FINAL REPORT

Live Site Classification Demonstration
Former Southwestern Proving Ground, Arkansas Former Joliet Army Ammunition Plant (JOAAP), Illinois

ESTCP Project MR-201423

SEPTEMBER 2018

Elise Goggin
Tetra Tech EC, Inc.

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Summary of Live Site Demonstrations performed at Former Southwestern Proving Ground, AR, and Former Joliet Army Ammunition Plant, IL.

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ACRONYMS AND ABBREVIATIONS

ASI	Acorn Science and Innovation
BTG	Black Tusk Geophysics
cm	centimeter
DU	Decision Unit
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
IDA	Institute for Defense Analyses
IMU	inertial measurement unit
ISO	Industry Standard Object
ISO 80	Industry Standard Object, Schedule 80 pipe nipple
IVS	Instrument Verification Strip
m	meter
mm	millimeter
MM	MetalMapper
MR	Munitions Response
MRS	Munitions Response Site
NRL	Naval Research Laboratory
OB/OD	Open Burn/ Open Detonation
PO	(ESTCP) Program Office
QA	quality assurance
QC	quality control
RF	Recovery Field
ROC	Receiver Operating Characteristic
SARA	Superfund Amendments and Reauthorization Act of 1986
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection
TOI	System Target of Interest
USACE	U.S. Army Corps of Engineers
UXO	Unexploded Ordnance

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ACKNOWLEDGEMENTS

Black Tusk Geophysics

Acorn Science and Innovation

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ABSTRACT

INTRODUCTION AND OBJECTIVES

In June 2013, Tetra Tech was awarded contract W912HQ-14-C-0023 for Environmental Security Technology Certification Program (ESTCP) project Number MR-201423 to perform two Live Site Classification Demonstrations using advanced electromagnetic induction (EMI) sensors to perform Advanced Geophysical Classification (AGC). This is one of a series of Environmental Security Technology Certification Program (ESTCP) demonstrations of classification technologies for Munitions Response (MR). These demonstrations are designed to evaluate classification methodology at live munitions response sites. Tetra Tech performed Live Site Demonstrations at the Former Southwestern Proving Ground (SWPG), AR and the Former Joliet Army Ammunition Plant (JOAAP), AR. The primary objective for these demonstrations was to gain experience with AGC technology. Additionally, each site presented unique challenges for the AGC process.

TECHNOLOGY DESCRIPTION

Two Advanced Electromagnetic Induction (EMI) sensors were used during these demonstrations: the Geometrics MetalMapper and the Naval Research Laboratory TEMTADS. Both systems are designed to enable classification of TOIs using 3-dimensional transmitter and/or receiver coils. These systems have been proven at multiple ESTCP live-site demonstrations to be effective at discriminating between unexploded ordnance (UXO) and non-UXO items. Tetra Tech operated the MetalMapper in the dynamic detection mode and the TEMTADs in both Dynamic and cued modes. Tetra Tech utilized Geosoft Oasis Montaj UX-Analyze software for all data processing. Black Tusk Geophysics utilized UXOLab to process and select targets from the dynamic data collected at SWPG.

PERFORMANCE AND COST ASSESSMENT

At SWPG, approximately 1 acre of dynamic data were collected, and 2491 targets were selected for cued interrogation. No TOI were missed on the final classified and ranked list and approximately 87% of the clutter was rejected.

At JOAAP, approximately 2 acres of dynamic data were collected, and 1005 targets were selected for cued interrogation. Two classified and ranked lists were generated. The first missed no TOI, but had a clutter rejection rate of only 22%. The second, missed several TOI, with a clutter rejection rate of 65%.

The biggest cost drivers on these two sites, were terrain, vegetation, anomaly density and defined TOI.

IMPLEMENTATION ISSUES

Due to the time that has lapsed since the field work and the preparation of the report, several factors related to implementing AGC technology have changed. The primary change is that the International Organization for Standardization 17025 Department of Defense Advanced Geophysical Classification Program (DAGCAP) Accreditation is now required to perform AGC for the DoD.

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EXECUTIVE SUMMARY

INTRODUCTION

In June 2013, Tetra Tech was awarded contract W912HQ-14-C-0023 for Environmental Security Technology Certification Program (ESTCP) project Number MR-201423 to perform two Live Site Classification Demonstrations using advanced electromagnetic induction (EMI) sensors to perform Advanced Geophysical Classification (AGC). This is one of a series of Environmental Security Technology Certification Program (ESTCP) demonstrations of classification technologies for Munitions Response (MR). These demonstrations are designed to evaluate classification methodology at live munitions response sites. Tetra Tech performed Live Site Demonstrations at the Former Southwestern Proving Ground (SWPG), AR and the Former Joliet Army Ammunition Plant (JOAAP), AR.

OBJECTIVES

The primary objectives for the demonstration at SWPG were:

- Provide an opportunity for experience to new demonstrators and receive an official (Receiver Operating Characteristic) ROC curve.
- Assess classification performance where dynamic and cued data are used for the classification process, and where 20 mm projectiles are included in the targets of interest.
- Perform both the dynamic detection and cued interrogation surveys using only advanced sensors.
- Work with Black Tusk Geophysics (BTG) to compare classification results from UXOLab and UX-Analyze to determine strengths and weaknesses of both processes.

The primary objectives for the demonstration at JOAPP were:

- Test advanced classification technology at a site where OB/OD activities were the primary source for UXO; Open Burn/ Open Detonation (OB/OD) activities can lead to kick outs of whole or partial munition items.
- Perform both the dynamic detection survey and cued interrogation surveys using only advanced sensors.
- Asses the usability of a Robotic Total Station (RTS) and prism for spatially positioning advanced classification dynamic survey and cued data collection

TECHNOLOGY DESCRIPTION

Advanced electromagnetic induction (EMI) sensors used for these demonstrations included the following:

- Geometrics MetalMapper (MM) - SWPG
- Naval Research Laboratory (NRL) TEMTADS - SWPG and JOAAP

Geodetic systems used for these demonstrations included:

- Leica real-time kinematic global positioning systems (RTK GPS) - SWPG
- Trimble RTK GPS - SWPG

- Leica robotic total station (RTS) – JOAAP

Data processing software used for these demonstrations included:

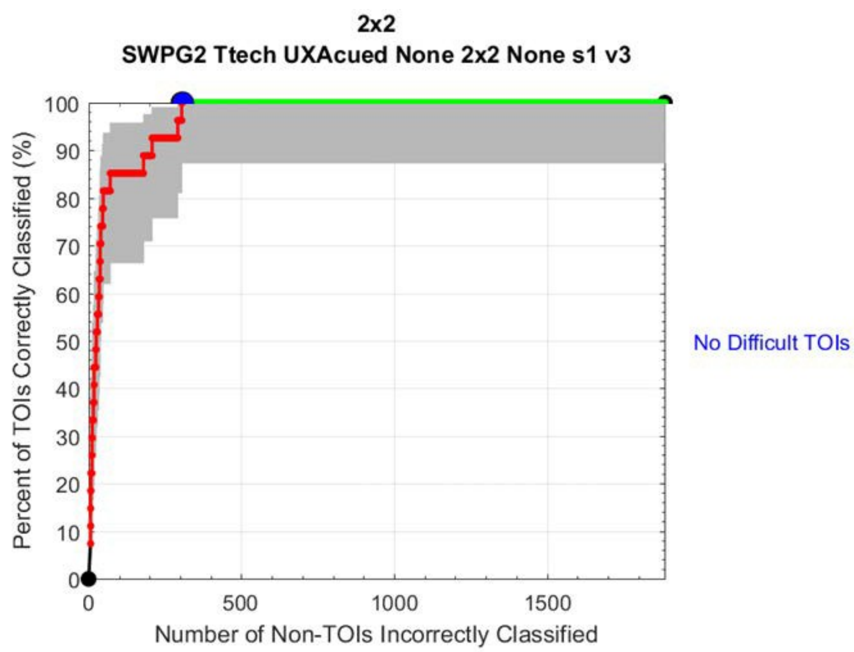
- TEM to .CSV conversion software
- Black Tusk Geophysics (BTG), UXOLab - SWPG
- Geosoft Oasis Montaj, UX-Analyze extension – SWPG and JOAAP

The two Advanced Electromagnetic Induction (EMI) sensors, the Geometrics MetalMapper and the Naval Research Laboratory TEMTADS, are both designed to enable classification of TOIs using 3-dimensional transmitter and/or receiver coils. These systems have been proven at multiple ESTCP live-site demonstrations to be effective at discriminating between unexploded ordnance (UXO) and non-UXO items. Tetra Tech operated the MetalMapper in the dynamic detection mode and the TEMTADs in both Dynamic and cued modes.Tetra Tech utilized Geosoft Oasis Montaj UX-Analyze software for all data processing. Black Tusk Geophysics utilized UXOLab to process and select targets from the dynamic data collected at SWPG.

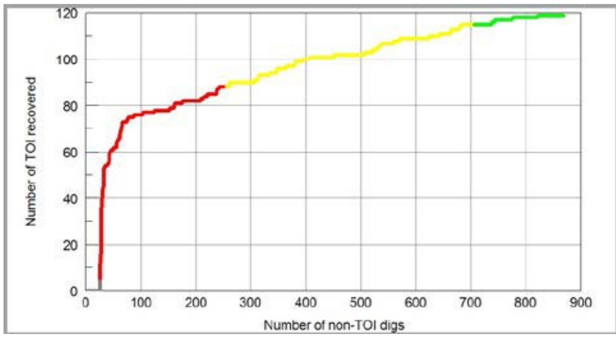
PERFORMANCE ASSESSMENT

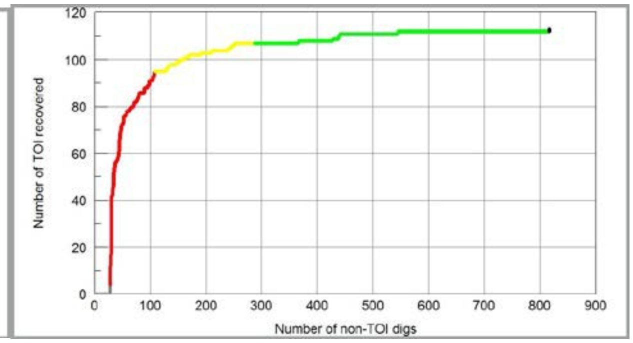
At SWPG, approximately 1 acre of dynamic data were collected, and 2491 targets were selected for cued interrogation. No TOI were missed on the final classified and ranked list and approximately 87% of the clutter was rejected.

At JOAAP, approximately 2 acres of dynamic data were collected, and 1005 targets were selected for cued interrogation. Two classified and ranked lists were generated. The first missed no TOI but had a clutter rejection rate of only 22%. The second, missed several TOI, with a clutter rejection rate of 65%. Native Fuzes were very difficult to classify due to the presence of similarly sized and shaped clutter items. The ROC Curves for each demonstration are provided below.



ROC Curve for SWPG





ROC Curves for JOAAP

COST ASSESSMENT

Primary cost drivers for AGC are as follows:

- Terrain/vegetation: challenging terrain/vegetation reduces production rate for dynamic and cued data collection and increases number of cued measurements that must be recollected
- Anomaly Density: Higher densities increase cued data production in the field, but decrease the production of processing dynamic data
- Size of the site: the larger the site, the more cost effective AGC will be
- TOI: Small/difficult TOI decrease processing production rates and reduce the clutter rejection rate.
- Equipment reliability: stopping for repairs impacts cost and schedule
- Sensor Availability: Costs vary significantly depending on the source of the AGC sensor: GFE, contractor-owned, commercially rented
- QC Issues: The more QC issues, the higher the cost

The cost benefit of AGC is directly related to the cost drivers listed above. In general, AGC is most cost effective when the TOI are very distinct relative to the expected clutter and the anomaly density is greater than approximately 400/acre. In this situation a 30-50% savings per anomaly can be achieved if AGC is utilized (with an ~80% clutter rejection rate) rather than intrusively investigating all targets. Sites with more difficult TOI will likely have lower clutter rejection rates and may have more QC issues. These factors may drive the cost of AGC to be more than intrusively investigating all targets, but the value of the higher quality data may motivate the use AGC regardless of the cost differential.

IMPLEMENTATION ISSUES

Due to the time that has lapsed since the field work and the preparation of the report, several factors related to implementing AGC technology have changed. The primary changes are as follows:

- The International Organization for Standardization 17025 Department of Defense Advanced Geophysical Classification Program (DAGCAP) Accreditation is now required to perform AGC for the DoD.

- The accreditation requires companies to have a thorough Quality Management System in place and requires all personnel who perform AGC to have completed an internal or external Demonstration of Capability (DOC) before performing work.
  - There are currently two companies that manage the DAGCAP Accreditation and provide annual audits of the accredited companies.
  - There are currently 11 companies accredited to perform this work.
- TEMTADS is no longer available as government furnished equipment (GFE).
- The original MetalMappers have mostly been replaced with updated electronics equivalent to those of the new commercially available system, the MetalMapper2x2. This is also manufactured by Geometrics and the design is based on the TEMTADS. These may or may not be available as GFE.
- The MetalMapper2x2 can be purchased for approximately $130K and can be rented for approximately $750 per day. These prices make renting equipment cost prohibitive for long-term projects.
- The latest model of the MetalMapper2x2 still has hardware and software issues that are being working on by Geometrics. It is also currently missing the real-time field inversion capabilities, which will impact the number of targets that need to be recollected after the data have been processed.

1.0 INTRODUCTION

In June 2013, Tetra Tech was awarded contract W912HQ-14-C-0023 for Environmental Security Technology Certification Program (ESTCP) project Number MR-201423 to perform two Live Site Classification Demonstrations using advanced electromagnetic induction (EMI) sensors to perform Advanced Geophysical Classification (AGC). This is one of a series of Environmental Security Technology Certification Program (ESTCP) demonstrations of classification technologies for Munitions Response (MR). This demonstration is designed to evaluate classification methodology at live munitions response sites.

1.1 BACKGROUND

In May 2015, the Former Southwest Proving Ground (SWPG) Formerly Used Defense Site (FUDS) near Hope, Arkansas was selected as the initial test demonstration site. This site provided a suitable location for the first demonstration as it provided a mix of munition types and sizes coupled with the open, level terrain ideal for the maneuvering of EMI sensors and arrays. The demonstration was performed in Recovery Field (RF) 15. Transects were collected in this area during the Remedial Investigation and part of this area was used during a 2013 ESTCP Classification Demonstration. During this demonstration, Weston Solutions, Inc. collected dynamic MM data over approximately 10 acres, and cued 2,000 targets.

In May 2016, Joliet Army Ammunition Plant (JOAAP) FUDS near Joliet, Illinois, was selected as the test site for the second demonstration. The extended buffer area around the former Explosive Burning Ground 1 (L2) and the former Demolition Area (L3) provided the ideal location for the demonstration as it provided access to a former Open Burn/Open Detonation (OB/OD) area with the presence of a variety of munition coupled with terrain that was fairly level for the maneuvering of classification sensors. This demonstration was designed to evaluate the effectiveness of AGC at a former OB/OD site where the potential for partially intact targets of interest (TOI) existed as the result of kick-outs from munition demolition activities. Additionally, the closed tree canopy at this site afforded the testing of classification technology utilizing a Robotic Total Station for spatially locating data, rather than a Real-Time Kinematic Global Positioning System (RTK GPS).

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objectives of the demonstrations are described in Table 1.1.

Table 1-1. Overall Demonstration Objectives

SWPG Objectives	JOAAP Objectives
Provide an opportunity for experience to new demonstrators and receive an official (Receiver Operating Characteristic) ROC curve.	Test advanced classification technology at a site where OB/OD activities were the primary source for UXO; OB/ODactivities can lead to kick outs of whole or partial munition items.
Assess classification performance where dynamic and cued data are used for the classification process, and where 20 mm projectiles are included in the targets of interest.	Perform both the dynamic detection survey and cued interrogation surveys using only advanced sensors.
Perform both the dynamic detection and cued interrogation surveys using only advanced sensors.	Asses the usability of a Robotic Total Station (RTS) and prism for spatially positioning advanced classification dynamic survey and cued data collection
Work with Black Tusk Geophysics (BTG) to compare classification results from UXOLab and UX-Analyze to determine strengths and weaknesses of both processes.	

To achieve these objectives, Tt personnel were trained to collect dynamic and cued MetalMapper and TEMTADS data. Tt geophysicists also processed dynamic and cued TEMTADS data using Geosoft Oasis Montaj.

1.3 REGULATORY DRIVERS

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

2.0 TECHNOLOGY DESCRIPTION

Advanced electromagnetic induction (EMI) sensors used for these demonstrations included the following:

- Geometrics MetalMapper (MM) – SWPG
- Naval Research Laboratory (NRL) TEMTADS - SWPG and JOAAP

Geodetic systems used for these demonstrations included:

- Leica real-time kinematic global positioning systems (RTK GPS) - SWPG
- Trimble RTK GPS – SWPG
- Leica robotic total station (RTS) - JOAAP

Data processing software used for these demonstrations included:

- .TEM to .CSV conversion software
- Black Tusk Geophysics (BTG), UXOLab - SWPG
- Geosoft Oasis Montaj, UX-Analyze extension – SWPG and JOAAP

2.1 TECHNOLOGY DESCRIPTION

The AGC sensors utilized for these demonstrations are discussed in the sections below.

2.1.1 MetalMapper

The Geometrics MM, shown in Figure 2-1, below, is the first commercially available advanced electromagnetic induction (EMI) sensor designed to enable classification of TOIs. It consists of three orthogonal 1-square-meter transmit coils and seven 10-centimeter (cm), 3-component orthogonal receiver coils (Figure 2-2 shows the coil arrangement). The system has been proven at multiple ESTCP live-site demonstrations to be effective at discriminating between unexploded ordnance (UXO) and non-UXO items. Tetra Tech will operate the MM both in dynamic detection and cued discrimination modes during the live-site demonstration at the former Southwestern Proving Grounds. Dynamic MM data will be processed using Geosoft Oasis Montaj software, with the UX-Analyze module. The MM will provide more accurate target positioning advantages over currently used technologies (e.g., EM61-MK2) because of its seven 3-component receivers, greater data density, and improved positioning electronics. A Leica RTK Digital Global Positioning System will be used in combination with a Microstrain 3DM-GX1 inertial measurement unit (IMU) to position the data.

Figure 2-1. Geometrics MetalMapper Deployed at SWPG

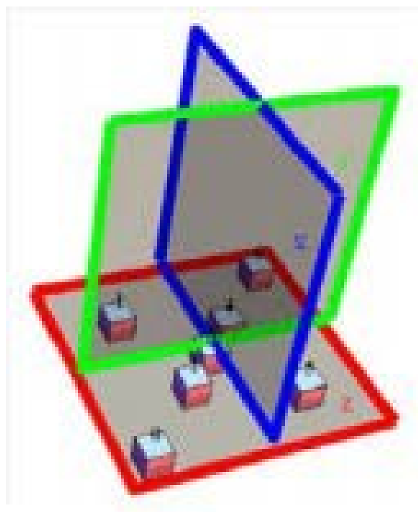


Figure 2-2. TX and RX Coil Arrangement

2.1.2 TEMTADS

The TEMTADS, shown in Figure 2.3, is an advanced EMI sensor designed by NRL to enable classification of TOIs. It is comprised of four TX coils and four 3-component RX cubes arranged in a 2x2 array as shown in Figure 2.4. The center-to-center distance between TX/RX components is 40 cm yielding an 80 cm x 80 cm array. The array was deployed on a set of four wheels resulting in a sensor-to-ground offset of approximately 20 cm. The transmitter electronics and the data acquisition computer are mounted in the operator backpack, as shown in Figure 2-3. The TEMTADS was operated in cued mode at SWPG and positioned with a Trimble RTK GPS and Microstrain 3DM-GX1 IMU. The TEMTADS was utilized for both dynamic detection and cued measurements at JOAPP and positioning data was acquired with a Leica RTS and Microstrain 3DM-GX1 IMU.

Figure 2-3. TEMTADS 2x2 Deployed at JOAAP

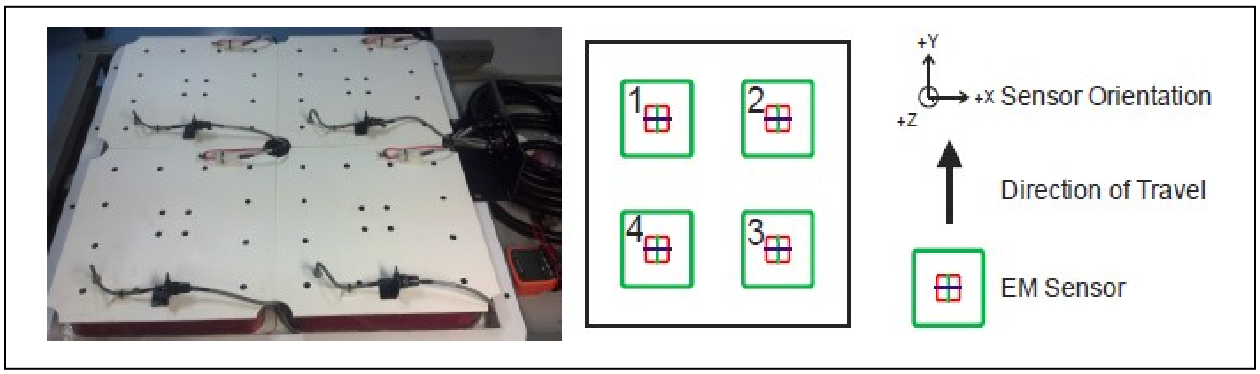


Figure 2-4. TEMTADS/3D EMI Sensor Array

2.1.3 UXOLab

BTG was subcontracted to process dynamic data and select targets at SWPG. These tasks were completed using UXOLab, a MATLAB®-based software package that contains modules for data visualization, data inversion, QC of inversion results, training data selection, and dig list creation via statistical or rule-based classification strategies.

2.1.4 Geosoft Oasis Montaj UX-Analyze

Oasis Montaj was used to process dynamic and cued data at SWPG and JOAAP. At SWPG dynamic data processing and target selection was performed by Acorn Science and Innovation (ASI). Tt performed all data processing at JOAAP. After data was converted from .TEM to .CSV format, it was imported in to Oasis Montaj for processing using the UX-Analyze extension. Purpose-built tools within UX-Analyze were utilized for data visualization, data inversion, QC of inversion results, training data selection, and dig list creation via statistical or rule-based classification strategies.

2.2 TECHNOLOGY DEVELOPMENT

No technology was developed as part of this demonstration.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Advantages of Advanced Geophysical Classification (AGC) technology are as follows:

- The sensors use a multi-TX/RX system so that a target is illuminated from multiple directions
- Multiple RX provide higher resolution data for detection of small TOI
- Dynamic data may be used for classification in a single data collection event.
- Cued data produce high quality and accurate inversions for anomaly classification, resulting in a reduction in the number of targets that must be intrusively investigated
- Library matching allow for quick, easy, and reliable classification of anomalies.

Limitations are as follows:

- Dynamic data collection is typically slower and therefore can be more expensive than conventional detection surveys.
- Cued data collection requires a previous dynamic survey (either conventional DGM or advanced classification sensor) to detect anomalies, resulting in increased geophysical survey costs

Advantages/Disadvantages of MM compared to TEMTADS systems:

- MM is bulky and requires the use of a vehicle (tractor, forklift, etc.) to deploy the system. TEMTADS is man-portable and can be used in more difficult terrain.
- MM data acquisition software allows for target locations to be loaded in the system which supports real-time reacquisition with the MM system. TEMTADS data acquisition software requires that targets be reacquired prior to collecting cued measurements.

3.0 PERFORMANCE OBJECTIVES

The performance objectives for each demonstration are summarized in the sections below.

3.1 SWPG OBJECTIVES

The performance objectives for the demonstration at SWPG are summarized in Tables 3-1 and 3-2. Table 3-1 lists the performance objectives for all field activities. These apply to all detection and classification work performed in the study area. Table 3-2 lists the performance objectives for the advanced classification activities. These apply to all such work performed using advanced classification data.

Table 3-1. SWPG Field Activity Performance Objectives

Performance Objectives for Field Activities			
Performance Objective	**Metrics**	**Success Criteria**	**Results**
Repeatability of instrument verification strip measurements (dynamic and cued)	Amplitude of EM anomaly measured target locations	*MM Dynamic Survey:* amplitudes ±25% Down-track location ±25 cm *TEMTADS Cued:* Library match ≥90% using UX-Analyze 3-criteria metric with equal weighting to all 3 criteria using first day's IVS inversion as the library item	Achieved for all IVS surveys
Complete coverage of the demonstration site (dynamic)	Footprint coverage (excludes inaccessible areas)	>= 85% coverage at 0.75-m line spacing, and >=98% coverage at 0.90-m line spacing	Achieved for all areas accessible to the dynamic system that could be covered in the allotted schedule
Along-line spacing (dynamic)	Point-to- point spacing from data set	98% < 15 cm along-line spacing	Achieved for all dynamic data
Detection of seed items (dynamic)	Percent detected of seed items	100% of seed items detected within 40- cm radius of the known position	Achieved for all detected seeds
Cued interrogation of anomalies	Instrument position	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location for seed items and fit location for all other targets	Achieved for all viable sources

Abbreviations and Acronyms:

cm – centimeter

EM – electromagnetic

IVS – instrument verification strip

m – meter

MM – MetalMapper

Table 3-2. SWPG Advanced Classification Field Activity Performance Objectives

Performance Objectives for Advanced Classification Activities				
Performance Objective	**Items**	**Metric**	**Success Criteria**	**Results**
Correctly classify QC Seeds	All QC seeds	Percent classified as TOI	100% classified as TOI	Achieved for all detected seeds
Correctly classify QA seeds and correctly classify native TOI	All QA seeds and all native TOI	Percent classified as TOI	100% classified as TOI	Achieved for all detected seeds
Correctly identify Group	All TOI and all excavated non-TOI	Percent of TOI and excavated non-TOI grouped correctly	85% correctly grouped in the small, medium and large groups	Achieved for all detected targets
Correct estimation of extrinsic target parameters	All excavated anomalies	Measured location and depth to center of mass of recovered items	98% of estimated anomaly locations have offsets: X, Y < 25 cm Z < 15 cm	Achieved for all detected targets
Maximize correct classification of non-TOI	All non-TOI	Number of false alarms eliminated	Reduction of clutter digs by >65% while meeting all other demonstration objectives	Achieved
Minimize number of anomalies that cannot be analyzed	All cued anomalies	Number of anomalies that must be classified as "Unable to Analyze"	Reliable target parameters can be estimated for >95% of anomalies on detection list	Achieved

Abbreviations and Acronyms:
cm – centimeter
EM – electromagnetic
MM – MetalMapper
QA – quality assurance
QC – quality control
TOI – target of interest

3.1.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

In addition to the factors described above, the reliability of the survey data depends on the proper functioning of the survey equipment. The repeatability of IVS measurements is confirmed though a twice-daily confirmation of sensor system performance.

3.1.1.1 Metric

The metrics for this objective are the amplitude and down-track position of the maxima for sensors used in dynamic survey mode, the percent match of the inverted data to the library for the specific Industry Standard Object (ISO) items, and the RMS repeatability of the measured transients for the advanced sensors used in cued mode. For all instruments, these metrics apply for each of the twice-daily surveys of the IVS.

3.1.1.2 Data Requirements

The IVS data will be used to judge this objective. The IVS measurements collected over each ISO on the first day will be used as the library basis for all future IVS comparisons during the project.

3.1.1.3 Success Criteria

This objective will be considered to be met for dynamic survey data if each IVS response is within 25% of the mean, and the down-track position of the anomaly is within 25 cm of the known location. The objective will be considered met for the advanced sensors in cued mode if the library matches are equal to or greater than 90 percent.

3.1.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability of the demonstrator to completely survey the site and obtain valid data.

3.1.2.1 Metric

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC tool. This metric applies only to accessible areas. Obstacles or inaccessible areas will be excluded from this metric.

3.1.2.2 Data Requirements

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

3.1.2.3 Success Criteria

This objective will be considered to be met if the survey achieved at least 85% coverage at 0.75-m line spacing and 98% at 0.9-m line spacing calculated using the UX-Process Footprint Coverage QC tool.

3.1.3 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The reliability of the survey data depends on the measurement density. This objective concerns the ability of the demonstrator to acquire sufficiently dense measurements to obtain valid data.

3.1.3.1 Metric

The metric for this objective is the point-to-point distance as measured using UX-Process point-to-point distance tool. This metric applies only to accessible areas. Obstacles or inaccessible areas will be excluded from this metric.

3.1.3.2 Data Requirements

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

3.1.3.3 Success Criteria

This objective will be considered to be met for dynamic MM surveys if 98% of the data have along-line spacing of 15 cm or less.

3.1.4 OBJECTIVE: DETECTION OF ALL SEED ITEMS

Quality data should lead to 100% detection of seed items emplaced at the site. This metric applies only to the detection phases of work.

3.1.4.1 Metric

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

3.1.4.2 Data Requirements

The list of potential dipole sources will be provided to Tetra Tech's QC geophysicist and Institute for Defense Analyses (IDA) personnel, who will score the detection probability of the QC and QA seeds respectively.

3.1.4.3 Success Criteria

The objective will be considered to be met if 100% of the seeded items are detected and are within a halo of 40 cm of their recorded locations.

3.1.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

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

3.1.5.1 Metric

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

3.1.5.2 Data Requirements

Tetra Tech will provide the ESTCP Program Office (PO) a weekly list of the location of the center of its instrument for each cued anomaly interrogated in the preceding week. The PO will review the offsets for the QC seeds and provide feedback to the demonstrator if the instrument was not within the acceptable distance. The demonstrator will be required to reacquire data for those anomalies and perform a root cause analysis for each failure.

3.1.5.3 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 seed items, and within 40 cm of the fit location for all other anomalies.

3.1.6 OBJECTIVE: CORRECTLY CLASSIFY QUALITY CONTROL SEEDS

This metric applies to QC seeds. Seed items are used to provide objective and quantitative measurement of the classification process, and are used to supplement advanced classification objectives. Any QC seed failures will require a root cause analysis and will be treated as training digs for the classification process.

The seeds for this demonstration will include small ISOs; 20 mm, 37 mm, 40 mm, 57 mm, 75 mm, and 90 mm projectiles; and 81 mm mortars. The objective for the advanced classification process for this demonstration is to correctly classify 100% of all TOI.

3.1.6.1 Metric

The metrics for this objective are the percentage of TOI correctly identified on the TOI lists.

3.1.6.2 Data Requirements

Initial classification of the data (basic classifier) will be performed on a daily basis to define the initial TOI/non-TOI lists.

3.1.6.3 Success Criteria

The objective will be considered met if 100% of the QC seeds each day are placed on the initial TOI list.

3.1.7 OBJECTIVE: CORRECTLY CLASSIFY QUALITY ASSURANCE SEEDS AND CORRECTLY CLASSIFY NATIVE TARGETS OF INTEREST

This metric applies to QA seeds and native TOI. Seed items are used to provide objective and quantitative measurement of the classification process and are used to supplement advanced classification objectives. The seeds for this demonstration will include small ISOs; 20 mm, 37 mm, 40 mm, 57 mm, 75 mm, 90 mm projectiles; and 81 mm mortars. The objective for the advanced classification process for this demonstration is to correctly classify 100% of all TOI.

3.1.7.1 Metric

The metrics for this objective are the percentage of TOI correctly identified on the TOI lists.

3.1.7.2 Data Requirements

Ranked anomaly lists, separated into TOI and non-TOI lists, will be used to judge the success of the QA seeds and native TOI.

3.1.7.3 Success Criteria

The objective will be considered met if 100% of the QC/QA seeds and native TOI are placed on the TOI list.

3.1.8 OBJECTIVE: CORRECTLY IDENTIFY GROUP

The demonstrators will attempt to correctly assign each TOI and non-TOI to either the small group (smaller than or similar in diameter or length to small ISO), medium group (similar in diameter or length to medium ISO), or large group (similar or larger in diameter or length to large ISO).

3.1.8.1 Metric

The metrics for this objective are the percentage of TOI and non-TOI correctly grouped in either the small, medium or large groups.

3.1.8.2 Data Requirements

Anomalies grouped as either small, medium or large, based on either length or diameter, will be used to judge the success of this objective. The data required to do so may depend on the usability of the $\beta 2$ and $\beta 3$ polarizability curves. If the quality of these cannot support the demonstrator's methodology, the demonstrator will identify the anomaly as "Cannot Analyze".

3.1.8.3 Success Criteria

The group assignment task will be considered successful if 85% or more of the group designations are correct.

3.1.9 OBJECTIVE: CORRECT ESTIMATION OF EXTRINSIC TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the cued analysis (data inversion). 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.

3.1.9.1 Metric

The accuracy of estimation of the extrinsic target parameters is the metric for this objective.

3.1.9.2 Data Requirements

Tetra Tech will produce a list of anomaly location and depth as part of the results submission and will compare these estimated parameters to those measured during the intrusive investigation.

3.1.9.3 Success Criteria

The objective will be considered to be met if the estimated X, Y locations are within 25 cm and the estimated depths are within 25 cm.

3.1.10 MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGET OF INTEREST

By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, we expect to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction.

3.1.10.1 Metric

The metric for this objective is the number of cued anomalies that can be correctly classified as non-TOI.

3.1.10.2 Data Requirements

Each demonstrator will prepare a prioritized non-TOI list from the cued anomaly list. IDA personnel will use their scoring algorithms to assess the results.

3.1.10.3 Success Criteria

The objective will be considered to be met if more than 65% of the non-TOI items can be correctly labeled as non-TOI while meeting the objectives or success criteria for TOI stated in Table 3-2.

3.1.11 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 will reduce the effectiveness of the classification process.

3.1.11.1 Metric

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

3.1.11.2 Data Requirements

Each demonstrator that estimates target parameters will provide a list of all parameters as part of his/her results submission along with a list of those anomalies for which parameters could not be reliably estimated.

3.1.11.3 Success Criteria

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

3.2 JOAAP OBJECTIVES

The performance objectives for the demonstration at JOAAP were based on the AGC-QAPP Measurement Quality Objectives (MQO) and are summarized in Tables 3-3 and 3-4. Table 3 3 lists the performance objectives for all field activities. These apply to all detection and classification work performed in the study area. Table 3-4 lists the performance objectives for the advanced classification activities. These apply to all such work performed using advanced classification data.

Table 3-3. JOAAP Field Activity Performance Objectives

Performance Objectives for Field Activities			
Performance Objective	**Metric**	**Success Criteria**	**Results**
Repeatability of instrument verification strip measurements (dynamic and cued)	Amplitude of EM anomaly measured target locations	*TEMTADS Cued:* Library match ≥90% using UX-Analyze 3-criteria metric with equal weighting to all 3 criteria using first day's IVS inversion as the library item	Achieved for all IVS surveys
Geodetic Functionality	Start and end of day, when RTS or DGPS is used	Positional error the RTK DGPS or RTS at a known/temporary monument will not exceed ± 0.328 foot (10 cm).	Achieved
Surface Clearance Coverage	Evaluated per DU. Minimum 5 coverage seeds per DU.	All surface seeds are recovered.	Achieved
Complete coverage of the demonstration site (dynamic)	Footprint coverage (excludes inaccessible areas)	>= 85% coverage at 0.75-m line spacing, and >=98% coverage at 0.90-m line spacing	Achieved for all areas accessible to the dynamic system that could be covered in the allotted schedule
Along-line spacing (dynamic)	Point-to-point spacing from data set	98% < 15 cm along-line spacing	Achieved for all dynamic data
Detection of seed items (dynamic)	Percent seed items detected	100% of seed items detected within 40-cm radius of the known position	Achieved for all detected seeds
Perform Sensor Function Test	Start and end of day, when TEMTADS power is cycled.	All sensor function tests' calculated response (mean static spike minus mean static background) is within 20% of standard response.	Achieved for all sensor function tests collected.
Confirm all background measurements are valid	Background measurements collected in the field	Ensure background variation does not impact ability to classify correctly	All background measurements used during processing are validated prior to use.

Abbreviations and Acronyms:

cm – centimeter

EM – electromagnetic

IVS – instrument verification strip

m – meter

TEMTADS - Time-domain Electromagnetic Multi-sensor Towed Array Detection

Table 3-4. JOAAP Classification Performance Objectives

Performance Objectives for Advanced Classification Activities				
Performance Objective	**Items**	**Metric**	**Success Criteria**	**Results**
Confirm inversion model supports classification: Fit coherence	Modeled responses fit coherence	Evaluated for all models derived from a measurement (i.e., single-item and multi- item models)	Derived model response must fit the observed data with a fit coherence ≥ 0.86	Achieved or targets were classified as Cannot Analyze
Confirm inversion model supports classification: Fit location	Fit target locations	Evaluated for derived target	Fit location estimate of item ≤ 0.4m from center of sensor	Achieved for all detected targets
Confirm inversion model supports classification: Seed location	Predicted target locations for QC seeds	Evaluated for predicted target locations compared to actual seed location	100% of predicted seed positions ≤ 0.25m from known position (x, y, z)	Not Achieved
Correctly Classify QC Seeds	TOI Lists	Percentage of TOI correctly identified on TOI lists	100% of QC seeds are placed on the initial TOI list	
Correctly Classify non-TOI Items	TOI Lists	Percentage of non-TOI correctly identified on TOI lists	100 % of non-TOI are confirmed to be non-TOI through intrusive investigation.	

Abbreviations and Acronyms:
cm – centimeter
EM – electromagnetic
MM – MetalMapper
QA – quality assurance
QC – quality control
TOI – target of interest

3.2.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

In addition to the factors described above, the reliability of the survey data depended upon the proper functioning of the survey equipment. The repeatability of IVS measurements was confirmed through a twice-daily confirmation of sensor system performance.

3.2.1.1 Metric

The metrics for this objective were the amplitude and down-track position of the maxima for sensors used in dynamic survey mode, the percent match of the inverted data to the library for the specific items, and the RMS repeatability of the measured transients for the advanced sensors used in cued mode. These metrics applied for each of the twice-daily surveys of the IVS.

3.2.1.2 Data Requirements

The IVS measurements collected over each item on the first day were used as the library basis for all future IVS comparisons during the project.

3.2.1.3 Success Criteria

This objective will be considered to be met for dynamic survey data if each IVS response is within 20% of the mean, and the down-track position of the anomaly is within 25 cm of the known location. The objective will be considered met for the advanced sensors in cued mode if the library matches are equal to or greater than 90 percent of UX-Analyze 3-criteria metric with equal weighting to all 3 criteria.

3.2.2 OBJECTIVE: GEODETIC FUNCTIONALITY

The spatial accuracy of survey data depended upon the proper functioning of the survey equipment. The accuracy of geodetic measurements was confirmed through daily checkshots performed at known or temporary monuments whenever the RTK-GPS or the RTS was in use on the site.

3.2.2.1 Metric

The metrics for this objective are the offsets between the daily recorded checkshot locations and the known locations of control points or temporary monuments.

3.2.2.2 Data Requirements

The checkshot coordinates and the control point coordinates are compared.

3.2.2.3 Success Criteria

The objective will be considered to be met for geodetic functionality when the positional error for the RTK DGPS or RTS at a known/temporary monument does not exceed ± 0.328 foot (10 cm).

3.2.3 OBJECTIVE: SURFACE CLEARANCE COVERAGE

The reliability of the surface clearance depended upon ensuring adequate coverage of the study area while performing the magnetometer assisted surface clearance.

3.2.3.1 Metric

The metrics for this objective is the emplacement of coverage seeds across the study area prior to the surface clearance, and the subsequent recovery of the coverage seeds while actively performing the surface clearance.

3.2.3.2 Data Requirements

Surface Clearance Seeding Results are verified and validated.

3.2.3.3 Success Criteria

This objective will be considered to be met for surface clearance coverage if all surface seeds were recovered during the magnetometer assisted surface clearance.

3.2.4 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability of the demonstrator to completely survey the site and obtain valid data.

3.2.4.1 Metric

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC tool. This metric applies only to accessible areas. Obstacles or inaccessible areas will be excluded from this metric.

3.2.4.2 Data Requirements

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

3.2.4.3 Success Criteria

This objective will be considered to be met if the survey achieved 100% coverage at 0.7-m line spacing using the UX-Process Footprint Coverage QC tool.

3.2.5 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The reliability of the survey data depends upon the measurement density. This objective concerns the ability of the demonstrator to acquire sufficiently dense measurements to obtain valid.

3.2.5.1 Metric

The metric for this objective is the point-to-point distance as measured using UX-Process point-to-point distance, Along Line Spacing tool. This metric applies only to accessible areas were data were collected. Obstacles or inaccessible areas were excluded from this metric.

3.2.5.2 Data Requirements

Each dynamically mapped survey data file is used to judge the success of this objective.

3.2.5.3 Success Criteria

This objective will be considered to be met for the dynamic TEMTADS survey of the demonstration site if at least 98% of the collected dynamic survey data having along-line spacing of 20 cm or less.

3.2.6 OBJECTIVE: DETECTION OF SEED ITEMS

The reliability of the survey data depends upon ensuring that the TEMTADS reliably detected all QC seed items.

3.2.6.1 Metric

The metric for this objective is the QC geophysicist’s review of all DGM data packages to ensure that seed items were detected in the geophysical data.

3.2.6.2 Data Requirements

DGM data packages and known seed locations will be used to judge the success of this objective.

3.2.6.3 Success Criteria

This objective will be considered to be met if 100% of seed items were detected within a 40 cm radius from their known position.

3.2.7 OBJECTIVE: SENSOR FUNCTION TEST

The reliability of the survey and classification data depended upon ensuring that the TEMTADS was functioning properly.

3.2.7.1 Metric

The metric for this objective is performing and recording a sensor function test at the beginning and end of day, and any time the TEMTADS is cycled off and on.

3.2.7.2 Data Requirements

Sensor function test response matches reference response.

3.2.7.3 Success Criteria

This objective will be considered to be met for TEMTADS sensor functions tests if the calculated response (mean static spike minus mean static background) is within 20% of standard response for all monostatic Tx/Rx combinations. The built-in software created by NRL alerts the TEMTADS user if a sensor function test has failed immediately upon test completion.

3.2.8 OBJECTIVE: CONFIRM ALL BACKGROUND MEASUREMENTS ARE VALID

Quality data are the product of quality background measurements. This metric applies only to the detection phases of work.

3.2.8.1 Metric

The metric for this objective are the background measurements collected in the field and ensuring that the variation between background measurements does not impact ability to classify.

3.2.8.2 Data Requirements

Validated background locations.

3.2.8.3 Success Criteria

The objective will be considered to be met if 100% of background measurements used during processing are validated prior to use.

3.2.9 OBJECTIVE: CONFIRM INVERSION MODEL SUPPORTS CLASSIFICATION (1OF 3); FIT COHERENCE

The reliability of the inversion model depends on acceptable modeled responses.

3.2.9.1 Metric

The metric for this objective is to evaluate all models derived from a measurement (i.e., single-item and multi- item models).

3.2.9.2 Data Requirements

Calculated fit coherence for each model.

3.2.9.3 Success Criteria

The objective will be considered to be met if all derived model response fit the observed data with a fit coherence ≥ 0.86.

3.2.10 OBJECTIVE: CONFIRM INVERSION MODEL SUPPORTS CLASSIFICATION (2OF 3); FIT LOCACTION

The reliability of the inversion model depends on accurate target fit locations.

3.2.10.1 Metric

The metric for this objective is to evaluate all derived target fit locations and their distance from the center of the TEMTADS.

3.2.10.2 Data Requirements

Fit location for each modeled source.

3.2.10.3 Success Criteria

The objective will be considered to be met if all derived target fit locations estimate of item ≤0.4m from center of sensor.

3.2.11 OBJECTIVE: CONFIRM INVERSION MODEL SUPPORTS CLASSIFICATION (3OF 3); SEED LOCACTION

The reliability of the inversion model depends on accurately predicted TOI (seed) locations.

3.2.11.1 Metric

The metric for this objective is to evaluate all predicted locations for items classified as TOI that are QC seeds.

3.2.11.2 Data Requirements

Blind seed locations compared to modeled locations.

3.2.11.3 Success Criteria

The objective will be considered to be met if 100% of predicted seed locations ≤ 0.25m from known position (x, y, z).

3.2.12 OBJECTIVE: CORRECTLY CLASSIFY QUALITY CONTROL SEEDS

This metric applies to QC seeds. Seed items are used to provide objective and quantitative measurement of the classification process and are used to supplement advanced classification objectives. Any QC seed failures will require a root cause analysis and will be treated as training digs for the classification process. The seeds for this demonstration will include small ISO80s. The objective for the advanced classification process for this demonstration is to correctly classify 100% of all TOI.

3.2.12.1 Metric

The metrics for this objective are the percentage of TOI correctly identified on the TOI lists.

3.2.12.2 Data Requirements

Blind seed types are compared to classification results.

3.2.12.3 Success Criteria

The objective will be considered met if 100% of the QC seeds each day are placed on the initial TOI list.

3.2.13 OBJECTIVE: CORRECTLY CLASSIFY NON-TOI ITEMS

This objective concerns the component of the classification problem that involves false alarm reduction and non-TOI items. The objective for the advanced classification process for this demonstration is to correctly classify 100% of all non-TOI. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, we expect to be able to classify the targets with high efficiency.

3.2.13.1 Metric

The metrics for this objective are the percentage of non-TOI correctly identified on the TOI lists.

3.2.13.2 Data Requirements

Ranked anomaly lists, separated into TOI, Non-TOI, and Inconclusive. Are compared to intrusive results.

3.2.13.3 Success Criteria

The objective will be considered met if 100 % of non-TOI are confirmed to be non-TOI through intrusive investigation.

4.0 SITE DESCRIPTION

The former SWPG is a 50,077-acre site located near Hope, Arkansas. The demonstration was conducted in a portion of RF 15. Current land use is privately owned agricultural. The MRS is regularly tilled and used for cattle grazing.

The former JOAAP is located approximately 60 miles southwest of Chicago and 17 miles south of Joliet, in Will County, Illinois. The location of the study area for this demonstration is within the Load-Assembly-Pack area of JOAPP, east of Route 53, within the L2-L3 Extended Buffer Area (EBA) MRS. Current land use surrounding the 2-acre study area includes open space areas, agricultural areas, and undeveloped wooded areas as part of the Midewin National Tallgrass Prairie. Currently, areas of the MNTP are open to the public for visitor and recreational use, though public access to the EBA MRS is restricted.

4.1 SITE SELECTION

The two demonstration sites were selected based on the unique challenges they presented.

4.1.1 SWPG

SWPG was primarily selected as a demonstration site due to the variety of TOI and the high anomaly density. Minimizing false positives on sites with high anomaly density and small TOI is challenging. Although a demonstration has already been performed on this site, using the former Southwestern Proving Ground for the demonstration discussed in this document provides opportunities to demonstrate the capabilities and limitations of the classification process while incorporating a wide range of TOI. Easy access, relatively easy terrain, and a clear sky view also make this site perfect for new demonstrators.

4.1.2 JOAAP

The selection of JOAAP for this demonstration provided an opportunity to demonstrate the capabilities and limitations of the classification process at an Open Burn / Open Detonation (OB/OD) site where the primary mechanism for the presence of MEC is the kick out of intact or partial items from incomplete demolition activities. The 2-acre study area was placed in adjacent to the L3 Demolition Area and partially overlaps the location of one of the MEC high density areas identified during the 2015 RI. Additionally, the ecological setting in this portion of JOAAP provides a means of testing the maneuverability of the TEMTADS in a forested environment. The tree canopy in the location prevents the use of RTK-GPS; therefore, this site also presented the opportunity to test the compatibility of the TEMTADS with an RTS to spatially located geophysical data.

4.2 BRIEF SITE HISTORY

The site histories for each demonstration site are discussed in the following sections.

4.2.1 SWPG

In 1941, construction began on the former Southwestern Proving Ground. Actual testing began in January 1942. Items tested at the facility included 250-pound and 500-pound bombs; mines; 60 mm and 81 mm mortars; hand and rifle grenades; 20 mm, 37 mm, 40 mm, 75 mm, 76 mm, 90 mm, 105 mm and 155 mm projectiles; and small rockets. While a fair majority of the rounds tested were inert/ballast, fillers also included high explosives, white phosphorous, and smoke mixtures. No chemical surety material was tested.

Operations continued until September 1945. Upon closure, subsequent range clearances were performed for surface contamination, with Certificates of Clearance being issued in 1947 and 1948, delineating specific areas as "surface use only." In the early 1950s, additional range clearances were performed by the U.S. Army Corps of Engineers clearance teams, with a final Certificate of Clearance being issued 16 March 1954.

4.2.2 JOAAP

The former JOAAP facility was a United States (U.S.) Army munitions production facility that operated from 1940 until 1999, when all defense contractor leases ended. Prior to military use, the land comprising JOAAP was used for agricultural purposes. Defense contractors used areas of JOAAP under facility use contracts from 1977 until 1999. Since then, the majority of the original 36,000 acres comprising the JOAAP installation has been transferred from military ownership. Over half of the transferred acreage (19,100 acres) was transferred to the MNTP, which is managed by the U.S. Forest Service. Currently, approximately 1,500 acres of JOAAP is still under military ownership, but the facility is no longer industrially active.

4.3 MUNITIONS CONTAMINATION

Both demonstration sites had a wide variety of TOI.

4.3.1 SWPG

The expected munitions at RF 15 are listed in Table 4-1. The bolded items in the table identify munitions types recovered within the recovery fields during the EE/CA. The non-bolded items were recovered at nearby locations either during the EE/CA or removal actions and are reasonable to anticipate as potential UXO present in RF 15.

Table 4-1. SWPG Known and Suspected Munitions Types*

RF 15	**20 mm**, 37 mm, **40 mm**, **57 mm**, 75 mm, **76 mm**, 81 mm mortar, **90 mm**, 105 mm, 155 mm

* Items in bold text were recovered within the RF during the EE/CA; non-bolded items are suspected based on the current conceptual site model

4.3.2 JOAAP

The expected munitions within the L2 and L3 EBA MRS are listed in Table 4-2.

Table 4-2. JOAAP Known and Suspected Munitions Types*

L2 and L3 EBA MRS	40mm rifle grenades, 57mm projectiles, 75mm HE and shrapnel projectiles, 155mm projectiles, 105mm projectiles, one M5 ceramic landmine, one 3.5-inch rocket warhead, M48 nose fuzes, M66 base fuzes, T83 fuze and partial fuzes, unidentified fuze, boosters and booster parts.

5.0 TEST DESIGN

The factors that were used in developing the test design for this demonstration are discussed below.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this program is to demonstrate a methodology for the use of classification in the MR process. The key components of this methodology are collection of high-quality dynamic classification data, advanced anomaly filtering to select potential sources in those data, cued data collection over the selected sources, analysis of the cued data 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.

5.2 SITE PREPARATION

Pre-demonstration activities are described in the following sections. The historical information gathered on these sites was been collected from available reports related to previous work performed at these sites.

5.2.1 Site Preparation for SWPG

The following sub-sections describe the site preparation activities for SWPG. Figure 5-1 shows the demonstration area within RF15.

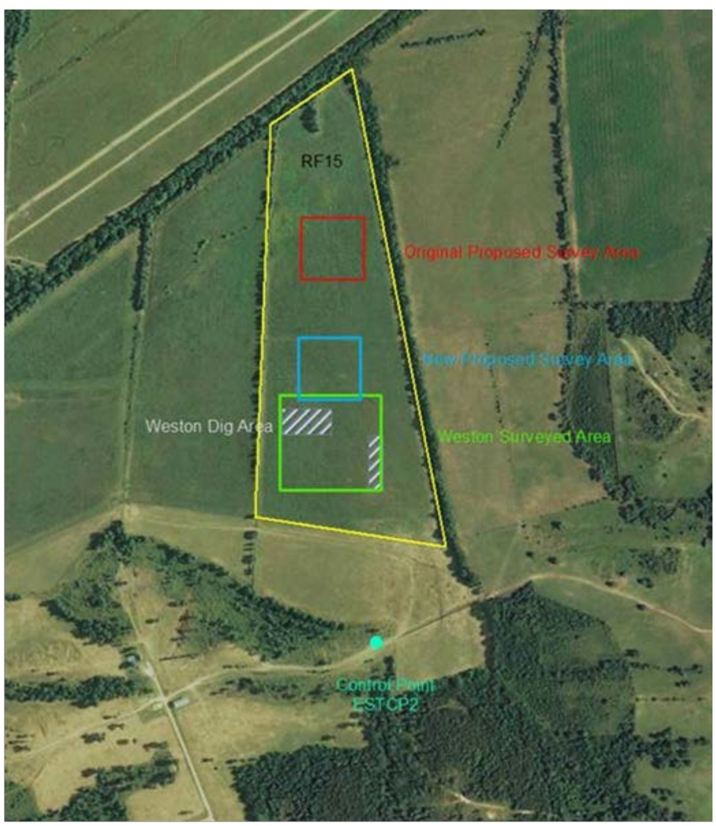


Figure 5-1. SWPG Demonstration Area

5.2.1.1 SWPG Project Control

Two first-order survey monuments were installed at the site during the previous demonstration. The labels and coordinates for these monuments are provided in Table 5-1, and the data sheets are attached as Appendix C to this plan.

Table 5-1. SWPG Geodetic Control Locations

ID	Latitude	Longitude	Elevation NAVD88 (m)	Northing (m)	Easting (m)	Ellipsoid Height (m)
ESTCP1	N33º47’56.89499	W93º37’49.72688	130.871	3740063.731	441639.431	103.855
ESTCP2	N33º49’51.69395	W93º39’42.87732	106.096	3743617.714	438752.724	79.057

5.2.1.2 SWPG Vegetation Removal

No vegetation removal was required at this site.

5.2.1.3 SWPG Surface Clearance

After the establishment of site control points and the emplacement of the site boundary a surface sweep was conducted by 2 qualified UXO personnel. All visible metal objects were removed from the surface at the final selected demonstration site.

5.2.1.4 SWPG Blind Seeding

To ensure that the number of TOI is sufficient to define a demonstrator’s classification performance, the site was seeded with 80 blind seeds to ensure reasonable statistics. The plan seeks to assess performance on all types of UXO present in each area, which may include UXO not currently documented in RF 15 but documented elsewhere on the former Southwester Proving Ground (see Section 4 for a complete list).

5.2.1.5 Establish Instrument Verification Strip at SWPG

A quiet location to the east of the demonstration area was selected to establish an IVS that was used for daily verification of proper sensor operation. Details of the contents of the IVS are provided in Table 5-2.

Table 5-2. Details of the Instrument Verification Strip

Item ID	Description	Design Easting (m)	Design Northing (m)	Depth (m)	Inclination	Azimuth (°cw from N)
T-001	Shot put	TBD	TBD	0.15	N/A	N/A
T-002	57 mm projectile			0.3	Horizontal	Across Track
T-003	37 mm projectile			0.15	Horizontal	Across Track
T-004	Blank space			N/A	N/A	N/A
T-005	90 mm projectile			0.45	Horizontal	Across Track

Abbreviations and Acronyms:
cw – clockwise
m – meters
mm – millimeters

N – north
N/A – not applicable
TBD – to be determined

5.2.2 Site Preparation for JOAAP

The following sub-sections describe the site preparation activities for JOAAP.

5.2.2.1 JOAAP Project Control

At JOAAP, four locations for control points were provided by AECOM, who had been working on the site for over a year. These locations are provided in Table 5-3. All coordinates are in State Plane Illinois East coordinate system, reported in feet.

Table 5-3. JOAAP Supplied First Order Control Points

PointID	Easting (X)	Northing (Y)	Elev (Z)
Park	1047728.479	1711003.416	618.319
Bridge	1047236.217	1711080.457	605.871
IronFence	1047422.806	1710600.047	620.82
SouthHill	1046842.308	1710316.469	594.616

Tt field personnel set up Lecia 1200 RTK-GPS base station at the control point identified as Park, in the AECOM parking lot, about a half mile from the demonstration are. A checkshot was performed at the point identified as Bridge, on a nearby bridge. Strong radio signal enabled the geo team to receive GPS signal with RTK correction in a small clearing near Starr Grove Cemetery and adjacent to the demonstration area. Four control points were acquired in the clearing and are listed in Table5-4.

Table 5-4. JOAAP Tetra Tech-Established Control Points

PointID	Easting (X)	Northing (Y)	Elev (Z)
cemetery1	1048186.063	1709670.836	642.24
cemetery2	1048180.508	1709670.681	642.316
cemetery3	1048180.599	1709676.125	642.604
cemetery4	1048190.538	1709641.361	642.363

A resection was performed with the Leica TS16 Robotic Total Station (RTS) using these four points. The resection was placed in such a way as to provide sight down a road adjacent to the demonstration area and allowed for the establishment of several conveniently located control points for the establishment of grid corners.

Once control point locations were established for the area, multiple resections performed with the RTS allowed TetraTech to emplace eight 100' X 100' grids in the demonstration area (see Figure 5-2). These grids are divided up into two equally sized Decision Units (DU1 and DU2). DU1 is comprised of the four southern-most grids, A1, A2, B1 and B2. DU2 is comprised of the four northern-most grids, C1, C2, D1 and D2. The grids were placed west of the road to Starr Grove Cemetery and outside of the 300' buffer from all AECOM operations.

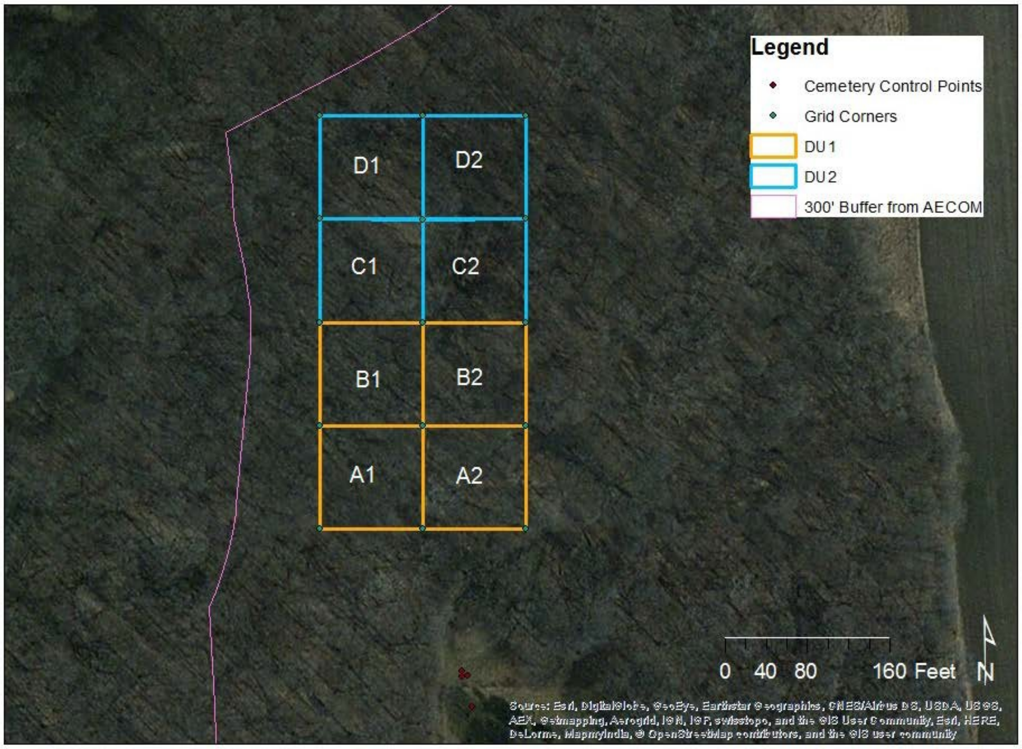


Figure 5-2. JOAAP Grids and Decision Units

5.2.2.2 JOAAP Vegetation Removal

After consultation with USFWS, the 2-acre site was cleared of small trees with a diameter less than 3 inches, deadfall, and downed debris. Due to the extensive amount of deadfall in the area, the decision was made to leave downed trees in place. This resulted in some data gaps.

5.2.2.3 JOAAP Surface Clearance

After the establishment of site control points and the emplacement of eight 100' X 100' grids in two DU, a surface sweep was conducted by 3 qualified UXO personnel. This surface sweep was performed utilizing CEIA analog detectors and was completed in accordance with the QAAP and SOP 13- Surface Clearance. The surface sweep recovered five T83 fuzes. These MEC items were deemed as safe to move, therefore, they were consolidated and disposed of by demolition. Additionally, all visible metal objects were removed from the surface at the final selected demonstration site.

5.2.2.4 JOAAP Blind Seeding

Approximately 40 blind seeds were installed at JOAAP. These seeds were installed in accordance with the QAAP and associated SOP-3 for Blind Seeding. After the surface sweep the blind seeds were installed by a 4-person team made up of two UXO-qualified personnel and two geophysicists.

First, a resection of the grid area was performed, and local control was established. A location was chosen for the seed based on location within the grid and availability of line-of-sight with the RTS. The blind seed installation team was mindful of providing adequate distribution across the demonstration site in order that at least one seed would be encountered per day during subsequent geophysical mapping operations. Once an appropriate location was identified, a qualified UXO technician cleared an area for seed burial using the CEIA analog detector. The hole was excavated to a depth appropriate for placing a small ISO at a depth of 2-6" below ground surface. Once the hole was dug, the Seed ID number was recorded on a small slip of paper and placed into a ziplock bag. This bag was sealed, tightly rolled and inserted into the open cavity of the ISO, and the ISO was placed in the excavation horizontal to ground surface. The depth of the ISO was recorded by placing a wooden stake across the hole, even with the ground's surface, and measuring the depth to the item's center of mass. The azimuth of the item was also recorded in degrees from north using a digital compass. A photo was taken of each seed in the hole showing the depth measurement of the item (as described above) and a white board recording the Seed Item number, date, depth, orientation and azimuth. An example of a seed installation photo is shown in Figure 5-3. Once the photo was taken, the seed's spatial location was recorded and stored using the Leica TS16 RTS. The locations of all seeds were stored as a password protected file in order to preserve the firewall between field installation and data processing/QC staff. After recording all seed data, the hole was backfilled.

Figure 5-3. Example Blind Seed Photo

5.2.2.5 Establish Instrument Verification Strip At JOAAP

A quiet location to the east of the demonstration area was selected to establish an IVS that was used for daily verification of proper sensor operation. Details of the contents of the IVS are provided in Table 5-5. In addition to emplacing the two IVS items along the main IVS line, offset lines were established along track to the items at 0.5m, 0.25m, and -0.25m to provide replicate dynamic measurements at maximum potential offset. A clear background area and background line was also established for daily TEMTADS background measurements in both cued and dynamic mode.

Table 5-5. Details of the JOAAP Instrument Verification Strip

Item ID	Description	Easting (m)	Northing (m)	Depth (inches)	Inclination	Azimuth (°from N)
IVS01	Small ISO 80	1048345.662	1709859.373	2	Horizontal	33
IVS02	Large ISO 80	1048354.668	1709855.387	6	Horizontal	36

5.3 SYSTEM SPECIFICATION

The system components are discussed in Section 2.1 of this report. The specific data collection settings for each system are shown in Tables 5.6 and 5.7.

Table 5-6. MetalMapper Dynamic Data Collection Settings

Window Width	Hold-off (µs)	Number of Stacks	Number of Blocks	Block Length (s)	TX Coils	Repeat
20	100	1	9	.1	Z	Continuous

Abbreviations and Acronyms:
µs - microseconds
s – seconds

Table 5-7. TEMTADS Dynamic and Cued Data Collection Settings

Parameter	Cued Survey	Dynamic Survey
Acq Mode	Decimated	Decimated
Gate Width	5%	20%
Stacks	18	1
Repeats	9	3
Stack Period	0.9	0.033

Positional data was collected at a minimum rate of 2Hz with the RTS and 5Hz with the GPS.

5.4 CALIBRATION ACTIVITIES

Daily IVS data collection and sensor function tests were essential to ensuring that the MM and TEMTADS were collecting quality data in the field. At each site the IVS was collected a minimum of twice daily, once in the morning prior to survey, and again at the end of the day. IVS data collection included dynamic and cued background measurements, and dynamic and cued measurements over the IVS items. Sensor function tests were performed for the TEMTADS using a small ISO placed in the standard holder. These were performed during the morning and evening IVS surveys and periodically throughout the day.

5.5 DATA COLLECTION

The following sections apply to data collection for both demonstration sites.

5.5.1 Sample Density

Dynamic data was collected with a design line spacing of 0.75 m for the MetalMapper and 0.7m for the TEMTADS. Along-line spacing was less than 20 cm from data point to data point. These parameters are consistent with USACE guidance.

5.5.2 Quality Checks

Daily QC checks over the IVS combined with regular sensor function tests for the TEMTADS provided ongoing verification that the system was working properly. Seed items were checked to ensure that they were detected and selected as a potential source. All data were verified using Geosoft Oasis Montaj UX Analyze built-in QC tools; velocity calculations, sample separation, and footprint coverage checks were performed on each data set. Noise levels in the dynamic data were monitored and background measurements were reviewed to ensure they were reasonable, based on site specific characteristics.

5.5.3 Data Handling

All raw data was uploaded to the Tetra Tech server on a daily basis. At SWPG Tetra Tech uploaded raw data to ASI and BTG's FTP sites for processing. Processed results were also pulled from this location and saved to the Tetra Tech server. At JOAAP the project Geophysicist and or assigned Data Processor was responsible for processing data and posting the resulting databases to the server and SharePoint Site. Target lists were developed and distributed to the Site Geophysicist for reacquisition. Intrusive data were managed by the designated data manager and kept blind from the Project Geophysicist and Data Processor until an official classified and ranked list was submitted for official scoring.

All raw data, target lists and intrusive results were also provided to ESTCP.

5.5.4 Scale

The scale of each demonstration was determined based on budget and schedule constraints.

5.5.4.1 SWPG Scale

At SWPG, the dynamic detection survey covered approximately 1 acre. 2491 targets were selected for cued interrogation. See Figure 5-4.

5.5.4.2 JOAAP Scale

At JOAAP, the dynamic detection survey covered approximately 2 acres. 1005 targets were selected for cued interrogation. See Figure 5-5.

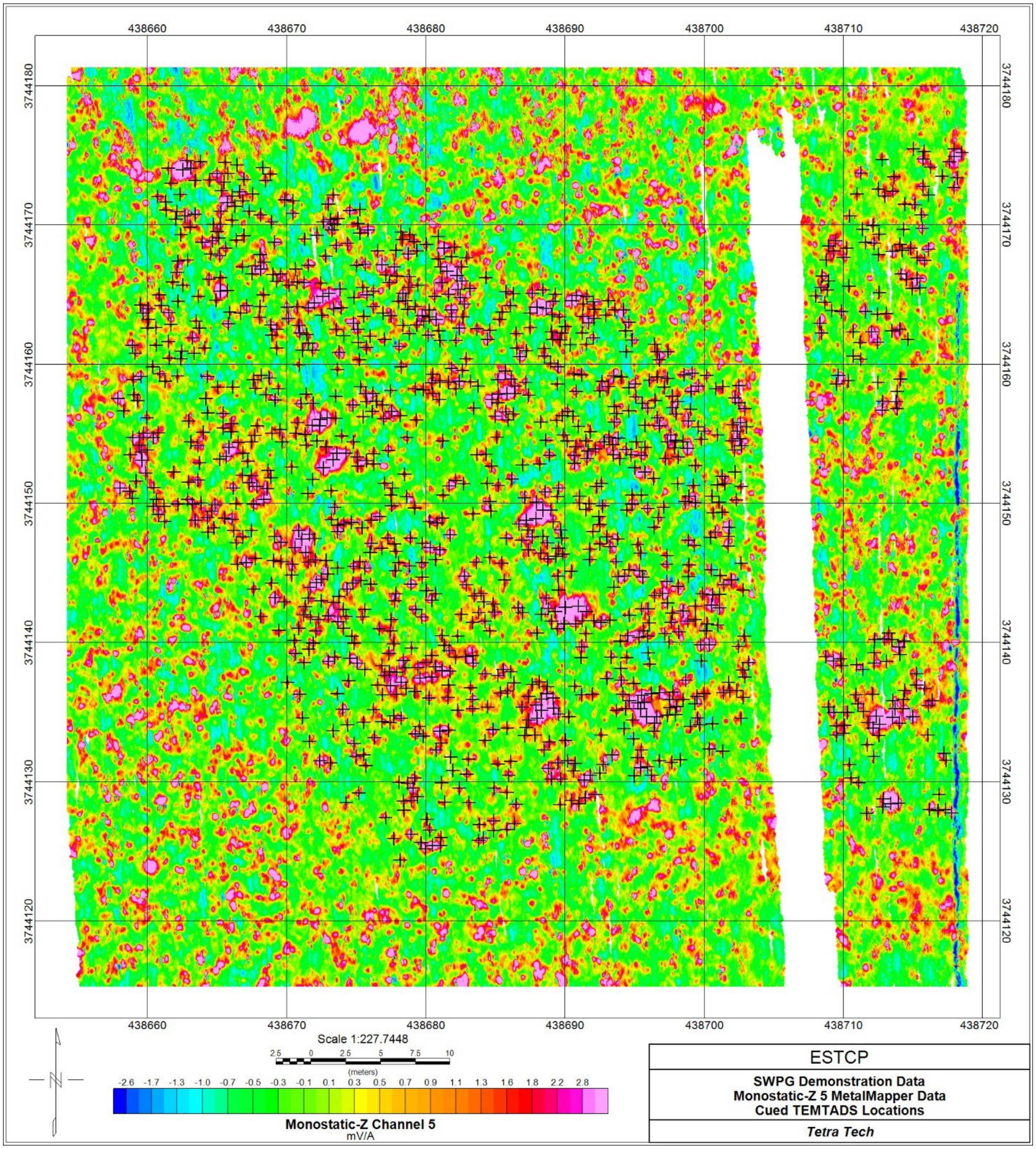


Figure 5-4. SWPG Dynamic Data and Cued Target Locations

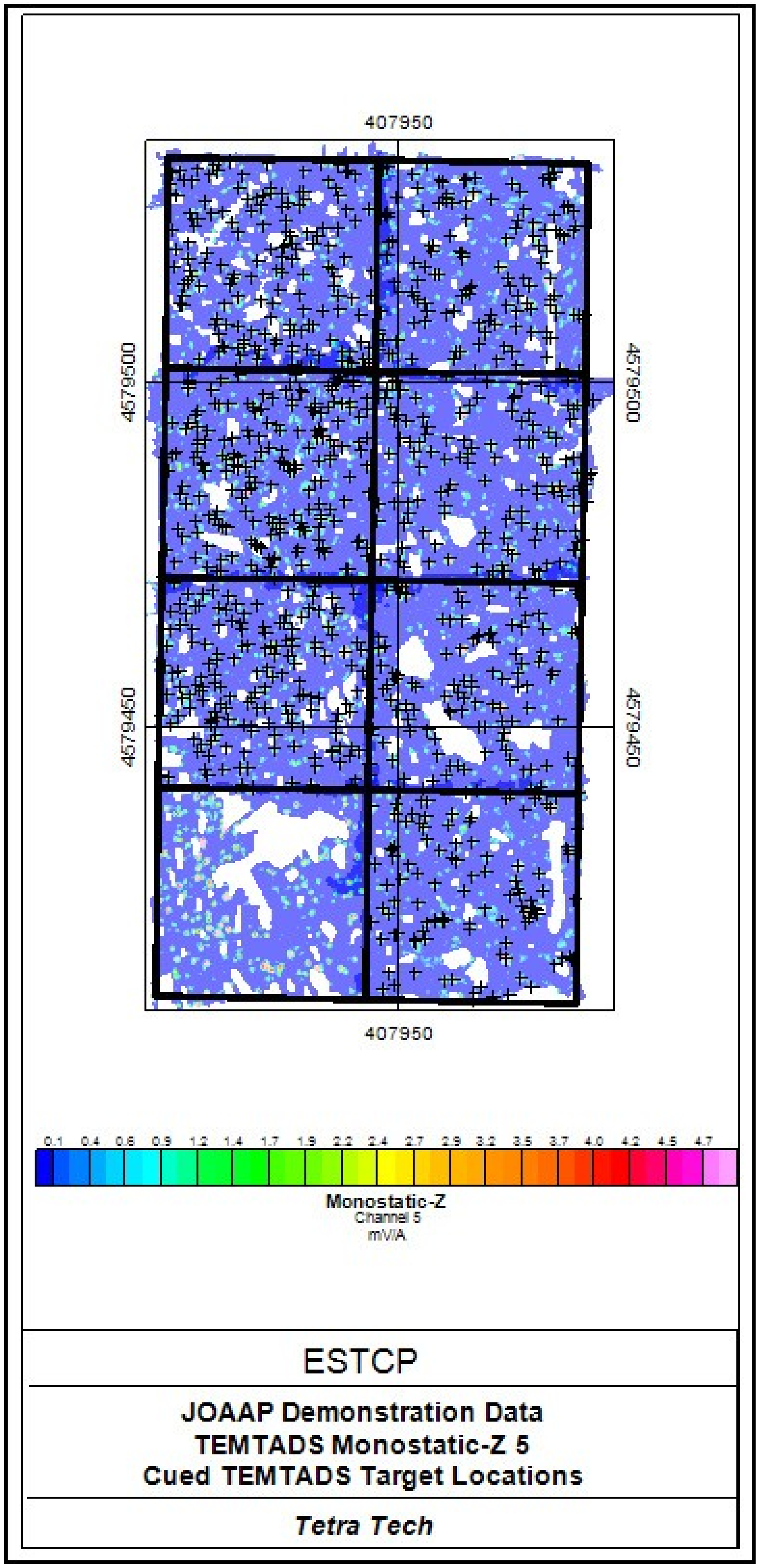


Figure 5-5. JOAAP Dynamic Data and Cued Target Locations

5.5.5 Data Summary

Data that did not meet the required performance metrics were thrown out and recollected. Raw data reside with the ESTCP office for other demonstrators to utilize with permission. All raw data were submitted, therefor, other demonstrators are responsible for performing QC of all data used for classification.

5.6 VALIDATION

At the conclusion of data collection activities and data inversion activities, all anomalies on the master dig list for the study area were excavated in accordance with industry guidance and Tetra Tech Standard Operating Procedures. Excavations were carried out with hand tools. Technicians dug slowly and meticulously to ensure that metallic objects can be surveyed before being disturbed. Each item encountered was identified, photographed, its depth measured, its location determined using cm-level global positioning system, and the item removed if possible. Tetra Tech's Senior UXO Supervisor determined the final status of all material potentially presenting an explosive hazard (MPPEH).

6.0 DATA ANALYSIS PLAN

The elements of the data analysis plan are presented in the following sections.

6.1 PREPROCESSING

Raw data were collected and stored as TEM files. Initial pre-processing of the raw .TEM files included conversion to a .csv file. Additional processing included correcting for background values, and converting the points from the geographic coordinate system used for collection to the local projection (for each receiver).

6.2 TARGET SELECTION FOR DETECTION

6.2.1 SWPG Target Selection

Targets for SWPG were selected by ASI and BTG. ASI utilized Geosoft Oasis Montaj UX-Analyze to invert the dynamic data so that dipole sources could be selected. BTG utilized UXOLab and selected targets based on amplitude and decay. Tetra Tech merged these two target lists by combining targets within 40cm of each other and producing a final list with unique target locations.

6.2.2 JOAAP Target Selection

Targets for JOAAP were selected using Geosoft Oasis Montaj UX-Analyze at a threshold of 4mV/A. This threshold was equivalent to 5 times the RMS noise observed at the site, and the modeled and measured response of the 40mm grenade at 6 inches. Dynamic data was collected over a partial T83 fuze at 4" bgs produced a minimum response of approximately 5mV/A. Based on the condition of the fuze, it was assumed that an intact fuze would likely be detected down to 6 inches with a target selection threshold of 4mV/A. No response curve or test stand data are available for this item to confirm this hypothesis; however, the majority of fuzes found at this site during previous investigations have been within 4 inches of the surface.

6.3 PARAMETER ESTIMATES

Tetra Tech utilized UX-Analyze to estimate parameters of cued data. At the time of the SWPG demonstration the algorithm solved for a single dipole source and multiple dipole sources. For JOAPP, the algorithm was changed to solve for 1, 2, and 3 dipole sources, rather than allowing for an open-ended multi-source solution. Outputs for the revised algorithm include polarizability plots similar to Figure 6-1. In field estimates relied on single sources solutions. These were used to determine the location to send the dig team to. Post analysis that took place after the completion of the field effort incorporated both single and multi-source solutions.

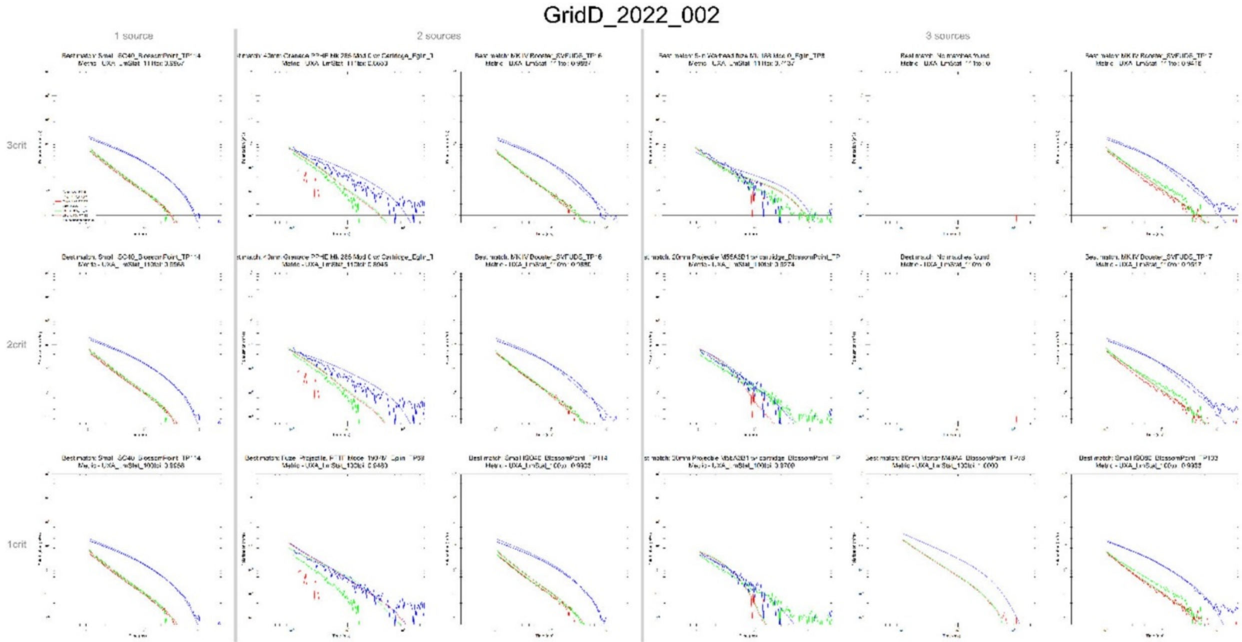


Figure 6-1. Example Plot Showing 1,2 and 3 Source Solutions

6.4 CLASSIFIER AND TRAINING

6.4.1 SWPG Classifier and Training

SWPG classification was primarily based on library matches and cluster analysis. The analyst matched the single source and multi-source solutions to a site-specific library and kept the best match for each target. Additionally, the targets were matched to each other to identify clusters of like anomalies, however, the cluster analysis did not result in any identified clusters that were not related to library matches. Due to the quantity of small fragmentation found at this site, the analyst chose to use a higher metric match for small items and a more conservative metric for large items.

In addition to the library match, the analyst visually reviewed all polarizability plots and manually added symmetric targets to the list. No training data was requested for SWPG.

6.4.2 JOAAP Classifier and Training

Two separate classifiers were developed for JOAAP by a single analyst. The first classifier followed the semi-automated UX-Analyze classification routine. The data were matched to a site-specific library and a cluster analysis was performed. The initial cluster analysis results were generally inconclusive. Most results formed a single large diffuse cluster in the presented parameter space. All were relatively weak, which was expected for a site where the majority of the sources are fuzes and frag. Visual analysis of the Beta decay curves focused on the central points for each cluster (“UXA_unique_signature”). Most points had very spherical signatures (all three Betas of comparable amplitude and decay rates). Results showed that there were two visually distinct classes of solutions – those with linear decays and those with curved or accelerating decays (when plotted in log space). A collection of these were identified as training digs. The two fuze items had distinctly curved decay rates in comparison to the frag items.

These were added to the site-specific library and the data were re-matched to the revised library. Solutions were classified and ranked according to their fit to the site-specific library using all three Beta decays. Targets which had a decision metric >0.85 were ranked as TOI. Targets with excessive positioning differences (array to solution >0.4m, array to flag >0.4m, flag to solution >0.6m) were eliminated. Remaining solutions within 0.2m were grouped together. Classified solutions from all grids were combined into a single list and reranked according to their category and decision metric. Targets which were subject to RCA1 were manually set to category 0 prior to reranking.

6.5 DATA PRODUCTS

In addition to the polarizability plots shown in Figure 6-1, additional data products were also produced to help the analyst defend the classification decisions. These included TX/RX Decay plots (Figure 6-2), Cluster Analysis plots (Figure 6-3), and Decision Plots that combine the polarizability curves with feature space analysis and other target meta-data (Figure 6-4).

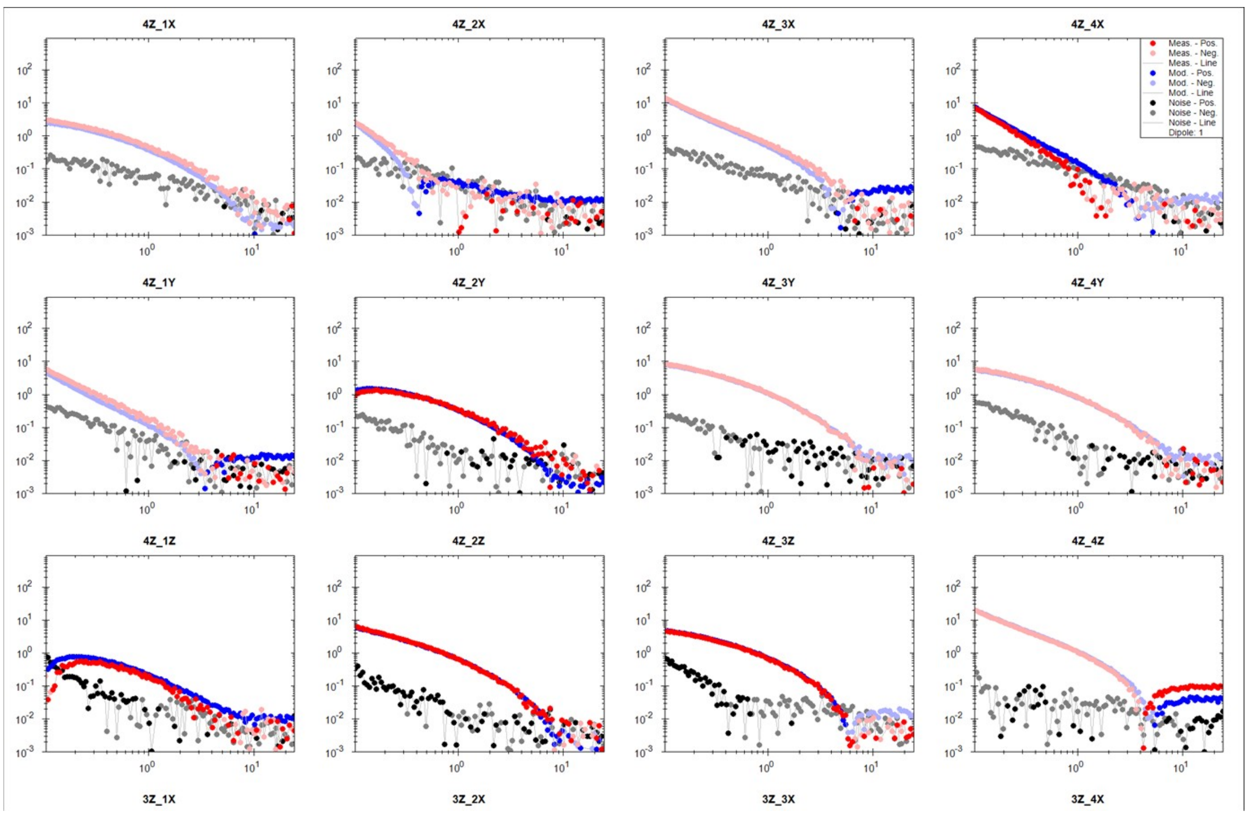


Figure 6-2. Partial TX/RX Decay Plot

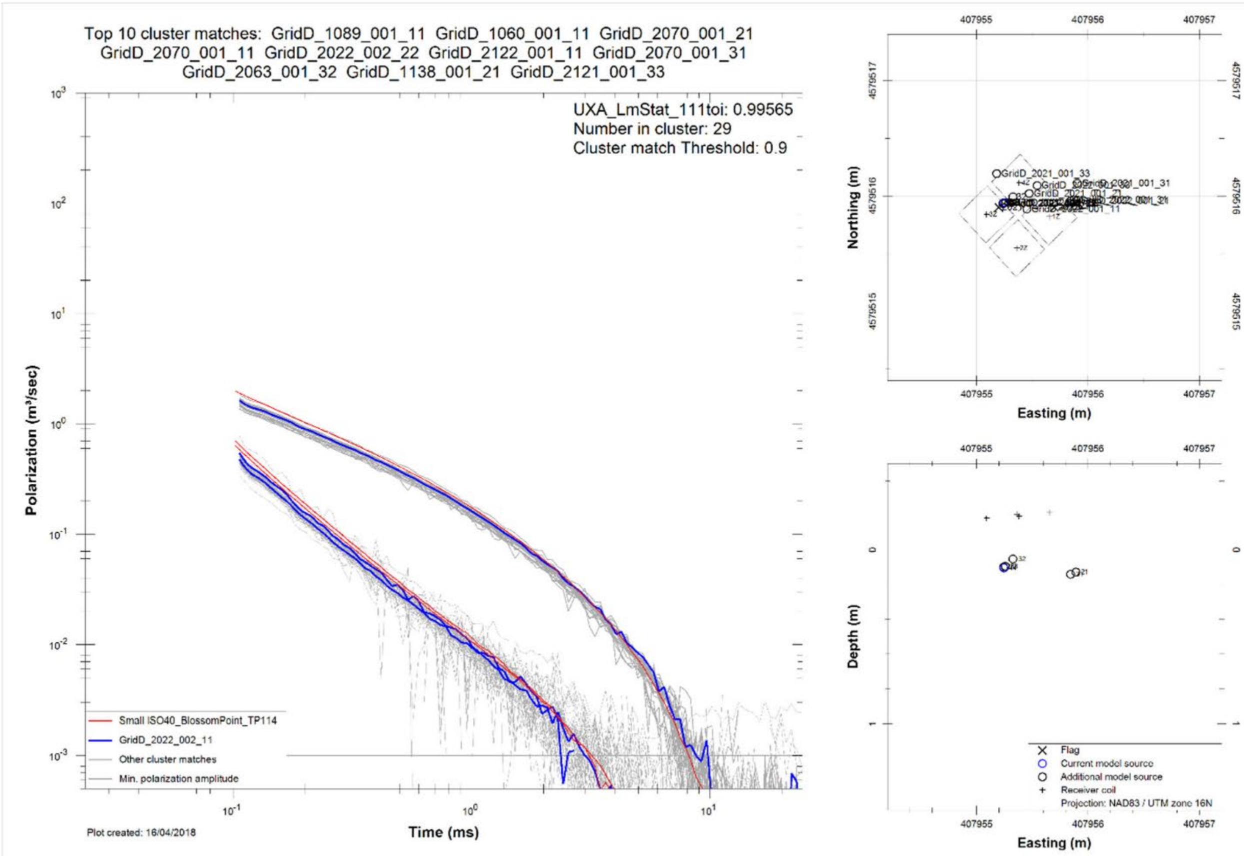


Figure 6-3. Cluster Analysis Plot

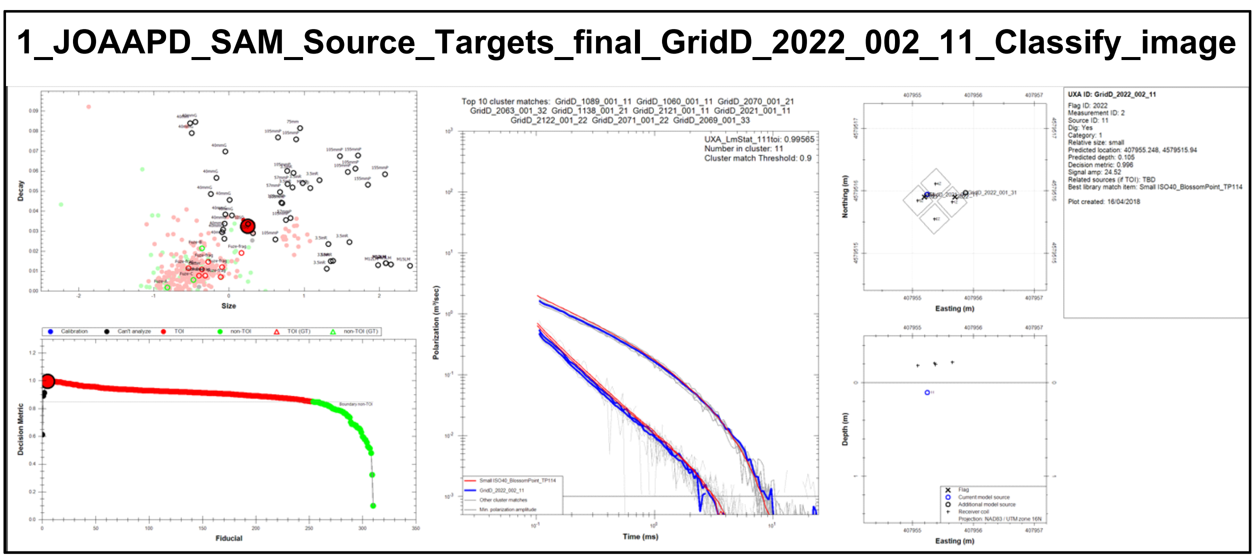


Figure 6-4. Example Decision Plot

7.0 PERFORMANCE ASSESSMENT

The success of the classifier is most easily represented by a Receiver Operating Characteristic (ROC) Curve. These curves are presented for both site in the sections below. Points along the curve represent every target on the classified and ranked target list. Vertical changes in the curve represent a TOI and horizontal changes represent a clutter item. A perfect classifier would result in a vertical line straight up from zero to the number of TOI followed by a perfectly horizontal line. A 45-degree line represents a poor performing classifier.

7.1 SWPG PERFORMANCE

The SWPG classification results are shown as a in Figure 7-1. No TOI were missed, and approximately 87% of the clutter was correctly classified and rejected. TOI that were identified late in the list were manually selected by the analyst. These were small and relatively deep TOI.

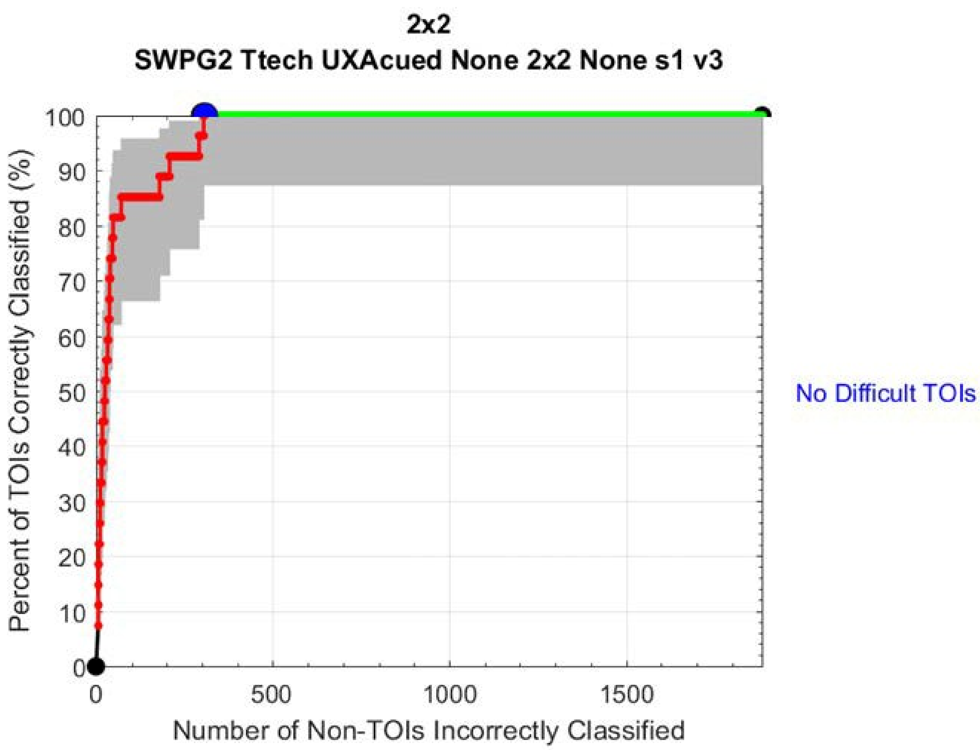


Figure 7-1. SWPG Analysis ROC Curve

7.2 JOAAP PERFORMANCE

The automated routines identified all TOI targets within the area, but with relatively poor performance in terms of discriminating between TOI and non-TOI (95% detection with 22% rejection). These results are shown in Figure 7-2. The manual intervention had better discrimination performance (88% detection with 65% rejection), but did not identify all of the TOI targets. Approximately 10% of the TOI were incorrectly classified. These are represented by the steps in the green section of the curve in Figure 7-3. Both of these results reflect the inherent difficulty of discriminating between small TOI (fuzes) and similarly sized frag.

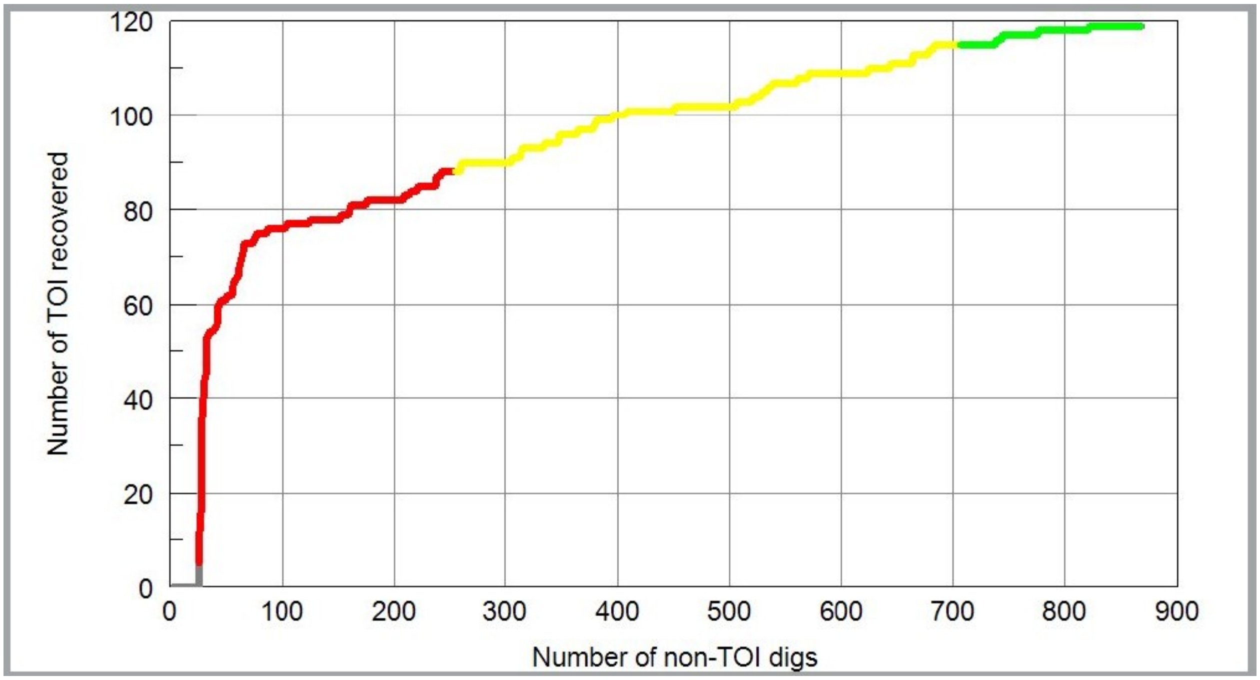


Figure 7-2. JOAAP Automated Classifier ROC Curve

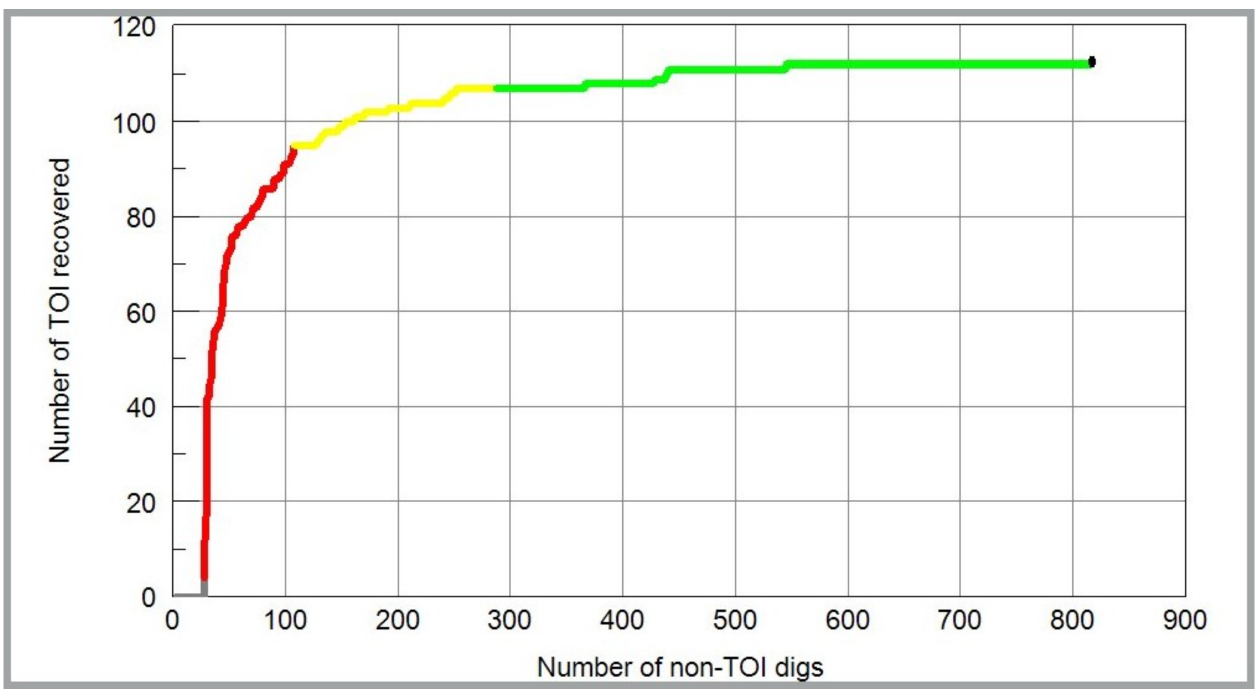


Figure 7-3. JOAAP Manual Classifier ROC Curve

8.0 COST ASSESSMENT

The cost assessment is based on the costs observed during both demonstrations as well as costs observed on projects worked since these demonstrations.

8.1 COST MODEL

Table 8-1. Cost Model

Cost Element	Data Tracked During Demonstration	Estimated Costs
Instrument cost	• All AGC sensors utilized during the demonstrations were furnished by the government at no cost. • The MetalMapper required repair before and after use. This system was already approximately 5 years old at the time and near the end of its lifespan. • GPS/RTS Costs • Telehandler is required for MetalMapper data collection. • Connex/site office costs. • Consumables.	• $1000 for equipment repair • $1500-$2000/month for GPS/RTS • $1500-$2000/month for telehandler • Connex $300-500/ month • $100-$200/day consumables during data collection.
Mobilization and demobilization	• For Data collection: 3 personnel • Equipment Shipping costs	• $3500-$6000 • $1000-$1500 shipping equipment each way
Site preparation	• Vegetation Clearance (extremely variable based on-site conditions) • Surface Clearance- 3-person team • Establish Site Control and installing boundaries/grids (depends on size of site)	• $0-$3500+/day for vegetation removal • $1000+/acre for average surface clearance. More if demo required. • $2000+ for establishing control and installing boundaries/grids
Instrument setup costs	• Unit Cost for IVS Installation and training • Minimum 3 personnel • Includes Site Specific training and Internal DOC • IVS Install and initial surveys typically take 4-8hrs to complete	• $6000-$9000
Survey costs	Unit: $ cost per acre Data requirements: • Hours per acre: 6+ depending on terrain • Personnel required: minimum 2 operators + Site Safety	• $3500+/acre dynamic • $3500+/175 cued targets
Detection data processing costs	Unit: $ cost per acre Data requirements: • Time required: Depends on target selection method and size of DU. Amplitude picking takes approximately ½ the time as source selection. QA time is dependent on anomaly density. • Personnel required: Data Processor/Project Geophysicist; QC Geophysicist; Data Manger	• $1400+/acre for amplitude-based target selection
Discrimination data processing	Unit: $ per 100 anomalies • Time required: depends on site specific TOI and remediation objectives. • Personnel required: Data Processor; Project Geophysicist; QC Geophysicist; Data Manger	• $1800+/100 anomalies

8.2 COST DRIVERS

Primary cost drivers for AGC are as follows:

- Terrain/vegetation: challenging terrain/vegetation reduces production rate for dynamic and cued data collection and increases number of cued measurements that must be recollected
- Anomaly Density: Higher densities increase cued data production in the field, but decrease the production of processing dynamic data
- Size of the site: the larger the site, the more cost effective AGC will be
- TOI: Small/difficult TOI decrease processing production rates and reduce the clutter rejection rate.
- Equipment reliability: stopping for repairs impacts cost and schedule
- Sensor Availability: Costs vary significantly depending on the source of the AGC sensor: GFE, contractor-owned, commercially rented
- QC Issues: The more QC issues, the higher the cost

8.3 COST BENEFIT

The cost benefit of AGC is directly related to the cost drivers listed in the previous section. In general, AGC is most cost effective when the TOI are very distinct relative to the expected clutter and the anomaly density is greater than approximately 400/acre. In this situation a 30-50% savings per anomaly can be achieved if AGC is utilized (with an ~80% clutter rejection rate) rather than intrusively investigating all targets. Sites with more difficult TOI will likely have lower clutter rejection rates and may have more QC issues. These factors may drive the cost of AGC to be more than intrusively investigating all targets, but the value of the higher quality data may motivate the use AGC regardless of the cost differential.

9.0 IMPLEMENTATION ISSUES

Due to the time that has lapsed since the field work and the preparation of the report, several factors related to implementing AGC technology have changed. The primary changes are as follows:

- ISO 17025 Department of Defense Advanced Geophysical Classification Program (DAGCAP) Accreditation is now required to perform AGC for the DoD.
  - The accreditation requires companies to have a thorough Quality Management System in place and requires all personnel who perform AGC to have completed an internal or external Demonstration of Capability (DOC) before performing work.
  - There are currently two companies that manage the DAGCAP Accreditation and provide annual audits of the accredited companies.
- There are currently 11 companies accredited to perform this work.
- TEMTADS is no longer available as government furnished equipment (GFE).
- The original MetalMappers have mostly been replaced with updated electronics equivalent to those of the new commercially available system, the MetalMapper2x2. This is also manufactured by Geometrics and the design is based on the TEMTADS. These may or may not be available as GFE.
- The MetalMapper2x2 can be purchased for approximately $130K and can be rented for approximately $750 per day. These prices make renting equipment cost prohibitive for long-term projects.
- The latest model of the MetalMapper2x2 still has hardware and software issues that are being working on by Geometrics. It is also currently missing the real-time field inversion capabilities, which will impact the number of targets that need to be recollected after the data have been processed.

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10.0 REFERENCES

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Fax Email	Role in Project
Dr. Herb Nelson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	571-372-6400 (V) herbert.h.nelson10.civ@mail.mil	Director SERDP & ESTCP Program Manager, MR
Mr. Andrew Schwartz	U.S. Army Engineering and Support Center, Huntsville (USAESCH) 4820 University Drive ATTN: CEHNC-EDC-G Huntsville, AL 35816	256-895-1604 (V) Andrew.b.schwartz@us.army.mil	USAESCH Representative
Ms. Elise Goggin	Tetra Tech 3801 Automation Way, Suite 100 Fort Collins, CO 80525	970-214-7108 (C) elise.goggin@tetratech.com	PI
Mr. Mark Dollar	Tetra Tech 3801 Automation Way, Suite 100 Fort Collins, CO 80525	970-206-4263 (V) 720-883-6051 (C)	Tetra Tech Project Manager
Dr. Len Pasion	Black Tusk Geophysics #401, 1755 West Broadway Vancouver, BC V6J 4S5 Canada	604-428-3380 (V) len.pasion@btgeophysics.com	Data Analyst
Mr. Kevin Kingdon	Black Tusk Geophysics #401, 1755 West Broadway Vancouver, BC V6J 4S5 Canada	604-428-3382 (V) kevin.kingdon@ btgeophysics.com	Data Analyst
Mr. Tom Furuya	AcornSI 1000 Centre Green Way Suite 200/232 Cary, NC 27513	919-539-8098 tfuruya@acrornsi.com	Data Analyst