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Cost and Performance Report

(MR-201161)

Demonstration of Advanced Geophysics and Classification Technologies on Munitions Response Sites

April 2015

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This document serves as the Environmental Security Technology Certification Program (ESTCP) Cost and Performance Report for the Demonstration of Advanced Geophysics and Classification Technologies on the Pole Mountain Target and Maneuver Area, Wyoming; Former Spencer Artillery Range, Tennessee; and Fort Rucker, Alabama Munitions Response Sites (MRS). This report summarizes the effectiveness of advanced geophysical sensors and physics-based data analysis tools for anomaly classification for three project sites.

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ACRONYMS AND ABBREVIATIONS

ANN	artificial neural network
ASCII	American Standard Code for Information Interchange
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cm	centimeter
dB	decibel
DERP	Defense Environmental Restoration Program
DGM	digital geophysical mapping
DLRT	distance likelihood ratio testing
DoD	Department of Defense
DQO	data quality objective
EM	electromagnetic
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	global positioning system
GSV	Geophysical System Verification
Hz	hertz
IMU	Inertial Measurement Unit
ISO	industry standard object
IVS	instrument verification strip
LM	library matching
m	meter
MD	munitions debris
MEC	munitions and explosives of concern
mm	millimeter
MM	MetalMapper
MMRP	Military Munitions Response Program
MRS	munitions response site
mV	millivolts
NA	not applicable
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NRL	Naval Research Laboratory
PMTMA	Pole Mountain Target and Maneuver Area

PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QC	quality control
RBA	rule-based analysis
RCRA	Resource Conservation and Recovery Act
RTK	real-time kinematic
RTS	Robotic Total Station
SARA	Superfund Amendments and Reauthorization Act of 1986
SI	site inspection
SNR	signal-to-noise ratio
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	target of interest
URS	URS Group, Inc.
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

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Mention of trade names or commercial products in this report is for informational purposes only; no endorsement or recommendation is implied.

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EXECUTIVE SUMMARY

The Environmental Security Technology Certification Program (ESTCP) contracted URS Group, Inc. (URS) to complete a Demonstration of Advanced Geophysics and Classification Technologies on munitions response sites (MRS) at three project locations: Pole Mountain Target and Maneuver Area (PMTMA), Wyoming; Former Spencer Artillery Range, Tennessee; and Fort Rucker, Alabama. Full information for each project location is contained in its respective Final Report.

OBJECTIVES OF THE DEMONSTRATION

ESTCP and other collaborators have developed advanced electromagnetic induction (EMI) sensors and geophysical data processing methods that have proven effective at classifying subsurface metallic objects as either targets of interest (TOI) (i.e., objects having the size, shape, and wall thickness associated with munitions and explosives of concern [MEC]) or non-targets of interest (non-TOI) (i.e., harmless scrap metal). These demonstrations served to:

- Demonstrate the cost and performance of these sensors and methods on increasingly challenging MRSs;
- Train Military Munitions Response Program (MMRP) contractors on the application of these sensors and methods to facilitate technology transfer and industry-wide adoption; and
- Identify opportunities for potential improvement of the sensors and classification methods.

TECHNOLOGY DESCRIPTION

At PMTMA, URS provided overall site management including site preparation, digital geophysical mapping (DGM) with EM61-MK2, and validation digging. The Geometrics MetalMapper (MM) output (collected under separate contract), advanced cued geophysical data, were analyzed by URS geophysicists to classify anomalies as TOI or non-TOI using a combination of tools, including rule-based analysis (RBA), artificial neural networks (ANN), distance likelihood ratio testing (DLRT), and library matching (LM). URS used several software applications, including Geosoft's Oasis Montaj UX-Analyze extension, Statistica (statistical analysis tools), MATLAB, Mathematica, and C++ software developed by URS.

At Former Spencer Artillery Range, URS provided overall site management (e.g., site preparation, DGM [EM61-MK2], and validation digging), advanced instrument data collection and processing (dynamic and cued mode data using Time-domain Electromagnetic Multi-sensor Towed Array Detection System [TEMTADS] 2x2 and MM), and MM analysis and anomaly classification. Anomalies were identified and subsequently analyzed in cued mode using both the MM and TEMTADS. The outputs from MM were analyzed to classify anomalies as TOI or non-TOI using LM, parameter thresholds, and data mining techniques, including clustering and ANN-based classifiers. URS used several software applications, including Geosoft's Oasis Montaj UX-Analyze extension, Sigma Plot, Weka (data mining software), and Geosoft scripts developed by URS.

At Fort Rucker, URS provided MM data collection and processing (dynamic survey and cued modes) and MM data analysis and anomaly classification (cued mode). The MM was custom mounted on a fork attachment to a compact track loader by URS to minimize damage to the golf course that might have occurred using other tow platforms. The inverted MM data were analyzed to classify anomalies as TOI or non-TOI using the LM protocols contained within the UX-Analyze extension to Geosoft's Oasis Montaj.

DEMONSTRATION RESULTS

Advanced geophysical sensors (e.g., TEMTADS and MM) and advanced data analysis methods were effectively used in a production environment to characterize MEC hazards at the three sites.

IMPLEMENTATION ISSUES

Industry-wide fielding of advanced geophysical sensor arrays will benefit from addressing several logistical and deployment-related concerns that would make the system more market-ready and improve deployment efficiency. The wide-scale use and acceptance of classification methods can be facilitated primarily through documentation of standardized methods, stakeholder communication and outreach, and reconciling some current policy/guidance inconsistencies. These will serve to make the process more transparent and increase the likelihood of stakeholder acceptance.

1.0 INTRODUCTION

1.1 BACKGROUND

ESTCP contracted URS Group, Inc. (URS) to test the effectiveness of advanced geophysical sensors and physics-based data analysis tools for anomaly classification on munitions response sites (MRS) at three project locations. Full information for each project location is contained in its respective Final Report.

- ***Pole Mountain Target and Maneuver Area (PMTMA):*** URS conducted site preparation activities, collected baseline electromagnetic induction (EMI) geophysical data (EM61-MK2), and demonstrated the use and performance of advanced anomaly classification methods for MetalMapper (MM) data (ESTCP, 2012a).
- ***Former Spencer Artillery Range:*** URS conducted site preparation activities, including a baseline subsurface anomaly density survey using EM61-MK2. URS used advanced EMI sensors (i.e., Time-domain Electromagnetic Multi-sensor Towed Array Detection System [TEMTADS] 2x2 and MM) in both dynamic survey mode and cued mode to investigate individual anomalies. URS processed and demonstrated the use and performance of advanced anomaly classification methods using the MM data (ESTCP, 2013b).
- ***Fort Rucker:*** URS used MM in dynamic survey mode and in cued mode. URS processed and demonstrated the use and performance of an advanced anomaly classification method using the MM data (ESTCP, 2013c).

1.2 OBJECTIVES OF THE DEMONSTRATION

Digital geophysical mapping (DGM) of former military ranges results in the identification and location of subsurface anomalies at a site. Typically, very few of the total number of these anomalies are munitions and explosives of concern (MEC). The majority of these anomalies are harmless metallic objects (e.g., munitions fragments, small arms projectiles, range-related debris, or cultural debris). ESTCP and other collaborators have developed advanced EMI sensors and geophysical data processing methods that have proven effective at classifying subsurface metallic objects as either targets of interest (TOI) (i.e., objects having the size, shape, and wall thickness associated with MEC) or non-targets of interest (non-TOI) (i.e., harmless scrap metal). These demonstrations serve to:

- Demonstrate the cost and performance of these sensors and methods on increasingly challenging MRSs;
- Train Military Munitions Response Program (MMRP) contractors on the application of these sensors and methods to facilitate technology transfer and industry-wide adoption; and
- Identify opportunities for potential improvement of the sensors and classification methods.

1.3 REGULATORY DRIVERS

The ESTCP Live Site Demonstrations are executed under the guidance of the Department of Defense (DoD) MMRP, which is a portion of the Defense Environmental Restoration Program (DERP). DERP is the DoD program to execute environmental response consistent with the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA); the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations 300); and Executive Order 12580, Superfund Implementation.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

URS used a variety of hardware and software technology at each demonstration site, as shown in Table 1.

Table 1. Technology used at the demonstration sites.

Demonstrated Technology	PMTMA	Former Spencer Artillery Range	Fort Rucker
DGM survey	Geonics EM61-MK2, paired with a Trimble R8 RTK GPS and Allegro CX field computer	Geonics EM61-MK2 paired with a Trimble R8 RTK GPS (in open areas) and a Trimble S6 RTS (in wooded areas) and Allegro CX field computer	EM61-MK2 data collected under separate contract and provided to URS
Advanced geophysical survey	Geometrics MM data collected under separate contract and provided to URS	Geometrics MM and the TEMTADS 2x2 array in dynamic survey mode and cued mode. RTK GPS mounted above the center of the array*	Geometrics MM in cued mode. Additional dynamic survey mode data were also collected and processed, but not analyzed by URS. RTK GPS mounted above the center of the array**
Software for analysis of the advanced geophysical data	Geosoft's Oasis Montaj UX-Analyze extension, Statistica (statistical analysis tools), MATLAB, Mathematica, and C++ software by URS.	Geosoft's Oasis Montaj UX-Analyze extension, Sigma Plot, Weka (data mining software), and Geosoft scripts developed by URS.	Geosoft's Oasis Montaj UX-Analyze extension

GPS = global positioning system
RTK = real time kinetic
RTS = Robotic Total Station
* At Former Spencer Artillery Range, MM was mounted on a front-end loader bucket mounted on a tractor, with the monitor attached to the tractor hood. TEMTADS is a self-contained man-portable cart-mounted system.
** At Fort Rucker, the MM was custom mounted on a fork attachment to a compact track loader by URS to minimize damage to the golf course that might have occurred using other tow platforms.

URS applied various methodologies to classify anomalies as TOI and non-TOI from the advanced geophysical data collected. Table 2 presents the anomaly classification methods and categories used at each demonstration site.

Table 2. Anomaly classification methods applied at the demonstration sites.

Anomaly Classification	PMTMA	Former Spencer Artillery Range	Fort Rucker
Methods	RBA, ANN, DLRT, and LM	LM, parameter thresholds, and data mining techniques, including clustering and ANN-based classifiers	LM
Categories	Category 0: Cannot analyze Category 1: Likely TOI Category 2: Cannot decide Category 3: Likely non-TOI	Category 1: Likely TOI Category 3: Likely non-TOI	Category 0: Cannot analyze Category 1: Likely TOI Category 3: Likely non-TOI

ANN = artificial neural networks
DLRT = distance likelihood radio testing
LM = library matching
RBA = rule-based analysis

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1 Dynamic Data Collection with Advanced Geophysical Sensor Arrays

Advantages: The ability to collect a single geophysical dataset that allows munitions response project teams to identify and distinguish individual anomalies and subsequently classify each anomaly as a TOI, (presumably MEC) or non-TOI (presumably harmless scrap), would dramatically decrease the total cost of munitions responses. It would also expedite munitions response schedules. Advanced geophysical sensor arrays would also more precisely locate target anomalies, improving geophysical survey quality in cluttered areas and reducing data management challenges related to linking geophysical anomalies with subsurface anomaly sources.

Limitations: Dynamic data collection with advanced sensors is typically slower and more costly than equivalent EM61 surveys.

2.2.2 Cued Data Collection with MetalMapper

Advantages: Collection of cued data using MM results in lower noise and higher resolution data, which typically produce more accurate inversion results and a better basis for anomaly classification.

Limitations: Cued data collection requires a previous dynamic survey to identify targeted anomalies, resulting in increased geophysical survey costs.

2.2.3 Library Matching

Advantages: LM, currently integrated within the Oasis Montaj UX-Analyze package, is conceptually easy to grasp and utilize. The tool is flexible in that it allows user inputs into the library, which allows easy adaptation to new sites and TOI types.

Limitations: LM is relatively limited in scope/utilization of existing data when compared to other data mining methods. The software is tied to a commercially available rather than publicly available software package.

2.2.4 Threshold Classification

Advantages: Threshold classification is very easy to implement and is equivalent to the current methods for selection of EM61 anomalies for intrusive investigation. It works very well in datasets like PMTMA, where all TOI were found within well-defined ranges of parameter values.

Limitations: It does not work if TOI that do not fit easily defined parameter ranges are present.

2.2.5 Artificial Neural Network

Advantages: ANN-based approaches have proven successful in eliminating 80% or more clutter from dig lists in multiple ESTCP demonstrations.

Limitations: The ANN approach is highly dependent on the quality and quantity of training data, and typically is site-specific.

2.2.6 Hybrid Classifiers

Advantages: Hybrid classifiers provide a more robust means of classification than a single classifier tool. ANN-based approaches have been successfully paired with LM in previous demonstrations, where ANN has reduced the number of TOI over LM alone, and LM has reduced the number of false negatives resulting from ANN alone. DLRT offers an additional “fail safe” by prioritizing those targets closest to ANN-identified TOI.

Limitations: The number of potential TOI identified for intrusive investigation is usually increased. DLRT is a nearest neighbor technique that is applied using the ANN TOI results as inputs into DLRT. Therefore, ANN TOI located near the ANN decision surface, often influence DLRT to select targets outside the ANN decision surface, increasing the number of TOI. DLRT used in this manner often contradicts the ANN results by increasing the number of TOI. This trade-off is acceptable since the new hybrid system allows much greater control of the location of the decision surface of the final classifier.

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3.0 PERFORMANCE OBJECTIVES

Performance objectives for the three demonstration projects, provided in Table 3, serve as a basis for the evaluation of the performance and costs of the demonstrated technologies. Details regarding the results are provided in Section 7 of this report.

Table 3. Quantitative performance objectives for the demonstration sites.

Performance Objective	Metric	Data Required	Success Criteria	Results		
				PMTMA	Former Spencer Artillery Range	Fort Rucker
Data Collection Objectives						
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	90% <15 cm along-line spacing	DQO achieved with exception noted in Section 7.1.1	DQO achieved	DQO achieved
Complete coverage of the demonstration site	Footprint coverage	Mapped production survey data	≥85% coverage at 0.5 m (Rucker: 0.75 m) line spacing and ≥98% coverage at 0.75 m (Rucker: 1 m) line spacing (Spencer/ Rucker: in open area only) calculated using UX-Process Footprint Coverage QC Tool	DQO achieved	DQO achieved	DQO achieved
Repeatability of IVS measurements	Amplitude of EM anomaly Measured target locations	Twice-daily IVS survey data	*EM61 cart:* amplitudes ±25% down-track location ±25 cm	NA	Pass (maximum 16%) / Fail for seed T-005 (Section 7.3.2)	NA
			Advanced Sensors Dynamic Survey: amplitudes ±10% down-track location ±10 cm	NA	*Not Assessed*	Refer to Section 7.3.3
			Advanced Sensors Cued: Polarizabilities ±10%	NA	Pass for seed T-003, fail for other seed items (Section 7.3.2)	Pass (for majority of seeds) / Fail for seed T-006 (Section 7.3.3)
Cued interrogation of anomalies	Instrument position	Cued mode data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	NA	*MM:* 99.5% *TEMTADS 2x2:* Not Assessed	Not able to be evaluated
Detection of all TOI	Percent detected of seeded items	Location of seeded items and anomaly list	100% of seeded items detected (Spencer/ Rucker: with 60 cm halo)	DQO achieved	DQO achieved	100% of seeded items detected, distance not able to be evaluated

Table 3. Quantitative performance objectives for the demonstration sites (continued).

Performance Objective	Metric	Data Required	Success Criteria	Results		
				PMTMA	Former Spencer Artillery Range	Fort Rucker
Analysis and Classification Objectives						
Maximize correct classification of TOI	Percent of TOI placed in Category 1	Prioritized anomaly lists and dig results	Correctly classify 100% of TOI	DQO achieved	ANN: 100% LM: 99.7%	95% correctly classified
Maximize correct classification of non-TOI	Percent of correctly classified non-TOI	Prioritized anomaly lists and dig results	>65% of non-TOI classified in Category 3	DQO achieved	Not applicable (NA)	NA
			>75% of non-TOI classified in Category 3while retaining all TOI	NA	ANN: 87% LM: 69%	LM: 62%
Specification of no-dig threshold	Percent of TOI placed in Categories 1 or 2 and percent of non-TOI placed in Category 3.	MM cued data, prioritized anomaly lists, and dig results	100% of TOI placed in Categories 1 and 2. >65% of non-TOI placed in Category 3	DQO achieved	NA	NA
		Prioritized anomaly lists and dig results	Threshold specified to achieve criteria above	NA	Achieved by ANN method. Missed last seed with LM method by 15 anomalies	Refer to Section 7.8.3
Minimize number of anomalies that cannot be analyzed	Percentage of anomalies classified as Category 0	Inverted MM (Spencer: and TEMTADS) cued data and prioritized anomaly dig list	Reliable target parameters can be estimated for >95% of anomalies on each sensor's detection list	DQO achieved	DQO achieved	DQO achieved
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Estimated and actual parameters (polarizabilities, XY locations, and depths [Z]) for seed items	Polarizabilities ±20% X, Y <15 cm (or 1 σ) Z <10 cm (or 1 σ)	NA	±20% not achieved X, Y < 15 cm, 69% Z < 10 cm, 66% (Section 7.10.2)	±20% not achieved X, Y, and Z were not evaluated (Section 7.10.3)

Table 3. Quantitative performance objectives for the demonstration sites (continued).

Performance Objective	Metric	Data Required	Success Criteria	Results		
				PMTMA	Former Spencer Artillery Range	Fort Rucker
Category 0 targets are categorized correctly	The polarization curves visually reflect a non-analyzable target	Inverted MM cued data and polarization curves	All targets placed in the "Can't Analyze" category will have polarization curves reflecting a non-analyzable target.	DQO achieved	NA	NA
Correctly extract feature scalars	Category 1 TOI should cluster in various feature space scatter plots	Derived target feature vectors, inverted MM cued data, and polarization curves	Various feature space scatter plots display distinct clustering	DQO achieved	NA	NA
Correctly classify Category 2 targets	Category 2 targets should display TOI-like properties	Polarization curves, derived target feature vectors, and dig results	Category 2 targets should be proximal to TOI clusters and/or polarization curves display TOI characteristics	DQO achieved	NA	NA

cm = centimeters
DQO = data quality objective
EM = electromagnetic
IVS = instrument verification strip
m = meters
NA = not applicable
QC = quality control

4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND HISTORY

The PMTMA is located in Albany County, Wyoming (Figure 1). The PMTMA site was used for military maneuvers. An artillery impact area was located between two observation bunkers, which were constructed in 1941, at Bisbee Hill and Merritt Hill. The demonstration area is located within the Bisbee Hill Maneuver Area MRS, located in the north-central portion of PMTMA. Due to the varied multi-use nature of PMTMA, other range operations may have occurred within this MRS (Innovative Technical Solutions, Inc., 2010).

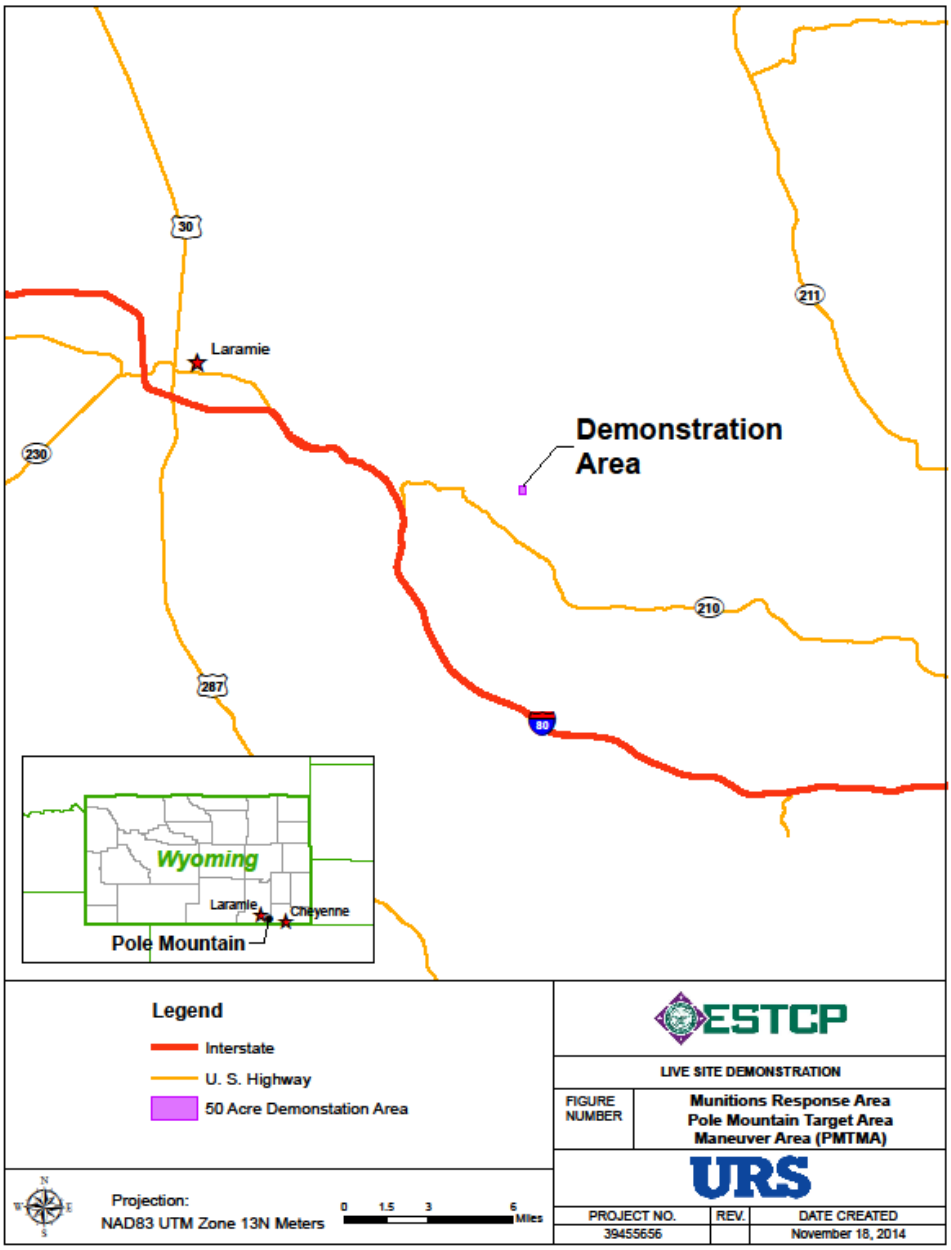

Figure 1. Site location map for PMTMA.

The Former Spencer Artillery Range is located in Van Buren County, Tennessee (Figure 2). In 1941, U.S. Army Corps of Engineers (USACE) constructed Spencer Range, including the Jakes Mountain and Bald Knob impact ranges, to serve as the main artillery range for Camp Forrest in Tullahoma, Tennessee (USACE, 2001). The demonstration area is within MRS-01, Jakes Mountain Impact Area. In 1944, Dyersburg Army Air Field used the area as an air-to-ground gunnery range. The land reverted to the original leaseholders in the summer of 1946.

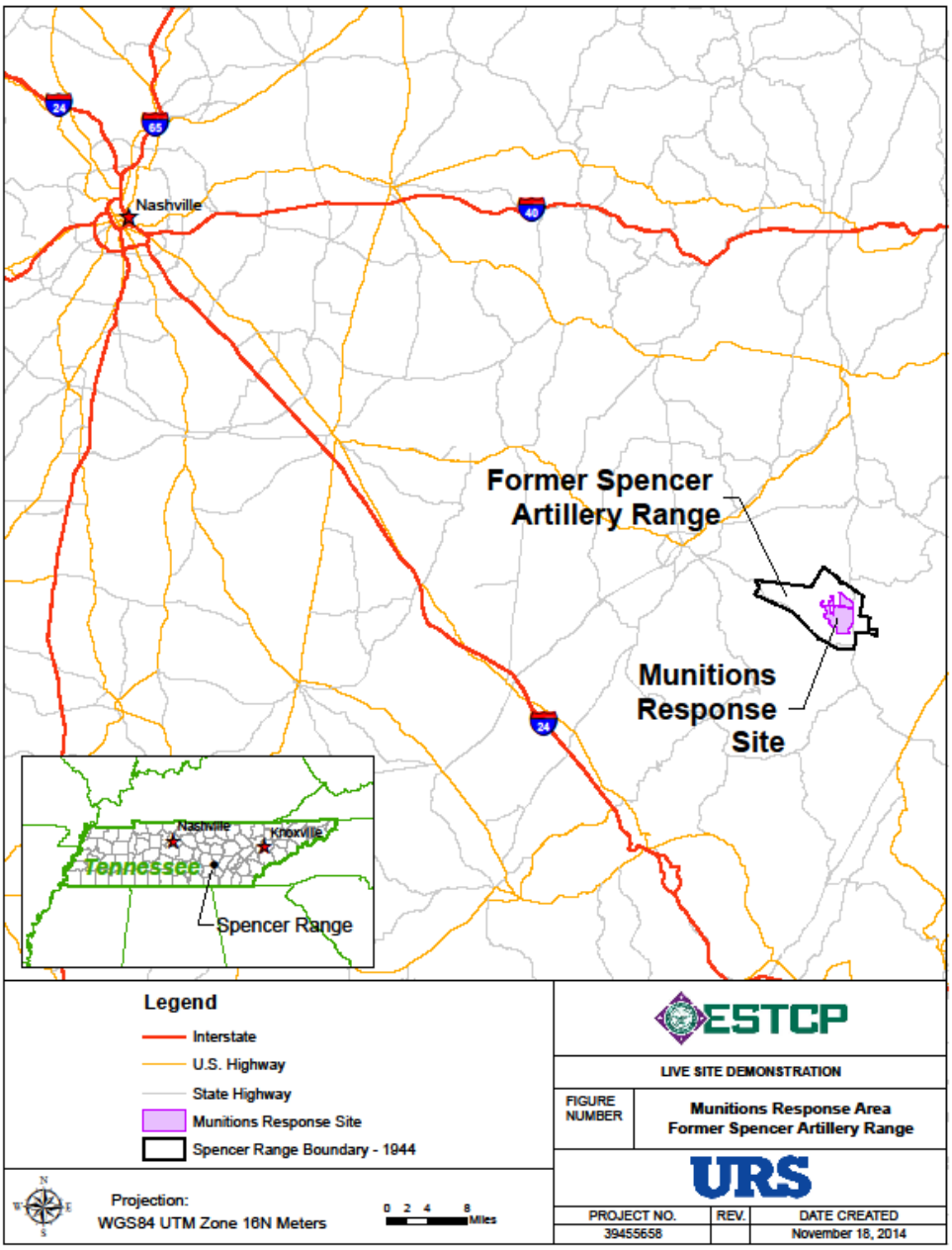

Figure 2. Site location map for Former Spencer Artillery Range.

Fort Rucker is located in Dale County, Alabama (Figure 3). From 1942 to 1951, the U.S. Army used the MRS as an anti-tank rocket/grenade range. During the mid-1950s, much of the former anti-tank rocket/grenade range (approximately 38 acres) was developed as part of a larger golf course that was constructed for use by Fort Rucker personnel. The MRS is within one of the three nine-hole courses that make up the Silver Wings Golf Course, and most of the MRS consists of well-maintained grassy areas with few trees. The golf course has been in continuous operation since construction, with various modifications to course design as well as irrigation layout (TetraTech EC, 2012).

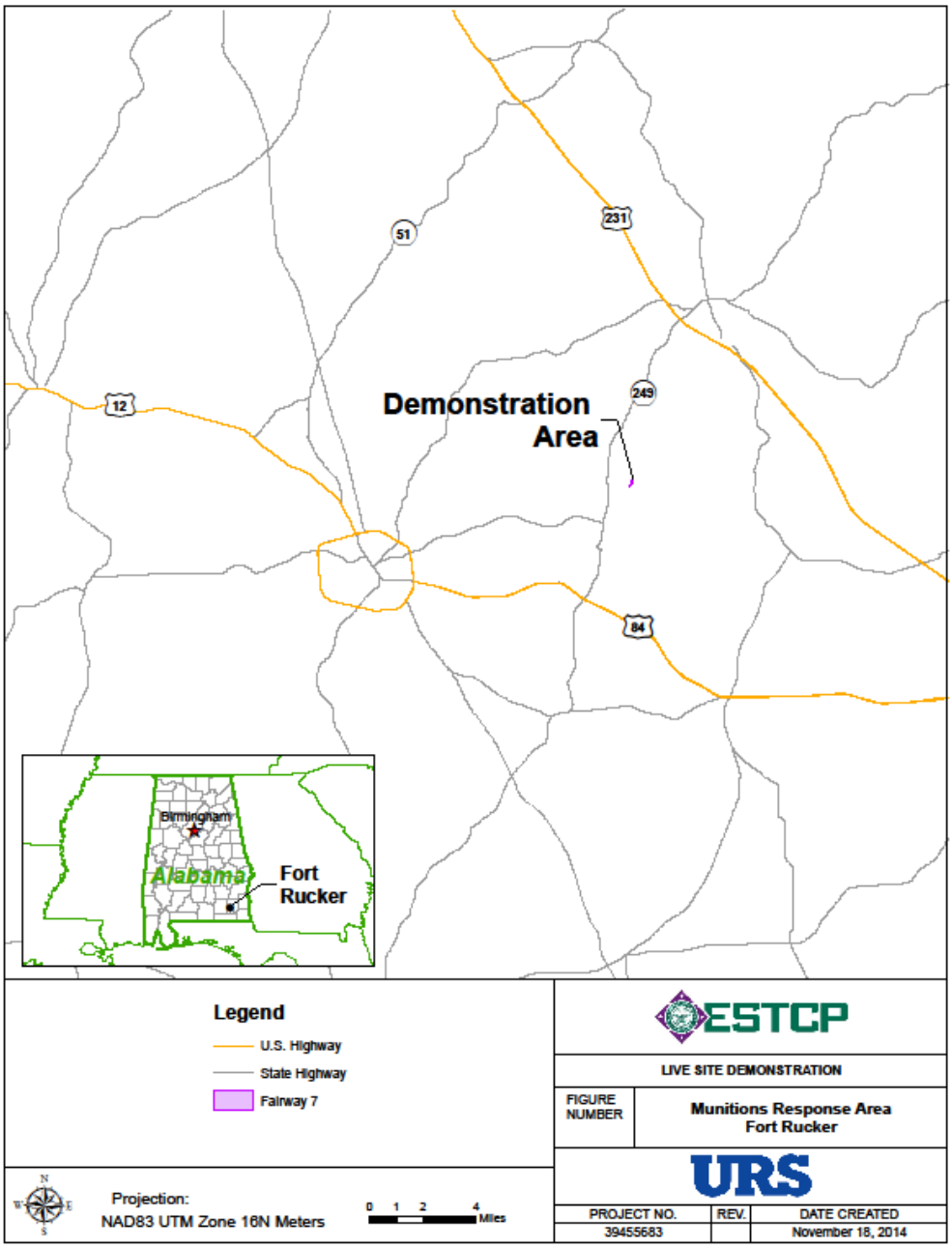

Figure 3. Site location map for Fort Rucker.

4.2 SITE GEOLOGY

At PMTMA, Cretaceous-age rocks underlying the area include the Fox Hills Sandstone and the Laramie Formation. Tertiary-age rocks are composed of the Chadron Formation (sandstone), the Brule Formation (siltstone), the Arikaree Formation (sandstone), and the Ogallala Formation (heterogeneous mix of materials) (USACE, 1996). Surface soil throughout Pole Mountain is relatively shallow (<20 inch deep) and is predominantly rocky with rock outcrop components.

The Former Spencer Artillery Range is underlain by Pennsylvanian era sandstone, shale, siltstone, and conglomerate. The rocks in this area consist of Pennsylvanian marine deposits of sandstone, shale, coal, and limestone. Bedrock is observed at the surface in some areas of the site. Where covered with soil, depth to bedrock generally ranges from approximately 2 feet to 6 feet below ground surface (USACE, 2001). The soil types on site include the Gilpin silt loam, Hartsells loam, Lonewood silt loam, and Udorthents-Mine Pits complex.

Fort Rucker lies in the East Gulf Coastal Plain physiographic section, with sedimentary origins dating to the Cretaceous, Tertiary, and Quaternary ages. Fort Rucker soils overlie the Buhrstone Escarpment, a formation held up by Early Tertiary shale and sandstone. Geologic formations that outcrop on Fort Rucker are Tertiary to Holocene in age and include the Tuscahoma Sand, Hatchetigbee and Tallahatta Formations, Lisbon Formation, Residuum, Alluvial High Terrace Deposits, and Low Terrace Deposits. These formations strike east-west, dipping to the south at a rate of 15 to 40 feet per mile (CH2M HILL, 2011).

4.3 MUNITIONS CONTAMINATION

At PMTMA, the following MEC hazards were encountered and documented during the previous Remedial Investigation (Innovative Technical Solutions, Inc., 2010):

- Projectiles (37 millimeters [mm] to 155mm and 2.95 inch),
- Shrapnel projectiles (75mm and 3 inch),
- 37mm projectiles,
- 3-inch Stokes mortars,
- 60mm mortars, and
- Small arms ammunition (.30 caliber and .50 caliber).

The Remedial Investigation at Former Spencer Artillery Range MRS reported the following munitions (USACE, 2011a; 2011b).

- Projectiles (37mm, 75mm, 76mm, 105mm, and 155mm).

At Fort Rucker, the Site Inspection (SI) (Malcolm Pirnie, 2005) and Resource Conservation and Recovery Act (RCRA) Facility Inspection (CH2M HILL, 2011) site visits detected numerous subsurface anomalies and the following munitions items:

- 2.36-inch and 3.5-inch rocket,
- Rifle grenade,

- M6 series 2.36-inch rockets,
- M9A1 rifle grenades, and
- MK II hand grenade.

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5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

This section discusses the activities that were executed by URS in support of this project, as shown in Table 4.

Table 4. Project components for the demonstration sites.

Project Component	PMTMA	Former Spencer Artillery Range	Fort Rucker
Demonstration/ Work Plan Development	Site-specific MEC-Quality Assurance Project Plan (QAPP) (ESTCP, 2011a).	Site-specific MEC QAPP (ESTCP, 2012b).	Abbreviated Demonstration Plan (ESTCP, 2013a)
Site Preparation	• 50-acre demonstration site • 160 seeds items • Surface clearance completed • IVS installed	• 9.24-acre demonstration site • 175 seeds items • Surface sweep completed • Vegetation removed (including tree stumps) • IVS installed	NA
EM-61 Data Collection	• 50 acres surveyed • 0.5 m line spacing	• 9.24 acres surveyed • 0.5 m line spacing	NA
MM Data Collection	NA	• 1.23 acres dynamic survey completed o 0.5 m line spacing • Collected 340 cued data targets in dynamic area • Collected 1,104 cued data targets in open area	• 4.4 acres dynamic survey completed on Fairway #6 o 0.75 m line spacing • Cued data collected o 407 anomalies Demo. Area o 377 anomalies Fairway #1 o 430 anomalies Fairway #6 o 137 anomalies Fairway #9
TEMTADS 2x2 Data Collection	NA	• 1.23 acres dynamic survey completed o 0.5 m line spacing • Collected 689 cued targets in wooded area • Collected 340 cued targets in dynamic area	NA
MM Data Processing	• Processed and inverted data with Geosoft UX-Analyze	• Processed and inverted data with Geosoft UX-Analyze	• Processed and inverted data with Geosoft UX-Analyze
MM Data Analysis and Classification	• 2,370 Static MM Points analyzed • Dig/No Dig List Produced	• Inversion results for each target used for classification using LM and data mining tools, including classifier and clustering algorithms augmented by visual data review	• Inversion results for 402 targets used to classify using LM
Intrusive Investigation	• 2,370 anomalies intrusively investigated • Each anomaly photographed and attribute information (e.g., nomenclature, size, depth, position and orientation) collected	• 2,133 anomalies intrusively investigated • Each anomaly photographed and attribute information (e.g., nomenclature, size, depth, position, and orientation) collected	NA

QAPP = Quality Assurance Project Plan

5.2 SITE PREPARATION

At PMTMA, unexploded ordnance (UXO) technicians emplaced 160 seeds (industry standard objects [ISO], inert projectiles, and inert mortars) within the 50-acre demonstration area. At Former Spencer Artillery Range, the URS conducted a surface sweep, removed vegetation, and emplaced 175 seeds (ISOs, inert projectiles, and inert mortars) within the 9.2-acre demonstration area.

At PMTMA and Former Spencer Artillery Range, URS installed and used an IVS with ISOs and inert munitions as reference seed items. The IVSs were used to verify the proper operation and function of the geophysical equipment and to measure site noise readings of each instrument before and after each day of field data collection. The IVSs were installed and operated using the specifications and descriptions contained in *Geophysical System Verification (GSV): A Physics-Based Alternative to Geophysical Prove Outs for Munitions Response* (ESTCP, 2009). The IVS also served to verify that geo-location systems provided accurate location data.

At Fort Rucker, URS used the IVS installed by TetraTech.

5.3 DATA COLLECTION

5.3.1 EM61-MK2 GEOPHYSICAL SURVEY

At PMTMA and Former Spencer Artillery Range, all data were collected at a sample frequency of 10 hertz (Hz). The teams used measuring tape, twine, and polyvinyl chloride (PVC) pin flags to establish the 0.5 m lane spacing and completed at least one pass inside the adjacent grids on either side of the surveyed grid. The field team circled each obstacle within the grid (i.e., rocks, trees, and large shrubs) that might have resulted in a coverage gap. To fill gaps identified by the data processor, the field teams collected data on a series of transects, including significant overlap of adjacent data to ensure that each gap was completely filled.

Daily field activities were coordinated during the morning briefing to ensure that the field teams maintained sufficient separation throughout the day to prevent interference between geophysical sensors. After completing the tailgate safety brief, the field teams performed a minimum 15-minute instrument warm-up to allow the EM61 to reach a stable operating temperature to minimize instrument drift. After warm-up, each team proceeded to the IVS where they performed and recorded the following series of QC tests: cable shake/personnel test, static test, spike test (Former Spencer Artillery Range only), seeded IVS, and background IVS. The IVS tests and a static test were also performed in the evening after data collection was complete.

The IVS data were evaluated using a physics-based process in which signal strength and sensor performance were compared to known response curves of four seed items to verify the DGM system was operating within manufacturer's specifications prior to and throughout site surveys. All instruments passed all IVS tests.

URS did not perform EM-61 data collection at Fort Rucker.

5.3.2 ADVANCED SENSORS IN DYNAMIC SURVEY MODE

URS did not perform advanced sensor data collection at PMTMA.

At Former Spencer Artillery Range, the dynamic survey mode consisted of complete coverage in the designated dynamic area with the TEMTADS 2x2; using taut lines to maintain transect spacing (Figure 1). At Fort Rucker, the dynamic survey mode consisted of complete coverage in Fairway #6, with the MM using an onscreen real-time display to maintain transect spacing (Figure 1). Data were collected along parallel transects with 0.5 m (Former Spencer Artillery Range) or 0.75 m (Fort Rucker) nominal transect spacing; however, it was necessary for some transects to deviate from a straight line path due to obstructions. Sample rate and survey pace were slow enough to ensure down-line spacing of less than 15 cm. Survey position was recorded and logged using an RTK GPS.

Figure 4. Dynamic data collection using the TEMTADS 2x2 (left, Former Spencer Artillery Range) and MM (right, Fort Rucker).

The following quality checks were performed while collecting advanced sensor data in dynamic mode:

- Equipment warm-up (per manufacturer's instructions);
- Static background test (Former Spencer Artillery Range only; morning and after data collection day);
- IVS (morning and after data collection day);
- Background noise test (Former Spencer Artillery Range only);
- Battery strength test;
- Six line test (Former Spencer Artillery Range only; over the IVS normal, slow, and fast paces); and
- Configuration and initialization files verification.

5.3.3 ADVANCED SENSORS IN CUED MODE

URS did not perform advanced sensor data collection at PMTMA.

The cued mode survey consisted of collecting data over anomalies identified from the EM61 survey (performed by URS at Former Spencer Artillery Range; previously collected by TetraTech at Fort Rucker). Cued data were collected over each identified anomaly, with measurements repeated as necessary due to offsets of the sensor relative to the anomaly source or other data quality issues. For anomalies interrogated using the TEMTADS at Former Spencer Artillery Range, locations were reacquired and marked based on the RTS or RTK GPS location selected by the data processor and were refined, when necessary, using an EM61.

Figure 5. Cued data collection using the MM at Former Spencer Artillery Range (left) and Fort Rucker (right).

When operating the MM at both demonstration sites, the data acquisition system software was used to select a new location based on the preliminary analysis where the software identified the anomaly source location. In these situations, data were collected directly over the anomaly source location if it was within 40 cm (Former Spencer Artillery Range) or 50 cm (Fort Rucker) of the original selected anomaly location. If an anomaly was located at a distance greater than specified from the original anomaly location, and not within that distance of another anomaly location, both the original and new locations were surveyed (original only at Fort Rucker). The data file for the new location was associated with the original anomaly identification and was recorded in the field log as an added point offset from the original location.

The following quality checks were performed while collecting advanced sensor data in cued mode:

- Equipment warm-up (per manufacturer's instructions);
- Static background test (Former Spencer Artillery Range only; morning and after data collection day);
- IVS (morning and after data collection day);
- Battery strength test;

- Background response measurement (cued background approximately once per hour or more often if restarting equipment or changing field conditions);
- Test pit (Former Spencer Artillery Range only; cued over variety of items);
- Six line test (Former Spencer Artillery Range only; over the IVS normal, slow, and fast paces); and
- Configuration and initialization files verification.

MM data were collected and stored as .tem files. Preprocessing of the .tem files was accomplished using a TEM2CSV conversion program. TEM2CSV subtracts the site background from the data point using a background file specified by the user; converts the points from the geographic coordinate system used for collection to the Universal Transverse Mercator (UTM) Zone 16N coordinate system used for processing; and exports the resulting data to a .csv file that can be imported into UX-Analyze. Preprocessing was typically completed in batches representing approximately 1 hour of data collection, with the day split to account for differing background data. Background files were collected approximately every hour during data collection in a predetermined geophysically quiet location within the survey area. Unless there appeared to be a problem with a specific file, data were typically corrected using a background file collected at a similar time and location.

5.4 VALIDATION

Intrusive investigations using "dig and verify" methods were completed at the PMTMA and Former Fort Spencer Artillery Range demonstration areas to determine whether the identified targets were MEC, munitions debris, or harmless scrap. A target list was derived from the DGM survey (PMTMA) or advanced sensor dynamic data collection (Former Spencer Artillery Range) and associated data processing/analysis. Subsurface anomalies were manually excavated in accordance with EM 385-1-97 (USACE, 2008). If the intrusive investigation of a target anomaly did not result in a finding (i.e., metallic object), 12 inches below specified depth, and 2 feet from the reacquisition target, URS abandoned the dig location as a "no contact."

All seed items and no MEC were recovered during validation. At Former Spencer Artillery Range, two munitions debris (MD) items required venting with explosive charges to confirm that they did not present an explosive hazard.

URS did not perform intrusive investigation at Fort Rucker.

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6.0 DATA ANALYSIS AND PRODUCTS

6.1 EM61-MK2 DGM PROCESSING AND INTERPRETATION

6.1.1 Processing

At PMTMA and Former Spencer Artillery Range, DGM data were corrected and processed using NAV61 and DAT61 software to convert binary files into American Standard Code for Information Interchange (ASCII) format and to interpolate locations for each DGM sample. Oasis Montaj was then used to:

- Convert location data from latitude and longitude to WGS 84 UTM, Meters;
- Interpolate DGM samples where vegetation interfered with the RTS system;
- Identify and apply latency corrections;
- Level data to remove instrument drift using an iterative filter that subtracts median values of background noise from the data;
- Grid data using a minimum curvature algorithm;
- Test cross-line and down-line spacing to ensure compliance with project metrics; and
- Identify target responses above the threshold using the Blakley method.

URS did not collect or process EM61-MK2 data at Fort Rucker.

6.1.2 Target Selection for Detection

At PMTMA, targets were picked using an EM61 MK-2 threshold value of 5.2 millivolts (mV) on channel 2, which is equivalent to the theoretical response of a 37mm at 30 cm below ground surface. A total of 2,370 targets were identified.

At Former Spencer Artillery Range, URS selected anomalies for advanced classification using a target response-based procedure. The threshold was set to detect all 37mm at 34 cm depth (above 4 mV in channel 2 for the EM61-MK2). A subset of anomalies was selected to detect all 37mm at 30 cm depth (above 5.2 mV in channel 2) and provided to the demonstrators by the ESTCP Program Office. A total of 2,568 targets were identified.

At Fort Rucker, targets were selected under separate contract and provided to URS for MM data collection at Fort Rucker.

6.2 MM PREPROCESSING

6.2.1 PMTMA

Data were inverted using Geosoft's Oasis Montaj UX-Analyze single and multi-source inversion utilities. This generated two sets of parameter values, which required a decision process to select a single data set that characterized the complete production data (all 2,370 targets). Unlike the

single source inversion, multi-source inversion introduced additional targets to the data set (for a total of 2,395 targets). Therefore, as expected, the number of targets increased.

Five parameters were used to identify analyzable data sets: 1) signal amplitude; 2) fit cohesion (correlation coefficient); 3) target size; 4) target offset; and 5) target depth. Assuming the data set was analyzable; the inversion result provided reliable estimates of target position and size. Previous ESTCP MM studies (ESTCP, 2010) established that reliable estimates of position and target size are obtained when signal-to-noise ratio (SNR) is >20 (26 decibels [dB]) and the correlation coefficient (√ fit cohesion) is >0.80.

6.2.2 Former Spencer Artillery Range and Fort Rucker

Geosoft UX-Analyze was used to process and invert the MM data. Prior to classification, inversion results were reviewed to determine whether data were of sufficient quality to classify the target anomaly source. Both single- and multi-source inversions were reviewed for data quality, to determine whether the inversion fits cohesions were greater the 0.75 and the inverted anomaly source locations were within 0.6 m of the MM location. Inverted results that did not meet these criteria were selected for re-collection. If the results were already re-collected data, no further attempts were made to collect additional data. However, due to schedule constraints and equipment issues at Fort Rucker, no points were re-collected at that site.

6.3 PARAMETER ESTIMATES, CLASSIFIER AND TRAINING

6.3.1 PMTMA

The MM cued geophysical data were analyzed to classify anomalies as TOI or non-TOI using a combination of tools, including RBA, ANN, DLRT, and LM. URS used several software applications, including Geosoft's Oasis Montaj UX-Analyze extension, Statistica (statistical analysis tools), MATLAB, Mathematica, and C++.

Feature vectors were then derived from transient curves using C++ algorithms. The URS classification scheme applied RBA to determine the Category 0 and 3 targets. Thereafter, ANN and/or DLRT were used to classify the targets. Finally, LM was applied to move poorly classified targets from Categories 2 and 3 into Category 1. Target parameters from historical munitions data were used to estimate a threshold target size in order to place any target in the analyzable category.

Figure 6 is a simplified diagram illustrating the processing flow that transformed target parameters extracted from the MM cued data into decisions about the likelihood that a particular target was ordnance or clutter and, if ordnance, the probable type.

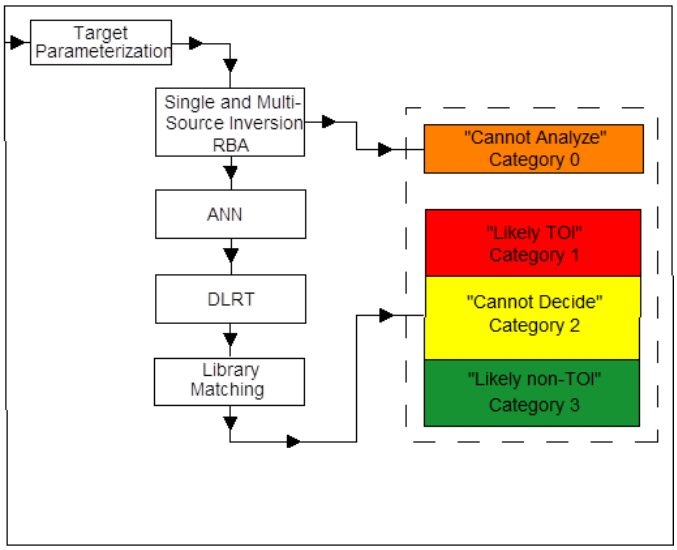

Figure 6. Simplified block diagram illustrating the processing steps used to generate a prioritized dig list at PMTMA.

Refer to Section 6 of the Final Report for PMTMA for an extensive review of the Data Analysis and Classification methods utilized on that project (ESTCP, 2012a).

6.3.2 Former Spencer Artillery Range

The MM cued geophysical data were analyzed to classify anomalies as TOI or non-TOI using a combination of tools, including LM, parameter thresholds, and data mining techniques (i.e., clustering and ANN-based classifiers). URS used several software applications, including Geosoft's Oasis Montaj UX-Analyze extension, Sigma Plot, Weka (data mining software), and Geosoft scripts.

Inversion results were classified using LM and data mining tools, including classifier and clustering algorithms augmented by visual review of the data. Initially three ranked anomaly lists were submitted. The first list was based on several ANN; the second list utilized a simple threshold on a series of parameters; and the third list used LM tools.

Lists were submitted for comparison to the QC seeds; QC failure results were incorporated into the LM and ANN lists following corrective action, including revised training data and better selection of parameters within each approach. QC failures indicated that the simple threshold-based list was not a viable approach for the Former Spencer Artillery Range. After QC failures resulting from undetected seed items were identified, a failure analysis was performed and only the ANN and LM lists were resubmitted. Finally, LM results were used to identify the expected type of TOI for each anomaly selected for intrusive investigation.

6.3.3 Fort Rucker

Inversion results were classified using LM in an iterative approach where targeted anomalies were group together based on "best fit" and evaluated based on any known sources for other anomalies within the group. Classification was conducted in four steps.

- Step 1: Cued inversion results were matched to their best fit TOI using the LM routine, and results that shared a best fit were grouped together in a cluster.
- Step 2: One or more examples from each cluster were chosen as training data. Training data were typically selected from among the best matches. Training data results were incorporated into the library of TOI responses, and the LM routine was repeated.
- Step 3: Anomalies that showed good fit to known TOI were selected for intrusive investigation or as further training data. Clusters with known TOI had additional training data selected to determine a threshold below which lower quality matches no longer represented TOI.
- Step 4: Step 3 was repeated until all groups were identified as either non-TOI or potential TOI, and a threshold between non-TOI and TOI within the potential TOI groups could be determined. For this project, three rounds of training were requested.

The UX-Analyze software contains inversion codes that allow for both a single source solution and an inversion determined number of sources (multi-source). The existing library consists of single-source solutions. URS utilized single-source inversion results, except when multi-source inversion results fit known TOI. These were then added to either the training data or the final target list.

6.4 DATA PRODUCTS

6.4.1 PMTMA

URS submitted four related prioritized target lists. Three target lists differed only in the number of targets placed in Category 1 and Category 2. The overall strategy was to use a hybrid classifier that used the output of one classifier (ANN) as the input of another (DLRT). LM was then applied as a means of moving a few misidentified targets from Category 2 or 3 to Category 1.

For target list 1, NnLmCa, URS used only the ANN and LM classifiers. Category 1 targets were identified by these two classifiers only (DLRT was not applied). For target list 2, NnLmDLRTsCa, the ANN, DLRT short TOI list, and LM were used to identify Category 1 targets. The short version of DLRT used a TOI cutoff of 50 targets based on an assessment (visual interpretation of the polarization curves) of where Category 1 targets ended. For target list 3, NnLmDLRTlCa, the ANN, DLRT full TOI list (based on a distance metric), and LM were used to identify the Category 1 targets. For each of these lists, 1 through 3, the reduced Category 0 target list was used. Target list 4, NnLmDLRTl, is identical to target list 3 except the reduced Category 0 list was not used; that is, all Category 0 targets were to be intrusively investigated. This was considered the safe list. Table 5 provides the general prioritized target list statistics. The complete prioritized target lists are contained in Appendix F of the Final Report for PMMTA (ESTCP, 2012a).

Table 5. PMTMA general prioritized target list statistics.

List Name	TOI Identified		Training Targets		Can't Analyze		List Length		Total Targets
	Qty.	%	Qty.	%	Qty.	%	Qty.	%	
NnLmCa	160	100	46	1.9	51	2.2	409	17.2	2,370
NnLmDLRTsCa	160	100	46	1.9	51	2.2	430	18.1	2,370
NnLmDLRTICa	160	100	46	1.9	51	2.2	477	20.1	2,370
NnLmDLRTl	160	100	46	1.9	107	4.5	533	22.5	2,370

URS prioritized target lists identified all TOI in Category 1. The ANN and LM identified all TOI; therefore, the hybrid classifier, which used DLRT as the second tier classifier, necessarily identified all the TOI. All target lists used the same training data and a minimum Category 0 list. One list used the full Category 0 list. The training data and Category 0 list accounted for a minimum of 4.1%, and a maximum of 6.4% of the targets. List length ranged from a minimum of 409 targets to be dug (17.2% of the total targets) to a maximum of 533 targets to be dug (22.5% of the total targets).

6.4.2 Former Spencer Artillery Range

Table 6 provides the general prioritized target list statistics. The complete prioritized target lists are contained in Appendix E in the Final Report for Former Spencer Artillery Range (ESTCP, 2013b).

Table 6. Former Spencer Artillery Range general prioritized target list statistics.

List Name	TOI Identified		Training Targets		Can't Analyze		List Length		Total Targets
	Qty.	%	Qty.	%	Qty.	%	Qty.	%	
Open URS LM01	82	99.6%	51	4.6%	0	0%	420	38%	1,104
Open URS ANN01	82	100%	51	4.6%	0	0%	240	22%	1,104
Dynamic URS LM01	25	100%	3	0.9%	0	0%	98	29%	340
Dynamic URS ANN01	25	100%	3	0.9%	0	0%	43	13%	340

Each of the URS prioritized target lists identified all TOI in Category 1, except for one TOI that was identified in Category 2 using the LM method in the open area. The number of targets to be dug was 420 in the open area and 98 in the dynamic area using the LM method; and 240 in the open area and 43 in the dynamic area using the ANN method.

6.4.3 Fort Rucker

Table 7 provides the general prioritized target list statistics for Fort Rucker. The number of targets on the dig list was 296, which was 74% of the total targets.

Table 7. Fort Rucker general prioritized target list statistics.

List Name	TOI Identified		Training Targets		Cannot Analyze		List Length		Total Targets
	Qty.	%	Qty.	%	Qty.	%	Qty.	%	
Fort Rucker LM	201	95%	163	40.10%	2	0.50%	296	74%	402

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7.0 PERFORMANCE ASSESSMENT

A summary of the performance objectives and results for the three demonstration projects are located in Section 3, Table 3 of this report.

7.1 ALONG-LINE MEASUREMENT SPACING

7.1.1 PMTMA

URS utilized Geosoft's Oasis Montaj UX-Process Sample Separation analysis module to calculate along-line measurement spacing. The separation distance was set to 0.15 m, and only 1.9% of the data exceeded that displacement, which is less than the allowable maximum of 10%. This includes end-of-line points; therefore, the actual percentage is lower than the displayed value.

Data collected by Team 2 on June 22 and June 23, 2011, did not meet this metric. Data were collected using an older DOS-based Allegro field computer. The acquisition software for Allegro does not collect data at uniform time windows; some responses may be 0.2 seconds to 0.3 seconds apart instead of the specified 0.1 seconds. During dynamic acquisition at a walking pace, this resulted in 15% to 20% of the down-line sample separations exceeding the 0.15 m metric. This problem was resolved in later data collection by replacing the Allegro with a newer Windows CE-based model. It was decided to keep the data after coordination with ESTCP. All seeded TOIs in the affected area were detected and properly targeted.

7.1.2 Former Spencer Artillery Range

URS utilized Geosoft's Oasis Montaj UX-Process Sample Separation analysis module to calculate along-line measurement spacing. The separation distance was set to 0.15 m, and the maximum percentage of the data that exceeded that displacement for any submitted dataset was 8.9%, which is less than the 10% criteria. This includes end-of-line points; therefore, the actual percentage is lower than the captured values.

7.1.3 Fort Rucker

URS utilized tools within Geosoft's Oasis Montaj to calculate sample separations. Currently, available processing tools for MM dynamic data do not interpolate locations between RTK GPS readings. The sample separation distances met performance objective criteria since 99.96% of samples were less than the 15 cm tolerance, relative to an allowed 90% of samples.

7.2 COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The DQO of having the specified coverage at varying line spacing widths was achieved at each specific site.

7.3 REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

7.3.1 PMTMA

The response amplitudes were not applicable to the PMTMA site.

7.3.2 Former Spencer Artillery Range

The response amplitudes were within acceptable ranges (±25%) for all of the IVS items during the EM61 survey. The locations of peak responses were within acceptable ranges (±25 cm) for all but two IVS locations for Seed T-005. The largest errors were in the direction of travel over the IVS, and likely reflect the difficulty in accurately locating the anomaly source for a double-peak anomaly since T-005 was laid along the direction of travel.

As no advanced sensor dynamic survey data were processed, repeatability of amplitudes and down track location were not assessed for advanced sensors.

Response amplitude for the MM was measured by calculating the zero moment polarizability (P_{0x}) for the primary polarizability of each response within the IVS. Results for the largest item, Seed T-003 were all within ±10%. Results for the next largest polarizabilities, Seed T-005, were within ±16%. Results for the remaining two seeds (T-001 and T-002) were within ±10% for 80% of the samples, but the outliers were quite large, with a maximum difference of 76%. The source of this variability is not known, but it is more significant with the smaller seed items suggesting a relatively constant magnitude of error when the issue occurs. One possible source may be errors in the removal of background responses. Refer to Section 7.10.2 for more information about impacts of these failures on the project results.

7.3.3 Fort Rucker

Advanced sensor dynamic survey data analysis tools were not available, so peak amplitude response of the center, horizontal receiver, over a summed window from 8 to 35 time gates after the pulse was used to evaluate repeatability within the IVS. Responses were leveled to a common background using a simple demedian filter to subtract the median value from the responses.

Responses to the center receiver in the vertical component (horizontal receiver loop) proved to be highly variable and unusable for purposes of evaluating repeatability.

Down-track peak locations showed considerable variability, likely associated with latency between the instrument response and the RTK GPS location. No latency correction was applied to the dynamic IVS data.

Response amplitude for the MM cued data was measured by calculating the zero moment polarizability (P_{0x}) for the primary polarizability of each response within the IVS. The zero moment is effectively an integrated value representing the area under the polarizability curve. Results for all items were within ±10% of the average primary polarizability, with the exception

of one inverted response over Seed T-006. This is the smallest seed item, which should show the largest percent variation in the presence of constant background noise.

7.4 CUED INTERROGATION OF ANOMALIES

7.4.1 PMTMA

The response amplitudes were not applicable to the PMTMA site.

7.4.2 Former Spencer Artillery Range

The center of the instrument was positioned within 40 cm of the actual anomaly location for 99.5% of the cued anomalies. This compares to a DQO of 90%.

7.4.3 Fort Rucker

The actual location of the anomaly sources was not recorded during intrusive investigation, which was performed by a separate contractor; therefore, the distance between the anomaly source and the center of the instrument was not evaluated.

7.5 DETECTION OF ALL TARGETS OF INTEREST

7.5.1 PMTMA

All 160 QC seed items were placed on the delivered target list.

7.5.2 Former Spencer Artillery Range

All 175 QC seed items were placed on the delivered target list.

7.5.3 Fort Rucker

The means for identifying target anomalies for MM dynamic data were not available; therefore, this check was not performed.

7.6 MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

7.6.1 PMTMA

All TOIs were identified on all four submitted prioritized target lists within Category 1.

7.6.2 Former Spencer Artillery Range

100% of the 107 TOI were correctly labeled as TOI on the ANN ranked anomaly list, and 99.7% of the total were correctly labeled TOI on the LM ranked anomaly list.

7.6.3 Fort Rucker

95% of the 201 TOI were correctly labeled as TOI on the ranked anomaly list.

7.7 MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

7.7.1 PMTMA

All four submitted lists achieved the DQOs.

7.7.2 Former Spencer Artillery Range

A total of 87% of the non-TOI were correctly classified by the ANN-based approach, and 69% of the non-TOI were correctly classified by the LM-based approach.

7.7.3 Fort Rucker

A total of 62% of the non-TOI were correctly classified by the LM-based approach.

7.8 SPECIFICATION OF NO-DIG THRESHOLD

7.8.1 PMTMA

To correctly establish the dig/no-dig threshold, URS isolated those targets nearest to the ANN (first classifier of the hybrid classifier) TOI using a nearest neighbor method. This was done based on the value of the nearest neighbor parameter (second classifier of the hybrid classifier) and by reducing the dimensions of feature space to those most prominent through a principal component analysis. The success criteria that 100% of TOI are identified in Categories 1 and 2, and greater than 65% of non-TOI are identified in Category 3 was met; therefore, this DQO was met.

7.8.2 Former Spencer Artillery Range

URS set a dig/no-dig threshold based on ANN method that resulted in more than 75% of the non-TOI items being correctly labeled as non-TOI, while correctly identifying 100% of the TOI. An alternate approach, the LM-based approach, failed to identify one TOI by choosing a cut-off that intersected the anomaly list 15 targeted anomalies prior to where the TOI appeared on the ranked list, an error in the no-dig threshold of roughly 1% of the total targeted anomaly list.

7.8.3 Fort Rucker

The final threshold established by URS did not successfully identify 100% of the TOI and did not correctly classify 75% of the non-TOI. The last TOI fell near the very end of the ranked list of anomalies, so further refinement of the threshold would not have resulted in either objective being achieved.

7.9 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

The DQO of estimating reliable target parameters for at least 95% of the anomalies on each sensor’s detection list for all three sites was successfully achieved.

7.10 CORRECT ESTIMATION OF TARGET PARAMETERS

7.10.1 PMTMA

The response amplitudes were not applicable to the PMTMA site.

7.10.2 Former Spencer Artillery Range

Polarizabilities: There is over an order of magnitude in variability in small ISO inverted polarizabilities; well beyond the ± 20 polarizability objective. The high variability in small ISO inverted polarizabilities likely results from difficulties in separating background response from measured signal; possible variations between seed items; effects stemming from the orientation and location of the seed relative to the sensor; and the variability inherent in the instrument and the inversion software.

Horizontal Locations: Only 69% of the inverted horizontal locations were within the objective of 15 cm of the recovered item location; 80% were within 40 cm; and 87% were within 60 cm. Some of this variability results from ambiguity between multiple inverted sources and multiple recovered items; recovered items were only matched to the 'best' fit to generate these results.

Vertical Locations: Only 66% of inverted depths were within the objective of 10 cm of the recovered item depth. The mean error was 3 cm too shallow, and the median error was 1 cm too deep. The median indicates that the inversion is slightly too deep, but the mean error is positive because there is a wider range of possible values deeper than the inverted depth. Some of this variability results from ambiguity between multiple inverted sources and multiple recovered items; recovered items were only matched to the 'best' fit to generate these results. Additional error may be added during the process of recovering and locating the anomaly sources.

It should be noted that although none of these metrics were met, the analysts were still able to achieve up to 100% detection of TOI while removing up to 87% of non-TOI. The DQO standards established for this project may be too stringent for advanced sensor target parameters.

7.10.3 Fort Rucker

Because the recovered X-Y locations and the recovered depths are not available, only the estimated polarizabilities were evaluated. Response amplitude for the MM cued data was measured by calculating the zero moment polarizability (P_{0x}) for the primary polarizability of each response within the IVS. The zero moment is effectively an integrated value representing the area under the polarizability curve. There is considerable variability in the inverted polarizabilities, well beyond the ±20% polarizability objective. This higher than targeted variation in polarizabilities may result from difficulties in separating background response from measured signal, possible variations between seed items, effects stemming from the orientation and location of the seed relative to the sensor, and the variability inherent in the instrument and the inversion software.

Locations and depths for recovered items were not captured during intrusive investigation, so the location metrics X-Y <15 cm (or 1σ) and depth metric Z <10 cm (or 1 σ) were not evaluated.

7.11 OBJECTIVES EXCLUSIVE TO PMTMA

7.11.1 CORRECTLY CLASSIFY CATEGORY 0 TARGETS

Inverted MM cued data and polarization curves indicated that all targets placed in Category 0 had polarization curves reflecting a non-analyzable target; therefore, the DQO was achieved. These Category 0 targets have polarization curves that were extremely noisy, response below the measurable limits, responses above the measurable limit, negative beta values (that are displayed graphically as positive), etc.

7.11.2 CORRECTLY EXTRACT FEATURE SCALARS

Review of derived target feature vectors, inverted MM cued data, and polarization curves indicated that various feature space scatter plots for TOI displayed distinct clustering; therefore, the DQO was achieved. URS verified that similar TOIs plotted in clusters and visually verified that the polarization curves similarly reflected TOIs.

7.11.3 CORRECTLY CLASSIFY CATEGORY 2 TARGETS

Derived feature scalars, polarization curves, and validation digging results indicated that Category 2 targets were proximal to Category 1 TOI clusters and/or polarization curves displayed TOI characteristics; therefore, the DQO was achieved. Visually, most scatter plots display a close proximal relationship between Category 2 targets and TOI clusters. In complement, many of the Category 2 targets had classification values just outside the decision surface, close to but less than 0.5 scalar value.

8.0 COST ASSESSMENT

8.1 COST SUMMARY

Table 8 presents a simple cost summary for the technology used at the three demonstration sites for this project.

8.2 COST DRIVERS

The primary cost considerations associated with the selection and broad implementation of advanced geophysics and classification technologies are:

- Cost of data collection with advanced sensor arrays (primarily labor, per diem, and equipment rental/repair);
- Cost of data processing, analysis, and anomaly classification (primarily labor); and
- Cost savings associated with reduction in number of anomalies requiring intrusive investigation (primarily labor, per diem, and equipment rental).

URS used both MM and TEMTADS for data collection. As shown in Table 8, at Former Spencer Artillery Range, the acreage of dynamic data collected was the same with both instruments, and cued data were collected over 40% more anomalies with MM than with TEMTADS. However, MM data collection costs were almost three-and-a-half times greater than TEMTADS. While the instruments were provided as government-furnished equipment, MM data collection required the rental of a tractor to tow the instrument. Additionally, more problems and delays were encountered with the MM than with TEMTADS. At Fort Rucker, MM problems, downtime, and repairs more than doubled the cost of data collection.

The cost per anomaly of MM data analysis/classification was higher at Fort Rucker than at PMTMA and Former Spencer Artillery Range. The classification of the anomalies was more challenging at Fort Rucker due to the relatively high concentration of anomalies located in close proximity to each other.

8.3 COST BENEFIT

The primary driver for developing advanced geophysics and classification technologies is to reduce the total cost associated with executing munitions responses. DoD recognizes that a large portion of the munitions response budget is and will be spent excavating and removing harmless metal fragments and non-munitions-related metal from MRSs. The implementation of advanced geophysics and classification has been demonstrated to reduce the total number of anomalies requiring intrusive investigation (i.e., excavation) by 60% to 90% in demonstration/validation projects. For advanced geophysics and classification to be broadly employed, these technologies must cost less to implement than the intrusive investigations that would be avoided by their implementation.

URS performed validation digging at PMTMA and Former Spencer Artillery Range. The costs reflected in Table 8 were for excavation of every anomaly where cued data were collected. For an actual production site, only a portion of the anomalies would have been excavated based on the results of geophysical classification.

Table 8. Cost model for the demonstration sites.

Cost Element	PMTMA		Former Spencer Artillery Range		Fort Rucker	
	Data Tracked During Demonstration	Estimated Costs	Data Tracked During Demonstration	Estimated Costs	Data Tracked During Demonstration	Estimated Costs
Project Planning	• Develop project-specific documents: o MEC QAPP o Health & Safety Plan o Data Analysis Plan • Kick-off meeting • Site setup activities	$45,105	• Develop project-specific documents: o MEC QAPP o Health & Safety Plan o Data Analysis Plan • Kick-off meeting • Site setup activities	$42,395	• Develop project-specific documents: o Project Demonstration Plan o Health & Safety Plan o Classification Decision Memo	$7,700
Site Preparation	• Set up on-site project area • Install blind seeds • Equipment rental • Travel and supplies	$55,952	• Set up on-site project area • Surface sweep • Vegetation removal • Initial EM61 data collection (density estimates) • Install blind seed items • Equipment rental • Travel and supplies	$143,171	NA	NA
EM61 Data Acquisition	• Two 3-person data collection teams o 50 acres surveyed • Project Geophysicist • Equipment rental • Travel and supplies	$214,524	• One 2-person data collection team o 9.24 acres surveyed • Project Geophysicist • Equipment rental • Travel and supplies	$64,109	NA	NA
MM Data Collection	NA	NA	• One 2-person data collection and processing team o Dynamic data on 1.23 acres o Cued data on 1,444 anomalies • Project Geophysicist • Equipment rental (not including rental costs for MM) • Travel and supplies	$83,473	• One 3-person data collection and processing team o Dynamic data on 4.4 acres in Fairway #6 o Cued data on 1,351 anomalies • Project Geophysicist • Equipment rental/repair • Travel and supplies	$120,197 (total cost includes 17.5 days of delays) $50,682 (est. cost of actual data collection)

Table 8. Cost model for the demonstration sites (continued).

Cost Element	PMTMA		Former Spencer Artillery Range		Fort Rucker	
	Data Tracked During Demonstration	Estimated Costs	Data Tracked During Demonstration	Estimated Costs	Data Tracked During Demonstration	Estimated Costs
MM Data Analysis/ Classification	• 2,370 anomalies analyzed	$83,396 18 min. per anomaly $35 per anomaly	• 1444 anomalies analyzed	$39,657 29 min. per anomaly $27 per anomaly	• 402 anomalies analyzed	$18,014 21 min. per anomaly $42 per anomaly
TEMTADS Data Collection	NA	NA	• One 2-person data collection team o Dynamic data on 1.23 acres. o Cued data on 1029 anomalies • Project Geophysicist • Equipment rental o Does not include rental costs for TEMTADS • Supplies • Travel	$24,198	NA	NA
Validation Digging	• Nine UXO Technicians • Equipment rental • Supplies • Travel 2816 anomalies; 2370 targets plus anomalies found in 60-cm radius of original target	$460,607 $163 per anomaly $194 per target location	• Seven UXO Technicians • Equipment rental • Supplies • Travel • 2568 anomalies; 2133 targets plus anomalies found in 60 cm radius of original target	$367,155 $143 per anomaly $172 per target location	NA	NA

Using the longest dig list (i.e., highest number of digs found in Table 5) for PMTMA may have resulted in approximately 1837 fewer anomalies dug. Extrapolating the per anomaly cost of each dig (Table 8), this would have resulted in a potential cost savings of $356,378 at PMTMA, which is a 77% cost savings as compared to digging every cued anomaly.

The longest dig lists for the open and dynamic areas at Former Spencer Artillery Range (Table 6) may have resulted in approximately 926 fewer anomalies dug out of the 1444 MM targets processed and classified. Extrapolating the per anomaly cost of each dig (Table 8), this would have resulted in a potential cost savings of $159,272 at Former Spencer Artillery Range. The cost of excavating all 1444 MM targets processed and classified at Former Spencer Artillery Range would have been $248,368, so use of geophysical classification would have resulted in an approximately 64% cost savings.

As with any new technology, efficiencies may be anticipated with respect to the cost of data collection, processing, analysis, and classification as processes are standardized and companies and personnel gain more experience.

9.0 IMPLEMENTATION ISSUES

Advanced geophysical sensors (e.g., TEMTADS and MM) and advanced data analysis methods were successfully used in a production environment to characterize MEC hazards at the three sites. Because URS' role in the Live Site Demonstration Program was to evaluate the implementation of these advanced sensors and classification methods from the perspective of a large-scale MMRP production project, URS documented issues/recommendations that will support implementation on an industry-wide scale. Industry-wide fielding of advanced geophysical sensor arrays will benefit from addressing several logistical and deployment-related issues. These issues focus on making the system more market-ready and improving deployment efficiency. The wide-scale use and acceptance of classification methods can be facilitated primarily through documentation of standardized methods, stakeholder communication and outreach, and reconciling some current policy/guidance inconsistencies. These will serve to make the process more transparent and increase the likelihood of stakeholder acceptance.

9.1 POLE MOUNTAIN TARGET AND MANUEVER AREA

No site-specific implementation issues were identified at PMTMA.

9.2 FORMER SPENCER ARTILLERY RANGE

9.2.1 Terrain Limitation

Advanced geophysical sensors typically include multiple coils to illuminate anomalies from multiple directions/angles. Most are large and vehicle-mounted or cart-mounted with very low clearance (i.e., less than 6 inches). As such, these instruments are generally limited to flat terrain with low/no vegetation or other obstacles. Conditions at many MRSs would preclude their use. ESTCP has several ongoing live site demonstrations of man-portable advanced EMI sensors that show promise to expand the portfolio of sites to which advanced geophysics and anomaly classification can apply.

9.2.2 Standard Configuration for MetalMapper

MM acquisition was generally straightforward and proceeded at a quick pace once initial setup hurdles were overcome. Two issues associated with data acquisition using MM are worth noting:

- At the outset of the live site demonstration, the required type of vehicle and mounting configuration for the MM was not clear. The project team recommends that the vendor communicate:
    - The type (or types) of vehicles that have been successfully used to deploy the array in the past.
    - The required type of three-point hitch. The user would be able to confirm with the vehicle supplier that the tractor has the proper hitch prior to delivery.
    - Vehicle configurations (e.g., counterweighting and mounting locations for monitor/controls) that have been used successfully and safely in the past. (The MM attached to a bucket mounted on the front of a tractor was front heavy and prone to

tipping. Former Spencer Artillery Range included moderate slopes and numerous ruts left by heavy equipment. When the front wheels of the tractor caught ruts or went down significant slopes, it destabilized the tractor and created the potential for a roll-over accident. URS utilized sandbags attached to the back of the tractor to help stabilize it. The MM computer mounting location in front of the tractor steering wheel caused partial impairment of the operator's field of view. In a subsequent field deployment at Camp Ellis, URS designed a system for mounting the MM on a reach lifter, which proved significantly more stable and safe. Figure 4 shows vehicle instability and blocked line of sight associated with the initial system mounting configuration. These were subsequently remedied through trial and error.)

- Specifications for Support Equipment/Components: The project team recommends the vendor develop and deliver a standard set of support equipment for MM, including spare system cables, deep cycle marine batteries, and series battery cables. Also, the vendor should provide all software and computer system specifications in advance of system delivery (i.e., when system is reserved).

Figure 7. Tractor instability while raising MM and tractor operator field of view.

9.2.3 Improved Default Display

The URS field crew collected nearly an entire day of MM data that had to be re-collected because of issues with the transmitter. These issues could have been recognized if the field teams had set the acquisition software to automatically display plots after each sounding. Corrective action was implemented to resolve this issue, including the field crew setting up the acquisition software so that response curves would be displayed after each measurement.

9.2.4 Disclaimer Regarding Time-domain Electromagnetic Multi-sensor Towed Array Detection System

The list of recommendations above focuses on MM. One reason is that this system was delivered to the site and the URS field team was primarily responsible for deploying, operating, and troubleshooting the system. TEMTADS, on the other hand, was accompanied by the system developers from the Naval Research Laboratory (NRL). The NRL staff supported the deployment and operation of the TEMTADS and performed troubleshooting and adjustments as needed during

data collection. Although this support was very helpful, it was less reflective of a true production setting.

9.2.5 Anomaly Classification

- Other demonstrators have typically trained directly with the software developers when performing advanced analysis. URS chose to perform analysis independently using tools available within UX-Analyze as well as an approach modified and expanded from previous demonstrations (ESTCP, 2011b). This proved to be a valuable learning experience, and will make future training more relevant than it would be without having the direct experience of using these tools independently.
- The library provided with UX-Analyze contains responses generally derived from single-source inversions. These inversion results are often not equivalent to multi-source inversion results, particularly in the amplitude of the inverted polarizabilities. For this reason, it is suggested that single- and multi-source inversion results both be captured in the response libraries.
- URS was unable to identify a straightforward way to automatically select items that were good matches to TOI but did not have a TOI as a primary match. This would significantly speed up the review of LM results, and allow for the inclusion of more non-TOI within the library without the fear that it would be more difficult to flag potential TOI using LM.

9.3 FORT RUCKER

9.3.1 Transmitter Issues

URS was able to achieve high rates of production for both cued and dynamic data collection, including averages of over 300 cued anomalies per day (723 in two days) and more than 1 acre per day during dynamic collection. However, the field effort was dominated by equipment problems specific to the MM, as four transmitter boards failed over the course of the field effort.

The first transmitter board failure occurred during the first day of data collection. Normal field operating procedures did not indicate a problem with the transmitter, but data analysis showed that the transmitter waveform was incomplete and did not reach the nominal peak transmitter current (see Figure 5). After collecting several days of data, the transmitter stopped completely.

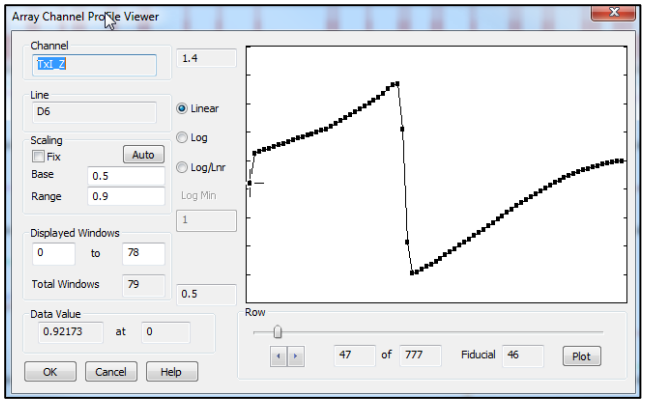

Figure 8. Fort Rucker MM waveform.

A replacement MM electronics box was sent to the site, which allowed collection of 407 cued anomalies in the demonstration area and 4.4 acres of dynamic data on Fairway #6. Then, prior to collecting additional cued anomalies in Fairways #1, #6, and #9, the MM electronics box would not turn on. While troubleshooting this issue, the field team connected the MM AC power supply to a battery that was powering the Inertial Measurement Unit (IMU). This resulted in 110V power from the inverter/battery shorting back through the IMU cable to the common ground on the battery, damaging the transmitter board within the MM electronics box.

The original MM electronics box was returned to the site from the manufacturer after 8.5 days of down time. Prior to data collection, the system continued to have transmitter issues, along with intermittent issues of one receiver not recording reasonable data during field checks. The field team partially disassembled the electronics box at the direction of Geometrics and replaced two damaged ribbon cables within the box. This is a known issue that Geometrics plans to resolve in later versions of the system – the ribbon cables are routed across two beveled metal corners that can cut into the relatively fragile cables over time. Replacing the ribbon cables resolved the receiver issue, but did not resolve the issues with the transmitter. This system was returned to Geometrics without collecting any new production data. After 3 days without an issue, the transmitter ceased transmitting prior to the morning tests on the fourth day. With only one additional day planned for data collection, the decision was made to end the survey.

While the cause for one of these failures was identified, the causes of the other transmitter board failures remain unknown. After the second transmitter board issue, each device was powered using a separate battery/power supply to avoid any potential issues with shorting back to a common ground.

9.3.2 Standard Configuration for MetalMapper

MM acquisition was generally straightforward and proceeded at a quick pace once when the equipment was operating as designed. URS developed a custom mount for attaching the MM on a fork attachment to a compact track loader. This configuration proved effective in generating high production rates and minimizing impact to the golf course.

9.3.3 Anomaly Classification

All the QC seeds were detected in the final target list. A total of 10 TOI were not detected in the final target list. Two of these TOIs, FR-10466 and FR-10510, were identified on a revised target list submitted August 21, 2013, that was not scored.

Of the remaining eight TOI, one response, FR-10171, should have been selected based on the selection criteria, but was ruled out by the analyst based on response characteristics atypical of a single TOI. The response best matched a 155mm projectile, with a fit of 70%. However, no 155mm projectiles were expected on the site and the response curve shown in Figure 6 shows the single inversion fit for an item that appears to be plate-like. Based on this reasoning, it was removed from the training data request list and not selected for intrusive investigation. In this case, the response represented a burial pit containing multiple TOI.

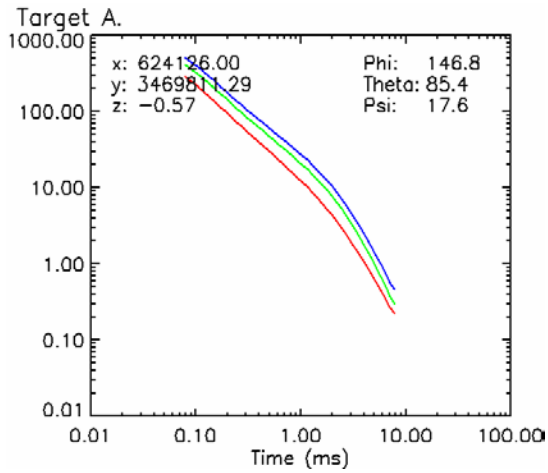

Figure 9. Polarizability inversion results for Fort Rucker FR-10171.

Two targeted anomalies, FR-10284 and FR-10692, were the only cued responses within their respective clusters that yielded TOI. FR-10692 did not match well with any responses in the TOI library, TOI from the training data, or TOI identified in the initial intrusive investigation results. The best fit was 14% to a 20mm projectile, but the actual intrusive investigation yielded a 2.36–in rocket motor and two pieces of munitions debris. FR-10284 matched well to a 57mm projectile, with a fit of 87%. The 57mm projectile was selected as training data and was found to be associated with target debris. Using this result, and expectations that no 57mm projectiles were present on site, this cluster of four anomalies was deemed to not be associated with TOI. After initial intrusive investigation results were incorporated into the TOI library, further LM indicated a best fit of 62% to FR-10553, a 3.5-in rocket motor. This fit was not of high enough quality to move FR-10284 into the intrusive investigation list submitted on August 21. Subsequent intrusive investigation revealed a 2.36-in rocket warhead and 10 pieces of MD.

Cued responses at FR-10047 and FR-10579 best fit the ‘Fuze Part’ included in the UX-Analyze library, along with 36 other responses; none of which yielded a TOI. The fit qualities to the ‘Fuze Part’ response were 54% and 55%, respectively, and represent poor fits as TOI are typically found at fits more than 75% to other TOI. After initial intrusive investigation results were incorporated

into the TOI library, further LM indicated a best fit of 54% and 32%, respectively, to FR-10597 where a 2.36–inch rocket and two pieces of fragment were recovered. These fits were deemed not sufficient to move FR-10047 and FR-10579 into the intrusive investigation list submitted on August 21. Subsequent intrusive investigation revealed a 2.36-inch rocket warhead and five pieces of MD at FR-10047 along with a 2.36-inch rocket motor at FR-10579.

Cued responses at FR-10107, FR-10496, and FR-10636 all fell within clusters that contained TOI. However, these responses all had low fit qualities (55%) not typically associated with TOI and did not match well with any of the TOI identified in the training data and initial intrusive investigations.

The TOI missed on the August 21 list did not match well with any of the other TOI recovered at the site through the training data; nor did they match well with any TOI recovered during the initial round of intrusive investigation comprising roughly one-half of the investigated anomalies. This suggests that any advanced analysis/data mining techniques will have difficulty with the inverted polarizabilities comprising this dataset, as they depend on associating similar responses to identify TOI.

The clustering approach used in this application of LM appears to have been unsuccessful, with three TOI appearing in two clusters that were deemed to not contain TOI based on training data and initial intrusive investigations. Future improvements might include a more comprehensive TOI library and clustering based on a more broad view of the response characteristics rather than just LM fits.

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APPENDIX A

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