TECHNICAL REPORT

Live Site Demonstration
Former Camp Ellis

ESTCP Project MR-201229

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Distribution Statement A

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List of Acronyms

ARCADIS	ARCADIS US, Inc.
BSI	Blind Seed Item
CEMR	Camp Ellis Military Range
cm	centimeter
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DoD	Department of Defense
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
GSA	General Services Administration
GPS	Global Positioning System
Hz	Hertz
IAW	In accordance with
IDA	Institute for Defense Analyses
IMU	Inertial Measurement Unit
ISO	Industry Standard Object
IVS	Instrument Verification Strip
m	meter
MetalMapper	MetalMapper™
mm	millimeters
MMRP	Military Munitions Response Program
MP	Man Portable
MR	Munitions Response
MRS	Munitions Response Site
µs	microseconds
m/s	meters per second
ms	milliseconds
mV	milliVolts
NA	Not Applicable
NAEVA	NAEVA Geophysics, Inc.
NRL	Naval Research Laboratory

QC	Quality Control
ROC	Receiver Operating Characteristic
RTK	Real-Time Kinematic
SAIC	Science Applications International Corporation
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	Target of Interest
USACE	United States Army Corps of Engineers
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This is one of a series of the Environmental Security Technology Certification Program (ESTCP) live site demonstrations of classification technologies for Munitions Response (MR). This demonstration is designed to evaluate advanced classification methodology at the Former Camp Ellis Military Range (CEMR), which is a site known to contain evidence of 2.36-inch practice rockets, hand grenades, and rifle grenades.

The project team consists of ARCADIS United States (U.S.) Inc. (ARCADIS) (principal investigator) with support by NAEVA Geophysics, Inc. (NAEVA). **Appendix A** provides the points of contact information for the ARCADIS team, as well as the primary U.S. Army Corps of Engineers (USACE) (and its subcontractors), ESTCP Program Office, and Illinois Environmental Protection Agency personnel. ARCADIS was responsible for managing and implementation of all field and office tasks associated with the live site demonstration at CEMR, and NAEVA provided field and office geophysical support. Additional support was provided by the Naval Research Laboratory (NRL), Geometrics, and Science Applications International Corporation (SAIC).

1.1 BACKGROUND

The Department of Defense (DoD) is responsible for investigating and cleaning up thousands of Munitions Response Sites (MRSs) comprising millions of acres that are potentially impacted by military munitions. Current industry-standard practice includes digital geophysical mapping (DGM) surveys and excavating a large number of subsurface metallic objects that are not munitions and explosives of concern (MEC). These non-MEC items are not an explosive hazard, yet their excavation represents most of DoD's MEC cleanup costs. Next generation electromagnetic induction (EMI) sensors and advanced software algorithms (*e.g.*, in UX-Analyze Advanced) are able to successfully classify geophysical targets at MRSs into feature classes that differentiate between MEC, non-hazardous munitions debris (MD), and scrap metal. The ability to classify targets will allow project teams to focus intrusive investigations on buried items that pose a potential explosive hazard (*e.g.*, MEC), reduce the costs of remediation, and minimize the impacts to the environment and the public who must evacuate areas during intrusive operations. This project evaluated the effectiveness of conducting DGM surveys with three geophysical sensors and applying advanced classification of dynamic and cued (*i.e.*, static) survey data from two advanced EMI sensors.

During this demonstration, ARCADIS used three geophysical sensors:

- EM61-MK2,
- Geometrics' MetalMapper™ (MetalMapper), and
- NRL's Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS) Man Portable (MP) 2x2.

Dynamic DGM data was collected with all three instruments, and static cued survey data was collected with the latter two instruments, which are both advanced EMI sensors. The ability to correctly classify anomalies as target of interest (TOI) and non-TOI using the advanced EMI

sensors operating in static or in dynamic mode (instead of the current industry standard approach) offers the potential to significantly reduce the DoD's MEC cleanup costs.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of the demonstration was to validate classification technology in a live site demonstration at the former CEMR. The overall objective of the advanced classification demonstration was to accurately classify each of the targets as one of the following:

- TOI that has a high likelihood of being unexploded ordnance (UXO); or
- Non-TOI that is likely another type of anomaly source such as MD, scrap metal, or some other metallic unrelated to UXO.

Additional objectives for this demonstration included the following:

- Comparing the effectiveness of the three dynamic DGM sensors in their ability to detect potential TOI.
- Comparing the effectiveness of the two advanced EMI sensors in correctly classifying anomalies as either TOI or non-TOI using the cued survey data.
- Comparing the potential ability to correctly classify anomalies as either TOI or non-TOI using the dynamic advanced EMI sensor data.
- Selecting a dig/no-dig threshold that recognizes all TOI (no false negatives/Type II error) while minimizing the number of false alarms (*i.e.*, minimizing false positives/Type I errors),
- Minimizing the number of targets classified as "can't analyze", and
- Correctly estimating target parameters such as polarizabilities, location, depth, and size of the identified anomalies.

ARCADIS performed the following tasks in order to achieve this overall objective:

- Dynamic DGM data using the Geonics EM61-MK2, MetalMapper, and the TEMTADS;
- Static, cued target interrogation using both the MetalMapper and TEMTADS;
- Processing and quality control (QC) of dynamic and static geophysical data;
- Target reacquisition;
- Intrusive investigation of all targets;
- Demolition of identified MEC; and
- Advanced classification of the static advanced EMI data.

1.3 REGULATORY DRIVERS

The Military Munitions Response Program (MMRP) is charged with characterizing and, where necessary, remediating MRSs. When an MRS is remediated, it is typically mapped with a geophysical system, (*i.e.*, either a magnetometer or EMI sensor), and the locations of all detectable signals are excavated. Many of these detections do not correspond to munitions, but rather to other harmless metallic objects or geology: field experience indicates that often in excess of 90% of objects excavated during the course of a MR are found to be nonhazardous

items. Current geophysical technology, as it is traditionally implemented, does not provide a physics-based, quantitative, validated means to discriminate between hazardous munitions and nonhazardous items.

With no information to suggest the origin of the signals, all anomalies are currently treated as though they are intact munitions when they are dug. They are carefully excavated by certified UXO technicians using a process that often requires expensive safety measures, such as barriers or exclusion zones. As a result, most of the costs to remediate a munitions-impacted site are currently spent on excavating targets that pose no threat. If these items could be determined with high confidence to be nonhazardous, some of these expensive measures could be eliminated or the items could be left unexcavated entirely.

The MMRP is severely constrained by available resources. Remediation of the entire inventory using current practices is cost prohibitive, within current and anticipated funding levels. With current planning, estimated MR completion dates on many sites are decades out. The Defense Science Board observed in its 2003 report that significant cost savings could be realized if successful classification between munitions and other sources of anomalies could be implemented (OSDA, 2003). If these savings were realized, the limited resources of the MMRP could be used to accelerate the remediation of MRSs that are currently forecast to be untouched for decades.

2.0 TECHNOLOGY

This demonstration consisted of dynamic and static data collection with a total of three geophysical sensor systems and analysis using conventional data processing methods to identify geophysical anomalies and advanced data processing to extract features and perform anomaly classification. Details of each technology and a brief description of the major components of the demonstration are provided below.

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Geonics EM61-MK2

The EM61-MK2 is a time-domain EMI sensor that transmits a current through an electrical loop that induces a primary magnetic field that magnetizes buried (or surface) objects. Turning off the transmit current causes an abrupt change in the magnetic field that excites eddy currents within the metallic object. These eddy currents decay as a function of time and are recorded by four receiver time gates.

The Geonics EM61-MK2 is the industry standard geophysical instrument for collecting DGM data at MRSs. It consists of a lower 0.5-meter (m) by 1.0-m transmit/receive coil and an upper 0.5-m by 1.0-m receive coil (see **Figure 2-1**). ARCADIS collected dynamic DGM data across the entire 5-acre demonstration site using the off-the-shelf EM61-MK2 technology.

Figure 2-1: Geonics EM61-MK2

2.1.2 Geometrics MetalMapper

The Geometrics MetalMapper is the first commercially available advanced EMI sensor designed specifically for the purpose of advanced classification. It consists of three orthogonal 1-m^2 transmit coils and seven 10 centimeter (cm), 3-component, orthogonal receiver coils (**Figure 2-2**). The system was developed in collaboration with ESTCP (Prouty, 2011) and was validated during the ESTCP live demonstration at the former Camp San Luis Obispo (Nelson et. al, 2010; Prouty, 2009) and other live-sites to be effective at correctly classifying TOI and non-TOI. ARCADIS operated the MetalMapper in dynamic detection mode across the entire site and static classification mode for approximately one half of the detected targets during the CEMR live-site demonstration. ARCADIS used the commercially available MetalMapper without making modifications to the system.

Figure 2-2: Geometrics MetalMapper

2.1.3 NRL's TEMTADS MP 2x2

The TEMTADS is a MP advanced EMI sensor array (see **Figure 2-3**) based on NRL's larger, 5x5 TEMTADS array. The TEMTADS MP 2x2 consists of four 35cm transmit coils with four 8 cm tri-axial receiver cubes. The TEMTADS MP 2x2 was developed through ESTCP (Kingdon, 2012) and has been shown to reliably retain the performance of the original TEMTADS in a much smaller size, which enables the MP version to access difficult terrain where mobility is limited (ESTCP, 2012a and 2012b; Kingdon, 2012). ARCADIS operated the TEMTADS system in dynamic detection mode across approximately 1 acre in the target area and static classification mode for approximately one half of the detected targets during the CEMR live-site demonstration. ARCADIS used the TEMTADS without making modifications to the system.

Figure 2-3: NRL's TEMTADS MP 2x2

2.2 TECHNOLOGY DEVELOPMENT

ARCADIS performed a live site demonstration at CEMR using existing technologies and did not develop new instrument technologies during this demonstration. Technologies used during this demonstration include the above three geophysical sensors, real time kinematic (RTK) differential global positioning system (DGPS), and the UX-Analyze Advanced module within Geosoft Oasis Montaj©. The MetalMapper, TEMTADS, and UX-Analyze Advanced were developed under ESTCP and further descriptions of their development can be found in the following reports:

- MetalMapper: Prouty, 2011;
- TEMTADS: Kingdon et. al, 2012;
- UX-Analyze Advanced: Keiswetter, 2009, and the following projects, which do not currently have technical reports that are available:
    - MR-201164: Demonstration of Physics-Inspired Classification Methodologies for MR
    - MR-201312: UXO Classification Demonstrations at Live Sites Using UX-Analyze

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The major advantage of the advanced EMI sensors and UX-Analyze Advanced module is that combined, they provide the ability to classify anomalies as being due to either TOI or non-TOI. This can lead to significant cost savings in MR cleanups. Conventional DGM sensors (*e.g.*, EM61-MK2) have very limited ability to correctly classify TOI and non-TOI. Other advanced

EMI sensors (*e.g.*, Berkeley UXO Discriminator) have also been successful in SERDP and ESTCP funded classification demonstrations; however, they were not used during this live site demonstration due to limited availability. Part of this investigation was to better determine the advantages of each of the EMI sensors operation. **Table 2-1** shows the advantages and limitations of each of the advanced EMI sensor technologies deployed at CEMR. Discussions of quantitative production rates for each sensor are presented in **Section 6.0**.

Table 2-1: Qualitative Advantages and Disadvantages of Deployed Technology

Category	Advantages and Limitations	EM61-MK2	MetalMapper	TEMTADS MP 2x2
General	Portability	Can be implemented in MP mode.	Requires the use of a forklift or other tow vehicle.	Can be implemented in MP mode.
	Sensor readiness for field deployment	Sturdy instrument with considerable use throughout the industry.	Limited durability (*e.g.*, uses a desktop computer is not ruggedized for fieldwork).	Field computer is rugged; however, backpack is relatively heavy. Field components are not currently easy to replace. Prototype design was not fit for rough terrain or potentially cold weather where plastic parts might break.
Dynamic Surveys	Dynamic Survey Efficiency	Quickest and has highest user familiarity of the dynamic survey modes. Requires setup of ropes for straight line positioning.	Limited set up time, has real time speed monitoring, and doesn't require ropes for straight-line profiling.	Requires the use of ropes for straight line positioning.
	Dynamic Sensor Deployment	Large standoff distance between sensor and ground surface decreases depth of detection	Use of the skid ensures sensor is close to the ground surface and maintains a relatively constant height above the ground.	Sensor height made it diffficult to push in over corn stalks that were slightly above ground.[1]
	Dynamic Advanced Classification Potential	Little to no ability	Yes	Yes
Static, Cued Interrogation	Static Advanced Classification Potential	Little to no ability	Yes	Yes
	Static Sensor Deployment	Not applicable (NA)	Sensor can be placed within 15 cm of the ground surface using the skid.	Sensor height placed the sensors within 20 cm of the ground surface.

Category	Advantages and Limitations	EM61-MK2	MetalMapper	TEMTADS MP 2x2
	Reacquisition procedures	NA	Integrated	Requires the use of Global Positioning System (GPS) to place pin flags for cued survey data collection.

Notes:

- Green highlighted cells indicate a relative advantage of the sensor.
- Yellow highlighted cells indicate a relatively neutral situation (*i.e.*, neither an advantage nor a limitation).
- Red highlighted cells indicate a relative limitation of the sensor.

1 – The TEMTADS has since been upgraded with wheels on the front of the sensor that likely corrects this limitation

3.0 PERFORMANCE OBJECTIVES

The performance objectives for this demonstration are summarized in **Table 3-1**. There are objectives for the data collection and data analysis portions of the demonstration.

In the Analysis and Classification Objectives section, the first three objectives refer to the classification part of the demonstration with the first two referring to the best results from each approach in a retrospective analysis and the third addressing how well each demonstrator is able to specify the correct threshold in advance. The final two objectives refer to the feature extraction part of the demonstration.

Table 3-1: Performance Objectives for This Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
Spatial coverage in detection survey	Extended footprint coverage	• Mapped survey data	98% coverage
Along-line measurement spacing	Point-to-point spacing from data set	• Mapped survey data	98% of data < 0.15 m
Detection of all TOI	Percent detected of seeded items	• Location of seeded items • Anomaly list	100% of seeded items detected within 0.6 m halo
Repeatability of instrument verification strip (IVS) measurements	Amplitude of EM anomaly Amplitude of polarizabilities	• Twice-daily IVS survey data	Detection: Amplitude within 25% Down-track location ±25 cm Cued: Polarizabilities ±10%
Production rate	Number of acres of data collection per day Time required to analyze each target	• Log of field work and data analysis time accurate to 15 minutes	Survey: 2 acres per day Analysis time: <5 minutes per target

Performance Objective	Metric	Data Required	Success Criteria
Cued interrogation of anomalies	Instrument position	• Cued survey data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location
Analysis and Classification Objectives			
Maximize correct classification of TOI	Number of TOI retained	• Ranked anomaly lists • Scoring reports from Institute for Defense Analyses (IDA)	Approach correctly classifies all TOI
Maximize correct classification of non-TOI	Number of false alarms eliminated	• Ranked anomaly lists • Scoring reports from IDA	Reduction of clutter digs required by >75% while retaining all TOI
Specification of no-dig threshold	Probability of correct classification of TOI and number of false alarms at demonstrator operating point	• Demonstrator - specified threshold • Scoring reports from IDA	Threshold specified by the demonstrator to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as “Cannot Analyze”	• Demonstrator target parameters	Reliable target parameters can be estimated for > 95% of anomalies on the detection list.
Correct estimation of target parameters	Accuracy of estimated target locations for seed items	• Target parameters • Results of intrusive investigation	X, Y < 15 cm (1σ) Z < 10 cm (1σ)

3.1 OBJECTIVE: SPATIAL COVERAGE FOR DETECTION

Detection surveys will cover the entire area of interest so that all detectable targets are detected. Targets are detectable if the transmitted field is sufficiently strong to reach the target and if the measured target response is sufficiently strong in return to exceed a given threshold.

3.1.1 Metric

The footprint of the detection survey systems will be compared with the surface area for the region to be studied in survey mode.

3.1.2 Data Requirements

The geographic coordinates for the perimeter of the region to be surveyed and the survey track will be utilized.

3.1.3 Success Criteria

Success completion of this objective requires 98% spatial coverage.

3.2 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The reliability of the survey data depends on the density of coverage of the site. This objective concerns the ability of the instrument operator to collect data with acceptable along-line measurement spacing.

3.2.1 Metric

The metrics for this objective are the percentage of data points within an acceptable along-line spacing.

3.2.2 Data Requirements

A mapped data file will be used to judge the success of this objective.

3.2.3 Success Criteria

Successful completion of this objective requires 98% of the data to have an along-line measurement spacing of less than 0.15 m.

3.3 OBJECTIVE: DETECTION OF ALL TOI

Quality data should lead to a high probability of detecting all TOI at the site.

3.3.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

3.3.2 Data Requirements

ARCADIS will prepare an anomaly list. IDA personnel will score the detection probability of the seeded items.

3.3.3 Success Criteria

Successful completion requires that 100% of the seeded items are detected within a halo of 0.6 m.

3.4 OBJECTIVE: REPEATABILITY OF IVS MEASUREMENTS

The reliability of the data also depends on the proper functioning of the equipment. This objective concerns the twice-daily confirmation of sensor system performance.

3.4.1 Metric

The metrics for this objective are the amplitude and down-track position of the maxima for the advanced systems in survey mode and the standard deviation of the polarizabilities for the advanced systems in cued mode obtained from each of the twice-daily surveys of the IVS.

3.4.2 Data Requirements

The data will be used to judge this objective.

3.4.3 Success Criteria

The objective will be considered met for the EM61-MK2 and advanced systems in survey mode if the measured amplitudes for each object are within 25% of the mean and the down-track position of the anomaly peak is within 25 cm of the known location. The objective will be considered met for the advanced systems in cued mode if the standard deviation of the estimated polarizabilities is within 10% of the mean.

3.5 OBJECTIVE: PRODUCTION RATE

3.5.1 Metric

The metric for this objective is the number of acres of data collection per day and the time required to analyze each target of cued survey data.

3.5.2 Data Requirements

ARCADIS will provide the Program Office a daily log of field work and data analysis with time accurate to 15 minutes to detail what work was performed on site. The Program Office will review the daily logs and provide feedback if time recorded on the logs is not accurate enough.

3.5.3 Success Criteria

The objective will be considered to be met if the production rate of 1 acre/day is met during dynamic data acquisition and if the production rate is less than 5 minutes per target on average for the cued anomaly interrogation.

3.6 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

The reliability of cued survey data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.6.1 Metric

The metric for this objective is the percentage of anomalies that are within the acceptable distance of the center of the instrument during data collection from the actual target location.

3.6.2 Data Requirements

ARCADIS will provide the Program Office a weekly list of the location of the center of the instrument for each cued anomaly interrogated in the preceding week. The Program Office will review the offsets for the QC seeds and provide feedback if the cued sensor was not within the acceptable distance. ARCADIS will reacquire data for those anomalies and perform a root cause analysis for each failure.

3.6.3 Success Criteria

The objective will be considered to be met if the center of the instrument is positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies.

3.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

This is one of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, targets will be classified with high efficiency. This objective concerns the component of the classification problem that involves correct classification of TOI.

3.7.1 Metric

The metric for this objective is the number of items on the anomaly list for a particular sensor that can be correctly classified as TOI by each classification approach.

3.7.2 Data Requirements

ARCADIS will prepare a ranked anomaly list for the targets on the sensor anomaly list. IDA personnel will use their scoring algorithms to assess the results.

3.7.3 Success Criteria

The objective will be considered to be met if all of the TOI are correctly labeled as TOI on the ranked anomaly list.

3.8 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This is the second of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, targets will be classified with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction.

3.8.1 Metric

The metric for this objective is the number of items on the sensor dig list that can be correctly classified as non-TOI by each classification approach.

3.8.2 Data Requirements

ARCADIS will prepare a ranked anomaly list for the targets on the sensor anomaly list. IDA personnel will use their scoring algorithms to assess the results.

3.8.3 Success Criteria

The objective will be considered to be met if more than 75% of the non-TOI items can be correctly labeled as non-TOI while retaining all of the TOI on the dig list.

3.9 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis as will be performed in this demonstration, it is possible to tell the true classification capabilities of a classification procedure based solely on the ranked anomaly list submitted by ARCADIS. In a real-world scenario, all targets may not be dug so the success of the approach will depend on the ability of an analyst to accurately specify their dig/no-dig threshold.

3.9.1 Metric

The probability of correct classification of TOI, Probability of Classification (P_{class}), and number of false alarms, Number of False Alarms (N_{fa}), at the ARCADIS-specified threshold are the metrics for this objective.

3.9.2 Data Requirements

ARCADIS will prepare a ranked anomaly list with a dig/no-dig threshold indicated. IDA personnel will use their scoring algorithms to assess the results.

3.9.3 Success Criteria

The objective will be considered to be met if more than 75% of the non-TOI items can be correctly labeled as non-TOI while retaining all of the TOI at the ARCADIS-specified threshold.

3.10 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be placed in the dig category and reduce the effectiveness of the classification process.

3.10.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.10.2 Data Requirements

ARCADIS will provide a list of all parameters as part of their results submission along with a list of those anomalies for which parameters could not be reliably estimated.

3.10.3 Success Criteria

The objective will be considered to be met if reliable parameters can be estimated for > 95% of the anomalies on the sensor anomaly list.

3.11 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.11.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

3.11.2 Data Requirements

ARCADIS will compare their estimated parameters for the seed items to those expected.

3.11.3 Success Criteria

The objective will be considered to be met if the estimated X, Y locations are within 15 cm (1σ) and the estimated depths are within 10 cm (1σ).

4.0 SITE DESCRIPTION

The site description material reproduced here is taken from the *Final Limited Site Investigation Report, Former Camp Ellis Military Range, Table Grove, Illinois* (CH2MHill, 2009). More details can be obtained in that report. The former CEMR is located in Fulton County, Illinois, between the towns of Ipava and Table Grove in western Illinois. The camp area covers approximately 17,455 acres, and the terrain of the former facility varies. Most of the former CEMR's land area is used for farming, though some parts of the former site also are used as pastureland, and a few wooded areas exist in the northern portion. Most of the area is undeveloped, occupied by corn and bean fields. Some parts of the former cantonment area remain unfarmed because the thick concrete slabs used as building foundations are difficult to remove. Tree groves exist in other areas.

A subset of the Rocket, Rifle, and Hand Grenades MRS (Area A) was selected for the ESTCP study. Area A is located in the northwest quadrant of the former CEMR and consists of approximately 52 acres of primarily cropland. **Figure 4-1** shows the former CEMR and the location of Area A.

4.1 SITE SELECTION

The location of the Area A demonstration site is shown in **Figure 4-2**, while **Figure 4-3** shows the Area A geophysical anomaly density, which was calculated from a geophysical transect survey conducted as part of the ongoing MR Remedial Investigation at the former CEMR. The anomaly density data shows one elevated anomaly density area relative to background. This area of higher anomaly density was interpreted to be a potential target area and ARCADIS investigated 5 acres within and around the potential target area. The proposed boundary of the area of investigation is shown on **Figure 4-3**.

4.2 SITE HISTORY

The War Department began surveying Fulton County in the fall of 1941 and selected the specific site for the camp in early 1942. Construction began on the camp in September 1942 and continued through the winter. Most of the area to be appropriated was farmland, although it included the small village of Bernadotte. The completed camp, originally intended to be a 75,000-acre army training facility, encompassed 17,455 acres and had more than 2,300 buildings, 1,100 of which were coal-heated barracks.

Camp Ellis trained a wide variety of soldiers for World War II. The camp had different small arms ranges, including four 1,000-inch courses, a transition range, combat ranges, a target pistol range, a submachine-gun course, a miniature anti-aircraft range, two infiltration courses, two bazooka and rifle grenade ranges, two live hand grenade courts, and a small "German Village" to train troops in the detection of land mines and booby traps.

Training at Camp Ellis reached its pinnacle in June 1944. Upon completion of their training, units were dispatched to the European and Pacific theaters. In January 1945, the engineer group stationed at the CEMR was disbanded, and other units trained at the camp soon followed. The camp, however, remained open with the primary mission of guarding Prisoners of War.

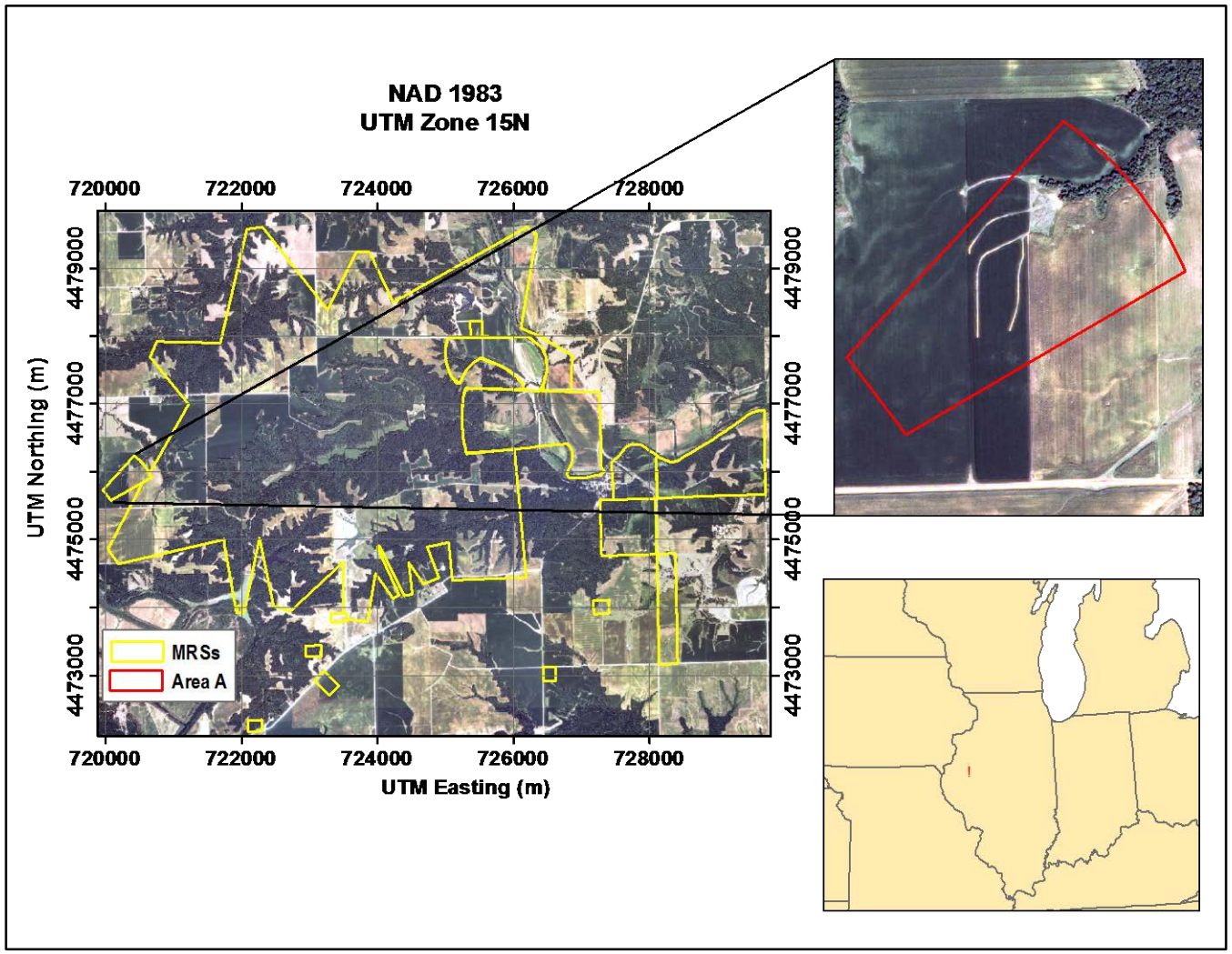

Figure 4-1: Aerial photograph of the demonstration site. A subset of Area A was selected for the ESTCP study.

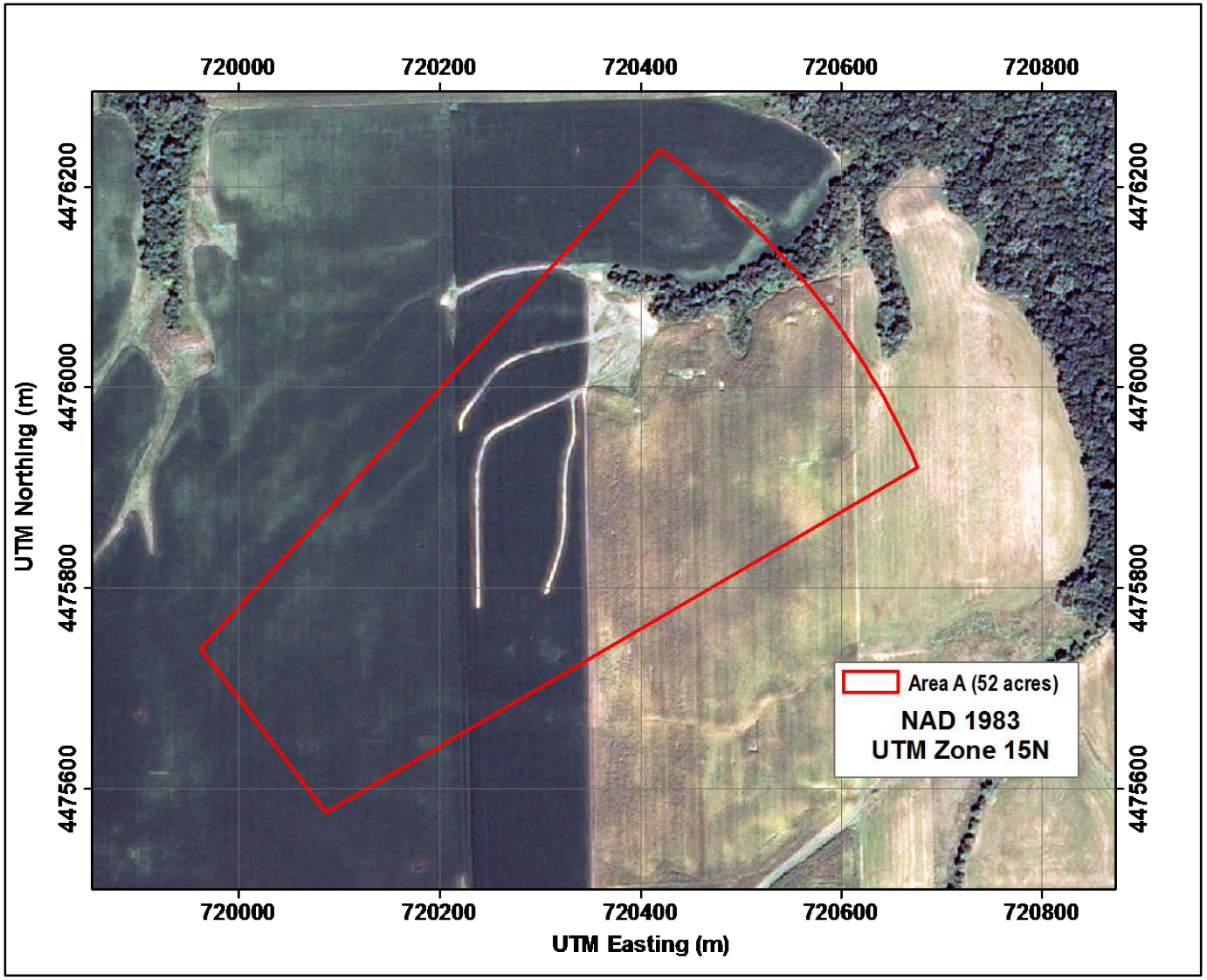

Figure 4-2: Area A Site Location Map

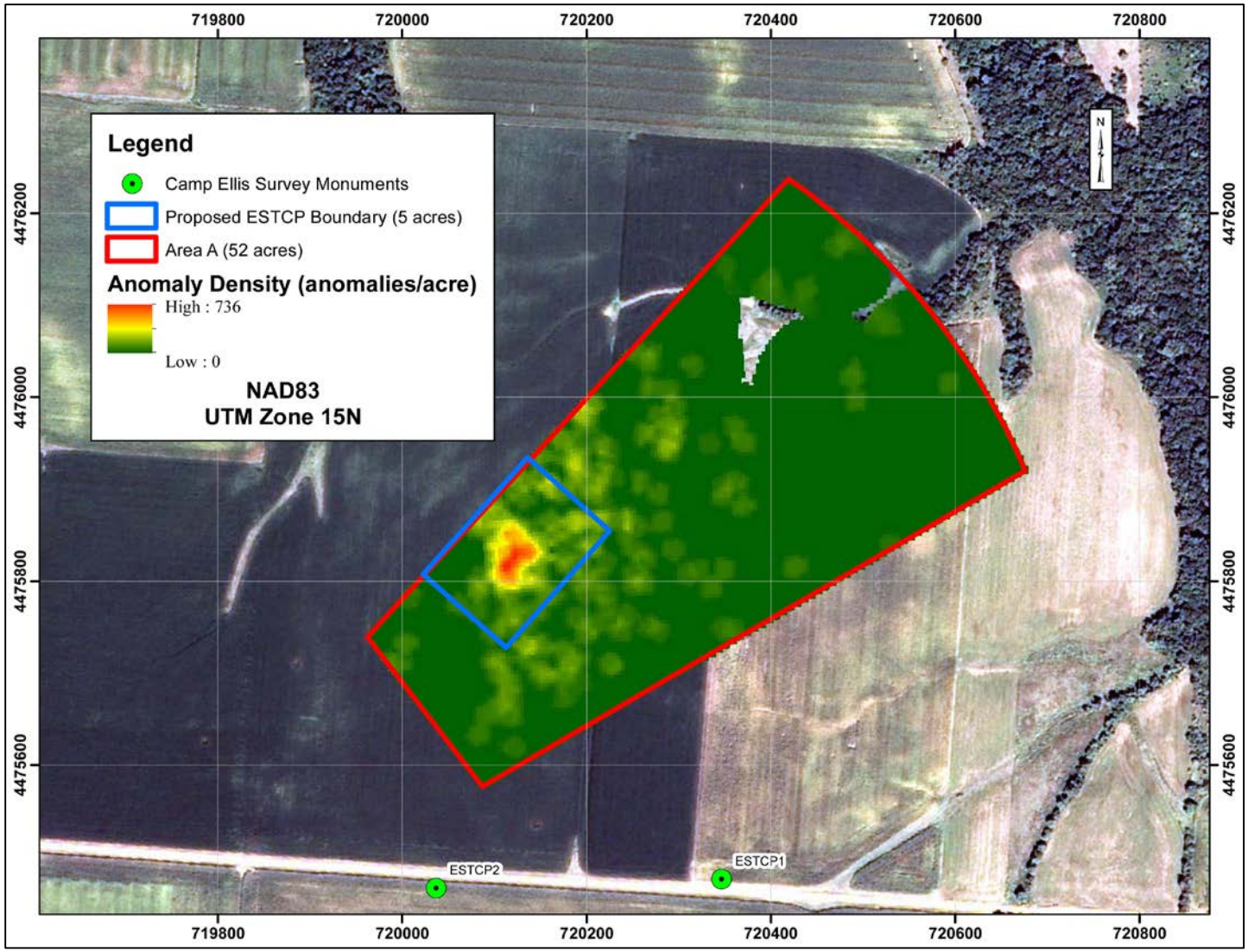

Figure 4-3: ESTCP Investigation Area Boundary with Geophysical Anomaly Density

Some of the land associated with Camp Ellis was allocated to local farmers as early as 1945, and the entire camp was declared surplus by October 1945. In April 1946, the War Department opted to keep Camp Ellis open as an Army Ground Forces training center. In 1950, the Department of Defense (DoD) screened the property for other government use, concluding that Camp Ellis should be considered surplus; the buildings were sold in June 1950. The General Services Administration (GSA) sold 2,000 acres of the property back to the original owners in late 1954. In January 1955, GSA held an auction to sell 4,000 additional acres, and the remaining property was sold throughout that year.

4.3 SITE GEOLOGY

There are three stratigraphic units at the former CEMR: shallow soil, glacial till, and bedrock (CH2MHill, 2009). The youngest of these units is the shallow soil, followed by the underlying glacial till, and then by bedrock, which is at greater depths. There are three types of shallow soils at the Area A MRS:

- Ipava Silt Loam, 0 to 2 percent slopes
- Sable Silty clay loam, 0-2 percent slopes
- Greenbush silt loam, 2 to 5 percent slopes (Nelson et. al, 2009)

All three of these soil types consist primarily of silt, with some clay. The underlying glacial till is between 6 to 15 meters in thickness and is composed of a mixture of sand, silt, clay, and gravel. The bedrock in the area is composed of sedimentary rocks, which are primarly shale, sandstone, and limestone.

Several small streams flow in the vicinity of the Area A MRS; however, none of them cross the live site demonstration area.

The site-specific soil, geology, and hydrogeology did not present a challenge to the technologies demonstrated during this demonstration.

4.4 MUNITIONS CONTAMINATION

Physical evidence of 2.36-inch practice rockets has been found in Area A. Rifle and hand grenades are also suspected as this range is historically identified as the Rocket, Rifle, and Hand Grenades MRS (CH2MHill, 2009).

5.0 TEST DESIGN

The objective of this program is to demonstrate a methodology for the use of classification in the MR process. The three key components of this methodology are collection of high-quality geophysical data and principled selection of anomalous regions in those data, analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and material properties, and the use of those parameters to construct a ranked anomaly list. Each of these components were handled separately in this program.

ARCADIS collected dynamic DGM and cued survey data for analysis andprocessed the individual dynamic and cued survey data sets using existing routines to extract target parameters. These parameters were passed to the classification routines that, after training on a limited amount of site-specific ground truth, were used to produce ranked anomaly lists.

Since this is a live site demonstration, all anomalies on the master dig list were intrusively investigated. The underlying target was uncovered, photographed, located with a cm-level GPS, and removed. ARCADIS was able to request ground truth data for training of our classifier.

At the conclusion of training, ARCADIS submitted ranked anomaly lists for both the MetalMapper and TEMTADS data sets. All anomalies were categorized and placed on the dig list in the following order:

- *Category -1:* anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
- *Category 0:* Anomalies for which ARCADIS was not able to extract reliable parameters.
- *Category 1:* Anomalies that had a high likelihood of being a TOI based on the ARCADIS classification method.
- *Category 2:* Anomalies for which ARCADIS was unsure whether the anomalies were TOI or non-TOI. Category 2 anomalies, as well as those listed above, were placed above the ARCADIS dig threshold.
- *Category 3:* Anomalies that had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

These inputs were scored by IDA with emphasis on the number of items that were correctly labeled nonhazardous (*i.e.*, non-TOI) while correctly labeling all TOI.

The primary objective of the demonstration was to assess how well ARCADIS was able to order our ranked anomaly lists and specify the threshold separating high confidence clutter from all other items. All fieldwork was conducted in accordance with (IAW) the approved Demonstration Plan, which included a Site Safety and Health Plan and the Explosives Siting Plan.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

ARCADIS performed the following tasks in order to achieve this overall objective:

- Site Preparation (*e.g.*, civil surveying and vegetation removal)

    - Civil Surveys (*e.g.* establishing First-order Navigation Points and site boundary surveys).
    - Surface Clearance
    - Establishing the IVS
    - Seeding the Site
- Data Calibration (see **Section 5.4**)
    - Twice daily IVS surveys
    - Static and dynamic test pit data collection
    - Blind seeding program
- Data Collection (see **Section 5.5**)
    - Dynamic DGM data collection using the Geonics EM61-MK2, MetalMapper, and the TEMTADS
    - Static, cued target data collection using both the MetalMapper and TEMTADS
- Data Analysis
    - Pre-Processing and QC (See **Section 6.1**)
    - Target selection for detection (See **Section 6.2**)
    - Parameter estimation (See **Section 6.3**)
    - Classification and classifier training (See **Section 6.4**)
    - Classification (See **Section 6.5**)
- Data Products (See **Section 6.6**)
    - Intrusive investigation dig list
    - Intrusive investigation results
    - Raw and Processed dynamic and static data.

5.2 SITE PREPARATION

Several activities occurred prior to data collection to ensure the resulting data would support a successful demonstration. These activities included a survey of historical records, a civil survey to establish survey control monuments for use as a base station for RTK DGPS and to survey the site boundary; a surface sweep to remove any MEC or metallic debris from the surface; construction of an IVS, and emplacement of blind seed items (BSIs) within the area of investigation. The following sections provide greater details on each of these site preparation activities.

5.2.1 Survey of Historical Records

Historical information on this site has been referenced to the *Final Limited Site Investigation Report, Former Camp Ellis Military Range, Table Grove, Illinois* (CH2MHill, 2009). This report was posted on the ESTCP FTP server and can be used for reference. No additional historical records were reviewed prior to the start of the Live Site Demonstration at the former CEMR.

5.2.2 Civil Surveys

It is important that all survey data collection and validation activities were conducted on a common coordinate system. The ESTCP Program Office established two survey control monuments at the project site. The location information and data sheet for the two first-order

control monuments that were used for this demonstration are included as **Appendix B** (see separate Addendum). After the ESTCP Program Office established the control monuments, ARCADIS subcontracted additional civil surveying activities to the Farnsworth Group, Inc., a professionally licensed surveyor in the state of Illinois, to survey:

- IVS seed item locations,
- BSI locations, and
- Southwest corners of each 30-m x 30-m grid established for DGM surveys.

The locations of the each of these items are contained in **Appendix B** (see separate Addendum) and **Figure 5-1** shows the locations of the IVS seed items and DGM grid boundaries relative to the ESTCP demonstration area.

5.2.3 Surface Clearance and Vegetation Removal

Prior to collecting DGM data, ARCADIS' UXO technicians conducted a surface clearance across the entire 5-acre demonstration area (see **Figure 5-1**) to remove metallic debris from the surface prior to the DGM surveys. The surface clearance removed all metal objects that were on the ground surface or partially buried which may interfere with the DGM data.

The demonstration area was open farmland and it was anticipated prior to mobilization that vegetation removal would not be required during the demonstration. Once the DGM survey crew mobilized to the site; however, the DGM team determined that corn stalks on the site were interfering with DGM data collection. In particular, the combined height of the corn rows and corn stalks were high enough that the corn stalks often hit the bottom receiver coil of the EM61-MK2. Therefore, ARCADIS paid the property owner to mow the corn stalks with a bush hog to a height suitable for DGM surveys. After the corn stalks were cut down close to the ground surface, ARCADIS recollected the EM61-MK2 DGM survey data.

5.2.4 IVS Establishment

ARCADIS established the IVS in an open area near the MRS that was relatively free of background anomalies. **Figure 5-1** shows the location of the IVS relative to the MRS boundary. The IVS was established IAW the Final GSV Report (Nelson et al., 2009).

Prior to establishing the IVS, the field team used the Geonics EM61-MK2, operating in the Monitor/Null mode, to determine whether the proposed IVS lines for seed items and a line for dynamic background noise measurements were relatively free of anomalies.

The IVS consisted of one hand grenade, two small industry standard objects (ISOs), one partial steel rifle grenade and an empty hole that was used as a background test location on the days for which static data was collected with the MetalMapper and/or TEMTADS. The ends of the line were marked in the field with PVC pin flags. The seed items were distributed sufficiently apart (approximately 10 feet) to prevent overlapping signals. **Table 5-1** presents the IVS seed item information, including the seed item number, description, northing and easting coordinates, depth to the center of mass, inclination and azimuth of each seed item. **Figure 5-2** shows the IVS layout. Each hole was dug following standard anomaly avoidance procedures. The seed

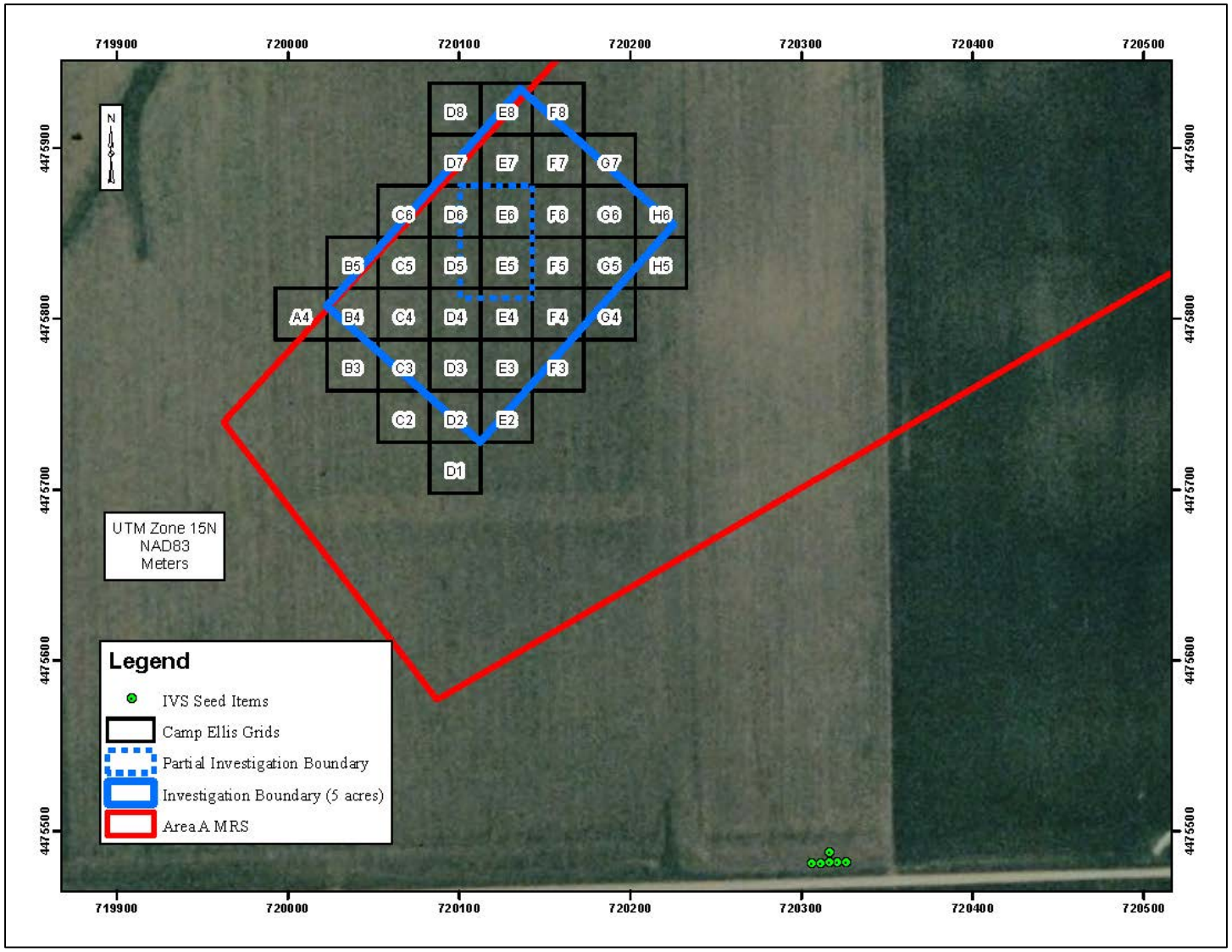

Figure 5-1: ESTCP Investigation Area and IVS Location

items were placed in designated orientation, with the depth measured from ground surface to the item's center.

Table 5-1: Details of the IVS

Item ID	Description	Easting (m)[1]	Northing (m)[1]	Depth (cm)	Inclination	Azimuth (°clockwise from North)
T-001	Hand grenade	720325.894	4475481.962	15	Horizontal	Across Track
T-002	Small ISO	720320.82	4475481.753	10	Horizontal	Across Track
T-003	Partial steel rifle grenade	720315.903	4475481.582	15	Horizontal	Across Track
T-004	Blank Space	720310.866	4475481.368	NA	NA	NA
T-005	Small ISO	720305.91	4475481.186	15	Horizontal	Across Track

Note:
1 – The coordinates are provided in UTM Zone 15N World Geodetic System 84, with units of meters.

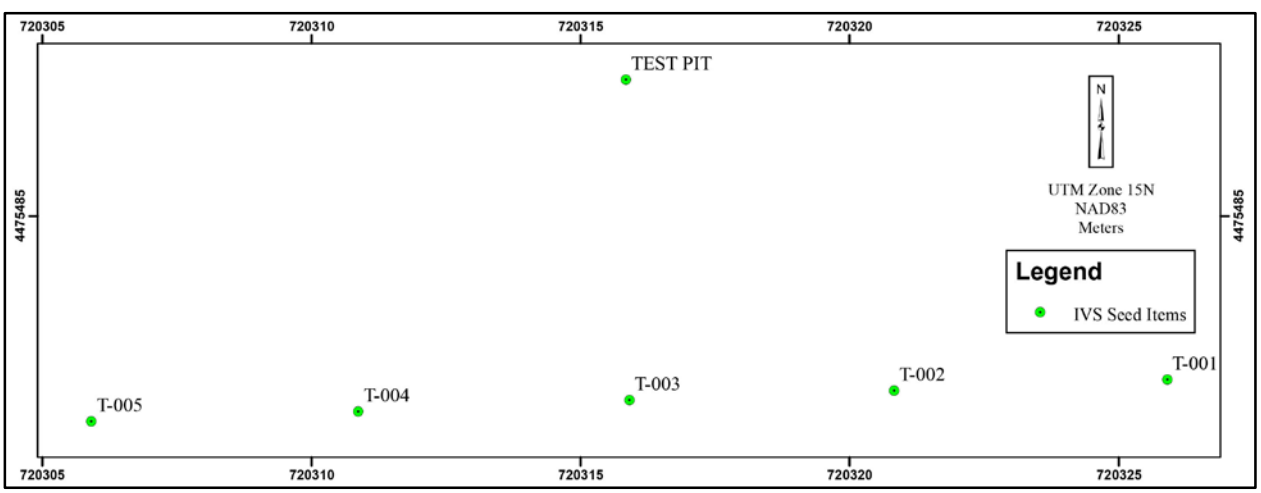

Figure 5-2: IVS Layout

All items were buried horizontally in the least favorable orientation. Depths were measured in cm and extend from the ground surface to the center of mass of the seed item.

The final horizontal location of the center of the seed items were measured by a PLS with a RTK DGPS rover receiver mounted to a range pole. Final seed item depths were measured to the

nearest 1/8 inch from ground surface to the center of each seed item. The item parameters (*i.e.*, the surveyed location, size, depth, orientation) were recorded and entered into the database. The field team marked the location of the seed items and start and end points of each IVS line at the ground surface with PVC pin flags or wooden stakes.

In addition to the IVS, a test pit was dug near the IVS to support collection of dynamic and cued (*i.e.*, static) MetalMapper and TEMTADS data over known TOI at known depths, orientations, and locations to be used for algorithm training, as needed. This test pit data, along with the IVS data was used to establish dynamic detection thresholds for the dynamic MetalMapper and TEMTADS data.

5.2.5 Seeding the Site

At a live site such as this, the ratio of clutter to TOI is such that only a small number of TOI may be found; far from enough to determine a demonstrator's classification performance with acceptable confidence bounds. To avoid this problem, ARDCADIS' UXO technicians emplaced BSIs in the demonstration area under the direction of the ESTCP Program Office.

The demonstration area was seeded with approximately 100 inert munitions (*i.e.*, 2.36" Rockets, hand grenades, rifle grenades, and ISOs). All seeds were initially blind to ARCADIS geophysicists involved in data collection, processing, analysis, and classification to allow for accurate evaluation of ARCADIS' classification performance. The ESTCP Program Office used a subset of the blind seeds to QC the data. If QC seed failures occurred, ARCADIS was required to conduct a root-cause analysis and potentially had to collect data. For this site, the BSI locations were only known to the ESTCP Program Office, the surveyors, and the UXO technicians responsible for seeding the site. The locations and depth of these targets were unknown to the ARCADIS Project Manager and geophysical team.

The exact (*x*, *y*) location, depth to the center of the target, and orientation were recorded for each emplaced BSI and are shown in **Appendix B** (see separate Addendum). The ESTCP Program Office chose the locations for the BSIs, as well as the preferred depth at which each BSI would be buried.

5.3 SYSTEM SPECIFICATION

5.3.1 EM61-MK2

The Geonics EM61-MK2 EMI sensor was used to collect dynamic DGM data across the entire demonstration site, as well as for post-dig anomaly resolution to ensure that the source(s) of anomalies were recovered during intrusive investigation. The EM61-MK2 was operated using the standard, factory-programmed four time gates on the bottom coil at 216, 366, 660, and 1266 microseconds (µs). Data was collected at a frequency of 10 Hertz (Hz) and positioned using a Trimble RTK DGPS that was updated at a frequency of 1 Hz. Ropes and measuring tapes were used to assist with straight line profiling. The EM61-MK2 was operated IAW the Geonics operations manual and the approved Demonstration Plan.

5.3.2 MetalMapper

The MetalMapper has two data acquisition modes: Single-Point-Mode (*i.e.*, static, cued) and Continuous-Mode (*i.e.*, dynamic). ARCADIS collected dynamic data on 0.5-m line spacing across the entire 5 acre site; dynamic data on 0.4-m line spacing over approximately 0.7 acres of the site centered on the target area; and static data over 1,195 targets in the southern portion of the site. Of the 1,195 static targets, 299 targets were collected with both the MetalMapper and the TEMTADS in the high anomaly density area in the target area.

Both dynamic and static, cued MetalMapper data were collected at CEMR. **Table 5-2** lists the data acquisition parameters that were used to collect data in both modes. In single-point-mode the system collects a data point and then terminates acquisition. The data are stored as a single data point in the output data file. In continuous-mode, the system initiates collection of a new data point concurrently with completion of the previous data point and continues until the operator intervenes. All of the data points are stored to the same output data file. Data were then exported to the TEM2CSV software where they were converted from the digital .TEM file to a comma spaced delimited text file (.csv file) that could be imported into Geosoft Oasis Montaj©. The primary processing difference between dynamic and static is that static data is background corrected in TEM2CSV and dynamic data is not. Instead, dynamic data is leveled (*i.e.*, background and instrument drift are removed) in Montaj©. Data processing of the dynamic data also included summing the z component of the inner five receiver coils for channels 6 through 11. All MetalMapper data was positioned with an RTK DGPS that and with an inertial measurement unit (IMU) that updated at a frequency of 1 Hz.

5.3.3 TEMTADS MP 2x2

ARCADIS collected TEMTADS data in dynamic mode over approximately 0.7 acres roughly centered on the target area and static TEMTADS data at 1,087 anomalies in the northern portion of the site. Of the 1,087 anomalies, 299 targets were collected with both the MetalMapper and the TEMTADS in the high anomaly density area in the target area. SAIC converted the dynamic TEMTADS data into a Geosoft XYZ format that ARCADIS imported into Geosoft Oasis Montaj© for processing using the UX-Detect module.

Table 5-3 lists the data acquisition parameters that were used to collect data in both dynamic and static modes. In static mode, the system collects a data point and then terminates acquisition. The data are stored as a single data point in the output data file. In dynamic survey mode, the system initiates collection of a new data point concurrently with completion of the previous data point and continues until the operator intervenes. All of the data points are stored to the same output data file. Software to convert dynamic TEMTADS data was not commercially available at the time of data collection; therefore, SAIC converted the raw .tem and .csv files and imported them to a Geosoft Oasis Montaj© database. The static data were directly imported into Geosoft Oasis Montaj©, where background corrections were applied and the data was analyzed using the UX-Analyze Advanced module.

Table 5-2: MetalMapper Data Acquisition Parameters

Mode	Tx Coils	Window Width	Hold Off Time (us)	Block Period (s)	Number of Repeats	Block Length	Number of Stacks	Decay Time (us)	No. Gates	Repeat
Dynamic	Z Only	20%	50	0.1	9	0.1	1	2498	18	Continuous
Static	ZYX	10%	50	0.9	27	0.9	10	8333	50	Once

Table 5-3: TEMTADS Data Acquisition Parameters

Mode	Acq Mode	Gate Width	Block Period (s)	Hold Off Time (us)	Number of Stacks	Stack Period (s)	Number of Repeats	Decay Time (us)	Number of Gates
Dynamic	Decimated	5%	0.033	50	1	0.1	3	2500	19
Static	Decimated	5%	0.90	50	18	0.9	9	2500	121

5.4 CALIBRATION ACTIVITIES

Five types of calibration activities were performed at CEMR:

1) Static background and static spike QC testing,
2) IVS measurements,
3) Cued background measurements,
4) Test pit measurements, and
5) UXO Technician instrument functionality testing.

Each of these calibration activities is described in greater detail in the following sections.

5.4.1 Static Background and Static Spike Testing

QC Static background and spike tests were collected with the EM61-MK2 on a twice daily basis (*i.e.*, at the beginning and end of each day) on days of data collection to verify that the instrument was operating properly. The static tests were conducted by placing a small ISO in a horizontal location on a wooden jig placed on top of the bottom coil to ensure that the test item was located in the same relative location for each test measurement.

The EM61-MK2 static background and static spike tests were not included in the performance metrics outlined within the approved demonstration plan; however, ARCADIS evaluated the data using the following industry standard performance metrics:

- Static BG: no exhibited spikes,
- Static Spike: recorded responses within 10% of the expected value.

All of the static data collected during this live site demonstration met these performance metrics. The largest variation from the mean of the static spike data was approximately 3.7%. The QC test data was included in the geophysical data deliverable provided to the ESTCP Program Office at the completion of the field effort and is included in **Appendix C** (see separate Addendum) of this report.

Although static background and spike tests were not collected with the advanced EMI sensors, they were tested at the IVS on a twice daily basis to ensure they were functioning properly.

5.4.2 Daily IVS Tests

The IVS was established by the UXO team as outlined in **Section 5.2.4** and was surveyed by the field geophysical team before and after dynamic and/or static geophysical surveys (*i.e.*, morning and evening for each data collection day). The IVS data was collected in order to verify that the equipment was operating properly and that the response of the instrument met the performance metrics established in the demonstration plan. The IVS seed item descriptions are provided in **Table 5-1**. The IVS geophysical data was provided to the ESTCP Program Office at the conclusion of the field activities and is included in **Appendix C** of this report. **Section 7.0** of this report discusses whether the performance metrics were met.

5.4.3 Background Measurements

Daily calibration efforts for the advanced sensors also consisted of collecting static background (no anomaly) data sets periodically throughout the day at quiet spots to determine the system background level for subtraction. An initial set of background spots was selected from the EM61-MK2 DGM survey data and vetted with the advanced EMI sensors prior to continued use. In general, the background response for a cued target was subtracted by using the nearest background dataset (in time) to the cued survey data; however, if QC identified issues with the background data set (*e.g.*, the response decay curve did not return to zero), the next nearest (in time) background data set was used for background subtraction. The background datasets were provided to the ESTCP Program Office at the conclusion of field activities and are included in **Appendix C** (see separate Addendum) of this report.

5.4.4 Test Pit Calibration Measurements

Test pit measurements of targets of interest were made with the MetalMapper and TEMTADS sensors in dynamic and static mode. **Table 5-4** summarizes the test pit items, approximate depths, and orientations of the test pit items that were collected early in the data collection process. Both static and dynamic data were collected to enable the test pit data to be added to site-specific classification libraries. ARCADIS did not perform classification of dynamic data; therefore only the static data was added to the MetalMapper and TEMTADS libraries during this demonstration. **Appendix C** (see separate Addendum) contains the test pit measurements for the MetalMapper and TEMTADS in both dynamic and static mode.

Table 5-4: Test Pit Calibration Data Measurement Summary

Test Pit Item	Approximate Depths (cm)	Orientations
Empty pit (static - 5 min)	NA	NA
Small ISO	5, 10	Nose Up (0º Inclination), Horizontal (90; along- and across-track), 45º Inclination, Nose Down (180º Inclination)
Hand Grenade	5, 20.3	
Steel Rifle Grenade	5, 15, 25.4	
Aluminum Rifle Grenade	5, 15, 25.4	
2.36 inch rocket	10, 45.72	

5.4.5 UXO Technician Instrument Functionality Testing

UXO technicians tested analog geophysical instruments used during intrusive operations at the IVS at the beginning of each day to ensure proper instrument functionality. Analog geophysical instruments were also checked to ensure instrument sensitivity was adequate to detect the anticipated TOI. Following these checks, settings (*i.e.*, sensitivity) for each analog sensor was recorded in the field logbook and any equipment that was found unsuitable was immediately removed from service.

5.5 DATA COLLECTION

5.5.1 Dynamic Data Collection

5.5.1.1. Scale

ARCADIS performed the following amounts of dynamic surveys:

- EM61-MK2: Entire 5 acre site.
- MetalMapper on 0.5-m line spacing: Entire 5 acre site.
- MetalMapper on 0.4-m line spacing: 0.7 acres in the partial investigation area roughly centered on the target area.
- TEMTADS data on 0.4-m line spacing: 0.7 acres in the partial investigation area roughly centered on the target area.

5.5.1.2. Sample Density

ARCADIS collected dynamic data with the following across-track line spacing:

- EM61-MK2: 0.75-meters
- MetalMapper: 0.5-m (entire site) and 0.4-m (in the partial investigation area)
- TEMTADS: 0.4-m in the partial investigation area.

The across-track line spacing for the MetalMapper was decreased from 0.75-m to 0.5-m, because only the inner five coils, which have a swath of 0.5-m, were planned to be used in data processing and target selection. The 0.5-m line spacing ensured there was overlap of the transmitter coil between adjacent lines. The TEMTADS line spacing was set to 0.4-m, because that is half of the instrument footprint. The additional MetalMapper data collected on 0.4-m line spacing was collected to enable comparisons with the MetalMapper data collected on 0.5-m line spacing to determine the potential effects of varying the line spacing, as well as to allow data comparisons to the TEMTADS data.

Table 5-5 presents a summary of the speeds achieved with each of the dynamic EMI sensors. The demonstration plan included a goal of having speeds less than 0.75 meters per second (m/s); however, this goal was not listed as one of the performance objectives. The main reasons to have a speed metric are to ensure that the along line measurement spacing metric is met and to minimize the potential for increased noise that can be caused by increased speeds. Industry standard is that 95% of data meet whatever the speed metric is. As seen in **Table 5-5**, the MetalMapper data met the speed metric; however, the EM61-MK2 and TEMTADS data did not. The MetalMapper field computer shows the speed of travel in real time, so the equipment operator can monitor speed to ensure data is collected within the project's performance objectives. The other two instruments did not have this capability, at least at the time of data collection. It should be noted that with the along line sampling density of 0.15 m and the 10 Hz sampling rate, one could travel 1.5 m/s and still meet the along line measurement spacing. In fact, 96.6% of the TEMTADS has a speed of less than or equal to 1.5 m/s, which is consistent with the along line measurement spacing. Although the planned speeds were not accomplished for all datasets, increased noise was not exhibited in the data and the down line and across line

sample density was sufficient to the meet the project's overall objective of identifying targets for cued interrogation and for comparisons between the various datasets.

Table 5-5: Dynamic EMI Speed Results

Performance Objective	EM61-MK2	MetalMapper (0.5m line spacing)	MetalMapper (0.4-m line spacing)	TEMTADS
Speed Metric Success Criteria	Speed less than 0.75 m/s			
Speed Above Success Criteria (%)	23.29%	0.47%	0.13%	64.4%
Percent Below Success Criteria (%)	76.61%	99.53%	99.87%	35.6%
Mean Speed (m/s)	0.63	0.18	0.16	0.89
Standard Deviation (m/s)	0.18	0.1	0.07	0.4

5.5.1.3. Quality Checks

In addition to the calibration activities described above in **Section 5.4**, dynamic mode quality checks included the following:

- At the beginning of each day, the field team allowed the EMI sensors to warm up for a minimum of 15 minutes.
- Static Background and spike measurements were collected for the EM61-MK2 only to ensure repeatability of response. Static repeatability of the advanced sensors were conducted at the IVS.
- For all sensors, dynamic repeatability tests were completed at the IVS on a twice daily basis. As discussed above, ARCADIS performed twice daily instrument function checks at the IVS to verify the dynamic response and positioning repeatability of the complete geophysical system.

5.5.1.4. Data Summary

For each dataset, the field team created a file using the date and a sequential alphabetic character. The naming convention varied for the different files types as follows:

- **EM61**
  - Data: MMDDXX, where
    - MMDD = Month and Day
    - XX = grid number
  - IVS: MMDDIVSX, where
    - MMDD = month, day
    - X = 1 (AM) or 2 (PM)
- **MetalMapper**

    - Data: EllisDynXXXXX.tem, where
        - XXXXX = Sequential number
    - IVS Filename: EllisDynIVSXXXXX.tem, where
        - XXXXX = Sequential number
- **TEMTADS**
    - Data and IVS: YYYYMMDD_XXXXX, where
        - YYYYMMDD = Year, Month, and day.
        - XXXXX = Sequential number

The production data was collected on individual lines, except for the TEMTADS data, which was collected along several continuous lines that resulted in collected data while turning around at the end of each line.

EM61 data were recorded into binary file formats with a .p61 extension. These formats were converted into the final .xyz format in Geosoft. MetalMapper and TEMTADS data were both collected in .tem format. The MetalMapper data was converted to a .csv file using the TEM2CSV program and then imported into a Geosoft database (.gdb) for processing. SAIC used proprietary software to convert the dynamic TEMTADS data from the raw .tem and import it into a Geosoft database (.gdb) for processing. Geophysical data is contained in **Appendix C** (see separate Addendum) and has been organized into raw and processed data folders. Each of the datasets is contained in a single .gdb file. Additional information on the organization of the data is contained in **Appendix C** (see separate Addendum).

5.5.2 Static, Cued Survey Data Collection

5.5.2.1. Scale

ARCADIS collected static data at a total of 1,983 targets. 299 of the targets were collected with both instruments; therefore, the total number of cued targets on the MetalMapper and TEMTADS target lists is 2,282. ARCADIS collected the following amount of static data:

- MetalMapper: 1,196 targets
- TEMTADS: 1,086 targets

5.5.2.2. Sample Density

Static data was collected at an individual point with fixed transmitter and receiver geometry; therefore, there is no corresponding along line or across line data density.

5.5.2.3. Quality Checks

In addition to the data calibration activities described in **Section 5.4**, ARCADIS also performed a QC of the static, cued survey data within 24 hours of data collection to ensure that data collected was sufficient for advanced classification purposes. As part of this QC, the data processor verified the following:

- Background data location did not exhibit signs of a local piece of metal within the readings;

- Static IVS decay responses were within performance metrics;
- Static IVS classification was consistent; and
- For cued targets, verification that the inverted target location was within 40 cm of the center of the array.

If the data processor found indication that the performance metrics were not going to be met (*e.g.*, inverted target location outside instrument footprint), the target was flagged to be re-collected and the field team was instructed to recollect the data.

5.5.2.4. Data Summary

For each dataset, the field team created a file using the date and a sequential alphabetic character. The naming convention varied for the different files types as follows:

- MetalMapper
  - Background: EllisBkgdXXXXX.tem, where
    - XXXXX =sequential number
  - Data: EllisStatXXXXX.tem, where
    - XXXXX = Sequential number
  - IVS and Testpit: EllisStatIVSXXXXX.tem, where
    - XXXXX = Sequential number
- TEMTADS
  - Background: bkgdxxxx.tem, where
    - XX = sequential number
  - Static Data: ttXXX.tem, where
    - XXX = sequential number
  - IVS: ivsYYttsXX, where
    - YY = am or pm
    - XX = sequential number
  - Testpit: tpttsXX, where
    - XX = sequential number
    - YYYYMMDD = Year, Month, and day.
    - XXXXX = Sequential number

The MetalMapper and TEMTADS data were collected in binary .tem files. MetalMapper data was converted to a .csv file using the TEM2CSV program and then imported into a Geosoft database (.gdb) for processing. TEMTADS data was exported to .csv file on the field computer and then imported into a Geosoft database (.gdb) for processing. Geophysical data is contained in **Appendix C** (see separate Addendum) and has been organized into raw and processed data folders. Each of the datasets is contained in a single .gdb file. Additional information on the organization of the data is contained in **Appendix C** (see separate Addendum).

5.6 VALIDATION

At the conclusion of data collection activities, all anomalies on the master dig list developed from the dynamic MetalMapper data were excavated by ARCADIS' UXO Technicians, who met the requirements of Technical Paper-18. Each item encountered was identified, photographed,

its depth measured, its location determined using cm-level RTK DGPS, and the item removed. Intrusive investigation and demolition procedures followed the standard operating procedures included in the approved Demonstration Plan. The intrusive investigation results were documented on field forms and transcribed into an MS Excel spreadsheet that was provided to the ESTCP Program Office and is included in **Appendix D** (see separate Addendum) of this report.

6.0 DATA ANALYSIS AND PRODUCTS

There were two facets to the data analysis for this demonstration:

- Dynamic data was pre-processed and, in conjunction with the ESTCP Program Office, target lists were generated from the MetalMapper and EM61-MK2 datasets that covered the entire site.
- Static, cued survey data was processed to subtract background measurements and to apply a geolocation (for the TEMTADS only).

Once the data static data was pre-processed, ARCADIS employed physics-based models to extract target parameters and then applied a library matching classification algorithms contained in Oasis Montaj's advanced UX-Analyze Advanced module to produce a ranked anomaly list.

6.1 PREPROCESSING

Data was preprocessed using instrument-specific procedures. These preprocessed data was provided for use in target parameter extraction. Below are the instrument-specific pre-processing steps that were employed during this demonstration.

6.1.1 EM61-MK2

ARCADIS performed data file QC review of and correction of the following:

- Transect or Grid name and location, and
- Line numbers, survey direction, start and end points.

Additional processing of the EM61-MK2 data was conducted in Geosoft Oasis Montaj© and included applying drift corrections (*i.e.*, leveling the data) and latency corrections. Once these corrections were applied, the data processor gridded the data and targets were selected.

6.1.2 MetalMapper

Dynamic and static MetalMapper data was pre-processed by converting the raw .tem file to the .csv file using Snyder Geoscience, Inc.'s TEM2CSV software package. TEM2CSV was also used to convert the GPS-supplied latitude/longitude data to UTM coordinates, correct the survey location point using attitude data for the MetalMapper platform (heading, pitch, and roll), and remove the background field from all of the receiver transients (for static data only).

Dynamic MetalMapper data was then leveled in Geosoft Oasis Montaj©. No latency correction was applied because there was no apparent latency in the dynamic dataset. The response for time gates 6 through 11 were then summed and average for the inner five receivers. The averaged response for the five inner receivers was then gridded for target selection.

After pre-processing static data in TEM2CSV, the .csv file was then imported into Geosoft Oasis Montaj© processing environment for further analysis.

6.1.3 TEMTADS MP 2x2

At the time of data collection, there was no commercially available software to convert the raw, dynamic TEMTADS data in .tem format to a .csv file; therefore, SAIC converted the files and imported them to an Oasis Montaj geodatabase. Once in Montaj, channel 4 of the monostatic Z response (*i.e.*, Z transmit and Z receive coil) was multiplied by -1 to make the response positive and then leveled. No latency correction was applied because there was no apparent latency in the dynamic dataset. Once the data were leveled, the leveled, channel 4 was gridded for target selection.

The static TEMTADS data was exported to .csv files on the field computer. In preprocessing on the field computer, the recorded signals were normalized by the peak transmitter current to account for any variation in the transmitter output. The .csv files were imported to Geosoft Oasis Montaj© and then background corrections were applied prior to further analysis, which is described below. The background response was subtracted from each target measurement using data collected at a nearby target-free background location. The background measurements were reviewed for variability and to identify outliers, which might have corresponded to measurements over metallic items.

6.2 TARGET SELECTION FOR DETECTION

Anomalies were selected from the dynamic DGM survey data using a target response-based procedure. The target selection threshold for each advanced EMI sensor was based on the response for the anticipated Area A TOI, which corresponded to the following:

- 2.36 inch rocket down to 18 inches (~7.2 milliVolts [mV] on EM61-MK2 channel 2)
- Hand grenade down to 8 inches (~9.4 mV on EM61-MK2 channel 2)
- Aluminum rifle grenade down to 10 inches (~25.5 mV on EM61-MK2 channel 2).

The approximate EM61-MK2 channel 2 response for the first two TOI listed above were estimated using NRL's Response Calculator, while the aluminum rifle grenade response was measured in the field at the test pit. The final target selection criteria was based on the smallest Channel 2 response of the 2.36-inch rocket and included greater than a 50% safety factor (*i.e.*, the final selection threshold was decreased by over half to account for response variations due to variations in instrument height). The target selection threshold for the dynamic MetalMapper and TEMTADS data was based on a comparison of the measured response of the advanced EMI sensors to the EM61-MK2 response for the TOI listed above at the TOI-specific target depths. The final targeting thresholds for each dataset are listed below:

- <u>EM61-MK2</u>: 3.0 mV channel 2
- <u>MetalMapper</u>: 3.0 mV sum channels 6-11 averaged on inner 5 Z coils
- <u>TEMTADS</u>: 1 mV on channel 8

Targets were selected from gridded EMI data for anomalies with responses greater than those listed above. **Figures 6-1** through **6-4** show the processed dynamic data for the EM61-MK2, MetalMapper (lines spaced 0.5-m apart), MetalMapper (lines spaced 0.4-m apart), and for the TEMTADS, respectively. The EM61-MK2 and MetalMapper datasets collected across the entire

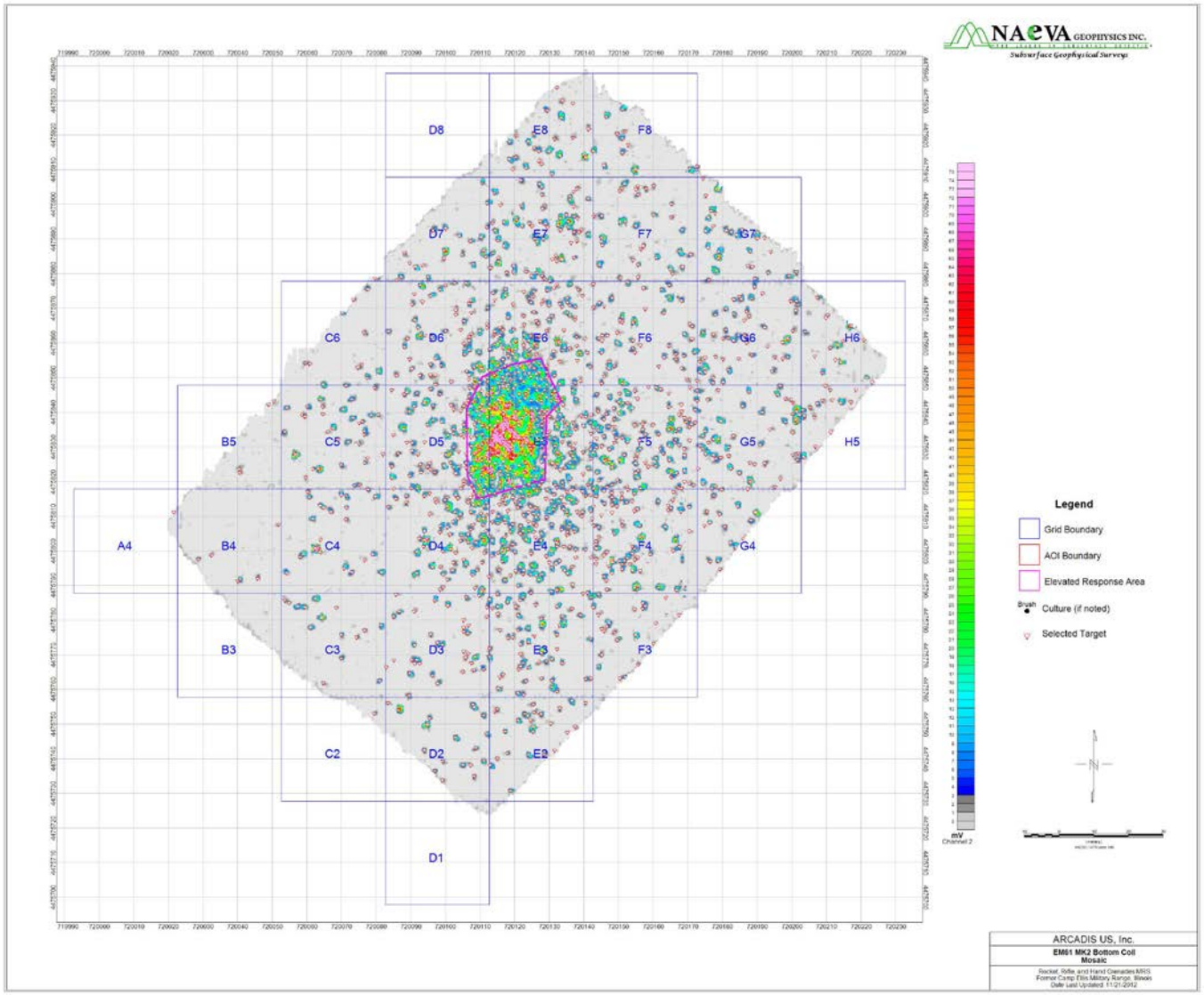

Figure 6-1: Dynamic EM61-MK2 Data

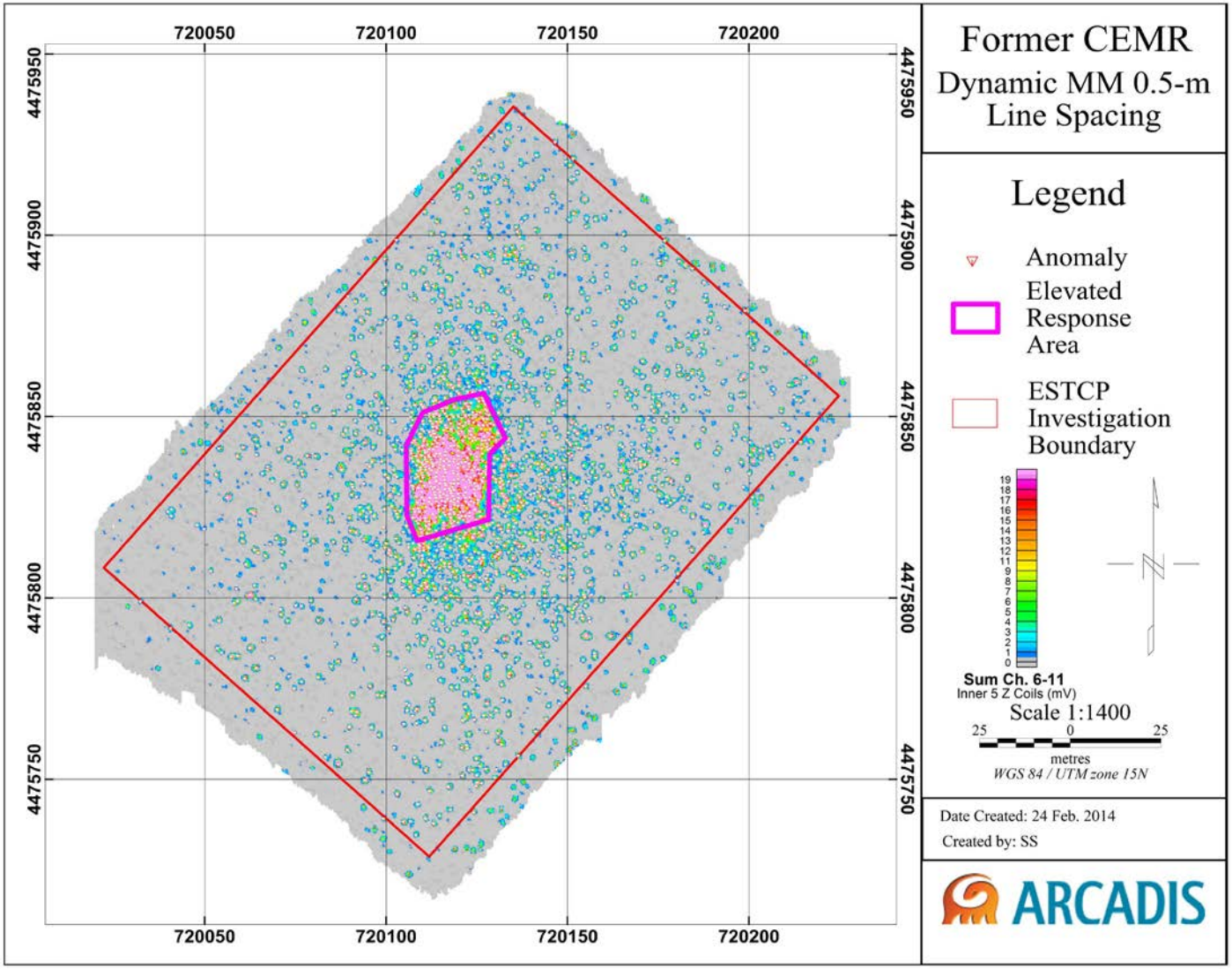

Figure 6-2: Dynamic MetalMapper Data on 0.5-m Line Spacing

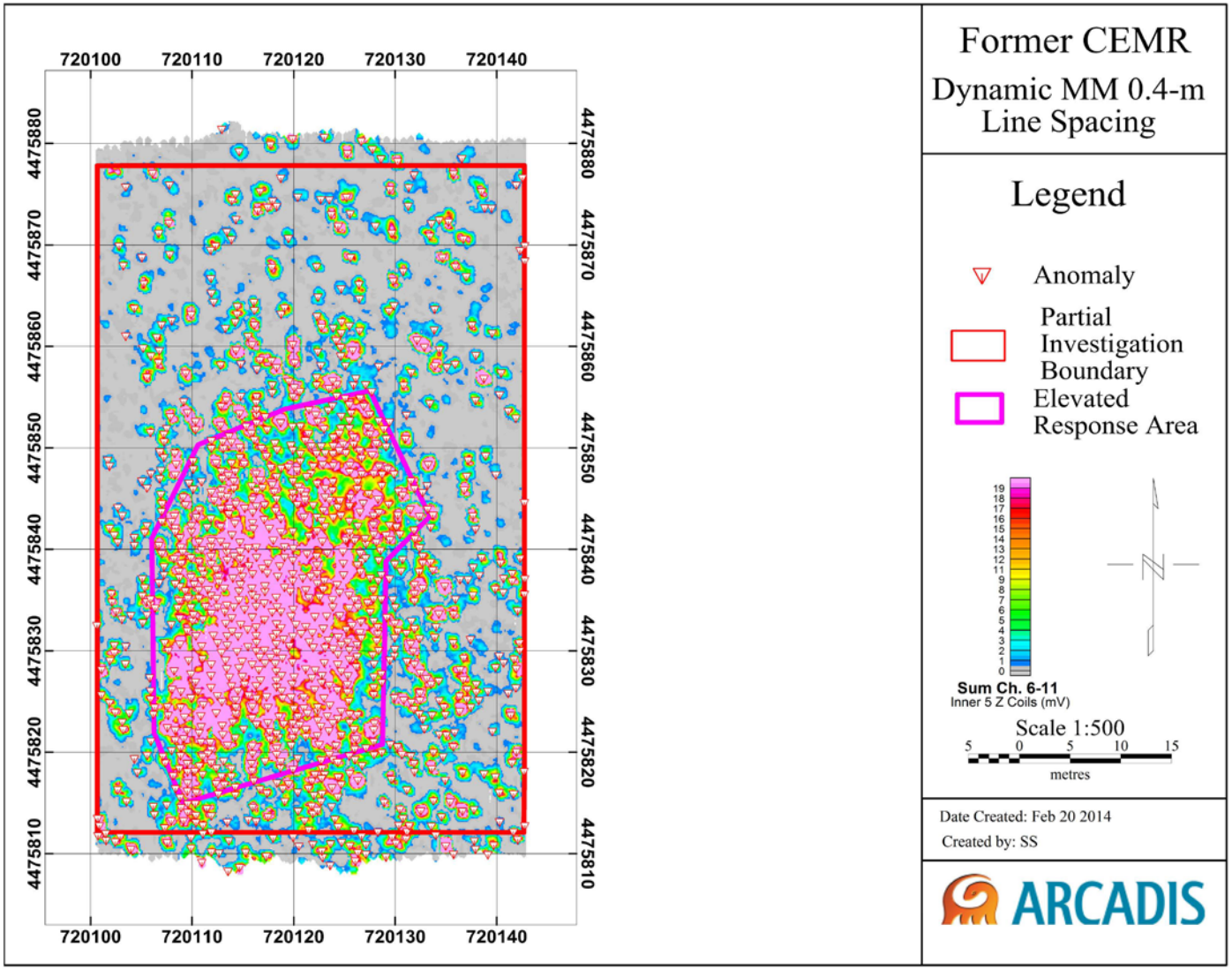

Figure 6-3: Dynamic MetalMapper Data on 0.4-m Line Spacing

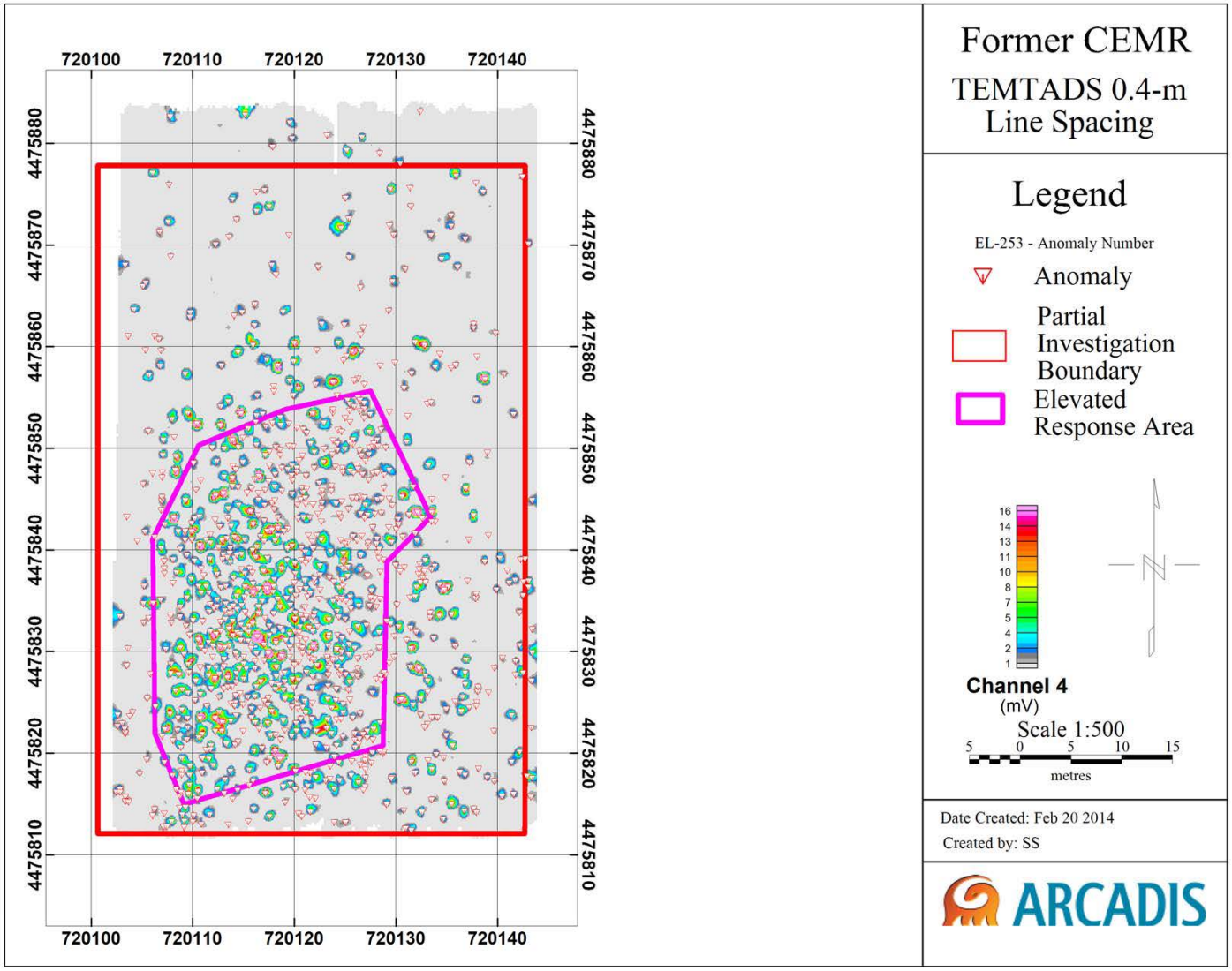

Figure 6-4: Partial Dynamic TEMTADS Data within Target Area

site had a total of 1,471 and 1,785 anomalies respectively. Initially, the plan was to use the EM61-MK2 targets to determine the targets at which static data would be collected; however, several blind ISOs were not detected within the 0.6-m search radius for the EM61-MK2. Both ISOs were detected, but the anomalies were double-peaked and the peaks were greater than 0.6-m from the center of the seed item. Because these targets failed the QC performance criteria, the MetalMapper data collected across the entire site was used instead to identify targets that would be collected using the advanced sensors in static mode. During static data QC, the QC geophysicist performed an inversion of the static data and evaluated the data to determine if there were potentially multiple targets at the target location. If multiple potential TOI were identified at a target location, an additional target was added to the target list. The target lists were provided to the ESTCP Program Office during the field effort. Targets EL-1 through EL-1785 were the initial MetalMapper targets, while targets with numbers greater than 1,785 were added during the static data QC. Static data was collected over the initial 1,785 targets as follows:

- 299 targets collected over the target area using both the MetalMapper and the TEMTADS;
- 740 targets collected over the southern half of the site with only the MetalMapper; and
- 746 targets collected over the northern half of the site with only the TEMTADS (see **Figure 6-5**).

Figure 6-6 shows a comparison of the anomaly response for a small portion of the site within the target area for the four different dynamic datasets: a) EM61-MK2 data with 0.5-m line spacing, b) MetalMapper data with 0.5-m line spacing, c) MetalMapper data with 0.4-m line spacing, and 3) TEMTADS data with 0.4-m line spacing. The vertical and horizontal black lines are northing and easting coordinates and are 5-m apart on all figures. The color scales for this figure are the same as for **Figures 6-1** through **6-4** for the respective dataset. A qualitative analysis shows that the general anomaly shapes for the EM61-MK2 and MetalMapper data in a) and b) are very similar. This is to be expected given that the summing of channels and averaging the response over the inner five z coils made the MetalMapper effectively quite similar to the EM61-MK2. Decreasing the line spacing of the MetalMapper to 0.4-m (see **Figure 6-6** part c) appears to have removed some of the smoothing seen in the first two images, while slightly increasing the ability to identify discrete anomaly peak. The TEMTADS data further reduces the smoothing and is much better than the other instruments at identifying discrete anomalies. The more discrete anomalies are likely due to not averaging the response across multiple sensors. A similar type of discretization of anomalies should be accomplishable using the split cubes on the MetalMapper (*i.e.*, not averaging across the inner 5 Z coils).

6.3 PARAMETER ESTIMATES

ARCADIS used the cued MetalMapper and TEMTADS data to perform advanced classification. Detection survey data was only used for identification of targets at which cued survey data was collected and to compare the datasets in a qualitative manner. Each selected anomaly was analyzed using the multi-object solver algorithm in the UX-Analyze Advanced module within Oasis Montaj. Both intrinsic (size, shape, materials properties) and extrinsic (location, depth, orientation) parameters were estimated in these analyses and a list of the relevant target parameters from each analysis compiled.

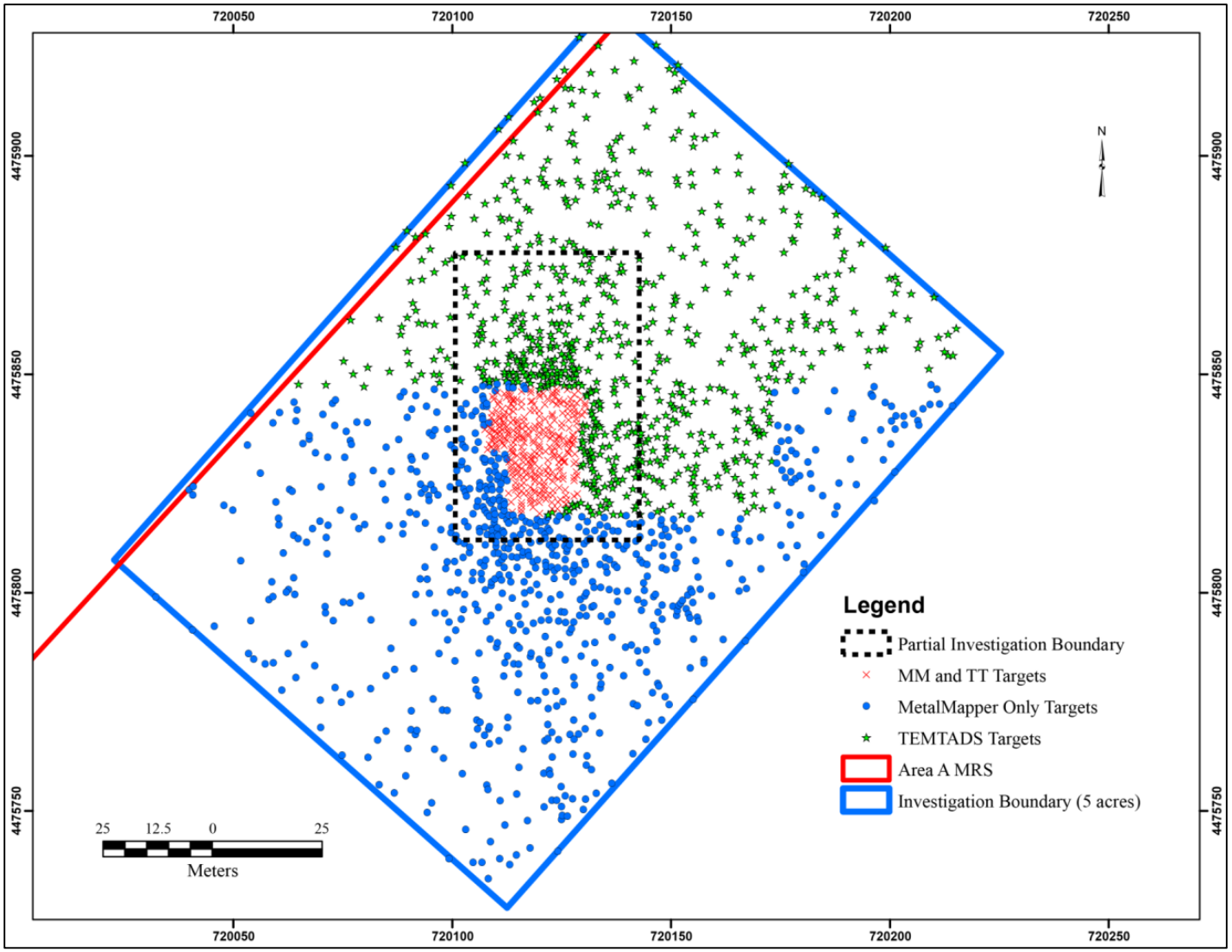

Figure 6-5: Static Data Collection Summary.

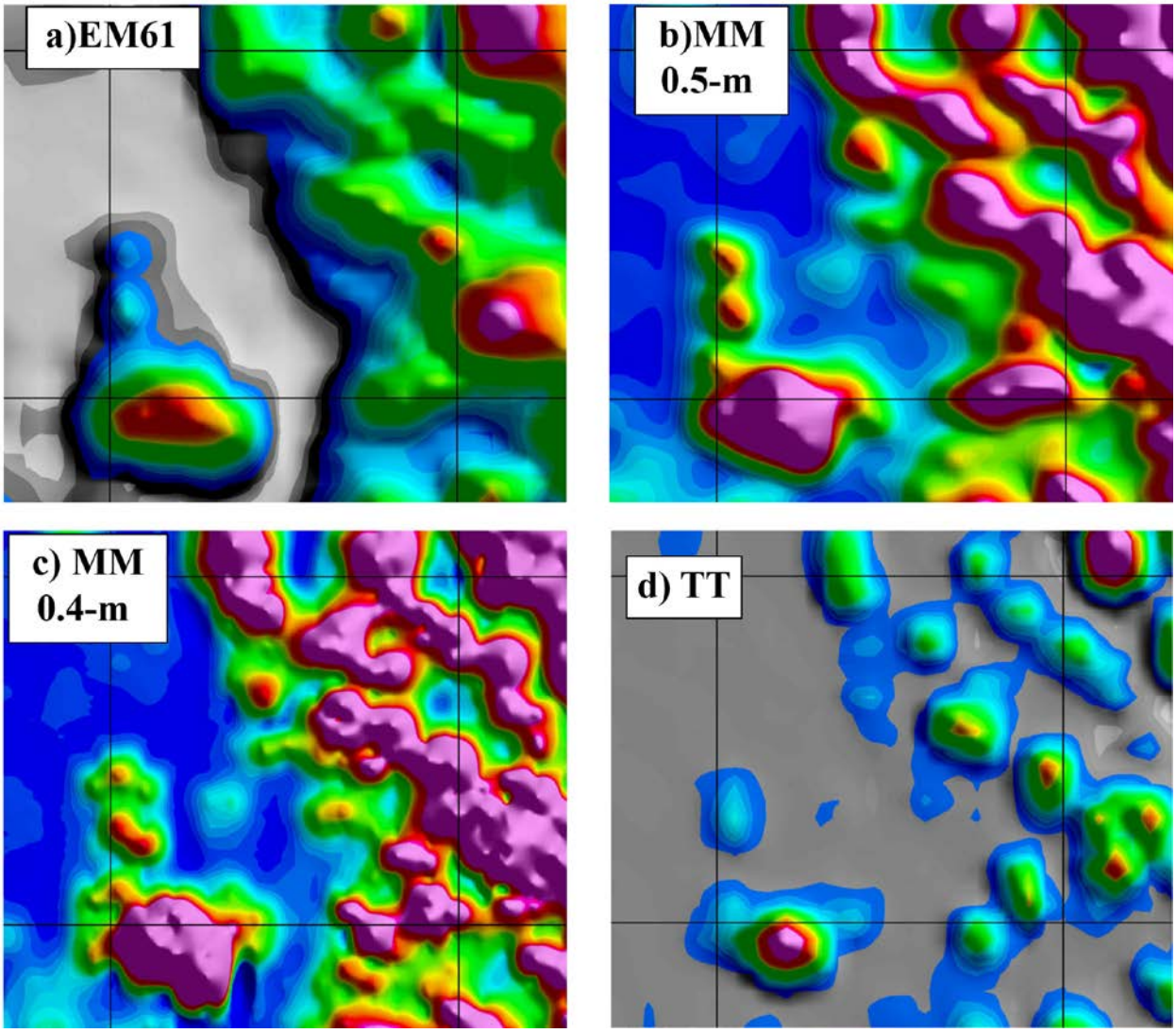

Figure 6-6: Dynamic Data Comparisons. Comparison of dynamic datasets within the target area. Black lines, representing northing and easting coordinates are 5-m apart. a) EM61-MK2 data collected on 0.5-m line spacing. b) MetalMapper data collected on 0.5-m line spacing. c) MetalMapper data collected on 0.4-m line spacing. d) TEMTADS data collected on 0.4-m line spacing.

The static data was processed using UX-Analyze Advanced module to extract the three principal axis polarizability curves for each target. For the static data, ARCADIS then matched the polarizability curves for each target to a library of polarizability curves to classify the target as either TOI or non-TOI.

6.4 CLASSIFIER AND TRAINING

ARCADIS' initial classifier for both advanced EMI sensors involved matching the measured polarizabilities to a library that contained TOI from previous sites and the site-specific TOI

tested in the test pit. The size and shape of polarizabilities (or βs) were matched to the known library items for the following three scenarios:

- **3 component target classification**
  - Size – β_1
  - Shape 1 – β_2/ β_1
  - Shape 1 – β_3/ β_1
- **2 component target classification**
  - Size – β_1
  - Shape 1 – β_2/ β_1
- **1 component target classification**
  - Size – β_1

Based on this initial classification, training data was requested from the program office for 49 MetalMapper and 51 TEMTADS targets. The training data was requested to verify the library matching model that was being proposed and included ground truth from excavations at this site. The particular training data that was requested tended towards relatively low confidence metrics (*e.g.*, 0.7 – 0.85) to aid in determining the appropriate location of the dig threshold. Of the requested training data, only 5 MetalMapper and 3 TEMTADS targets were actually TOIs. Nearly all of the remaining requested training were munitions debris (MD); primarily 2.36" Rocket Weights (see **Figure 6-7**) and 2.36" Rocket Motors (see **Figure 6-8**). Both of these MD items have similar characteristics to the TOI at the site. The rocket weights are very similar to the small ISOs that were used for blind seeding and the rocket motors were very similar in size and shape to actual 2.36" rockets. In order to account for the apparently large number of rocket weights and motors at the site, five MD items from both the MetalMapper and TEMTADS training data were added to their respective libraries and all targets were re-classified for the 3-, 2-, and 1-component matches.

Figure 6-7: Example 2.36" Rocket Weight

Figure 6-8: Example 2.36" Rocket Motor

6.5 CLASSIFICATION

6.5.1 Initial Classification

ARCADIS produced one ranked anomaly list for the MetalMapper library matching approach and two ranked anomaly lists for the TEMTADS library matching approach. The library matching approach for both sensors included matching to both TOI and the MD clutter items added to the library that are discussed above. The final classification used a combined

confidence metric that averaged the confidence metric for the best fitting TOI (or clutter item in the library) for the 3-, 2-, and 1- component matches. The best fitting TOI (or clutter item) for the 3-component match was then assigned as the TOI Type. ARCADIS then classified each anomaly as one of the following categories:

- *Category -1:* anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
- *Category 0:* Anomalies for which ARCADIS was not able to extract reliable parameters.
- *Category 1:* Anomalies that had a combined metric match to TOI greater than 0.85. These anomalies were believed to have a high likelihood of being TOI.
- *Category 2:* Anomalies that had a combined metric match to TOI between 0.8 and 0.85. ARCADIS was unsure whether these anomalies were TOI or non-TOI.
- *Category 3:* Anomalies that had a combined metric match to TOI less than 0.8 or a combined metric match to Clutter greater than 0.85. These anomalies had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

Figure 6-9 shows a size-decay plot for the best 3-component matches for the TEMTADS data. Items classified as one of the MD clutter items are shown in green squares. Two clusters of clutter items are seen: one near the top and one in the central region of the size decay plot. These clusters are circled in red on **Figure 6-9**. The central clutter cluster has considerable overlap with small ISOs, which are displayed as pink circles. As discussed above, ARCADIS attempted to try to identify anomalies that were likely to be due to clutter MD items to reduce the number of digs required to identify all of the TOI on the site. In order to do this, ARCADIS classified targets that had a confidence metric greater than 0.85 and a best fit to a Clutter Item as a category 3 anomaly. One ranked dig list was submitted for the MetalMapper data and two ranked dig lists were submitted for the TEMTADS: Dig List A (for aggressive) and Dig List C (for conservative). No modifications were made to the Dig List C; however, the TEMTADS Dig List A was further modified to attempt to remove the central clutter cluster seen in **Figure 6-9** from the dig list. For TEMTADS Dig List C, all anomalies within the central cluster were re-classified as Category 3 and placed below the cut line.

Table 6-1 shows an example of how ARCADIS ordered our ranked anomaly list. Category -1, 0, 1, 2 anomalies were placed above the dig threshold in descending order, while Category 3 anomalies were placed below the dig threshold. The first items on each ranked anomaly list were those targets for which ground truth labels were requested (training data). Following this, anomalies for which reliable parameters could not be extracted and therefore had to be dug were listed. Next were the items that ARCADIS was the most confident are “highly likely” to be TOI. The items were ranked according to decreasing confidence that the item is TOI. Any items that ARCADIS was able to analyze, but were not able to classify (*i.e.*, Category 2 anomalies) were placed next on the anomaly list. Finally, all Category 3 items that ARCADIS was confident were not TOI were ranked by their confidence. The Category 3 anomalies were ordered in descending order based on their confidence metric, which led to the best match to clutter items being the highest ranking Category 3 anomaly on the dig list.

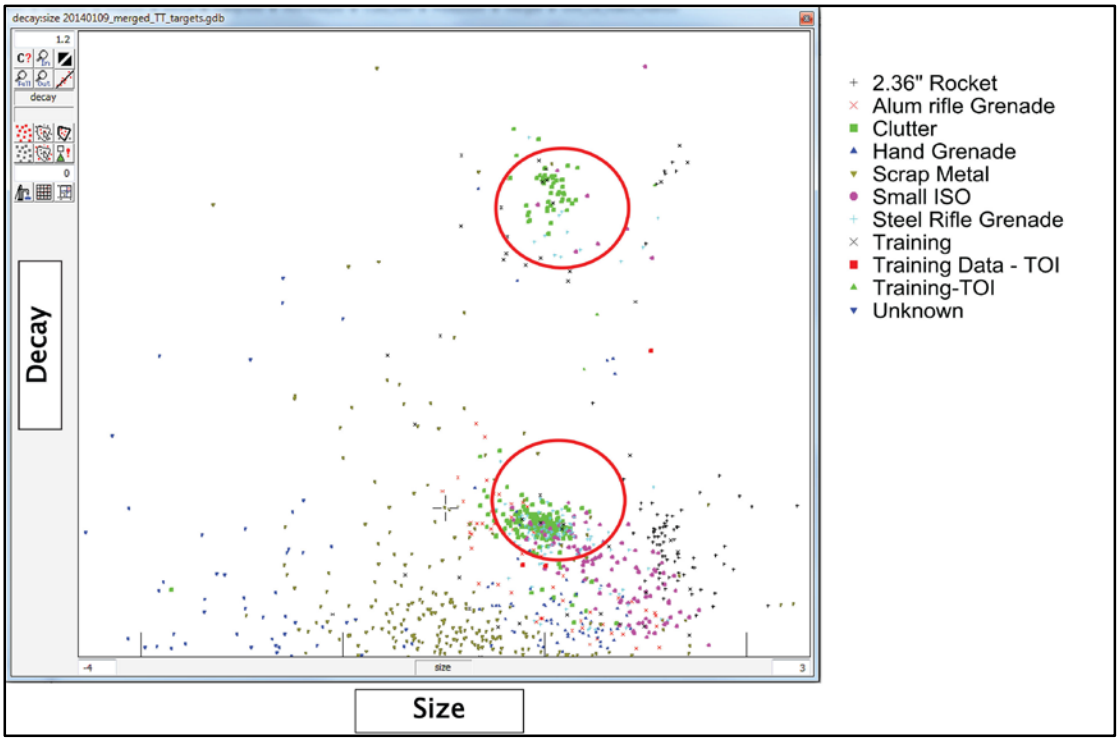

Figure 6-9: Size-Decay X-Y Scatter Plot of TEMTADS Data. Green squares represent the targets classified as clutter items (*i.e.*, 2.36" Rocket Weights or Motors). Two clusters of clutter items are circled in red: one in the top and one in the central portion of the size decay plot.

Table 6-1: Example Ranked Anomaly List

Target ID	Category	Dig Decision (1=Dig; 0=Do Not Dig)	Type (mm)	Confidence Metric	Comment
EL-24	-1	1	127	1	Training Data
…	…	…	…	…	Training Data
EL-339	-1	1	127	0.65	Training Data
EL-17	0	1	127	9999	Can't Analyze
…	…	…	…	…	…
EL-862	0	1	127	9999	Can't Analyze
EL-841	1	1	25	1	High Confidence Match to TOI
…	…	…	…	…	…
EL-562	1	1	25	0.85	High Confidence Match to TOI

Target ID	Category	Dig Decision (1=Dig; 0=Do Not Dig)	Type (mm)	Confidence Metric	Comment
EL-625	2	1	60	0.85	Cannot Decide
…	…	…	…	…	…
EL-167	2	1	60	0.8	Cannot Decide
EL-710	3	0	0	1	High Confidence Match to Clutter Items
…	…	…	…	…	…
EL-1006	3	0	0	0.8	High Confidence Match to Clutter Items
EL-631	3	0	0	0.79	Low Confidence Match to TOI and Clutter Items
EL-978	3	0	0	0	Low Confidence Match to TOI and Clutter Items

Note:
mm – millimeter

In addition, ARCADIS provided an assignment to the 'Type' column, indicating the specific type of munition caliber (*i.e.*, 75 mm). The final, ranked anomaly lists are provided in **Appendix E** (see separate Addendum).

6.5.2 Feedback Based on QC Seed Performance

The initial ranked anomaly lists were analyzed to confirm that all QC seeds had been classified correctly. QC seed items were not marked to be dug on the initial dig list; therefore, the ESTCP Program Office provided the location and identity of the misclassified QC seeds as additional on-site training data. ARCADIS used this additional information to modify our classification procedures to ensure that the revised methods correctly classify the seeds missed originally. A second stage list was then submitted accompanied by a Failure Analysis memo outlining the causes of the misclassification, the revisions made in classification procedures, and a demonstration that the revised procedures successfully classified the missed seeds. **Appendix F** (see separate Addendum) contains the QC Seed Failure Memos for the MetalMapper and TEMTADS dig lists. Upon acceptance of the memos by the ESTCP Program Office, ARCADIS submitted Final Ranked Dig Lists (see **Appendix E** in separate Addendum) to the Program Office and the second stage list was scored by IDA.

6.6 DATA PRODUCTS

6.6.1 Ranked Anomaly Lists and Results

As discussed above, ARCADIS submitted a total of three ranked anomaly lists: one for the MetalMapper and two for the TEMTADS data. Upon submittal of the final ranked dig lists, IDA constructed Receiver Operating Characteristic (ROC) curves for each anomaly list. **Figures 6-**

10, **6-11**, and **6-12**, show the ROC curves for the MetalMapper, TEMTADS Dig List A, and TEMTADS Dig List C, respectively.

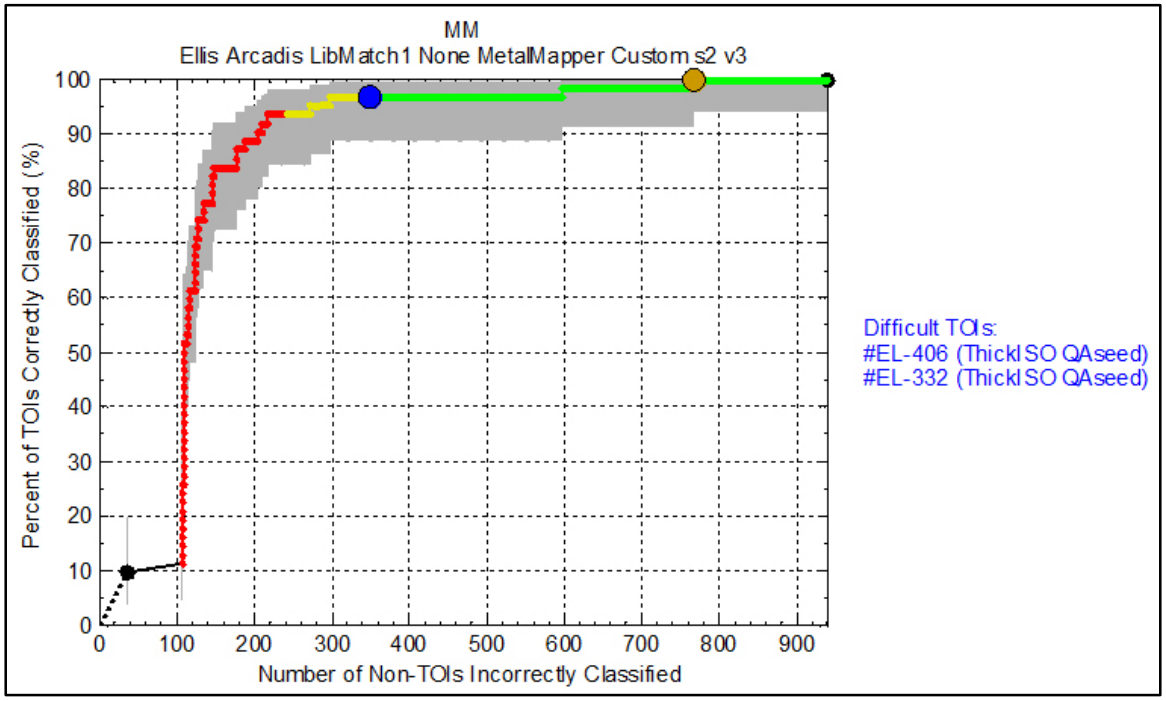

Figure 6-10: MetalMapper ROC curve with four points of interest indicated

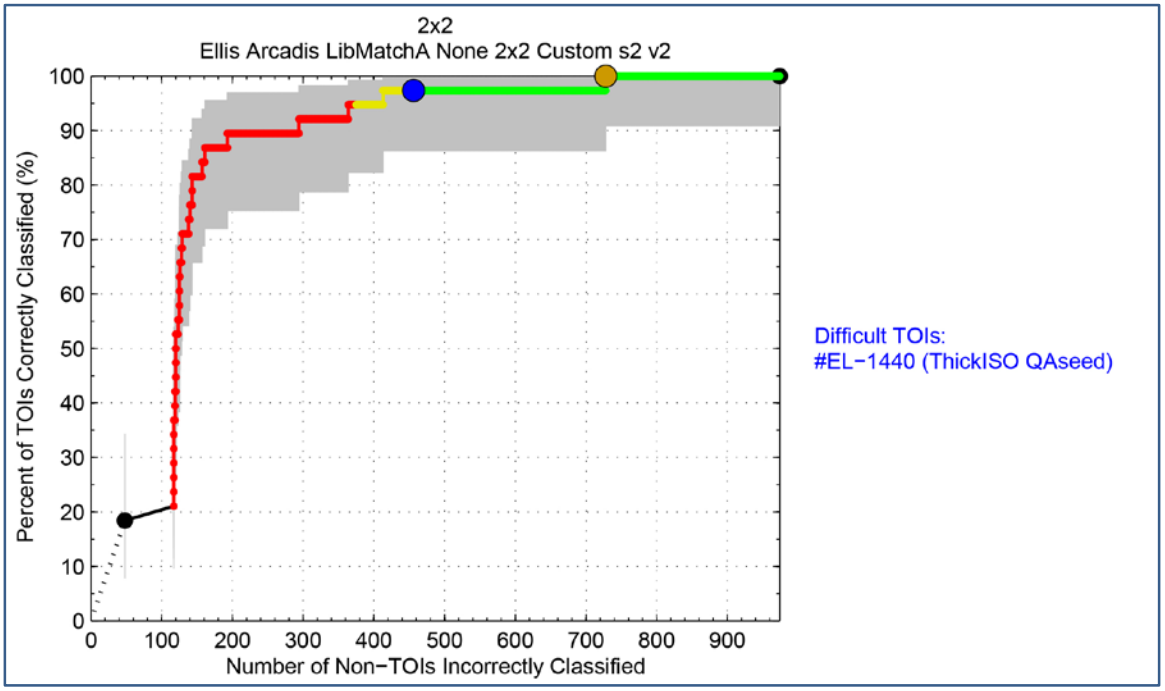

Figure 6-11: TEMTADS Dig List A ROC curve with four points of interest indicated

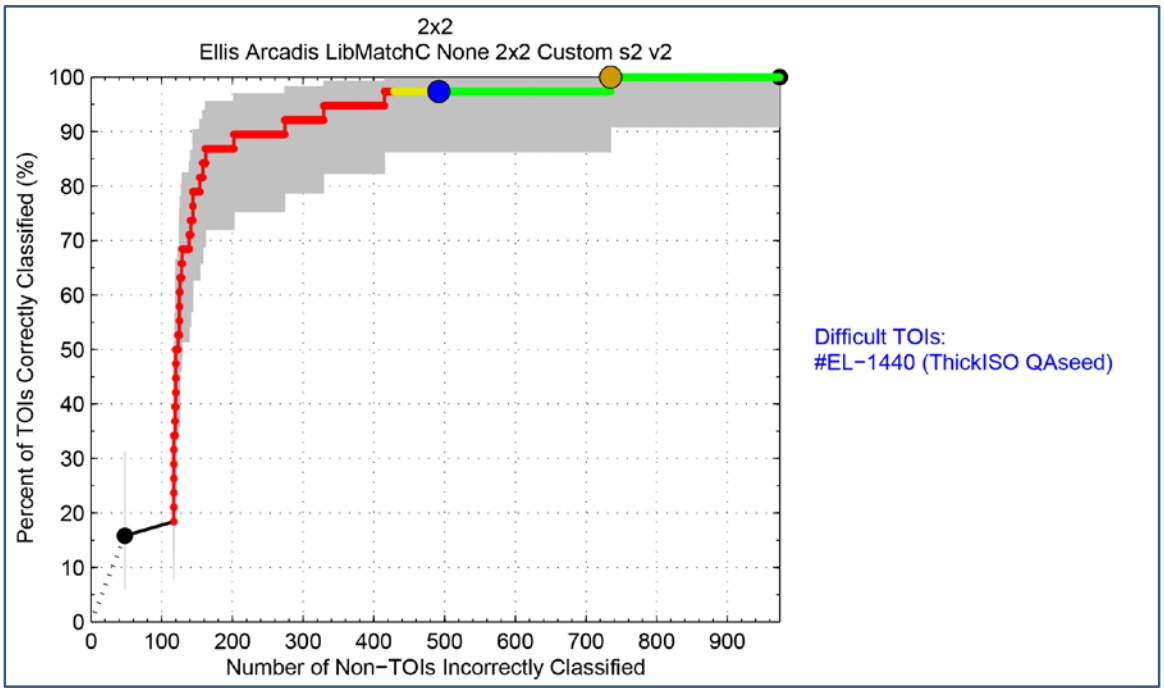

Figure 6-12: TEMTADS Dig List C ROC curve with four points of interest indicated

The key regions to interpret the ROC curves are:

- The black dashed line corresponds to the targets that were dug for training data.
- The solid black line corresponds to the targets that were categorized as "can't extract reliable parameters" that were treated as potential TOI because no meaningful classification could be done. At least one TOI was identified in this part of the curve for each of the three ROC curves.
- Targets in red, yellow, green, correspond to Category 1, 2, and 3 targets, respectively.
- The blue dot corresponds to the dividing point between TOI and not-TOI.
- The orange dot corresponds to the point at which ARCADIS detected all TOI.

As discussed in **Section 3.0**, the primary performance metric was the point at which the ROC curve reaches 100% identification of TOI. The number of clutter items correctly identified at this point is a measure of the savings possible for each method. As seen in **Figures 6-10** through **6-12**, ARCADIS missed two TOI on the MetalMapper dig list and one TOI on each of the TEMTADS dig lists. **Section 7.0** contains an assessment as to why these TOI were incorrectly classified as non-TOI. As a secondary metric, the number of items before point B, those that could not be reliably analyzed, will be assessed.

6.6.2 Intrusive Investigation Results

As discussed in **Section 5.6**, ARCADIS UXO technicians dug each target location and recorded the type of item, its measured depth, its location determined using cm-level RTK DGPS, if the item was removed, as well as took a photograph of each recovered item. Intrusive investigation results are included in **Appendix D** (see separate Addendum) of this report and the photographs of recovered items are on file with the ESTCP Program Office.

6.6.3 Raw and Processed Dynamic and Static Data

As discussed above, the dynamic and static QC, IVS, and production area data are included in **Appendix C** (see separate Addendum) of this report and are on file with the ESTCP Program Office.

7.0 PERFORMANCE ASSESSMENT

Performance objectives were established in the demonstration plan to evaluate the quality of data collected as part of this demonstration. These performance objectives were first discussed in **Section 3.0** of this report. This section documents the results and evaluates the data quality and whether the performance metrics were met. **Table 7-1** shows the performance results for each of the performance objectives, which include the following:

- **Data Collection Objectives**
  - Spatial Coverage in Detection Survey
  - Along-line Measurement Spacing
  - Detection of all TOI
  - Repeatability of IVS Measurements
  - Production Rate
  - Cued Interrogation of Anomalies
- **Analysis and Classification Objectives**
  - Maximize Correct Classification of TOI
  - Maximize Correct Classification of Non-TOI
  - Specification of No-Dig Threshold
  - Minimize Number of Anomalies that Can't be Analyzed
  - Correct Estimation of Target Parameters.

The following sub-sections present the results of the performance assessment.

7.1 DATA COLLECTION OBJECTIVES

7.1.1 Objective: Spatial Coverage for Detection Results

As discussed above, four dynamic detection surveys were conducted during this demonstration: EM61-MK2 and MetalMapper surveys across the entire 5-acre site, and MetalMapper and TEMTADS surveys across the partial investigation area centered on the target area. Success for the partial Spatial Coverage metric was that 98% coverage was achieved. The percent coverage was calculated for each of the datasets using the calculate footprint coverage algorithm in Geosoft Oasis Montaj's UX-Detect module. **Table 7-1** shows the results for each of the datasets and **Figures 7-1** through **7-4** show the results for the full EM61-MK2, full MetalMapper, partial MetalMapper, and partial TEMTADS datasets, respectively. Due to the large number of receivers on the MetalMapper, the line paths completely obscure the coverage footprint; therefore **Figure 7-2a** shows the lines paths and **Figure 7-2b** shows just the footprint coverage. All of the datasets pass the coverage metric, with the exception of the partial TEMTADS dataset. During data collection with the TEMTADS, the PVC handle broke from the platform and had to be repaired. The handle repair took several days to collect the appropriate parts and perform and the project team determined that completing the data collection on the western side of the site and filling in the missing line was not required to perform the comparison with the other dynamic datasets.

Table 7-1: Performance Results

Performance Objective	Metric	Data Required	Success Criteria	EM61-MK2 Results	MetalMapper Results	TEMTADS Results
Data Collection Objectives						
Spatial coverage in detection survey	Extended footprint coverage	Mapped survey data	98% coverage	Pass: 99.99% coverage	Pass: 0.5m line spacing:100% coverage 0.4m line spacing: 100% coverage	Fail: 95.3% coverage achieved before handle broke on instrument. After repair of the instrument, did not recollect missing lines since sufficient data existed for comparisons to EM61-MK2 and MetalMapper data.
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	98% of data < 0.15 m	Pass: 100% < 0.15m down-line spacing	Pass: 0.5m line spacing and 0.4m line spacing datasets had 99.95% and 99.99% < 0.15m down-line spacing	Fail: 96.5% < 0.15m down-line spacing.
Detection of all TOI	Percent detected of seeded items	Location of seeded items; Anomaly list	100% of seeded items detected with 0.6 m halo	Fail: 2 seed items failed. Both seed items were detected as double-peaked anomalies. Targets were selected at the two peaks, but each target was more than 0.6 m away from the center of the seed item.	0.5m line spacing: pass 0.4m line spacing: NA; intentionally collected data on a small portion of the site	NA; intentionally collected data on a small portion of the site.
Repeatability of IVS measurements	Amplitude of EM anomaly	Twice-daily IVS survey data	Detection: Amplitude within 25%	Pass: All amplitudes within 25% of expected amplitude.	Pass: All amplitudes within 25% of expected amplitude	*Not Assessed*
			Detection: Down-track location ±25 cm	Pass: All offsets less than 25 cm	Pass: All offsets less than 25 cm	*Not Assessed*
	Amplitude of polarizabilities		Cued: Polarizabilities ±10%	NA	Pass: All polarizabilities within +/-10% of expected	Pass: All polarizabilities within +/-10% of expected
Production rate	Number of acres of data collection per day	Log of field work and data analysis time accurate to 15 minutes	Survey: 1 acres per day	Pass: 1.15 -1.83 acres/day (average of 1.5 acres/day)	Pass: 1.28-1.61 acres/day (average of 1.45 acres/day) for 0.5-m line spacing; 0.75 acres/day for 0.4-m line spacing	Fail: 0.8 acres/day
	Time required to analyze each target		Analysis time: <5 minutes per target	NA	Pass: Analysis time = 3.8 minutes per target	Pass: Analysis time = 3.8 minutes per target
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	NA	Fail: All anomalies pass except EL-406, which had an offset between the MetalMapper array and the seed item of 0.51 meters	Fail: All anomalies pass except EL-143 had an offset between the TEMTADS array center and the seed item of 0.49 meters.

Performance Objective	Metric	Data Required	Success Criteria	EM61-MK2 Results	MetalMapper Results	TEMTADS Results
Analysis and Classification Objectives						
Maximize correct classification of TOI	Number of TOI retained	Ranked anomaly lists; Scoring reports from IDA	Approach correctly classifies all TOI	NA	Fail: Anomalies El-332 and El-406 incorrectly classified as non-TOI	Fail: Anomaly EL-1440 incorrectly classified as non-TOI
Maximize correct classification of non-TOI	Number of false alarms eliminated	• Ranked anomaly lists • Scoring reports from IDA	Reduction of clutter digs required by >75% while retaining all TOI	NA	Fail: submitted dig list only reduced clutter digs by 59.2%. Actual number of digs to retain all TOI resulted in approximately 17.2% reduction in clutter digs.	Fail: submitted dig lists A and C reduced clutter digs by approximately 55% and 50%, respectively. Actual number of digs to retain all TOI resulted in approximately 28% and 28% reduction in clutter digs.
Specification of no-dig threshold	Probability of correct classification of TOI and number of false alarms at demonstrator operating point	• Demonstrator - specified threshold • Scoring reports from IDA	Threshold specified by the demonstrator to achieve criteria above	NA	Category 1: > 0.85 confidence metric match to TOI Category 2: < 0.85 and >0.8 confidence metric match to TOI Category 3 (non-TOI): < 0.8 match to TOI and > 0.85 match to clutter items in library	
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as “Cannot Analyze”	• Demonstrator target parameters	Reliable target parameters can be estimated for > 95% of anomalies on the detection list.	NA	Fail: 7.02% of targets did not have reliable target parameters	Fail: 6.82% of targets did not have reliable target parameters
Correct estimation of target parameters	Accuracy of estimated target locations for seed items	• Target parameters • Results of intrusive investigation	X, Y < 15 cm (1σ) Z < 10 cm (1σ)	NA	Fail: seven seed item targets failed the horizontal metric and three failed the vertical metric.	Fail: four seed item targets failed the horizontal metric and three failed the vertical metric.

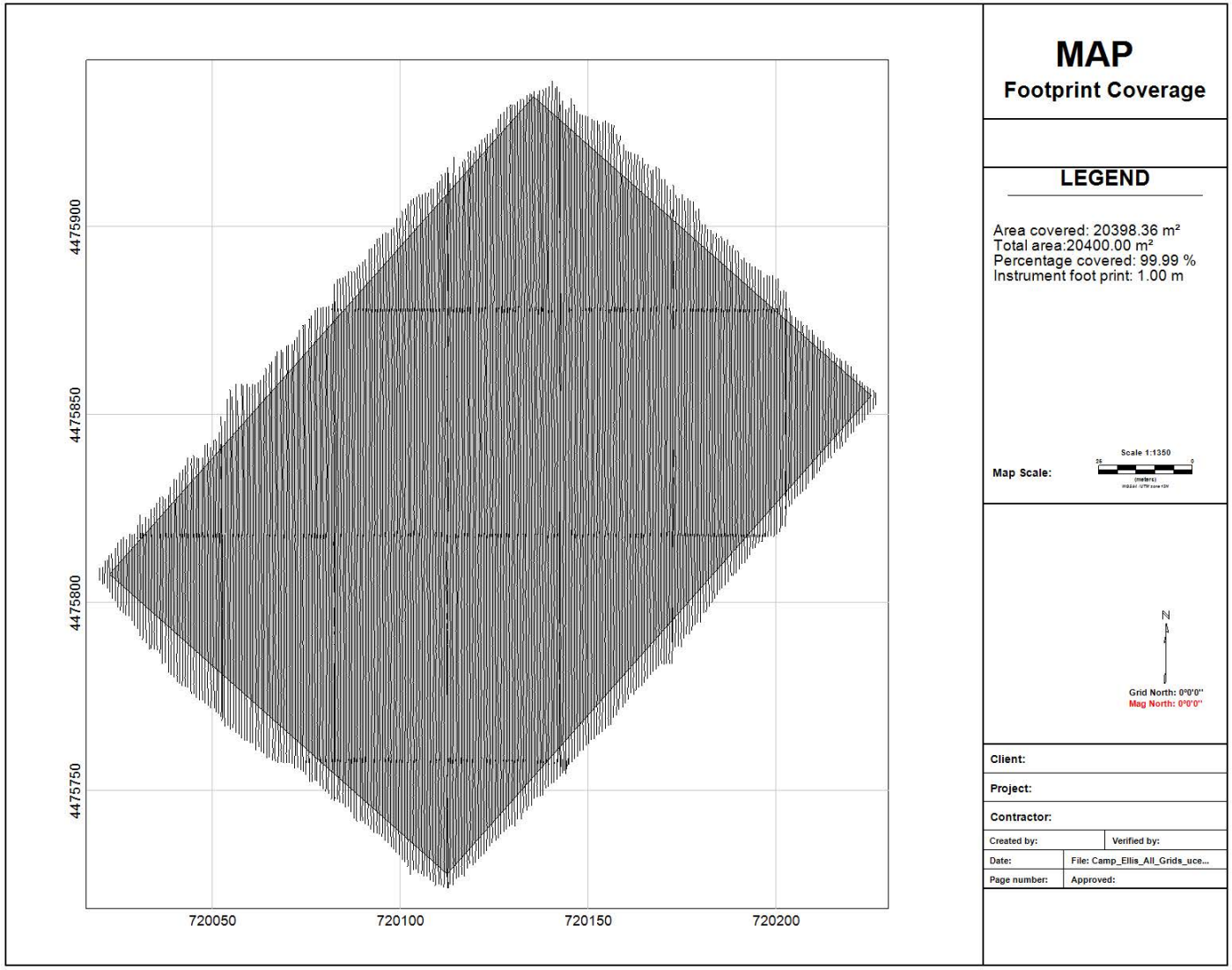

Figure 7-1: EM61-MK2 Data Coverage

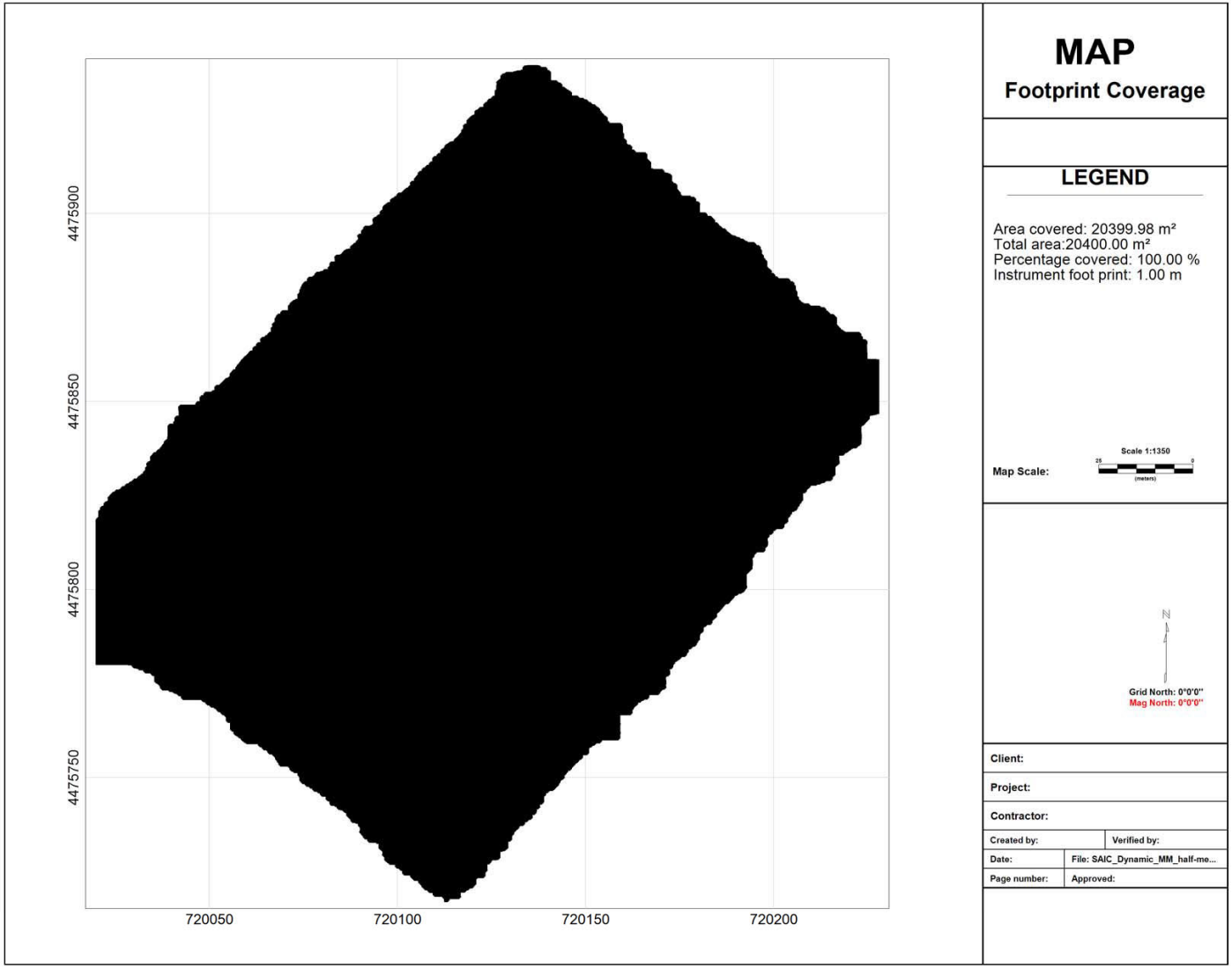

Figure 7-2a: Full MetalMapper Dataset Data Coverage – Data Line Paths only

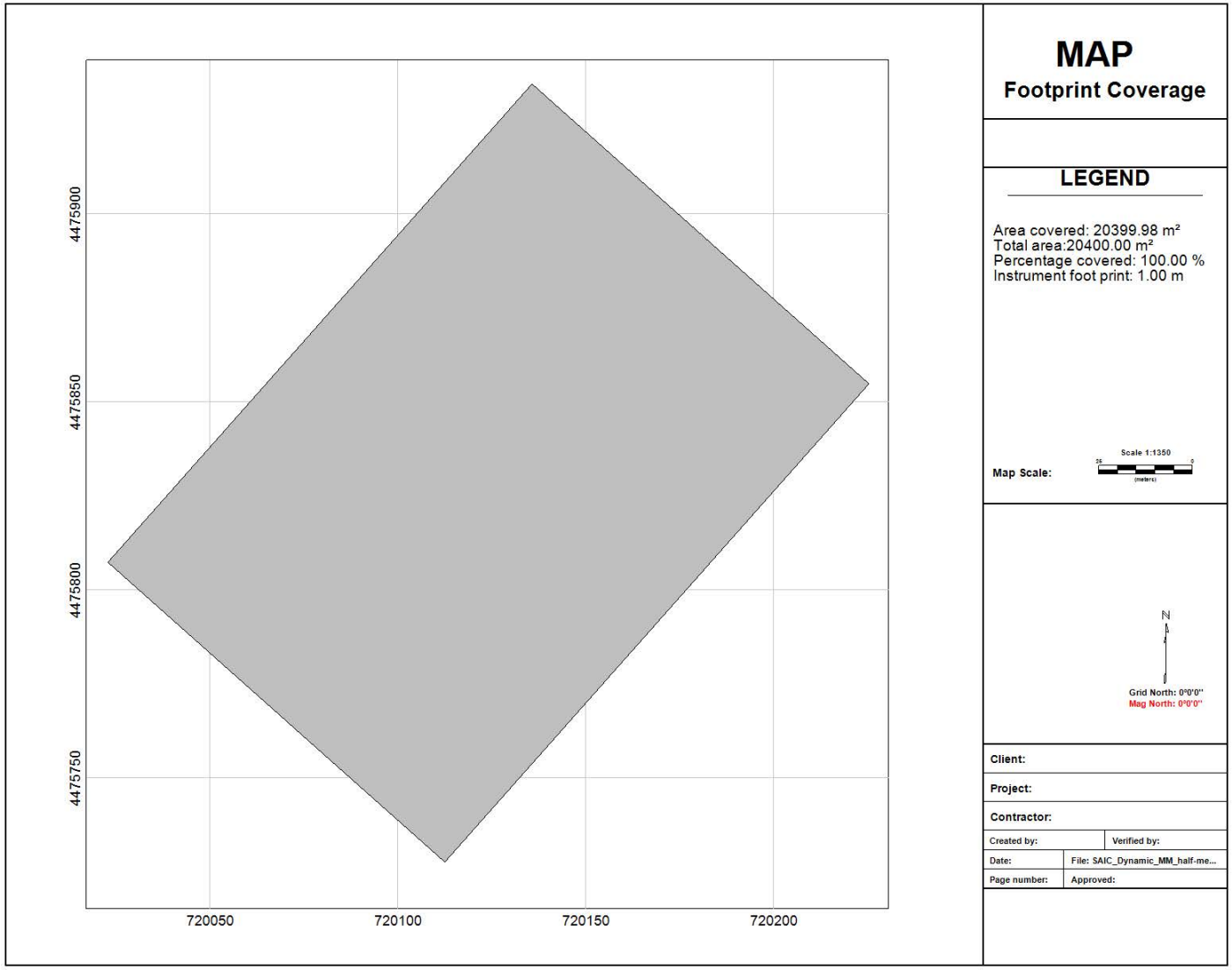

Figure 7-2b: Full MetalMapper Dataset Data Coverage without Line Paths

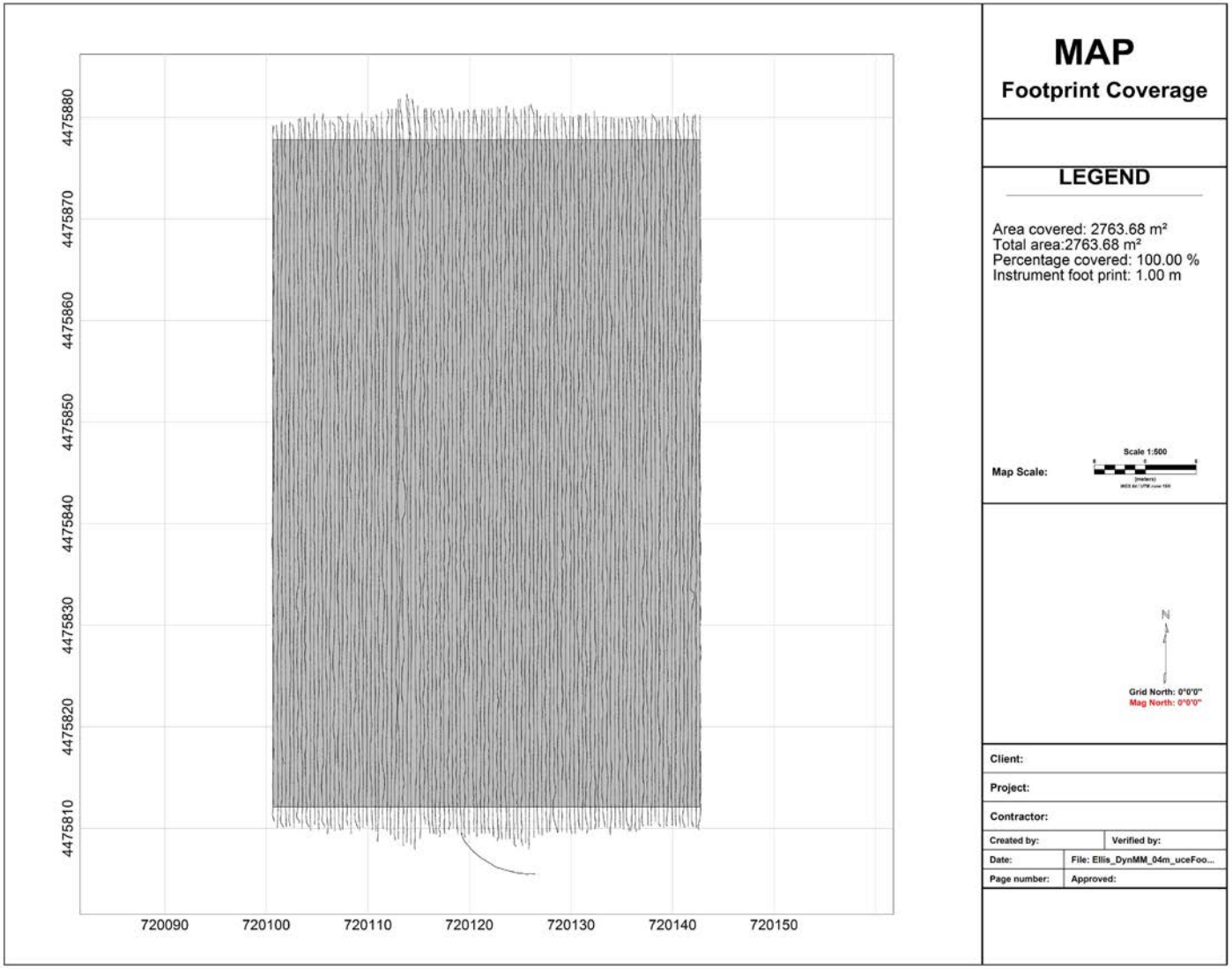

Figure 7-3: Partial MetalMapper Dataset Data Coverage

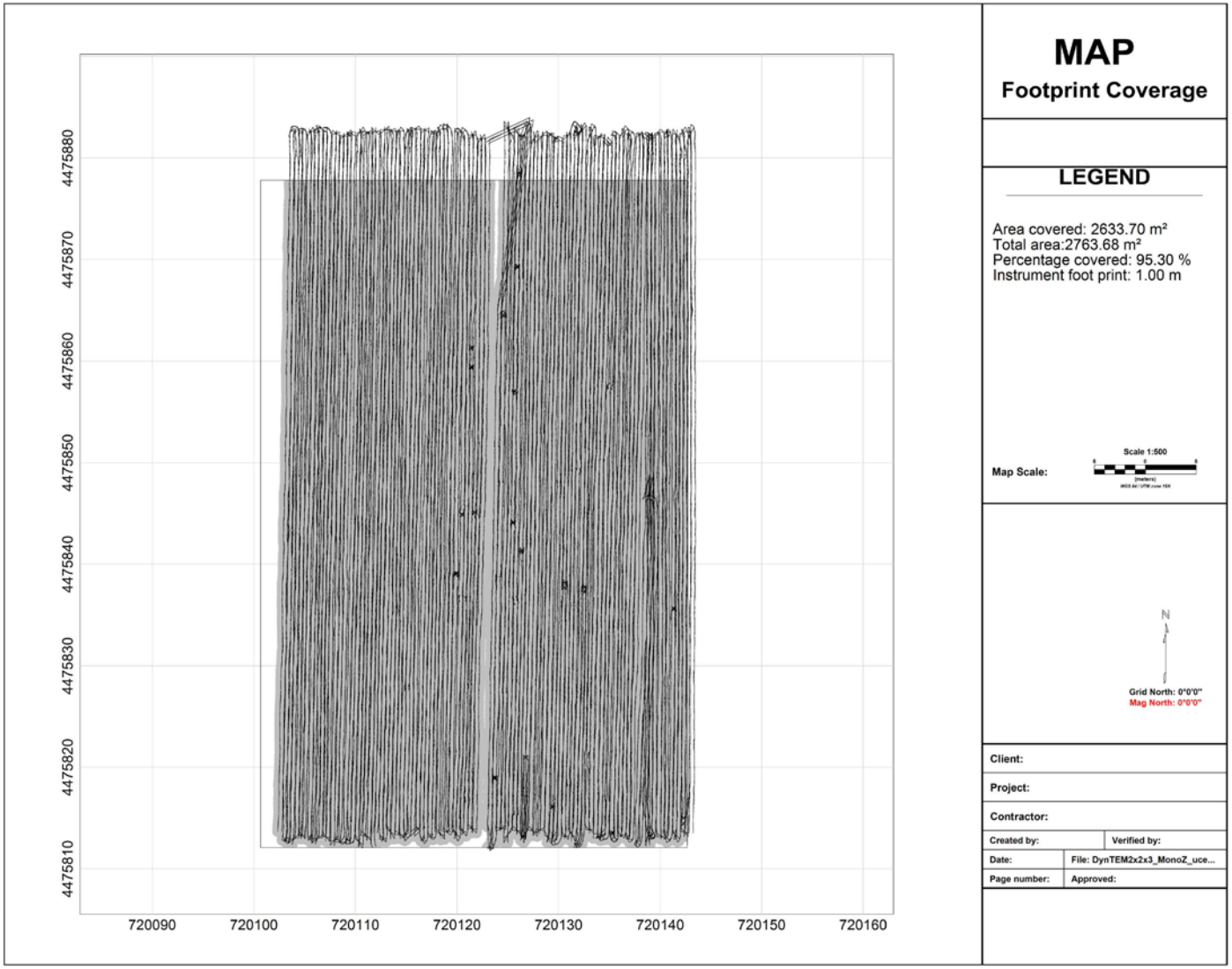

Figure 7-4: Partial TEMTADS Dataset Data Coverage

7.1.2 Objective: Along-Line Measurement Spacing Results

The reliability of the survey data depends on the density of coverage of the site. This objective concerns the ability of the instrument operator to collect data with acceptable along-line measurement spacing. The along line measurement spacing was calculated using Geosoft Oasis Montaj© to determine if greater than 98% of the data had along line measurement spacings less than 15 cm. **Figures 7-5** through **7-8** show the along line data results for the EM61-MK2, full MetalMapper dataset, partial MetalMapper dataset, and the TEMTADS dataset, respectively. As see on the figures and on **Table 7-1**, all of the datasets met the performance objective with the exception of the TEMTADS dataset. 3.5% of the TEMTADS dataset exceeded the along line measurement spacing; however, over 99.8% of the dataset had a data spacing less than 20 cm. It should also be noted that typical along line data spacing requirements are typically on the order of 25 cm. The source of the exceedances are that the instrument was being pushed too quickly.

7.1.3 Objective: Detection of All TOI Results

The EM61-MK2 and MetalMapper datasets collected across the entire site had a total of 1,471 and 1,785 anomalies identified within them, respectively. The ESTCP Program Office evaluated the performance of the dynamic detection of all TOIs so that the seed items remained blind to ARCADIS geophysicists. The initial demonstration plan was to use the EM61-MK2 targets to determine the targets at which static data would be collected; however, several blind ISOs were not detected within the 0.6-m search radius for the EM61-MK2. Both ISOs were detected, but the anomalies were double-peaked and the peaks were greater than 0.6-m from the center of the seed item. Because these targets failed the QC performance criteria, the ESTCP Program Office evaluated the targets from the full MetalMapper dataset and determined that the MetalMapper dataset successfully located all of the seed items within the 0.6-m halo and was, therefore, used as the basis for the cued target locations.

7.1.4 Objective: Repeatability of IVS Measurements

IVS measurements were collected twice a day (one in the morning and one at night) to confirm proper instrument functionality and sensor system performance. The metrics for this objective were the amplitude and down-track position of the maxima for the advanced EMI systems in survey mode and the standard deviation of the polarizabilities for the advanced systems in cued mode obtained from each of the twice-daily surveys of the IVS.

The dynamic data from the EM61-MK2 and MetalMapper in dynamic were met if the measured amplitudes for each object are within 25% of the mean and the down-track position of the anomaly peak is within 25 cm of the known location. The objective will be considered met for the advanced systems in cued mode if the standard deviation of the estimated polarizabilities is within 10% of the mean. All IVS data passed these metrics and the IVS data is contained in **Appendix C** (see separate Addendum).

7.1.5 Objective: Production Rate Results

The metric for this objective is the number of acres of data collection per day and the time required to analyze each target of cued survey data. The objective will be considered to be met if the production rate of 1 acre per day is met during dynamic data acquisition and if the production

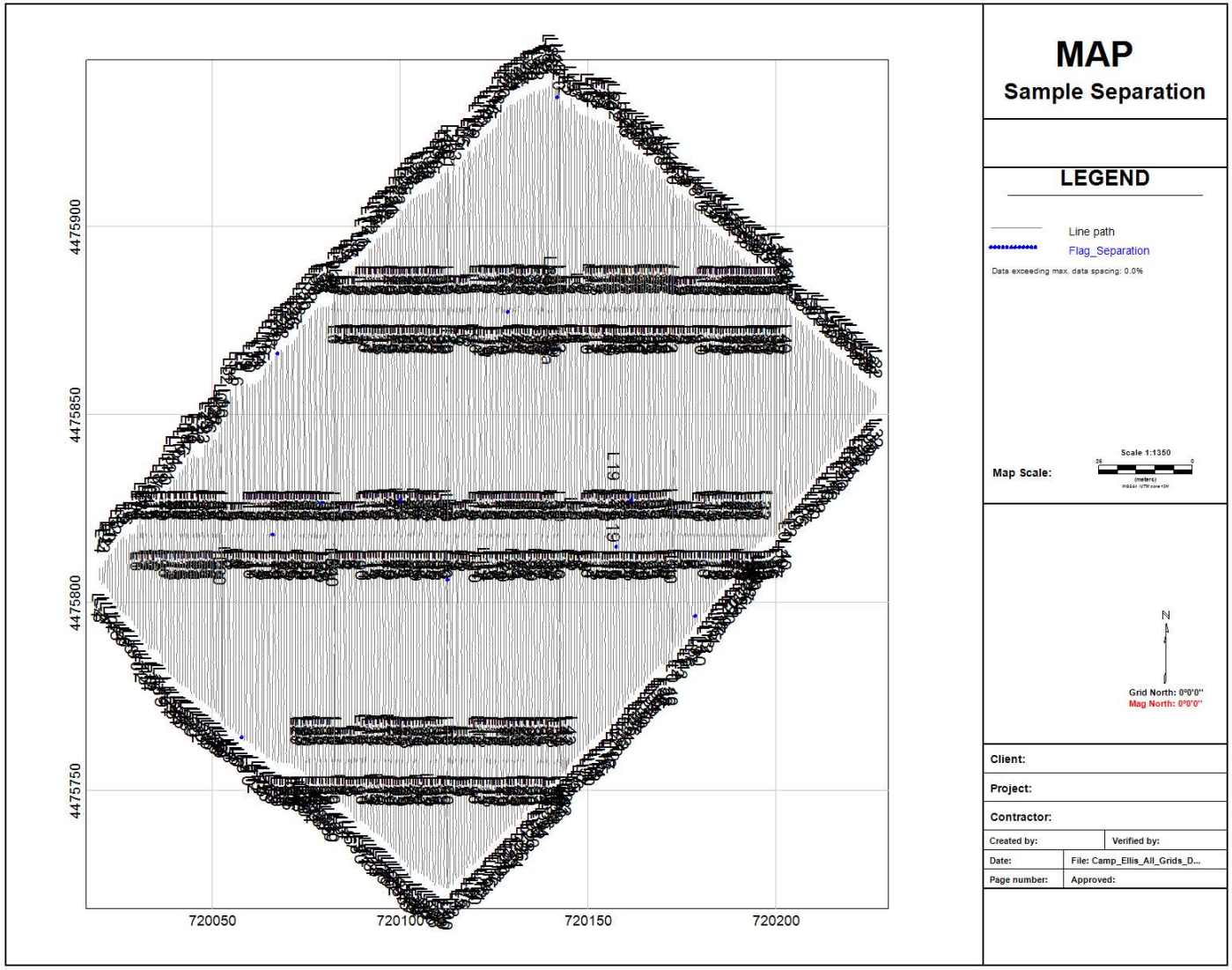

Figure 7-5: EM61-MK2 Along-line Measurement Spacing

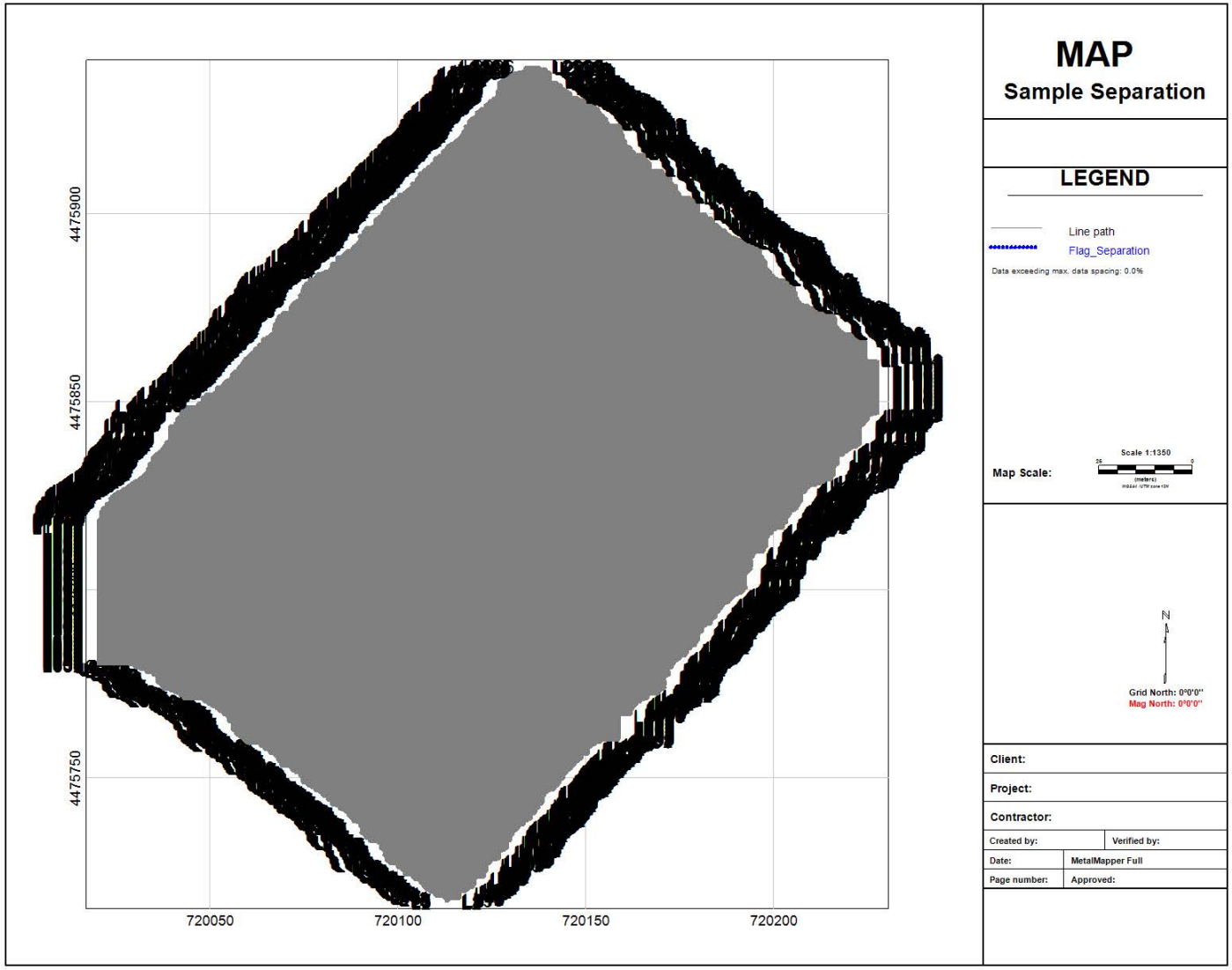

Figure 7-6: Full MetalMapper Dataset Along-line Measurement Spacing

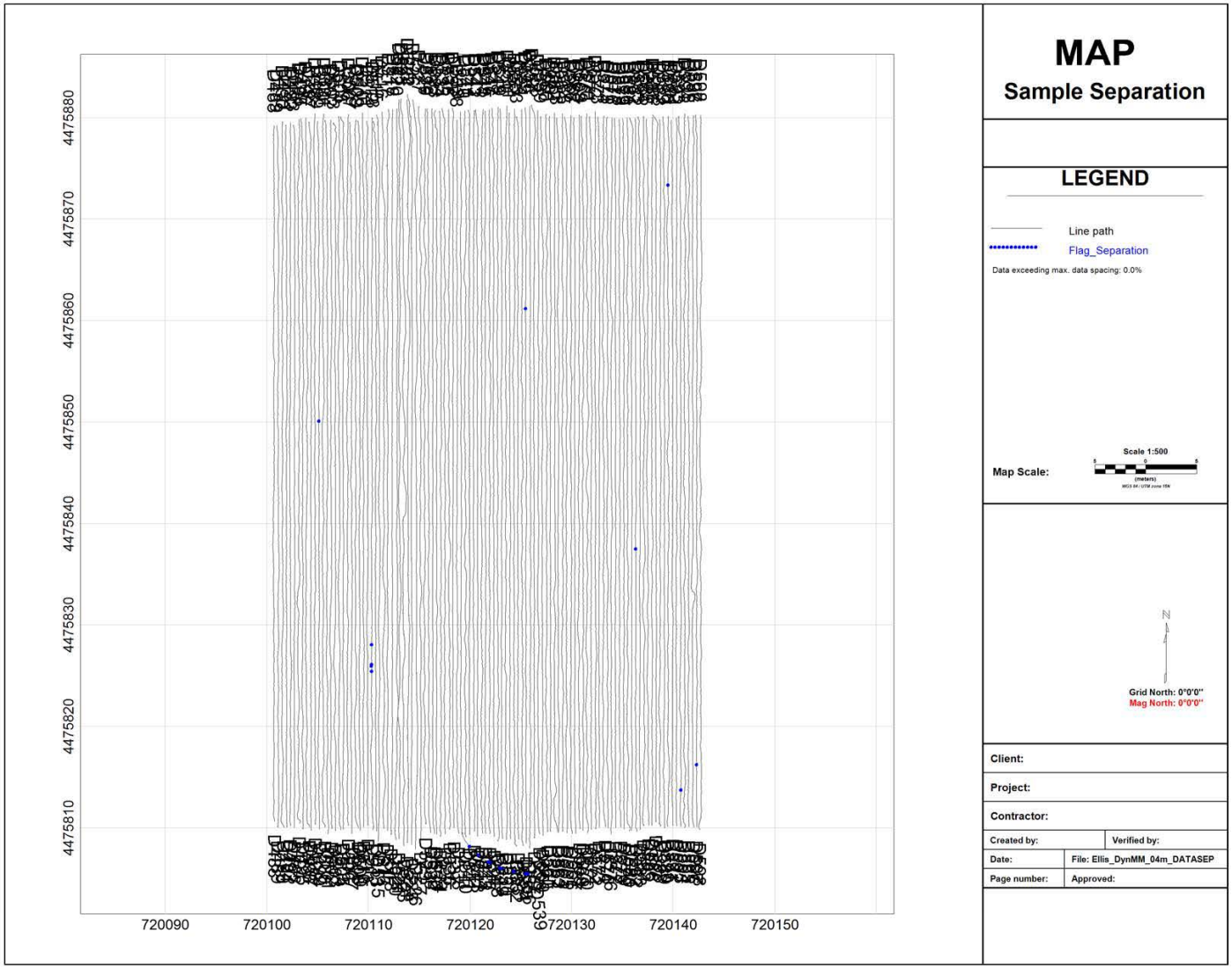

Figure 7-7: Partial MetalMapper Dataset Along-line Measurement Spacing

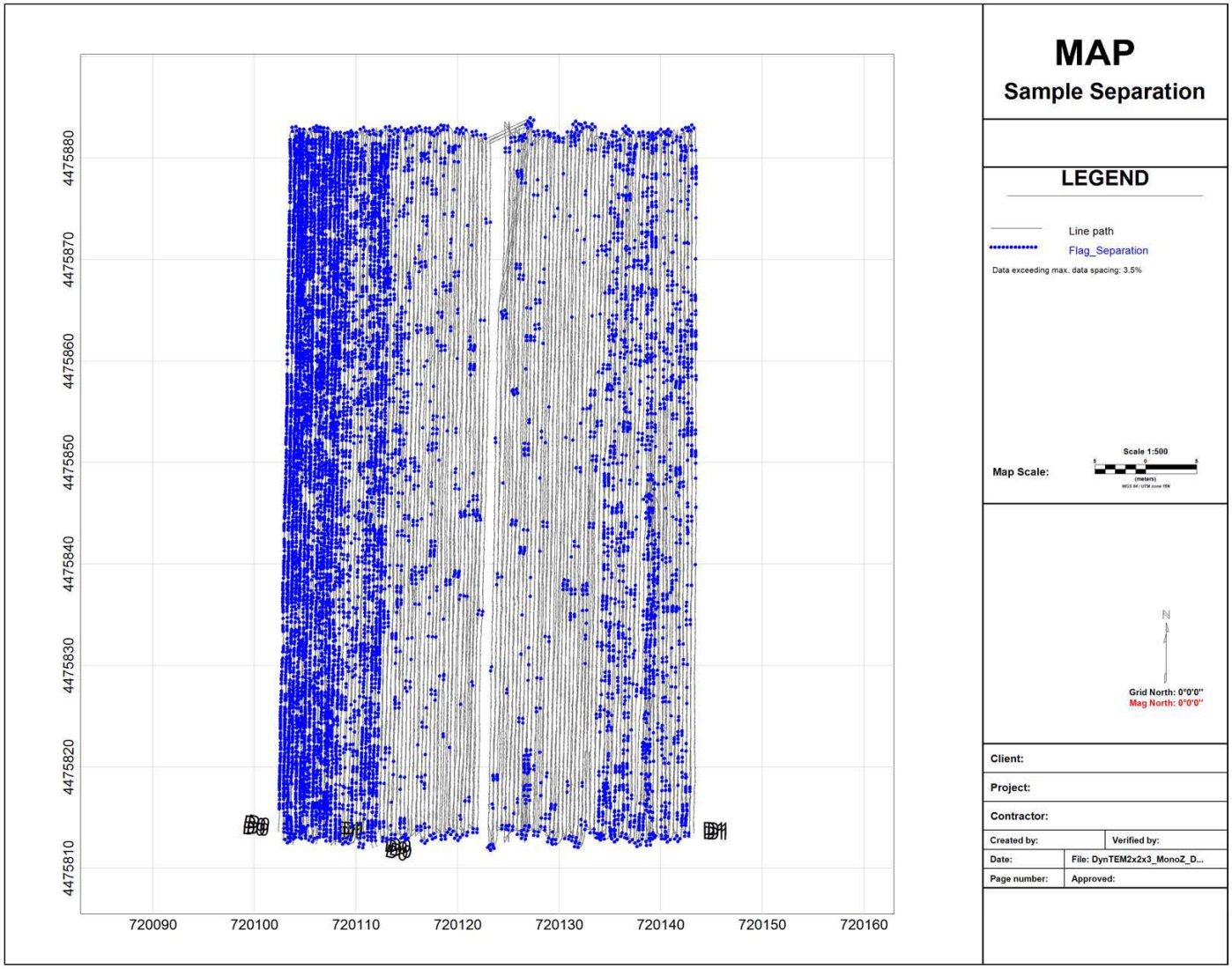

Figure 7-8: Partial TEMTADS Dataset Along-line Measurement Spacing

rate is less than 5 minutes per target on average for the cued anomaly interrogation. The achieved dynamic production rates were:

- EM61-MK2: 1.15 – 1.83 acres/day (average of 1.5 acres/day)
- Full MetalMapper Dataset: 1.28 – 1.61 acres/day (average of 1.45 acres/day)
- Partial MetalMapper Dataset: 0.75 acres/day
- Partial TEMTADS Dataset: 0.8 acres/day

Both of the full datasets exceeded the 1 acre/day performance metric and therefore, pass. The partial datasets had a smaller line spacing (*i.e.*, 40cm vs. 50 cm) and, therefore, took a longer time to collect. Both partial datasets fail the metric established in the demonstration plan; however, the established metric was designed for the larger line spacing and not for the partial datasets that were added at a later time.

The static data analysis time was calculated based on the amount of time spent to QC and analyze the static data. Both the MetalMapper and TEMTADS data took approximately 3.8 minutes per target, which is below the 5 minutes per target metric and therefore, both pass.

7.1.6 Objective: Cued Interrogation of Anomaly Results

The reliability of cued data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location. The objective was considered to be met if the center of the instrument is positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies. The objective was evaluated by measuring the distance of the seed item center location vs. the location of the center of the cued sensor used to collect data over the seed items. The center of the cued sensors were within the 0.4-m metric for all seed items except for one for each of the sensors. The center of the MetalMapper was 0.51-m away from the center of the seed item at target EL-406, while the center of the TEMTADS was 0.49-m away from the center of the seed item at target EL-143.

7.2 ANALYSIS AND CLASSIFICATION OBJECTIVES

7.2.1 Objective: Maximize Correct Classification of TOI Results

This is one of the two primary measures of the effectiveness of the classification approach. This objective concerns the component of the classification problem that involves correct classification of TOI. The metric for this objective is the number of items on the anomaly list for a particular sensor that can be correctly classified as TOI by each classification approach.

ARCADIS prepared ranked anomaly lists for the cued MetalMapper and TEMTADS datasets and IDA personnel used their scoring algorithms to assess the results. The objective was considered to be met if all of the TOI were correctly labeled as TOI on the ranked anomaly list.

Figures 6-10, **6-11**, and **6-12** show the ROC curves for ARCADIS' MetalMapper, TEMTADS Dig List A, and TEMTADS Dig List C, respectively. As seen on these figures, ARCADIS incorrectly classified two TOI on the MetalMapper (EL-406 and EL-332) and one TOI on both of the TEMTADS dig lists (El-1440). The following sub-sections discussed the reason for the failure to correctly classify each of these targets.

7.2.1.1. EL-332 Assessment

As shown on **Figure 6-10**, ARCADIS incorrectly classified EL-332 as non-TOI. **Figure 7-9** shows one realization of the fit results for EL-332, while **Figure 7-10** shows the two best library matches for the 3-, 2-, and 1-component matches. As seen on **Figure 7-10**, the best two matches for the three matches are all to Clutter items in the library, except for the second best match for the 2-component match, which that has a fit metric of 0.9434 to an ISO from Camp Butner. Further analysis of this target indicates that it had high fit metrics to ISOs for all three fit matches and should have been identified as a TOI based on the high fit metric.

7.2.1.2. EL-406 Assessment

As shown on **Figure 6-10**, ARCADIS incorrectly classified EL-406 as non-TOI. **Figure 7-11** shows one realization of the fit results for target EL-406 and **Figure 7-12** shows one realization of the fit results to target EL-417, which is closely located to target EL-406. Target A at each target location have fit locations that are within 0.06 meters of each other and are the same subsurface item, which is the location where the TOI was found. While the Target A location had a relatively good fit to the seed item, the fit at EL-406 Target B, had a higher metric match and was the target used to classify the target location. Target EL-406 had a fit metric of 0.76 to a 2.36-inch rocket, while EL-417 was correctly classified as a small ISO and was placed on the dig list as a category 2 anomaly. Although ARACADIS put EL-406 below the dig threshold, the seed item would have been found because the dig team would have recovered the seed item while digging target EL-417.

7.2.1.3. EL-1440 Assessment

As shown on **Figures 6-11** and **6-12**, ARCADIS incorrectly classified target EL-1440 as non-TOI on both TEMTADS datasets. **Figures 7-13** and **7-14** show the fit results and the best two matches to target EL-1440 for the 3-, 2-, and 1- component matches, respectively. Target A on **Figure 17-13** has the best fit to TOI and clutter in the library and is the target that was fit to the library items shown in **Figure 17-14**. EL-1440 had a combined fit metric of 0.9 and its best matches for the 3-component and 2-compoent fits were to clutter items. The polarization curves shown on **Figure 17-13** do not exhibit normal decay (*i.e.*, betas decreasing as a function of time). Instead, the Target A β_2 curve shows a relatively flat decay over the middle time gates. β_3 also quickly goes into the noise, which is seen by the dashed lines starting around 0.7 milliseconds. The poor decays for the secondary and tertiary betas suggest that this target had a low amplitude and the algorithm had difficulty extracting useful polarization parameters throughout the decay curve. In addition, the non-normal decay of the β_2 curve suggests there also might have been a poor background correction that caused the curve to remain relatively constant over time. Based on these observations, the analyst should have either re-performed the background correction, or only used the 1-component metric match in the classification.

7.2.2 Objective: Maximize Correct Classification of Non-TOI

This is the second of the two primary measures of the effectiveness of the classification approach. This objective concerns the component of the classification problem that involves false alarm reduction. The metric for this objective is the number of items on the sensor dig list that can be correctly classified as non-TOI by each classification approach. The objective was

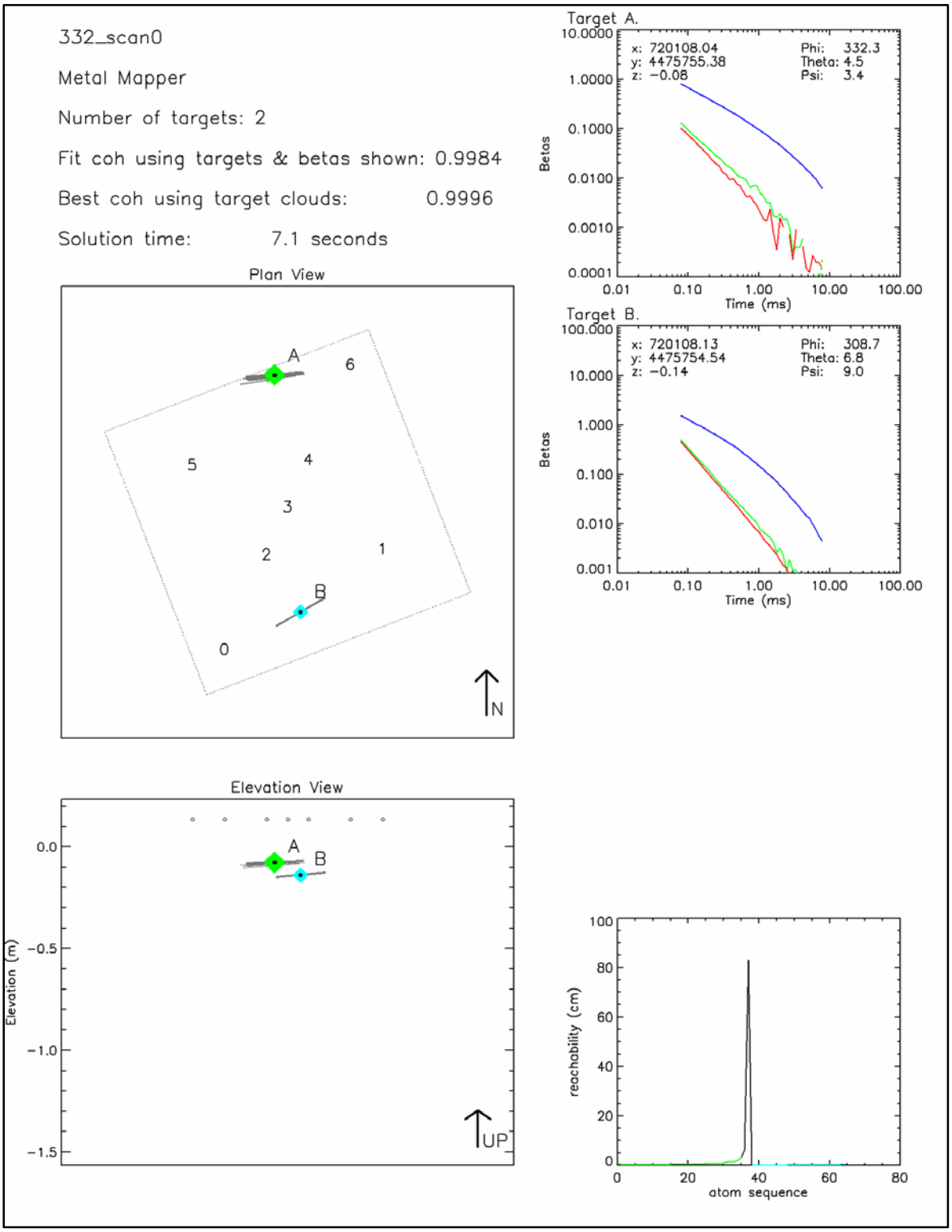

Figure 7-9: EL-332 Fit Results

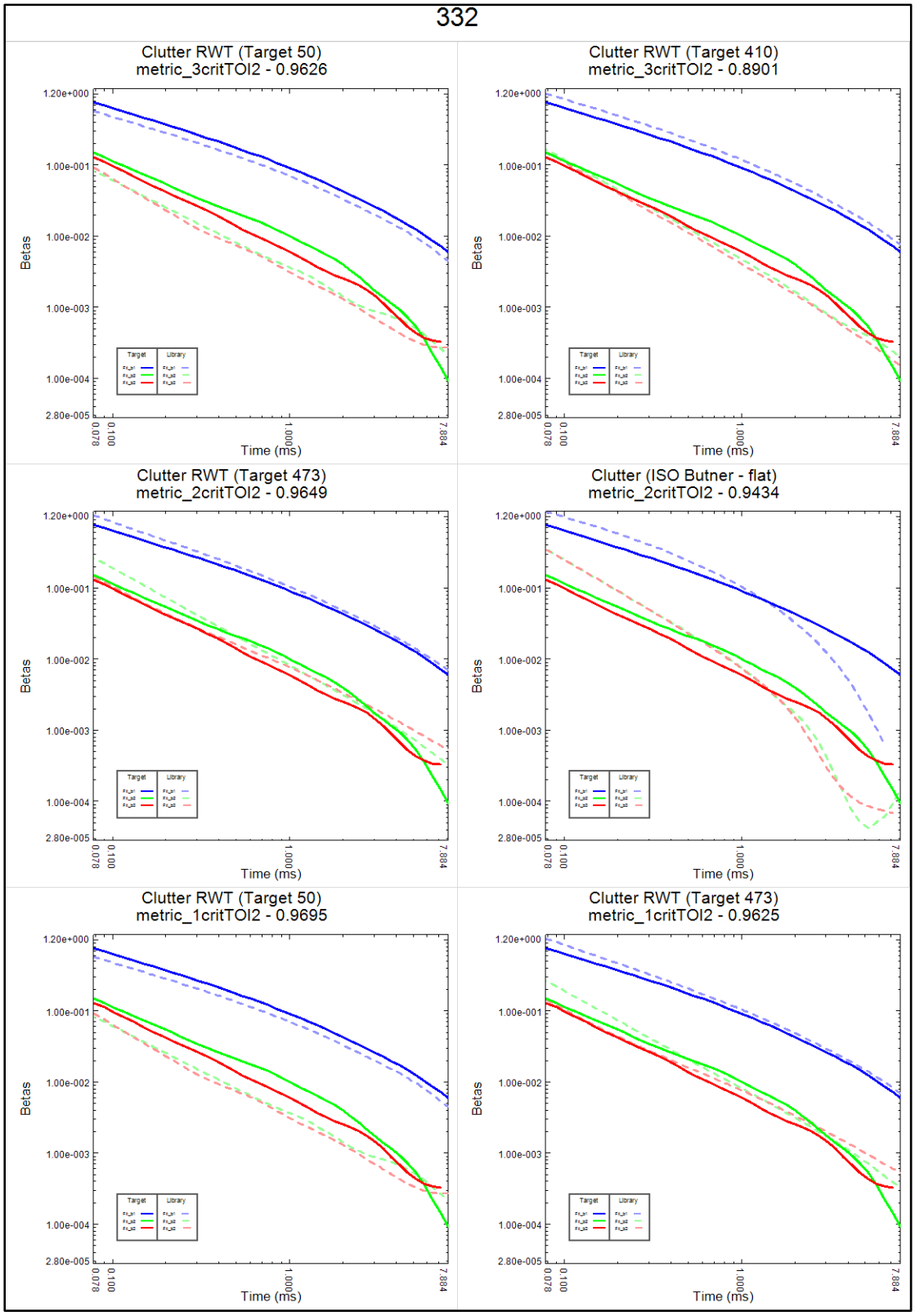

Figure 7-10: Best 2 Library Matches for 3-, 2-, and 1-Component Matches to Target 332

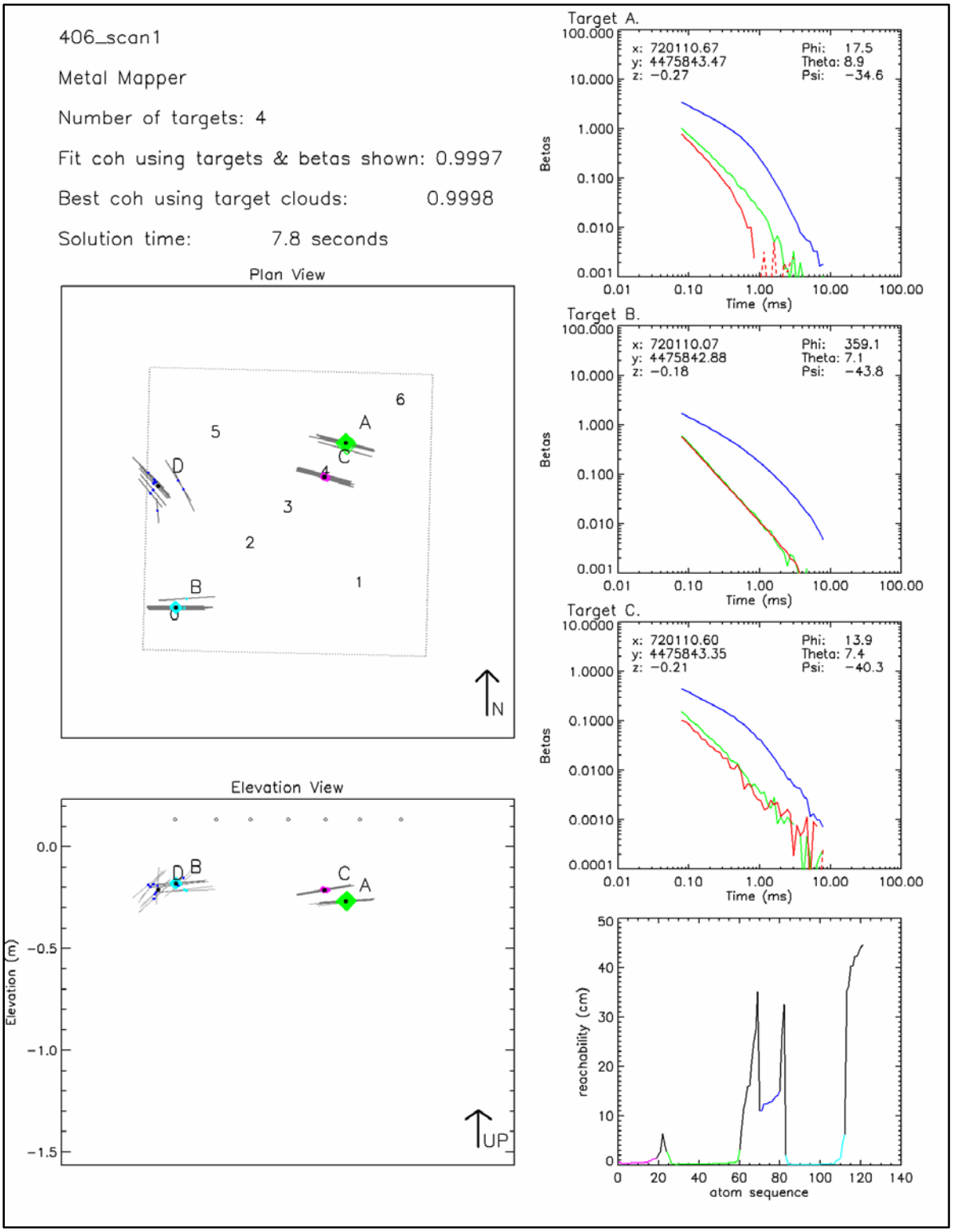

Figure 7-11: EL-406 Fit Results

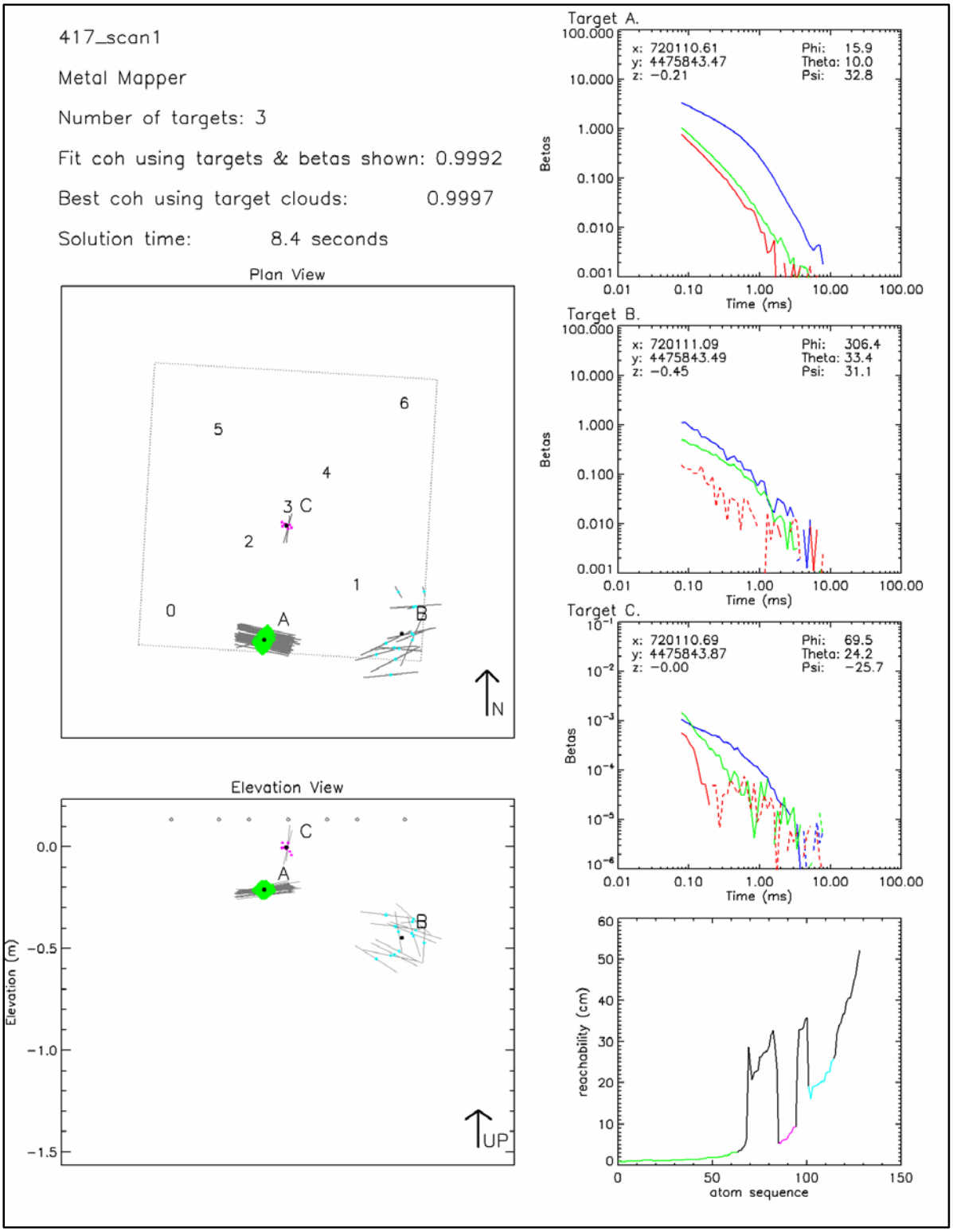

Figure 7-12: EL-417 Fit Results

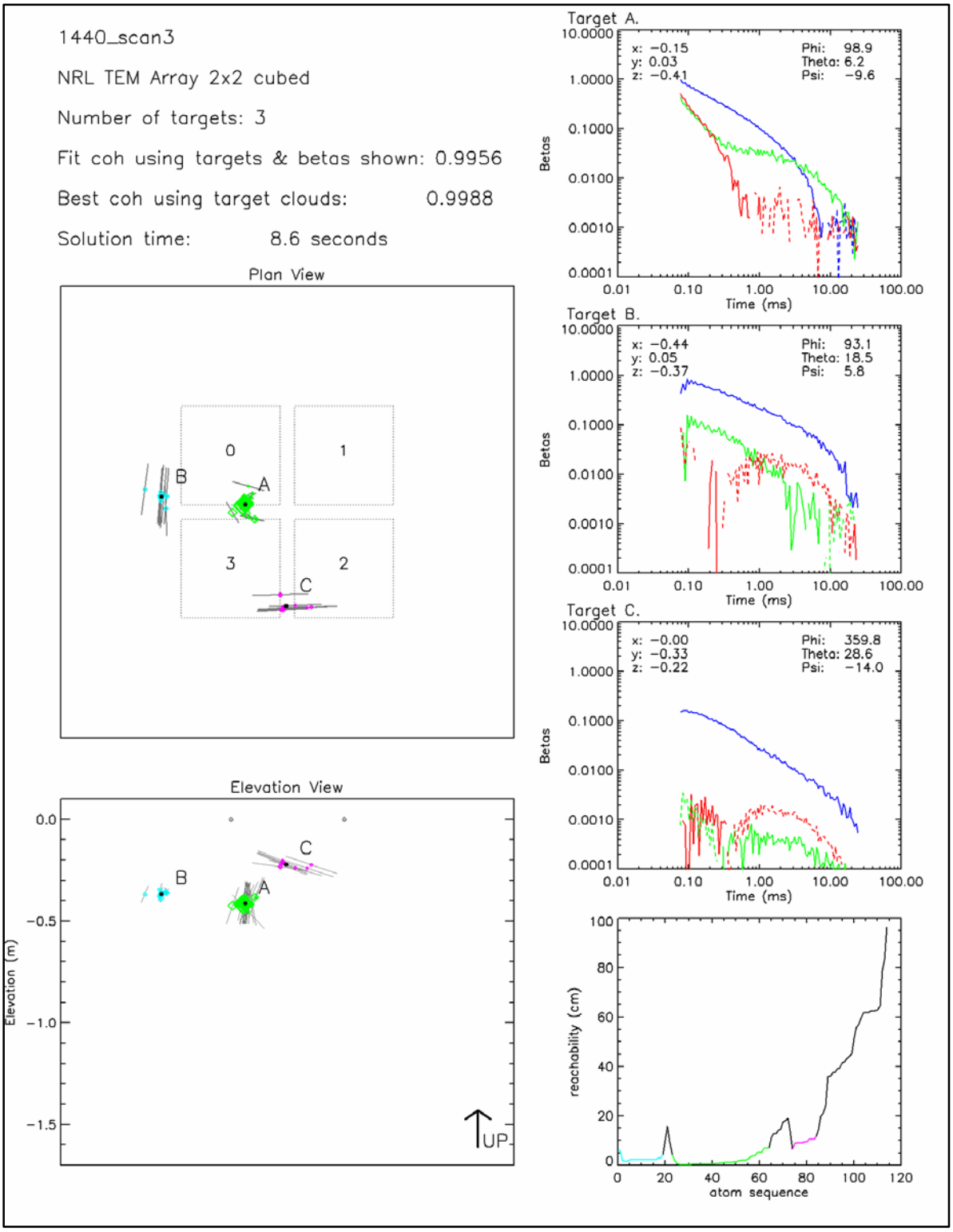

Figure 7-13: EL-1440 Fit Results

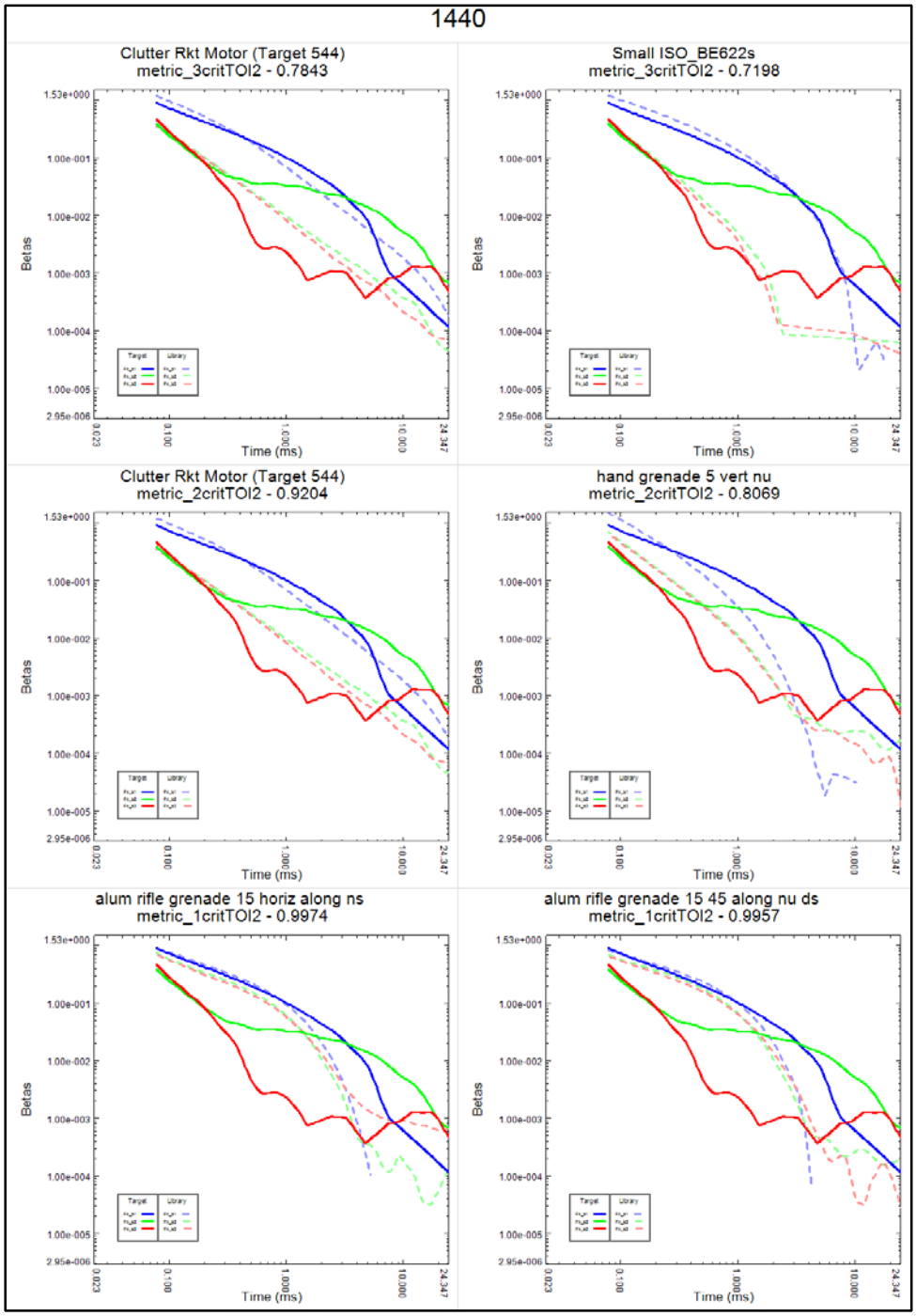

Figure 7-14: Best 2 Library Matches for 3-, 2-, and 1-Component Matches to Target EL-1440

considered to be met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI on the dig list. As discussed above, neither dig list correctly identified all TOI and therefore this performance metric was not met. Furthermore, if all TOI had been identified with the submitted dig list, the dig reduction would still not have been met. **Table 7-2** lists the percent reduction in the number of clutter digs if all TOI had been found at the dig threshold and the actual percent reduction of clutter items at the point where all TOI items were found. It should be noted that the actual percent reductions were negatively impacted by placing the best fits to clutter items immediately below the dig threshold, which had the effect of pushing the missed TOI further down the dig list.

Table 7-2: Reduction of Clutter Digs

Dig List	Percent Reduction of Clutter Digs if all TOI found at Dig Threshold	Actual Percent Reduction of Clutter Items at Point of Finding all TOI
MetalMapper	59%	17%
TEMTADS Dig List A	55%	28%
TEMTADS Dig List C	50%	28%

7.2.3 Objective: Specification of No-Dig Threshold Results

In a retrospective analysis as was performed in this demonstration, it is possible to tell the true classification capabilities of a classification procedure based solely on the ranked anomaly list submitted by ARCADIS. In a real-world scenario, all targets may not be dug so the success of the approach will depend on the ability of an analyst to accurately specify their dig/no-dig threshold. As discussed above, the No Dig Threshold was that anomalies that had less than a 0.8 match to TOI or greater than a 0.85 match to clutter items in the library were placed below the dig threshold. The objective was not met since less than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI at the ARCADIS-specified threshold.

7.2.4 Objective: Minimize Number of Anomalies that Can’t be Analyzed Results

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be placed in the dig category and reduce the effectiveness of the classification process. The ARCADIS ranked anomaly lists includes those anomalies for which parameters could not be reliably estimated as Category 0 anomalies. The objective was considered to be met if reliable parameters were estimated for > 95% of the anomalies on the ranked anomaly list. **Table 7-3** shows the percent of anomalies that were placed in the “Can’t

Table 7-3: Can’t Analyze Anomalies

Dig List	Number of Targets	Number of Can't Analyze Targets	Percent of Can't Analyze Targets
MetalMapper	1003	71	7.08%
TEMTADS Dig List A	1012	69	6.82%
TEMTADS Dig List C	1012	69	6.82%

Analyze" category for each ranked anomaly list. The percent of can't analyzed targets are 6.82% and 7.02% for the TEMTADS and MetalMapper dig lists, respectively. This performance metric was not met for either sensor.

7.2.5 Objective: Correct Estimation of Target Parameters

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately. Accuracy of estimation of target parameters is the metric for this objective. ARCADIS compared the estimated parameters for the seed items. The objective was considered to met if the estimated X, Y locations were within 15 cm (1σ) and the estimated depths are within 10 cm (1σ). Eleven of the seed items had horizontal offsets greater than 10 centimeters: seven for the MetalMapper and four for the TEMTADS datasets. **Table 7-4** summarizes the targets that had offsets between the seed item location and predicted X and Y locations that are greater than 15 cm. Most are only still are within 20 cm of the actual target location, but EL-406 is an outlier. EL-406 was a missed TOI and was discussed above in **Section 7.2.1.2**. The incorrect target fit results were submitted on the ranked dig list, which caused the very large offset. It should be noted that target EL-417 was close to EL-406 and correctly classified the missed seed item; therefore, the dig team still would have found the item. All estimated depth were within 10 centimeters of the measured depth.

Table 7-4: Anomalies with Horizontal Offsets Greater than 15 cm

Instrument	Anomaly	Measure Easting[1]	Measured Northing[1]	Predicted Easting[1]	Predicted Northing[1]	Horizontal offset (cm)
MetalMapper	EL-23	720060.313	4475815.42	720060.269	4475815.51	10.17
	EL-108	720087.428	4475835.39	720087.555	4475835.28	16.93
	EL-406	720110.092	4475842.88	720110.671	4475843.47	82.81
	EL-879	720123.585	4475816.66	720123.772	4475816.6	19.71
	EL-974	720126.166	4475817.05	720126.238	4475817.14	11.47
	EL-1552	720161.979	4475789.37	720161.772	4475789.35	20.85
	EL-1784	720062.164	4475800.14	720062.013	4475800.13	15.13
TEMTADS	740	720119.86	4475880.33	720119.744	4475880.43	15.35
	1226	720135.576	4475894.94	720135.571	4475895.1	15.79
	1353	720143.755	4475822.59	720143.737	4475822.77	18.09
	1543	720160.651	4475826.73	720160.491	4475826.72	15.97

Note:

1- Coordinates are provided in UTM WGS84 Zone 15N with units of meters.

Six seed item targets had depths that exceeded the 10 cm metric: three MetalMapper and three TEMTADS targets. **Table 7-5** summarizes the anomalies that had measured depths that were greater than 10 cm off from the measured depth. Most only slightly exceed the depth difference; however, EL-1235 has a large depth difference and was a missed QC seed and is further discussed in the TEMTADS failure QC seed failure memos contained in **Appendix F** (see separate Addendum).

Table 7-5: Anomalies with Depth Differences Greater than 10 cm

Instrument	Anomaly	Measured Depth (cm)	Predicted Depth (cm)	Depth Difference (cm)
MetalMapper	EL-108	29	16.82	12.18
	EL-324	18	5.36	12.64
	EL-406	15	26.77	11.77
TEMTADS	939	13	-2.19	15.19
	1235	26	65	39.0
	1564	21	0.84	20.16

8.0 COST ASSESSMENT

This section provides cost information to aid in helping professional involved in MR project to reasonably estimate costs for implementation at a given site. This section is broken down into sub-sections that discuss the cost model, cost drivers, and cost benefit of the various technologies employed at the former CEMR.

8.1 COST MODEL

ARCADIS tracked costs throughout the ESTCP live site demonstration at the former CEMR and developed a simple cost model to aid professionals in the field to understand costing implications. The cost model reflects all cost elements that would be required for implementing the technologies described in this report, as well as the planning, and reporting requirements. **Table 8-1** presents the cost elements for implementing the CEMR live site demonstration including the data tracked during the demonstration.

Table 8-1: Details of the Costs Tracked by ARCADIS

Cost Element	Data Tracked During Demonstration	Estimated Costs
Project Planning	• Develop project-specific plans: o Demonstration Plan o Health and Safety Plan • General pre-planning activities	$26,746
Mobilization	• Mobilization of geophysical and UXO teams and equipment.	$58,740.36
Site Preparation	• Site Boundary Surveys • Blind Seeding • IVS setup • Test Pit Measurements • Instrument Training	$39,067
EM61-MK2 Data Collection	• Data collection and processing of 6 acres (5 acres and 1 acre of re-collected data)	**Total Cost:** $43,430 (6 acres) Cost per Acre: $7,238
TEMTADS Survey Data Collection	• Dynamic TEMTADS data collection • IVS and QC tests (TEMTADS rental costs are not included)	**Total Cost:** $5,761 (0.68 acres) Cost per Acre: $8,472
MetalMapper Survey Data Collection	• Dynamic MetalMapper data collection • IVS and QC tests (MetalMapper rental costs are not included, but tractor costs	**Total Cost:** $36,803 Cost per Acre: $6,479

Cost Element	Data Tracked During Demonstration	Estimated Costs
	are)	
TEMTADS Cued Data Collection / QC	• Target reacquisition • Cued TEMTADS data collection • Data Processing and QC • IVS and QC tests (TEMTADS rental costs are not included)	**Total Cost:** $68,061 (1087 anomalies) Cost per Anomaly: $62.6
MetalMapper Cued Data Collection/QC	• Cued MetalMapper data collection • Data Processing and QC • IVS and QC tests (MetalMapper rental costs are not included, but tractor costs are)	**Total Cost:** $46,219 (1,195 anomalies) Cost per Anomaly: $36.8
Cued Data Analysis	• Target parameter extraction • Advanced anomaly classification	**Total Cost:** $18,276 (2,282 anomalies) Cost per Anomaly: $8.1
Validation Digging	• Target reacquisition • Intrusive investigation • Intrusive results reporting • Post-dig anomaly QC	**Total Cost:** $300,516 (1,785 anomalies) Cost per Anomaly: $166.4
Final Report	• Develop project-specific reports: • Final Report • Final Cost and Performance Report	$20,000 (estimated)

8.2 COST DRIVERS

In general, the intrusive investigation costs are the largest cost drivers on MR projects. Additional cost drivers include the following.

- **Dynamic data collection:** The EM-61-MK2 and MetalMapper dynamic data costs are very similar on a per/acre basis; however, the TEMTADS is slightly more costly due to increased site preparation (e.g., setting up ropes in grids) and slower production rates due to
- **Static data collection:** In general, MetalMapper data collection rates were greater than with the TEMTADS. This is largely due to two data positioning needs: the TEMTADS requires the reacquisition of target locations prior to cued data collection, while the MetalMapper does not, and not using a GPS with the TEMTADS likely caused a larger number of targets to be re-collected due to poor positioning.
- **Intrusive investigation cost savings:** The cost savings associated with a reduced number of non-TOI can lead to a large cost savings since the intrusive investigation costs are the

largest cost drivers. Although the total number of non-TOI reduced during this demonstration did not meet the performance objectives, more experienced demonstrators have shown in their analysis of the former CEMR advanced EMI data that the reduction of non-TOI anomalies by 75% is accomplishable at this site.

8.3 COST BENEFIT

The primary driver for implementing advanced classification is to reduce the number of non-TOI targets that require intrusive investigation and thereby, decrease the overall costs of DoD's MMRP cost to complete. Advanced classification has been shown to reduce the overall number of non-TOI digs by 60-90% at other sites. ARCADIS successfully reduced the number of non-TOI digs by approximately 70% at Pole Mountain, while retaining all of the TOI; however, we were unsuccessful at reducing the number of non-TOI digs (while retaining all of the TOI) by more than 20% at CEMR. Other, more experienced demonstrators, however, were successful at reducing the number of non-TOI digs by 75% at CEMR. **Tables 8-2** and **8-3** provide cost-benefit analyses for performing advanced classification using the costs listed in **Table 8-1** for the MetalMapper and TEMTADS, respectively. Static costs (*e.g.*, planning, reporting, and mobilization) and costs with minimal variability (*e.g.*, site preparation) are not included in the cost-benefit analysis. Each scenario is compared against performing a traditional MR projects that includes an EM61-MK2 survey and intrusive investigation of all anomalies. For the advanced classification costs, it is assumed that the respective advanced EMI sensor is used to collect both dynamic survey data and cued data.

Tables 8-2 and **8-3** each contain three scenarios:

- **Scenario 1:** Greatest cost savings associated within reducing the number of targets requiring intrusive investigation by 75%.
    - MetalMapper Cost Savings: 44%
    - TEMTADS Cost Savings: 28%
- **Scenario 2:** Intermediate cost savings associated within reducing the number of targets requiring intrusive investigation by 50%.
    - MetalMapper Cost Savings: 22%
    - TEMTADS Cost Savings: 5%
- **Scenario 3:** No cost savings scenario. This is the scenario at which there is no advantage to performing advanced classification. The percent reduction in digs for this scenario for the MetalMapper and TEMTADS are 36.5 and 43, respectively.

The MetalMapper costs shown in **Table 8-1** were lower than the TEMTADS costs, and therefore result in much greater cost savings than the TEMTADS.

Table 8-2: MetalMapper Cost Evaluation

Cost Scenarios	Cost Element	Cost per Unit	Unit	Quantity	Traditional MR Costs	Classification Costs
MetalMapper Scenario 1 - Greatest Cost Savings: 75% Anomaly Reduction with MetalMapper	EM61-MK2 Survey	$7,238.0	Acres	5	$36,190	$0
	MetalMapper Survey	$6,479.0	Acres	5	$0	$32,395
	Cued MetalMapper	$36.8	Anomaly	2000	$0	$73,600
	Classification	$8.1	Anomaly	2000	$0	$16,200
	Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
	Dig 25% of Anomalies	$166.4	Anomaly	500	$0	$83,200
	Total:				**$368,990**	**$205,395**
	Cost Savings ($):					**$163,595**
	Cost Savings (%)					**44%**
MetalMapper Scenario 2 - Intermediate Cost Savings: 50% Anomaly Reduction with MetalMapper	EM61-MK2 Survey	$7,238.0	Acres	5	$36,190	$0
	MetalMapper Survey	$6,479.0	Acres	5	$0	$32,395
	Cued MetalMapper	$36.8	Anomaly	2000	$0	$73,600
	Classification	$8.1	Anomaly	2000	$0	$16,200
	Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
	Dig 50% of Anomalies	$166.4	Anomaly	1000	$0	$166,400
	Total:				**$368,990**	**$288,595**
	Cost Savings ($):					**$80,395**
	Cost Savings (%)					**22%**
MetalMapper Scenario 3 - No Cost Savings: 36.5% Anomaly Reduction with MetalMapper	EM61-MK2 Survey	$7,238.0	Acres	5	$36,190	$0
	MetalMapper Survey	$6,479.0	Acres	5	$0	$32,395
	Cued MetalMapper	$36.8	Anomaly	2000	$0	$73,600
	Classification	$8.1	Anomaly	2000	$0	$16,200
	Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
	Dig 63.5% of Anomalies	$166.4	Anomaly	1480	$0	$246,272
	Total:				**$368,990**	**$368,467**
	Cost Savings ($):					**$523**
	Cost Savings (%)					**0%**

Table 8-3: TEMTADS Cost Evaluation

Cost Scenarios	Cost Element	Cost per Unit	Unit	Quantity	Traditional MR Costs	Classification Costs
MetalMapper Scenario 1 - Greatest Cost Savings: 75% Anomaly Reduction with TEMTADS	EM61-MK2 Survey	$7,238.0	Acres	5	$36,190	$0
	TEMTADS Survey	$8,472.0	Acres	5	$0	$42,360
	Cued TEMTADS	$62.6	Anomaly	2000	$0	$125,200
	Classification	$8.1	Anomaly	2000	$0	$16,200
	Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
	Dig 25% of Anomalies	$166.4	Anomaly	500	$0	$83,200
	Total:				**$368,990**	**$266,960**
	Cost Savings ($):					**$102,030**
	Cost Savings (%)					**28%**
MetalMapper Scenario 2 - Intermediate Cost Savings: 50% Anomaly Reduction with TEMTADS	EM61-MK2 Survey	$7,238.0	Acres	5	$36,190	$0
	TEMTADS Survey	$8,472.0	Acres	5	$0	$42,360
	Cued TEMTADS	$62.6	Anomaly	2000	$0	$125,200
	Classification	$8.1	Anomaly	2000	$0	$16,200
	Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
	Dig 50% of Anomalies	$166.4	Anomaly	1000	$0	$166,400
	Total:				**$368,990**	**$350,160**
	Cost Savings ($):					**$18,830**
	Cost Savings (%)					**5%**
MetalMapper Scenario 3 - No Cost Savings: 44% Anomaly Reduction with TEMTADS	EM61-MK2 Survey	$7,238.0	Acres	5	$36,190	$0
	TEMTADS Survey	$8,472.0	Acres	5	$0	$42,360
	Cued TEMTADS	$62.6	Anomaly	2000	$0	$125,200
	Classification	$8.1	Anomaly	2000	$0	$16,200
	Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
	Dig 56% of Anomalies	$166.4	Anomaly	1120	$0	$186,368
	Total:				**$368,990**	**$370,128**
	Cost Savings ($):					**-$1,138**
	Cost Savings (%)					**0%**

9.0 IMPLEMENTATION ISSUES

In general, the former CEMR was a relatively easy site at which to perform advanced classification. The site terrain was flat and the only vegetation that was of concern were corn stalks that rose above the ground surface approximately 4 inches. Neither terrain nor vegetation proved to impact implementation once the corn stalks were cut down to the ground. The former CEMR was the site at which ARCADIS collected advanced EMI and therefore, there were some lessons learned regarding the implementation of the technology, which are summarized below.

- MetalMapper Data Acquisition
  - At the time ARCADIS collected the dynamic MetalMapper data, there was no visual method for determining whether the transmit coil was turned on. This led to inadvertently collecting data without the transmit coil turned on, which led to extra costs to re-collect the data.
  - Prior to CEMR, the MetalMapper had typically been moved via a tractor. At CEMR , the MetalMapper was instead mounted on a forklift that provided the following benefits:
    - The forklift had a heated cab in which the field technician sat during data collection. CEMR was conducted in winter, so the heated cab improved working conditions and helped minimize the potential for cold-stress injuries.
    - The cab provided a waterproof location for the placement of the computer monitor, which was not ruggedized or water proof.
    - At prior live site demonstration, MetalMapper data collection had been performed using a tractor with a monitor placed in the field of view of the tractor driver (see **Figure 9-1**). At CEMR, ARCADIS placed a smaller monitor within the heated cab that increased the visibility of the equipment operator (see **Figure 9-2**).
- TEMTADS Data Acquisition
  - The TEMTADS was difficult to push through the project site during dynamic data acquisition due to several factors, including:
    - Low height of the instrument, which caused it to get caught on corn stalks, even after the corn stalks were cut down to near the ground surface.
    - There were only two wheels on the back end of the instrument (note that this has since been rectified and there are now 4 wheels on the TEMTADS).
- The angle of the handle was not adjustable. When shorter field personnel (e.g., 5 ft 2-inch tall personnel) collected data, they had to push the instrument from a relatively high position that required extra effort. Field training was provided by the instrument manufacturers during the live site demonstration; however, this training was primarily focused on data collection and data collection QC in the field and did not include office

QC procedures. Although both SAIC and NAEVA provided some as-needed office QC procedures; more codified data processing and evaluation QC procedures are recommended.

Figure 9-1: Traditional MetalMapper Tractor Operator Field of View (URS, 2013)

Figure 9-2: CEMR MetalMapper Equipment Operator Field of View

10.0 REFERENCES

CH2MHill. 2009. *Final Limited Site Investigation Report, Former Camp Ellis Military Range, Table Grove, Illinois*.

ESTCP, 2012a. *ESTCP Live Site Demonstrations Massachusetts Military Reservation, Camp Edwards, MA.*

ESTCP. September 2012b. *ESTCP Live Site Demonstrations Massachusetts Military Reservation Camp Edwards, MA, ESTCP MR -1165 Demonstration Data Report Central Impact Area TEMTADS MP 2x2 Cart Survey.*

Keiswetter, Dean. February 2009. *Description and Features of UX-Analyze, ESTCP Project MetalMapper-0210.*

Kingdon, James B. et. al. April 2012. *TEMTADS Adjust Sensor Systems Hand-Held EMI Sensor for Cued UXO Discrimination (ESTCP MR-200807) and Man-Portable EMI Array for UXO Detection and Discrimination (ESTCP MR-200909) Final Report.*

Nelson Herb et al. July 2009 Geophysical System Verification (GSV): A Physics-Based Alternative to Geophysical Prove-Outs for Munitions Response

Nelson, Herb. et al. May 2010. *ESTCP Pilot Program Classification Approaches in Munitions Response San Luis Obispo, California*.

Office of the Under Secretary of Defense for Acquisition (OSDA), Technology and Logistics. 2003. *Report of the Defense Science Board Task Force on Unexploded Ordnance*, Washington, DC.

Parsons, Inc. May 2011. *ESTCP Munitions Response Live Site Demonstrations MetalMapper at Former Camp Beale.*

Prouty, Mark. July 2009. *MetalMapper System: Camp San Luis Obispo Discrimination Study ESTCP Project MetalMapper-0603, San Luis Obispo.*

Prouty, Mark. et. al. February 2011. *MetalMapper: A Multi-Sensor TEM System for UXO Detection and Classification ESTCP project MR-200603.*

Snyder, Donald .D. et al. 2010. *UXO Classification with MetalMapper™ Data.*

URS, 2013. *Demonstration of Advanced Geophysics and Classification Technologies on Munitions Response Sites Former Spencer Artillery Range Van Buren County, Tennessee.*

Appendix A: Points of Contact

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Appendix B: GPS Control Point Data Sheets

A separate Addendum contains information regarding Appendices B through F of the ESTCP Munitions Response Live Site Demonstration Report detailing work conducted at Former Camp Ellis by Mr. Steve Stacy of ARCADIS-US, Inc. Appendices B through F contain ancillary data and results that are not formatted for release through a webpage and instructions to obtain these appendices are available in the Addendum.

Appendix C: Geophysical Data

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Appendix D: Intrusive Results

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Appendix E: Ranked Anomaly Lists

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Appendix F: QC Seed Failure Memos

A separate Addendum contains information regarding Appendices B through F of the ESTCP Munitions Response Live Site Demonstration Report detailing work conducted at Former Camp Ellis by Mr. Steve Stacy of ARCADIS-US, Inc. Appendices B through F contain ancillary data and results that are not formatted for release through a webpage and instructions to obtain these appendices are available in the Addendum.