, vehicular systems from 30-400 acres and airborne over 400 acres. All costs are in thousands of dollars and include fixed mobilization costs.

TEM-8

Acres	100%	50%	25%	10%	2%
1000	$291	$234	$189	$184	$180
2000	$433	$319	$242	$219	$214
5000	$833	$518	$380	$286	$257
20,000	$2786	$1456	$852	$541	$365
50,000	$6835	$3399	$1893	$995	$511

All costs are in thousands of dollars and include fixed mobilization costs.

Vehicle

Acres	100%	50%	25%	10%	2%
1000	$575	$325	$200	$125	$85
2000	$1075	$575	$325	$175	$95
5000	$2575	$1325	$700	$325	$125
20,000	$10,075	$5075	$2575	$1075	$275
50,000	$25,075	$12,575	$6325	$2575	$575

All costs are in thousands of dollars and include fixed mobilization costs.

Man

Acres	100%	50%	25%	10%	2%
1000	$1585	$815	$430	$199	$76
2000	$3125	$1585	$815	$353	$107
5000	$7745	$3895	$1970	$815	$199
20,000	$30,845	$15,445	$7745	$3125	$661
50,000	$77,045	$38,545	$19,295	$7745	$1585

All costs are in thousands of dollars and include fixed mobilization costs.

Number of Covered Acres

Acres	100%	50%	25%	10%	2%
1000	1000	500	250	100	20
2000	2000	1000	500	200	40
5000	5000	2500	1250	500	100
20,000	20,000	10,000	5000	2000	400
50,000	50,000	25,000	12,500	5000	1000

Costs for MTADS surveys may vary from those estimated in Table 13. The following was extracted from a relevant IDA report (Andrews et al., 2001):

> For this demonstration, the MTADS total cost was $377,296. If the excavation costs of $169,096 and the reporting costs of $24,000 are removed, the MTADS costs for the deployment, survey, and analysis parts of this demonstration were $184,200. Note that this does not separate out the costs of the EMI work. The MTADS surveyed a total of more than 150 acres for a cost of $1,222 per acre.

According to the IDA report conclusions, “Cost estimates prepared by the performers indicate that the per acre cost of the MTADS is about 2–3 times higher than those of airborne systems. These figures are very rough estimates and may not accurately reflect the cost differences seen in operational surveys.” As noted earlier, TEM-8 airborne surveys have higher cost than those referenced in Andrews et al., (2001) due to their narrower swath width.

In Table 13, we provided costs for airborne surveys covering between 2% and 100% of the area of interest with ground-based surveys covering 2% of the area of interest. An unresolved question is where the equivalency would lie between airborne and ground-based technologies: Which is more valuable, a 10% airborne survey, or a 2% ground-based survey? The answer would clearly lie in the ability to detect the ordnance of interest at the site for both systems and the uncertainty about ordnance contamination in areas that are not surveyed. The greater sensitivity of ground-based systems must be balanced against the probability of ordnance contamination within areas that are not surveyed. The choice will likely vary from site to site. Ground-based systems have more cost constraints that are site-dependent than airborne systems (e.g., unnavigable terrain, vegetation that must be cleared, vibration-sensitive ordnance), and this may also affect the selection of approaches.

9.4 COST CONCLUSIONS

As demonstrated above, comparing costs of fundamentally different technology approaches is both difficult and inconclusive. The previously discussed cost comparison provided a range of answers to the same question, namely, what are the costs of deploying each technology over the same size area under the same conditions?

For consideration of DoD-wide application of the airborne technology, a number of factors must be considered when evaluating the appropriateness of the airborne technology and potential for substantial cost savings. While initially impressive, it is not possible to simply apply these types of cost savings across the entire DoD UXO program. Sites must be of sufficient geographic extent to warrant a deployment given the high costs associated with mobilization and demobilization. In addition, survey objectives, terrain, geology, vegetation, and cultural artifacts must also be considered for such a deployment. Extremely variable terrain and/or the presence of tall vegetation can greatly limit or impede the use of the airborne technology for the UXO objectives of interest. Finally, the project objective must be consistent with the detection limits and capabilities of the airborne system to make such a deployment feasible.

10.0 IMPLEMENTATION ISSUES

10.1 REGULATORY ISSUES

In order to operate, each system must have Federal Aviation Administration approval (Supplemental Type Certificate [STC]). The required testing and evaluation was completed before mobilization. In addition, ground crews are required to complete the 40-hour Hazardous Waste Operations and Emergency Response (HAZWOPER) course and to maintain their annual 8-hour refreshers for operation at most UXO sites. We are aware of no additional regulatory requirements for operation at the FKPBR site.

10.2 END-USER ISSUES

The primary stakeholders for UXO issues at the FKPBR site have not been specified.

This page left blank intentionally.

11.0 REFERENCES

Battelle. 2008a. Demonstration of an Enhanced Vertical Magnetic Gradient System for UXO Final Report, ESTCP Project MM-0633. 157 pp.

Battelle. 2008b. Expanded Study of Beep Mat Technology for UXO Detection/Discrimination in Magnetic Terrains. Report to U. S. Army Environmental Command, May 27, 2008. 29 pp.

Beard, L.P., W.E. Doll, J.S. Holladay, T.J. Gamey, J.L.C. Lee, and D.T. Bell. 2004. Field Tests of an Experimental Helicopter Time-Domain Electromagnetic System For Unexploded Ordnance Detection. Geophysics, v. 69, n. 3, p. 664-673.

Doll, W.E., T.J. Gamey, L.P. Beard, D.T. Bell, and J.S. Holladay. 2003. Recent advances in airborne survey technology yield performance approaching ground-based surveys. The Leading Edge, v. 22, n. 5, p. 420-425.

Gamey, T.J., W.E. Doll, L.P. Beard, and D.T. Bell. 2004. Analysis of correlated noise in airborne magnetic gradients for UXO detection. Jour. Env. and Eng. Geophysics, v. 9, n. 3, p. 115-125, 2004.

Harbaugh, G.R., D.A. Steinhurst, and N. Khadr. 2007. Wide area UXO contamination evaluation by transect magnetometer surveys. Pueblo Precision Bombing and Pattern Gunnery Range #2, Victorville Precision Bombing Ranges Y and 15, Final Report, 100 pp., available at http://www.estcp.org/viewfile.cfm?Doc=MM%2D0533%2DTR%2DPueblo%2DVictorville%2Epdf.

Holladay, J.S., W.E. Doll, L.P. Beard, J.L.C. Lee, and D.T. Bell. 2006. UXO time-constant estimation from helicopter-borne TEM data. Jour. Env. and Eng. Geophysics, v. 11, n. 1, p. 43-52.

McDonald, J.R., and H.H. Nelson. 1999. MTADS Live Site Demonstration at Pueblo of Laguna, NM, Report No. NRL/PU/6110-00-398, August 1999.

ORNL. 2004a. Final Report, ESTCP Project 200101, Demonstration of Airborne Electromagnetic Systems for Detection and Characterization of Unexploded Ordnance at the Badlands Bombing Range, SD, August 2004, 110 pp.

ORNL. 2004b. Final Report on 2002 Airborne Geophysical Survey at Pueblo of Laguna Bombing Targets, NM, ESTCP Projects 200037 and 37, April 2004, 60 pp.

Wright, D., and R. Fonda. 2009. Advances in Helicopter Borne Magnetometer Systems for Wide-Area Assessment, Abstract in Technical Program UXO Forum 2009, Orlando, FL, August 24-27 2009, p. 234.

This page left blank intentionally.

APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone Fax E-Mail	Role
Raye Lahti	AMEC E&E 800 Marquette Avenue Suite 1200 Minneapolis, MN 55402	715-794-2889 651-767-2335 raye.lahti@amec.com	Project Manager
William E. Doll	Battelle 105 Mitchell Road Suite 103 Oak Ridge, TN 37830	865-483-2548 865-599-6165 dollw@battelle.org	Airborne Survey Manager
David T. Bell	Battelle 105 Mitchell Road Suite 103 Oak Ridge, TN 37830	865-483-2547 865-250-0578 belldt@battelle.org	Battelle-Oak Ridge Office Manager
Jon Haliscak	AFCEE 3300 Sidney Brooks Brooks AFB, TX 78235-5863	210-536-5522 Jonathan.Haliscak@brooks.af.mil	ESTCP Project COR

This page left blank intentionally.

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

E-mail: estcp@estcp.org
www.estcp.org