TECHNICAL REPORT

Live Site Demonstration Munitions Response Program Site UXO 01 at Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, California

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Steve Stacy
ARCADIS-US, Inc.

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6. AUTHOR(S)
Stacy, Stephen M., PG

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Arcadis U.S., Inc.
3101 Wilson Blvd., Suite 550
Arlington, VA 22201

8. PERFORMING ORGANIZATION REPORT NUMBER
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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ESTCP
4800 Mark Center Drive, 17D08
Suite 17D08
Alexandria, VA 22350-3605

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14. ABSTRACT
This is one of a series of the Environmental Security Technology Certification Program (ESTCP) live site demonstrations of advanced geophysical classification (AGC) technologies for Munitions Response (MR). This demonstration was designed to evaluate the use of AGC methodology during a Remedial Investigation (RI) at Munitions Response Program Site UXO 01 at Marine Corps Air Ground Combat Center (MCAGCC) at Twentynine Palms, California. During this demonstration, Arcadis conducted dynamic surveys with the MetalMapper and cued data with the TEMTADS. The cued TEMTADS data was used to classify targets as either targets of interest (TOI) or non-TOI. Arcadis developed a unique approach to characterizing the nature and extent of munitions and explosives of concern (MEC) during the RI through the use of the Validate Library tool within UX-Analyze Advanced. This approach used cluster analysis to identify unique clusters of anomalies that were intrusively investigated to characterize the nature and extent of MEC when the number of digs was limited to approximately 40 targets.

15. SUBJECT TERMS
Advanced geophysical classification, Munitions Response, MetalMapper, TEMTADS

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List of Acronyms

A	amp
Acorn	Acorn Science and Innovation, Inc.
AGC	Advanced Geophysical Classification
Arcadis	Arcadis US, Inc.
β	Polarizability
bgs	below ground surface
BSI	Blind Seed Item
CA	California
cm	centimeter
CSV	Comma Space delimited text file
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DoD	Department of Defense
DTSC	Department of Toxic Substances Control
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
FS	Feasibility Study
ft	feet
GDB	Geosoft Database
GIS	Geographic Information System
GPS	Global Positioning System
GSV	Geophysical Systems Verification
HE	High Explosive
Hz	Hertz
IAW	In accordance with
IDL	Interactive Data Language
IMU	Inertial Measurement Unit
Inc	Incorporated
ISO	Industry Standard Object
IVS	Instrument Verification Strip
JV	Pika International Inc.-Malcolm Pirnie Joint Venture

LLC	Limited Liability Corporation
LSAP	Land Survey and Planning Consultants
m	meter
MCAGCC	Marine Corps Air Ground Combat Center
MD	Munitions Debris
MEC	Munitions and Explosives of Concern
MetalMapper	MetalMapper^{TM}
mm	millimeter
MMDR	MetalMapper Dipole Response
MMPP	MetalMapper Peak Picking
MMRP	Military Munitions Response Program
MP	Man Portable
MQO	Measurement Quality Objective
MR	Munitions Response
MRP	Munitions Response Program
MRS	Munitions Response Site
µs	microseconds
ms	milliseconds
mV	milliVolts
NA	Not Applicable
NAD83	North American Datum 1983
NC	No Contact
NRL	Naval Research Laboratory
OD	Other Debris
OSDA	Office of the Under Secretary of Defense for Acquisition
PLS	Professionally Licensed Surveyor
PM	Project Manager
POC	Point of Contact
QA	Quality Assurance
QC	Quality Control
RI	Remedial Investigation
ROC	Receiver Operating Characteristics
RTK	Real Time Kinematic

RWQCB	Regional Water Quality Control Board
Rx	Receiver
SARTS	Small Arms Remote Target System
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	Target of Interest
Tx	Transmitter
US	United States
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
Volt	Volt
VSP	Visual Sample Plan
WP	White Phosphorous

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1.0 INTRODUCTION

This is one of a series of the Environmental Security Technology Certification Program (ESTCP) live site demonstrations of advanced geophysical classification (AGC) technologies for Munitions Response (MR). This demonstration was designed to evaluate AGC methods during a remedial investigation (RI) to determine the nature and extent of munitions and explosives of concern (MEC) for the Munitions Response Program (MRP) Site Unexploded Ordnance (UXO) 01 at the Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, California (CA).

The project team consists of Arcadis United States (U.S.) Inc. (Arcadis), who led the demonstration as the principal investigator, and Acorn Science and Innovation, Inc. (Acorn), who provided dynamic data processing support. Advanced electromagnetic induction (EMI) sensors, sensor training, and additional support was provided by the Naval Research Laboratory (NRL) for the Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS) Man Portable (MP) 2x2 (TEMTADS) and by Geometrics, Inc. for the MetalMapper^{TM} (hereafter MetalMapper). The live site demonstration was carried out in parallel to the RI that the PIKA-Pirnie JV, Limited Liability Corporation (LLC)[1] (hereafter referred to as the JV) conducted at the MCAGCC Twentynine Palms for the U.S. Navy. **Appendix A** provides the points of contact for the Arcadis team, as well as personnel from the JV, MCAGCC Twentynine Palms, U.S. Navy, ESTCP Program Office, CA Department of Toxic Substances Control (DTSC), and the CA Regional Water Quality Control Board (RWQCB). Arcadis was responsible for managing and implementing all field and office tasks associated with the live site demonstration at MCAGCC Twentynine Palms, as well as providing field and office geophysical support.

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 MEC. These non-MEC items do not have an explosive hazard, yet their excavation represents most of DoD's MEC cleanup costs. Next generation 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 and 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.

Arcadis used three geophysical sensors during the RI and ESTCP demonstration at MCAGCC:

- Geonics' EM61-MK2,

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[1] The JV is comprised of protégé firm PIKA International, Incorporated (Inc.) and its mentor Arcadis U.S., Inc. (formerly Malcolm Pirnie, Inc.).

- Geometrics' MetalMapper, and
- NRL's TEMTADS.

Dynamic DGM surveys were conducted with the EM61-MK2 and MetalMapper, while cued data was collected with the TEMTADS.

1.2 OBJECTIVE OF THE DEMONSTRATION

Arcadis has previously demonstrated AGC approaches at another ESTCP live site demonstration (Arcadis, 2013). Arcadis' previous demonstration, as well as many other ESTCP MR live-site demonstrations, have focused on performing AGC in pilot studies to determine the effectiveness of the technology in minimizing the amount of intrusive investigations that are required during a removal action while still recovering all of the targets of interest (TOIs), which include MEC and industry standard objects (ISOs) used for blind seeding purposes. During the live site demonstration at MCAGCC Twentynine Palms, Arcadis evaluated the effectiveness of using AGC during an RI to characterize the nature and extent of MEC in a former mortar range when the number of digs permitted by the JV's contract with the Navy was approximately 40. During RIs that don't use AGC, 1,000 or more digs may be required to fully characterize the nature and extent of MEC.

The goals of the data collection included:

- Determine the nature and extent (both horizontal and vertical) of MEC in the MRS.
- Identify the locations of detectable metallic items in the subsurface of a representative portion of the site.
- Record data sufficient to be used for advanced geophysical analysis to classify each item such that a determination can be made as to whether it is a TOI or non-TOI.
- Evaluate the effectiveness of using MetalMapper and TEMTADS during an RI.
- Determine areas within MRP Site UXO 01 where MetalMapper and/or TEMTADS can/can't be used (*e.g.,* high geologic noise, anomaly density is too high for AGC technologies) to help develop remedial alternatives during the feasibility study (FS).
- Collect cost data for use in the FS.

The principal study questions for the demonstration at MCAGCC Twentynine Palms were:

- What is the nature (*i.e.*, types) and extent (both horizontal and vertical) of MEC within the MRS?
- To determine the nature and extent of MEC, which detected subsurface anomalies are TOIs (MEC and ISOs) that may represent a MEC hazard and which anomalies are non-TOI?

Arcadis performed the following tasks in order to achieve these objectives:

- Dynamic DGM data using the Geonics EM61-MK2 and MetalMapper;
- Static, cued target interrogation using the TEMTADS;
- Processing and quality control (QC) of dynamic and static geophysical data;
- Target reacquisition;

- Intrusive investigation of 42 targets;
- Demolition of identified MEC; and
- AGC of the static TEMTADS 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 scrap metal.

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 RI phase within the MMRP program does not require intrusive investigation of all anomalies on an MRS; however, there are often regulatory or other site-specific constraints that limit the amount of intrusive investigation that may occur within an area. Such constraints could include, but are not limited to:

- Funding availability;
- Requirements to minimize impacts to threatened and endangered species that can limit the timeframe during which field investigations may occur; and
- The evacuations of nearby residents or other persons (*e.g.*, personnel on an active military installation) must be limited.

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 (Office of the Under Secretary of Defense for Acquisition [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 DGM data acquisition using the MetalMapper and cued data collection with the TEMTADS. In addition, the EM61-MK2 was used for dynamic data collected as part of the RI. 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 Geonics EM61-MK2 is the industry standard geophysical instrument for collecting DGM data. It consists of a lower, 1.0-meter (m) x 0.5-m transmitter (Tx) /receiver (Rx) coil and an upper, 1.0-m x 0.5-m Rx coil (see **Figure 2-1**). The EM61-MK2 is a time-domain EMI sensor that transmits a current through an electrical loop, which induces a primary magnetic field that magnetizes buried (or surface) objects. Turning off the Tx current causes an abrupt change in the magnetic field, which in turn excites eddy currents within the metallic object. These eddy currents decay as a function of time and are recorded by four Rx time gates.

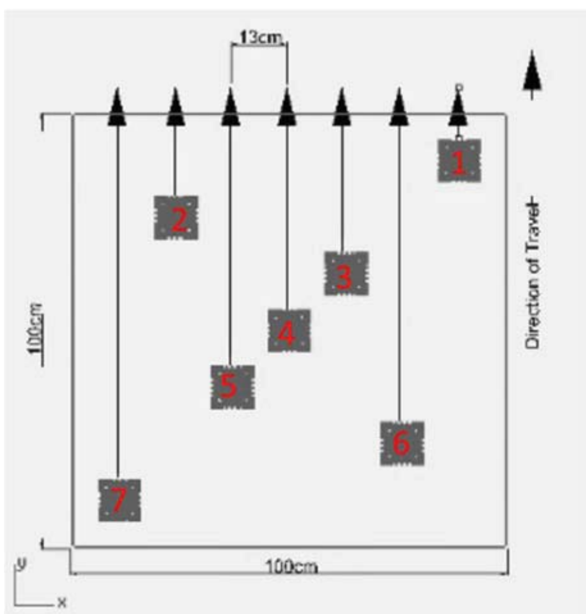
Figure 2-1: Geonics EM61-MK2

2.1.2 Geometrics MetalMapper

The Geometrics MetalMapper is the first commercially available advanced EMI sensor designed specifically for the purpose of AGC. It consists of three orthogonal 1-m^2 Tx coils and seven 10 centimeter (cm), 3-component, orthogonal Rx coils (see **Figures 2-2** and **2-3**). The system was developed in collaboration with ESTCP (Prouty, 2011)

Figure 2-2: Geometrics MetalMapper

Figure 2-3: Geometrics MetalMapper Rx Coil Geometry



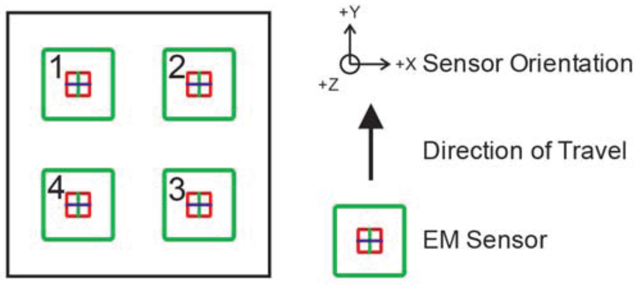
and was validated during the ESTCP live demonstration at the former Camp San Luis Obispo (Nelson et. al, 2010; Prouty, 2009) and other live-sites to be effective at correctly classifying TOI and non-TOI. Arcadis used the commercially available MetalMapper without making modifications to the system.

2.1.3 NRL's TEMTADS MP 2x2

The TEMTADS is a MP advanced EMI sensor array (see **Figure 2-4)** based on NRL's larger, 5x5 TEMTADS array. The TEMTADS MP 2x2 consists of four 35cm Tx coils with four 8 cm tri-axial Rx cubes (see **Figure 2-5**). 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 static survey mode at MCAGCC without making modifications to the system.

Figure 2-4: TEMTADS 2x2

Figure 2-5: TEMTADS Coil Geometry



2.2 TECHNOLOGY DEVELOPMENT

Arcadis performed a live site demonstration at MCAGCC Twentynine Palms using existing technologies and did not develop new instrument technologies. 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.*, Man Portable Vector) have also been successful in ESTCP funded AGC demonstrations; however, they were not used during this live site demonstration. Part of this investigation was to better determine the advantages of each of the EMI sensors operation during the RI. **Table 2-1** shows the qualitative advantages and limitations of each of the advanced EMI sensor technologies deployed at MCAGCC Twentynine Palms. 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	Sub-Category	EM61-MK2	MetalMapper	TEMTADS
General	**Portability**	Can be implemented in MP mode.	Requires the use of a skid steer 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 that 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.
Dynamic Surveys	**Dynamic Survey Efficiency**	Quickest set up time and has highest user familiarity of the dynamic survey modes. Requires setup of ropes for straight line positioning.	Lengthier set up time, has real time speed monitoring, and doesn't require ropes for straight-line profiling. Turning is time consuming and tow vehicle may digs deeply into loose, sandy soils.	Moderate set up time. Requires the use of ropes for straight line positioning, although the relatively small size and low weight of the instrument allow for easy, non-intrusive turning.
	Dynamic Sensor Deployment	Large standoff distance between sensor and ground surface decreases depth of detection, although large wheels allow for easy clearance of most ground obstructions.	Use of the skid ensures sensor is close to the ground surface and maintains a relatively constant height above the ground, although skid is easily snagged on brush.	Standoff distance between sensor and ground surface decreases depth of detection, but is less than the EM61-MK2. Large wheels allow for easy clearance of most ground obstructions.
	Dynamic AGC Potential	No ability	Yes	Yes
Static, Cued Interrogation	**Static AGC Potential**	No ability	Yes	Yes

Category	Sub-Category	EM61-MK2	MetalMapper	TEMTADS
	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.
	Reacquisition procedures	NA	Integrated	Requires the use of global positioning system (GPS) to place pin flags for cued survey data collection.

3.0 PERFORMANCE OBJECTIVES

Performance objectives or measurement quality objectives (MQOs) were developed and document in the project UFP-QAPP to measure the quality of the data collected during the ESTCP live site demonstration. MQOs were developed for both dynamic and cued data collection and interpretation and are outlined below.

3.1 DYNAMIC DATA PERFORMANCE OBJECTIVES

The performance objectives for the dynamic MetalMapper data collection and interpretation are summarized in **Table 3-1** and in the below sections.

3.1.1 Initial Instrument Function Test

A sensor function test measurement was performed once after assembly of the MetalMapper to confirm that all Tx and Rx components of the instrument sensor were operational.

3.1.1.1. Metric

The metrics for this objective was the instrument's response amplitude during a static test.

3.1.1.2. Data Requirements

The initial instrument sensor function test (*i.e.*, static test) of the instrument was used to evaluate the success of this objective.

3.1.1.3. Success Criteria

Success completion of this objective required the mean static spike minus mean static background within 20% of predicted response for all Tx/Rx combinations.

3.1.2 Objective: Spatial Coverage for Detection

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

3.1.2.1. Metric

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

3.1.2.2. Data Requirements

The geographic coordinates for the perimeter of the region to be surveyed and the survey tracks were used to evaluate the success of this objective.

3.1.2.3. Success Criteria

Success completion of this objective required 100% spatial coverage at the 0.5-m cross-track measurement spacing for all accessible areas.

Table 3-1: Dynamic MetalMapper Data Collection Objectives

Performance Objective	Metric	Data Required	Success Criteria
Initial Instrument Function Test	Instrument Response Amplitude	Sensor function test (*i.e.*, static test)	Response (mean static spike minus mean static background) within 20% of predicted response for all Tx/Rx combinations
Spatial coverage in detection survey	Extended footprint coverage	Mapped survey data	100% at ≤0.5-m cross-track measurement spacing
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	98% ≤ 0.25-m between successive measurements
Dynamic detection performance	Percent detected of seeded items	Location of seeded items and anomaly list	100% of blind seed items (BSIs) detected within 0.4-m halo
Instrument Verification Strip (IVS) Repeatability	Amplitude of anomaly and polarizability (β)	Twice-daily IVS survey data	Detection: Amplitude within 25%; Derived Position within 0.5-m Cued: Polarizabilities ±5%
Sensor Tx Current	Per Dataset	Mapped survey data	Peak Tx current between 4.2 and 5 amps (A)
Acceptable Sensor Response	Response Amplitude within valid range	Mapped survey Data	MetalMapper Responses must be approximately between 0 and 10^3 millivolt (mV)/A
Valid position data (1)	GPS status	Mapped survey data	GPS status indicates RTK fix
Valid position data (2)	Inertial Measurement Unit (IMU) Status	Mapped survey data	Valid orientation data

3.1.3 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.

3.1.3.1. Metric

The metric for this objective was the percentage of data points within acceptable along-line spacing.

3.1.3.2. Data Requirements

A mapped data file was used to evaluate the success of this objective.

3.1.3.3. Success Criteria

Successful completion of this objective requires 98% of the data to have an along-line measurement spacing of less than 0.25-m.

3.1.4 Objective: Dynamic Detection Performance

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

3.1.4.1. Metric

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

3.1.4.2. Data Requirements

Arcadis prepared an anomaly list and an Arcadis geographic information system (GIS) specialist not involved in the data collection or processing evaluated the target list to determine if BSIs were detected within performance metrics.

3.1.4.3. Success Criteria

Successful completion required that 100% of the seeded items were detected within a halo of 0.4-m.

3.1.5 Objective: IVS Repeatability

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

3.1.5.1. Metric

The metrics for this objective were the amplitude and down-track position of the maxima for the advanced systems in survey mode.

3.1.5.2. Data Requirements

The twice daily IVS survey data and the known IVS seed item locations were used to evaluate the success of this objective.

3.1.5.3. Success Criteria

The objective was considered met for the advanced systems in survey mode if the measured amplitudes for each object were within 25% of the mean and the down-track position of the anomaly peak was within 50 cm of the known location.

3.1.6 Objective: Sensor Tx Current

The instrument's detection depth capability was dependent on the instrument Tx functioning as intended.

3.1.6.1. Metric

This metric was evaluated for each dataset.

3.1.6.2. Data Requirements

The mapped survey data was used to evaluate the success of this objective.

3.1.6.3. Success Criteria

Successful completion required that the peak Tx current was between 4.2 and 5 A.

3.1.7 Objective: Acceptable Sensor Response

3.1.7.1. Metric

The metric for this objective was the response amplitude for each dataset.

3.1.7.2. Data Requirements

The mapped survey data was used to evaluate the success of this objective.

3.1.7.3. Success Criteria

Successful completion required that the instrument response be approximately between 0 and 10^3 mV/A.

3.1.8 Objective: Valid Position Data – GPS

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the GPS.

3.1.8.1. Metric

The GPS status flag and GPS quality metric were used to evaluate performance.

3.1.8.2. Data Requirements

The mapped survey data was used to evaluate the success of this objective.

3.1.8.3. Success Criteria

Successful completion required that the GPS status flag indicate RTK fix.

3.1.9 Objective: Valid Position Data – IMU

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the IMU.

3.1.9.1. Metric

The IMU status was used to evaluate the success of this objective.

3.1.9.2. Data Requirements

The mapped survey data was used to evaluate performance under this objective.

3.1.9.3. Success Criteria

Successful completion required a valid orientation on the data.

3.2 STATIC DATA PERFORMANCE OBJECTIVES

The performance objectives for the cued TEMTADS data collection and interpretation are summarized in **Table 3-2** and the below sections.

3.2.1 Objective: Initial Sensor Function Test

An initial function test measurement was performed once after assembly of TEMTADS to confirm that all Tx and Rx components of the instrument sensor were operational.

3.2.1.1. Metric

The metric for this objective was the instrument's response amplitude during the initial static test.

3.2.1.2. Data Requirements

The initial instrument sensor function test (*i.e.*, static test) was used to evaluate the success of this objective.

3.2.1.3. Success Criteria

Successful completion of this objective required the mean static spike minus mean static background within 20% of predicted response for all Tx/Rx combinations.

3.2.2 Objective: System Functionality

A systems functionality test was conducted to determine whether each Tx and Rx was functioning properly.

3.2.2.1. Metric

The metrics for this objective were the polarizabilities of each measurement.

3.2.2.2. Data Requirements

Arcadis collected five measurements over a small ISO80 target: 1 each directly under each of the Rx Coils and 1 directly under the center of the TEMTADS 2x2 sensor.

3.2.2.3. Success Criteria

The objective was considered to be met if the match metric was greater than or equal to 0.95 for each of the test locations.

Table 3-2: Cued TEMTADS Data Collection and Analysis Objectives

Performance Objective	Metric	Data Required	Success Criteria
Initial Sensor Function Test	Instrument Response Amplitude	Sensor function test (*i.e.*, static test)	Response (mean static spike minus mean static background) within 20% of predicted response for all Tx/Rx combinations
System Functionality	Polarizabilities	Five measurements over a small ISO80 target: 1 each directly under each of the Rx coils and 1 directly under center of array.	Match metric of ≥ 0.95 for each of the inverted polarizabilities
Initial IVS Background Measurement	Background Measurement Response	Five background measurements 1 centered at the flag and 1 offset 40cm in each cardinal direction	Amplitude Response curves were repeatable and indicated there are no metal objects at the background location.
Initial IVS derived β accuracy	β	Initial IVS test and surveyed seed item location	Library Match metric ≥ 0.95 for each set of inverted polarizabilities
Derived IVS target position accuracy	Fit location	Initial IVS test and surveyed seed item location	All IVS item fit locations within 0.25m of ground truth locations
Ongoing IVS Background Measurements	Decay amplitudes	Twice daily IVS background measurements	Amplitude response curves were repeatable and indicated there were no metal objects at the background location
Ongoing derived IVS polarizabilities precision	Fit metric	Twice daily IVS tests	Library Match to initial polarizabilities metric ≥ 0.95 for each set of three inverted polarizabilities
Ongoing derived target position precision (IVS)	Fit location	Twice daily IVS tests	All IVS item fit locations within 0.25m of the known seed item location
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument is

Performance Objective	Metric	Data Required	Success Criteria
			positioned within 40 cm of the BSI location
Initial measurement of production area background locations	Background Measurement Response	Five background measurements: 1 centered at the flag and 1 offset 40cm in each cardinal direction)	Repeatable amplitude response curves indicate there were no metal objects at the background location.
Ongoing production area background measurements	Background Measurement Response	Background data nominally collected every 2 hours	Repeatable amplitude response curves indicate there were no metal objects at the background location.
Ongoing instrument function tests	Sensor response	Static sensor function test with every background measurement	Response within 25% of predicted response for all Tx/Rx combinations
Tx current levels	Sensor response	Cued survey data	Peak Tx current between 5.5 and 9 A.
Sensor response within valid range	Sensor response	Cued survey data	Values must be within ± 4.2 Volts (V)
Confirm all background measurements are valid	Sensor response	Background measurements	All decay amplitudes qualitatively agree with initial measurement
Confirm all measurements have an applicable background	Background measurements	Cued survey data	Time Separation between background measurement and anomaly measurement < 2 hrs
Confirm GPS precision	GPS Position of control monument	Daily geodetic function tests	Control Monument positions repeatable to within 10 cm
Valid Position Data (1)	GPS status flag	Cued survey data	GPS status flag indicates RTK fix
Valid Position Data (2)	Orientation data	Cued survey data	Orientation data valid data input string checksum passes
Confirm inversion model supports classification (1 of 2)	Fit Coherence	Cued survey data	Derived model response must fit the observed data with a fit coherence ≥ 0.8
Confirm inversion model supports classification (2 of 2)	Fit location	Cued survey data	Fit location estimate of item ≤ 0.4m from center of sensor

Performance Objective	Metric	Data Required	Success Criteria
Confirm derived features match ground truth (1 of 2)	Fit Location	Prioritized classification dig list and dig results	100% of recovered (excluding can't analyze category) item positions ≤ 0.25-m from predicted position (x, y)
Confirm derived features match ground truth (2 of 2)	AGC results	Prioritized AGC dig list and dig results	100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size
Validation of TOI/non-TOI thresholds	AGC results	Prioritized AGC dig list and dig results	100% of predicted non-TOI intrusively investigated are non-TOI

3.2.3 Objective: Initial IVS Background Measurement

The reliability of the IVS data required background measurements that were free of metallic objects that could adversely affect background corrections. Initial measurements were taken at the IVS background location to demonstrate that no metallic objects that could interfere with background measurements were located near the background measurement location.

3.2.3.1. Metric

The metric for this objective was the IVS background measurement response.

3.2.3.2. Data Requirements

Arcadis collected five background measurements at the IVS background location: one centered at the proposed background location and one offset approximately 40 cm in each cardinal direction.

3.2.3.3. Success Criteria

The objective was considered to be met if amplitude response curves were repeatable and indicated there were no metal objects at the background location.

3.2.4 Objective: Initial IVS Derived Polarizability Accuracy

After the initial IVS dataset was collected, the derived polarizabilities were compared to the target library and static datasets to determine whether the polarizabilities allowed the IVS seed items to be accurately classified.

3.2.4.1. Metric

The metric for this performance objective were the initial polarizabilities for each of the IVS seed items.

3.2.4.2. Data Requirements

The data requirements included the initial IVS test results, the test item library, and the surveyed seed item location and depth.

3.2.4.3. Success Criteria

The objective was considered to be met if the Library Match metric was greater than or equal to 0.95 for each IVS seed item.

3.2.5 Objective: Derived IVS Target Position Accuracy

The reliability of the data also depended on the ability to accurately classify targets such that the location of TOI could be accurately determined.

3.2.5.1. Metric

The metric for this performance objective was the fit location of the classified target.

3.2.5.2. Data Requirements

The twice daily IVS survey data and the known IVS seed item locations were used to evaluate the success of this objective.

3.2.5.3. Success Criteria

The objective was considered met if all IVS item fit locations were within 0.25m of the surveyed IVS seed item locations.

3.2.6 Objective: Ongoing IVS Background Measurements

The reliability of the IVS data required background measurements that were free of metallic objects that could adversely affect background corrections. Initial measurements were taken at the IVS background location to demonstrate that no metallic objects that could interfere with background measurements were located near the background measurement location.

3.2.6.1. Metric

The metric for this objective was the IVS background measurement response.

3.2.6.2. Data Requirements

This performance objective required twice daily IVS background measurements.

3.2.6.3. Success Criteria

The objective was considered to be met if amplitude response curves were repeatable and indicated there were no metal objects at the background location.

3.2.7 Objective: Ongoing Derived IVS Polarizabilities Precision

The reliability of the data also depends on the proper functioning of the equipment and the ability to correctly classify targets on a consistent basis. This objective concerned the twice-daily confirmation of sensor system and AGC performance.

3.2.7.1. Metric

The metric for this objective was the fit metric

3.2.7.2. Data Requirements

Data required for this test were the twice daily IVS tests.

3.2.7.3. Success Criteria

The objective was considered to be met if the Library Match to initial polarizabilities metric was greater than or equal to 0.95 for each seed item.

3.2.8 Objective: Ongoing IVS Target Position Precision

The reliability of the data also depended on the proper functioning of the equipment and the ability to correctly locate targets through the AGC process on a consistent basis. This objective concerned the twice-daily confirmation of sensor system and AGC performance.

3.2.8.1. Metric

The metric for this objective was the fit location of the cued anomaly.

3.2.8.2. Data Requirements

Data required for this test were the twice daily IVS tests.

3.2.8.3. Success Criteria

The objective was considered to be met if all IVS item fit locations were within 0.25m of the surveyed seed item locations.

3.2.9 Objective: Cued interrogation of anomalies

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

3.2.9.1. Metric

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

3.2.9.2. Data Requirements

Arcadis prepared an anomaly list and an Arcadis GIS specialist not involved in the data collection or processing, evaluated the target list to determine if cued data was collected over the BSIs within performance metrics.

3.2.9.3. Success Criteria

The objective was considered to be met if the center of the instrument was positioned within 40 cm of the actual anomaly location for 100% of the BSIs.

3.2.10 Objective: Initial measurement of production area background Locations

The reliability of the production data requires background measurements that were free of metallic objects that could adversely affect background corrections. Initial measurements were taken at each background location to demonstrate that no metallic objects that could interfere with background measurements were located near the background measurement location.

3.2.10.1. Metric

The metric for this objective was the IVS background measurement response.

3.2.10.2. Data Requirements

Arcadis collected five background measurements at the IVS background location: one centered at the proposed background location and one offset approximately 40 cm in each cardinal direction.

3.2.10.3. Success Criteria

The objective was considered to be met if amplitude response curves were repeatable and indicated there were no metal objects at the background location.

3.2.11 Objective: Ongoing Production Area background measurements

The reliability of the production data required background measurements that were free of metallic objects that could adversely affect background corrections. Ongoing background measurements were required to minimize time-variable changes in background response.

3.2.11.1. Metric

The metric for this objective was the background measurement responses.

3.2.11.2. Data Requirements

Background measurements were used to evaluate the success of this objective.

3.2.11.3. Success Criteria

The objective was considered to be met if amplitude response curves were repeatable and indicated there were no metal objects at the background location.

3.2.12 Objective: Ongoing instrument function tests

The reliability of the production data required the TEMTADS, GPS, and IMU equipment to be functioning properly throughout the day. This test provided an in-field function test for the field team to determine whether there were instrument issues during data collection.

3.2.12.1. Metric

The metric for this objective was the sensor response.

3.2.12.2. Data Requirements

Static sensor function tests were collected whenever a background measurement was collected. The results of the sensor function tests were field verified (*i.e.*, no data is collected).

3.2.12.3. Success Criteria

The objective was considered to be met if the response was within 25% of predicted response for all Tx/Rx combinations.

3.2.13 Objective: Tx Current Levels

The instrument's detection depth capability and the ability to perform AGC were dependent on the instrument Tx functioning as intended.

3.2.13.1. Metric

This metric was evaluated for each cued target.

3.2.13.2. Data Requirements

The cued survey data was used to evaluate success of this objective.

3.2.13.3. Success Criteria

Successful completion required that the peak Tx current was between 5.5 and 9 A.

3.2.14 Objective: Sensor Response within Valid Range

The reliability of AGC results depended on the instrument functioning properly and the instrument response being within the expected range.

3.2.14.1. Metric

The metric for this objective was the Rx response.

3.2.14.2. Data Requirements

The cued survey data was used to evaluate success of this objective.

3.2.14.3. Success Criteria

The objective was considered to be met if the response values were within plus or minus 4.2V.

3.2.15 Objective: Confirm all background measurements are valid

The reliability of the production data required background measurements that were free of metallic objects that could adversely affect background corrections. Ongoing background measurements were required to minimize time-variable changes in background response.

3.2.15.1. Metric

The metric for this objective was the background measurement responses.

3.2.15.2. Data Requirements

The initial and ongoing cued background measurements were used to evaluate success of this objective.

3.2.15.3. Success Criteria

The objective was considered to be met if decay amplitudes qualitatively agreed with the initial background measurement.

3.2.16 Objective: Confirm all measurements have an applicable background

The reliability of the production data required that background measurements be collected to record time-variable effects in background response to minimize their impact to the AGC results.

3.2.16.1. Metric

The metric for this objective was the background measurement responses.

3.2.16.2. Data Requirements

Background measurements were nominally collected every 2 hours.

3.2.16.3. Success Criteria

The objective was considered to be met if the time separation between background measurement and anomaly measurement was less than 2 hrs.

3.2.17 Objective: Confirm GPS Precision

The reliability of the positions of the GPS required daily tests to document that the GPS was functioning properly.

3.2.17.1. Metric

The metric for this objective was the GPS position of the control monument.

3.2.17.2. Data Requirements

Daily geodetic function tests where the field crew measured the location of the known control monument at the beginning of each day.

3.2.17.3. Success Criteria

The objective was considered to be met if the control monument positions were repeatable to within 10 cm.

3.2.18 Objective: Valid Position Data – GPS

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the GPS.

3.2.18.1. Metric

The GPS status flag and GPS quality metric were used to evaluate performance.

3.2.18.2. Data Requirements

The GPS position of the cued survey data was used to evaluate success of this objective.

3.2.18.3. Success Criteria

Successful completion required that the GPS status flag indicate RTK fix.

3.2.19 Objective: Valid Position Data – IMU

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the IMU.

3.2.19.1. Metric

The IMU status was used to evaluate success of this objective.

3.2.19.2. Data Requirements

The mapped survey data was used to evaluate performance under this objective.

3.2.19.3. Success Criteria

Successful completion required a valid orientation on the data.

3.2.20 Objective: Confirm Inversion Model Supports AGC (1 of 2)

The reliability of the AGC results depended on collecting data that had a relatively high fit coherence to indicate the data could be modeled.

3.2.20.1. Metric

The metric for this objective was the fit coherence.

3.2.20.2. Data Requirements

The modeled and detected cued survey data were used to evaluate success of this objective.

3.2.20.3. Success Criteria

Successful completion required that the derived model response fit the observed data with a fit coherence of greater than or equal to 0.8.

3.2.21 Objective: Confirm Inversion Model Supports AGC (2 of 2)

The reliability of the AGC results depended on collecting data where the sensor was above the subsurface metallic object.

3.2.21.1. Metric

The metrics for this objective were the sensor array and fit location.

3.2.21.2. Data Requirements

The cued survey data and AGC fit locations were used to evaluate success of this objective.

3.2.21.3. Success Criteria

The objective was considered to be met if the fit location estimate of the subsurface item was less than or equal to 0.4m from center of sensor.

3.2.22 Objective: Confirm derived features match ground truth (1 of 2)

The reliability of the AGC results depended on reliably being able to classify targets at their respective location.

3.2.22.1. Metric

The metrics for this objective were the fit location and the known BSI location.

3.2.22.2. Data Requirements

The cued survey data were used to evaluate success of this objective.

3.2.22.3. Success Criteria

The objective was considered to be met if 100% of predicted seed positions were less than or equal to 0.25-m from known position (x, y, z).

3.2.23 Objective: Confirm derived features match ground truth (2 of 2)

The reliability of the AGC results depended on reliably being able to classify targets at their respective location.

3.2.23.1. Metric

The metric for this objective were the AGC and results.

3.2.23.2. Data Requirements

The prioritized AGC dig list and dig results were used to evaluate success of this objective.

3.2.23.3. Success Criteria

The objective was considered to be met if 100% of recovered object size estimates (excluding can’t analyze category) qualitatively matched the predicted size.

3.2.24 Objective: Validation of TOI/non-TOI thresholds

The data reliability depended on the AGC approach to correctly identify TOI and non-TOI.

3.2.24.1. Metric

The metric for this objective was the AGC results.

3.2.24.2. Data Requirements

The prioritized AGC dig list and dig results were used to evaluate success of this objective.

3.2.24.3. Success Criteria

The objective was considered to be met if 100% of predicted non-TOI intrusively investigated were non-TOI.

4.0 SITE DESCRIPTION

The site description material presented here is taken from the *Final Preliminary Assessment* (Battelle, 2003) and the *Final Site Inspection* (Trevet, 2011). More details can be obtained in those reports. MCAGCC Twentynine Palms is the largest Marine Corps training installation and is located in south-central San Bernardino County, CA. It covers approximately 935 square miles of remote desert (see **Figure 4-1**). The installation is used primarily for live fire combined arms exercises. The southern boundary of the base is adjacent to the city of Twentynine Palms. The northern boundary is located south of Interstate 40.

MRP Site UXO 01 is located in the central part of MCAGCC, northwest of Mainside, and northeast of Rainbow Canyon Road. The general location of MRP Site UXO 01 at MCAGCC is shown on **Figure 4-1,** while the location of the MRP Site UXO 01 demonstration site is shown on **Figure 4-2**.

4.1 SITE HISTORY

MRP Site UXO 01 is comprised of the "other than operational" portions of two former ranges, Range 106 (Small Arms Remote Target System [SARTS] and Range 107 (Mortar Range). The term "other than operational" describes areas that were formerly used for range-related purposes, but are no longer considered operational ranges due to their current use or encroachment by other uses. Range-related training and use no longer occurs at "other than operational" portions of former ranges. **Figure 4-2** shows the range boundary of the former Ranges 106 and 107, as well as the MRP Site UXO 01 MRS boundary. The MRS boundary includes the areas associated with former Ranges 106 and 107 that are designated as closed, as well as a buffer outside the ranges to the east and southwest of the former range boundaries.

The former Ranges 106/107 had a firing line near the southwestern portion of Ranges 106 and 107 (see **Figure 4-2**). Range 106 first appeared on installation maps in 1974 as the SARTS facility, which included 20 small arms "pop-up" targets with a maximum range of 1,000-m (Battelle, 2003). Range 107 was identified in installation documents as a mortar range where firing of 60-millimeter (mm) and 81-mm mortars occurred from the firing line to the northeast with target ranges varying from 500 to 3,500 m (Battelle, 2003).

4.2 SITE GEOLOGY

The MCAGCC is located in the Morongo Basin, which is characterized by unconsolidated deposits of eolian sand, alluvial sands and gravels, and lacustrine silts, clays, and evaporates in playa lakes. The near-surface deposits are underlain by older alluvial sand deposits with minor gravel layering. Bedrock in the basin near MCAGCC is 1,000 to 3,000 feet (ft) below ground surface (bgs) and is composed of crystalline igneous and metamorphic rocks. The ranges are located on Cajon soils (Jacobs Engineering Group, Inc., 1995) derived from alluvial fan materials and are primarily composed of light brownish-gray fine sand. These soils are well drained and have moderate to high permeability. The Cajon soils are located in a zone corresponding to the occurrence of the alluvial fan and lie between the adjacent lacustrine soils of the playa lake (*i.e.*, Mesquite Lake) and the outcropping quartz monzonite bedrock of the Bullion Mountains. The Bullion Mountains are the parent material of the alluvial fan/Cajon soils. The erosion of the quartz monzonite in the Bullion Mountains and deposition of ferromagnesian minerals on UXO 01 could lead to varying electromagnetic response due to geology.

Environmental investigations in the area have encountered fine to medium alluvial fan deposits with sand and some angular cobbles and gravel fragments. Occasional thin gravel lenses or clayey silt and sand lenses also have been encountered during environmental drilling operations. These alluvial deposits are interlaced with lacustrine clays that are the predominant lithology near the bottom, or downslope area, of the Mainside Area of MCAGCC.

4.3 MUNITIONS CONTAMINATION

The following munitions were identified as “allowable munitions” in the *Standing Operating Procedures for Range/Training Areas and Airspace* (MCAGCC Twentynine Palms, 1984) for use on Ranges 106 and 107:

- 60mm high explosive (HE),
- 60mm White Phosphorous (WP),
- 60mm Illumination,
- 81mm HE,
- 81-mm WP, and
- 81mm Illumination.

The term “allowable munitions” refers to the types of munitions that, based on the Standard Operating Procedures for the range, would have been used. Historical records for Ranges 106 and 107 do not provide information on the estimated total number or munitions used on these ranges or the amount of munitions or debris removed from the ranges during periodic operational range clearance activities. Although not specifically allowed on Ranges 106 and 107, munitions used on nearby ranges that may also have been used on these ranges include:

- Flares,
- Smoke grenades,
- Small caliber and sub-caliber munitions,
- 40mm grenades,
- AT-4, and
- 25mm projectiles.

In 2002, an investigation was conducted that extended into a portion MRP Site UXO 01. In April 2002, a MCAGCC explosive ordnance disposal unit performed a surface reconnaissance of the portions of the former Ranges 106 and 107 that were to be included as part of the investigation. During that exercise, the following MEC were identified:

- Three 60mm HE,

Figure 4-1: MCAGCC Twentynine Palms Location Map

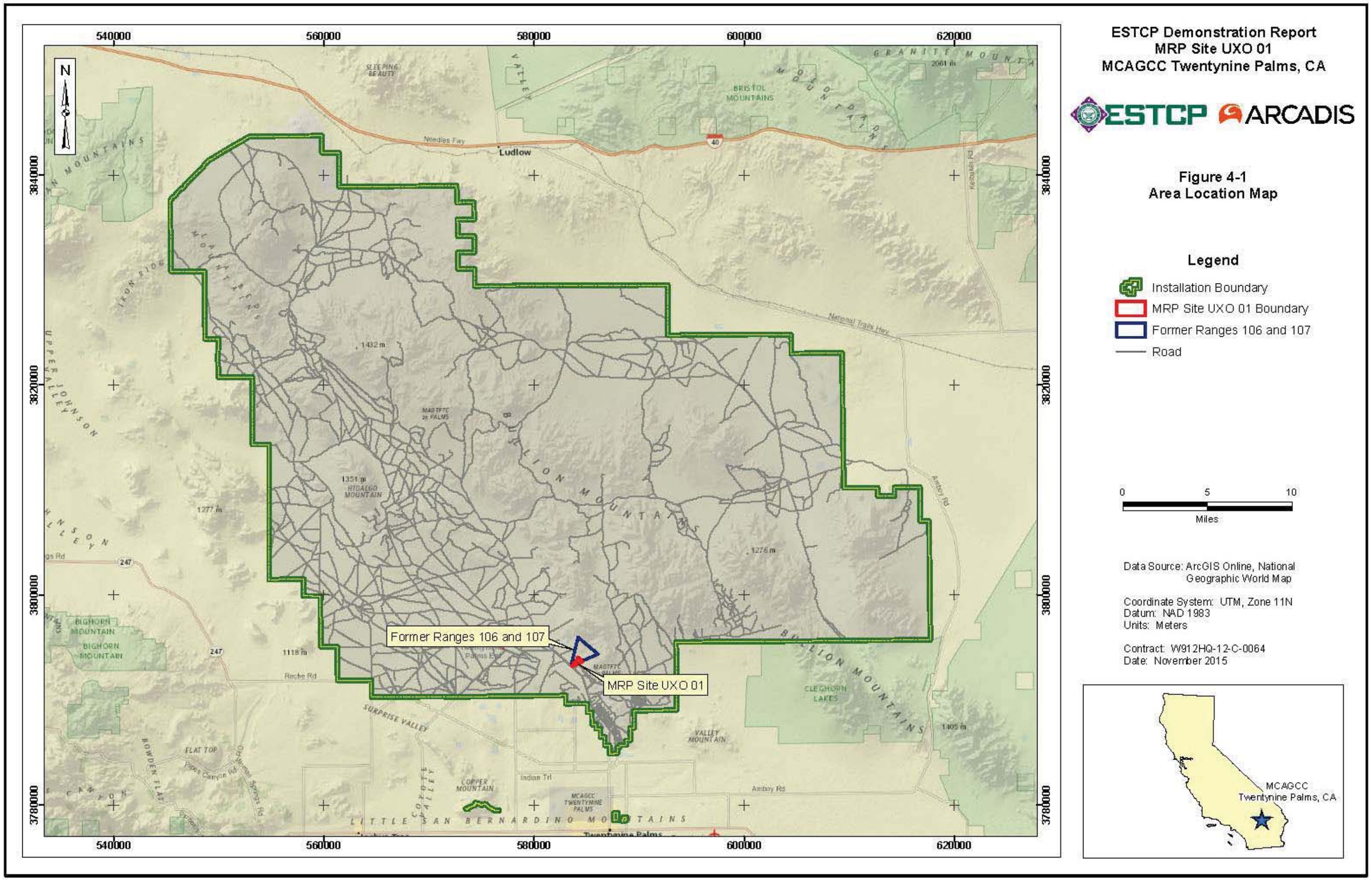
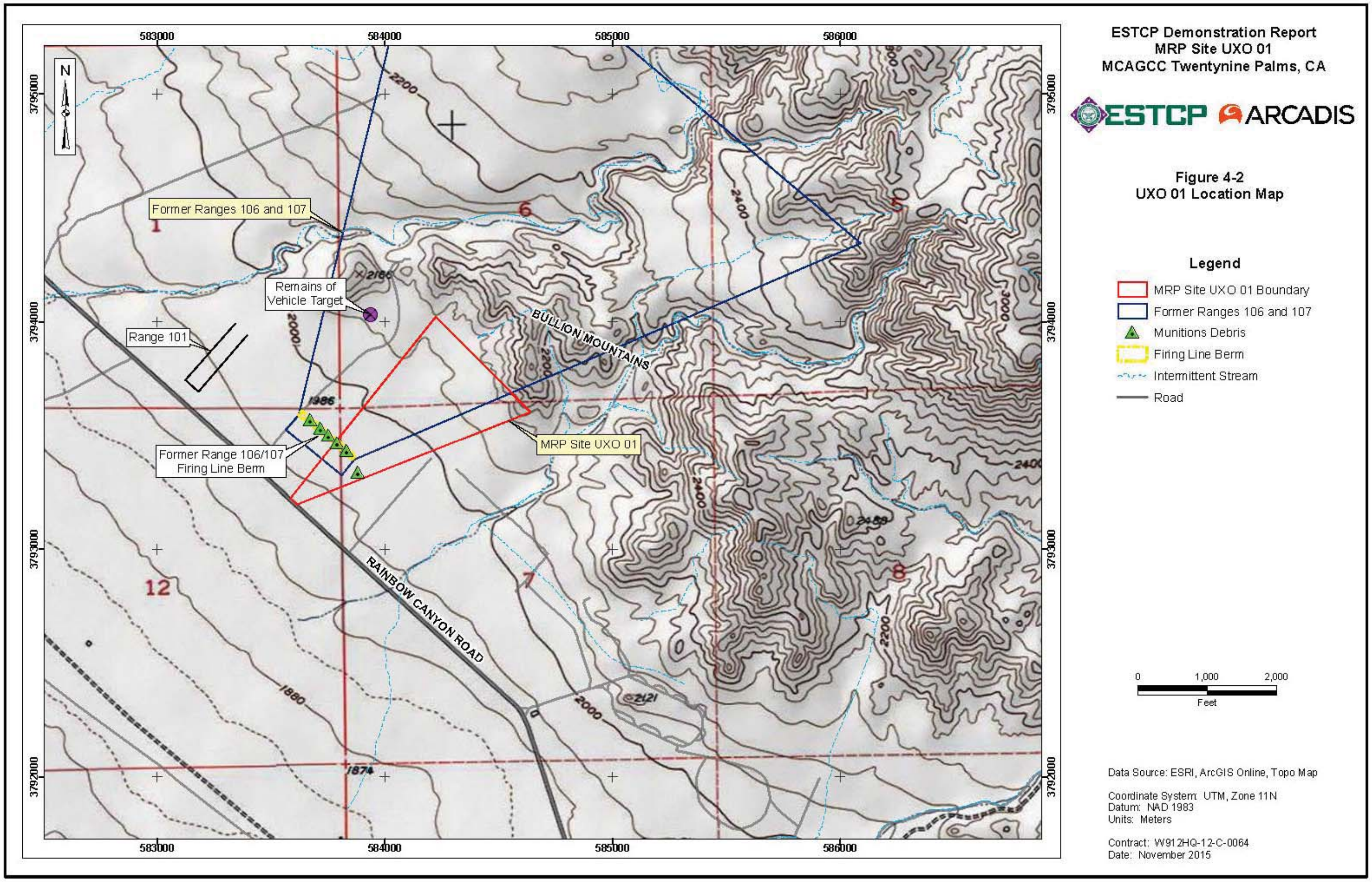


Figure 4-2: MRP Site UXO 01 Location Map



- Three 60mm WP,
- Five 60mm Illumination,
- Seven 81mm HE,
- Two 81mm WP, and
- Three 81mm Illumination.

In 2004, a geophysical survey was conducted of portions of the former Ranges 106 and 107 (see **Figure 4-2**). The After Action Report for the 2004 geophysical survey and intrusive investigation stated that 13 UXO were found; however, it did not state the location of specific UXO and the report only listed the following 11 UXO:

- Three 81mm Mortar HE,
- One 60mm Mortar HE,
- Four 60mm Mortar WP,
- Two 60mm Mortar Illumination, and
- One Signal Flare.

Figure 4-3 shows the dig results for the 2004 survey, including the locations of UXO, MD, emplaced items (*i.e.*, seed items), construction debris, and "No Finds." The highest anomaly and MEC densities are in the western portion of the removal action area. This area is roughly in the center of the MRP Site UXO 01 and approximately 500-m from the firing line, which corresponds to the minimum targeting range for Ranges 106 and 107 (Battelle, 2003). The UXO density within the western portion of the removal action area is approximately 2.5 UXO/acre.

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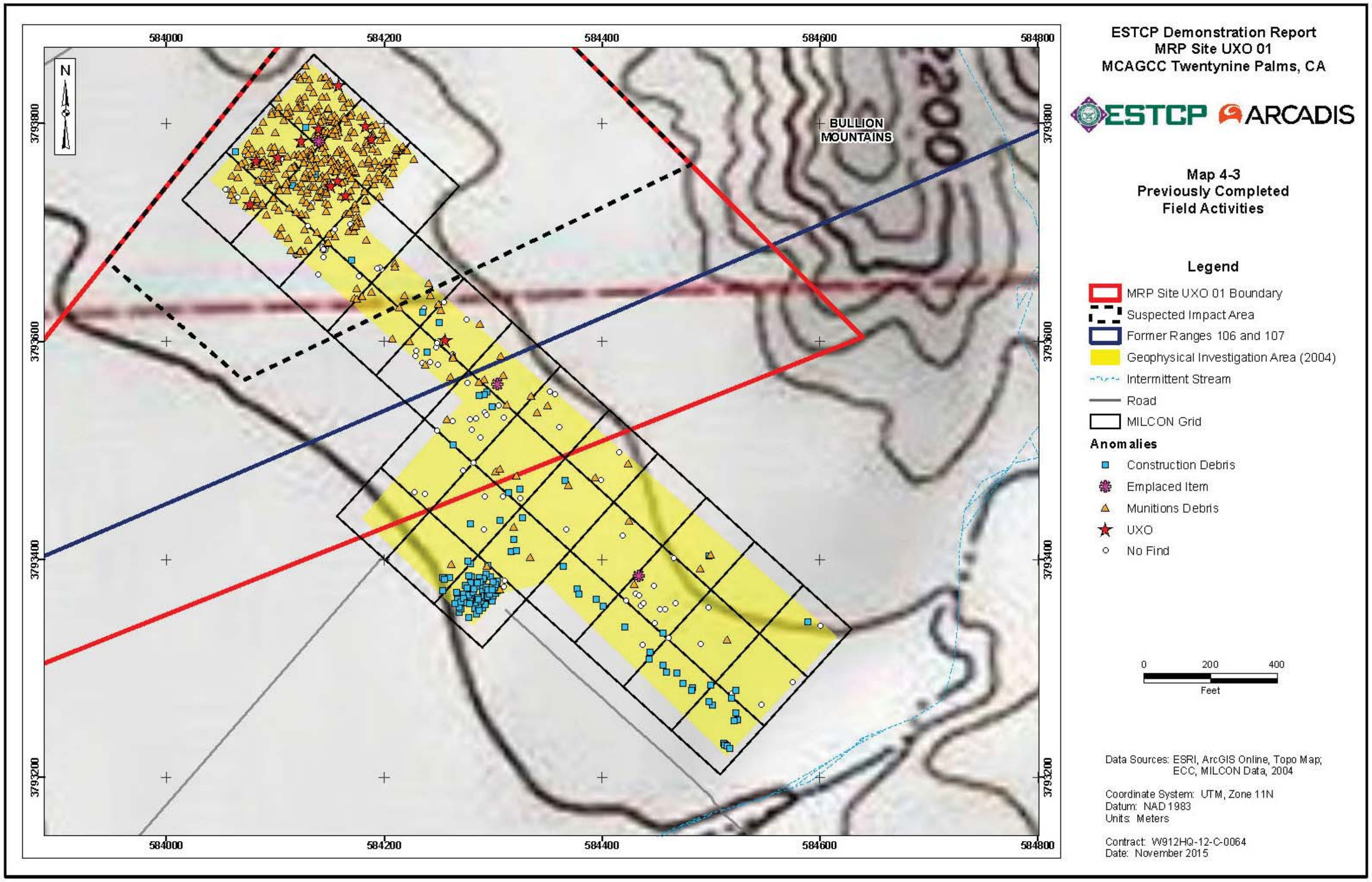
Figure 4-3: Previously Completed Field Activities



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5.0 TEST DESIGN

The objective of this project is to demonstrate a methodology for the use of AGC 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 was handled separately in this program.

Arcadis collected dynamic DGM and cued survey data for analysis and processed the individual dynamic and cued survey data sets using existing routines to extract target parameters. The cued parameters were passed to the AGC routines that were used to produce ranked anomaly lists that were used to identify a select group of anomalies that were intrusively investigated to characterize the nature and extent of MEC at MRP Site UXO 01.

The number of intrusive investigations that could be conducted at the site was limited; therefore, not all detected anomalies were intrusively investigated. Targets were selected for intrusive investigation for each cluster of TOI and non-TOI to characterize the nature of anomalies on the site. Additional targets were selected to characterize the extent of clusters with confirmed TOI. For each anomaly selected for intrusive investigation, the underlying target was uncovered, photographed, located with a cm-level GPS, and removed.

Arcadis submitted a ranked anomaly list for the TEMTADS data sets. All anomalies were categorized and placed on the dig list in the following order:

- *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 AGC 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.

Note that no training data was requested; therefore, there were no Category -1 anomalies on the dig list. Because all of the detected anomalies weren't intrusively investigated, the AGC results could not be scored by the Institute for Defense Analyses and a receiver operating characteristics (ROC) curve could not be obtained. The detection and correct AGC of TOI was used to determine the success of the AGC process.

The primary objective of the demonstration was to assess how well Arcadis was able to characterize the nature and extent of MEC at MRP Site UXO 01, while limiting the total number of intrusive investigations that were conducted. This approach was taken to determine if using AGC in conjunction with a limited number of intrusive investigations could successfully characterize the nature and extent of MEC during an RI.

All fieldwork was conducted in accordance with (IAW) the approved Demonstration Plan (Arcadis, 2014) and the Final RI Work Plan (JV, 2014), which included a Site Safety and Health Plan and the Explosives Safety Submission.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

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

- Site Preparation (see **Section 5.2**)
  - Civil Surveys (*e.g.* establishing first-order control monuments and grid corners surveys)
  - Surface Clearance
  - IVS Construction
  - Emplacing BSIs
- 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 and MetalMapper
  - Static, cued target data collection using the 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**)
  - Classifier (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 grid corners; a surface sweep to remove any MEC or metallic debris from the surface; construction of an IVS, and emplacement of 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 Site Inspection Report, Former Ranges 106 and 107 and Former Naval Auxiliary Air Station Rifle Range, MCAGCC, Twentynine Palms, CA* (Trevet, 2011). No additional historical records were reviewed prior to the start of the

Live Site Demonstration at the former ranges. See **Section 4.0** of this report for further details on the historical site information.

5.2.2 Civil Surveys

It is important that all survey data collection and validation activities were conducted on a common coordinate system. Land Survey and Planning Consultants (LSAP), a professionally licensed surveyor (PLS) in the state of CA, established three survey control monuments at the project site. The location information for the first-order control monuments that were used for this demonstration is included in **Appendix B**. LSAP also surveyed the following points at the demonstration site:

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

The locations of the control monuments and IVS seed items are shown on **Figure 5-1**. The IVS seed item locations are further discussed below.

5.2.3 Surface Clearance and Vegetation Removal

Prior to collecting DGM data, the JV's UXO technicians conducted a surface sweep across 75 30-m x 30-m grids as part of the RI. The surface sweep was conducted to remove metallic debris from the surface prior to the geophysical surveys; to determine the anomaly density and distribution across MRP Site UXO 01; and to determine which 38 of the 75 grids would be DGM surveyed and intrusively investigated. The Surface Sweep Technical Memorandum was submitted to the ESTCP program office to document the results of the surface sweep and the rationale for selection of DGM and dynamic MetalMapper survey grids.

The demonstration area is generally defined by moderately rolling desert topography with very little vegetation. The JV's UXO technicians performed vegetation removal as needed to allow the dynamic EM61-MK2 and MetalMapper surveys to be conducted. This included using hand tools to cut bushes down to the ground surface. The sparse grasses present at the site were not cut during the demonstration since they did not impede the dynamic geophysical surveys.

5.2.4 IVS Construction

Arcadis constructed 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 and **Figure 5-2** shows the IVS layout. The IVS was established IAW the Final Geophysical Systems Verification (GSV) Report (ESTCP, 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 seven small ISOs, and three 60mm mortars. **Table 5-1** presents the IVS seed item information, including the seed item number, description, Northing and Easting

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Figure 5-1: ESTCP Investigation Area and IVS Location

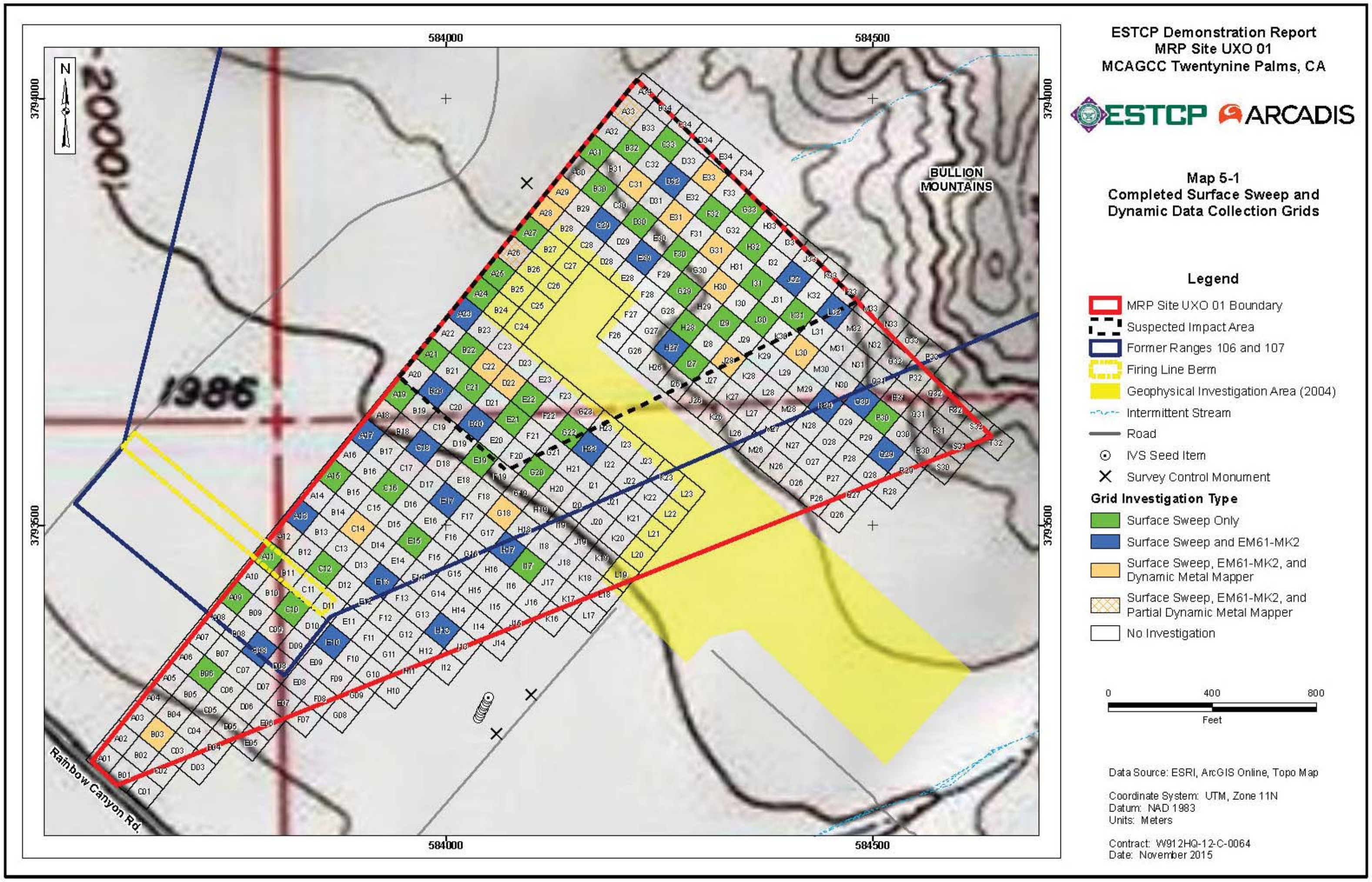

Figure 5-2: IVS Layout

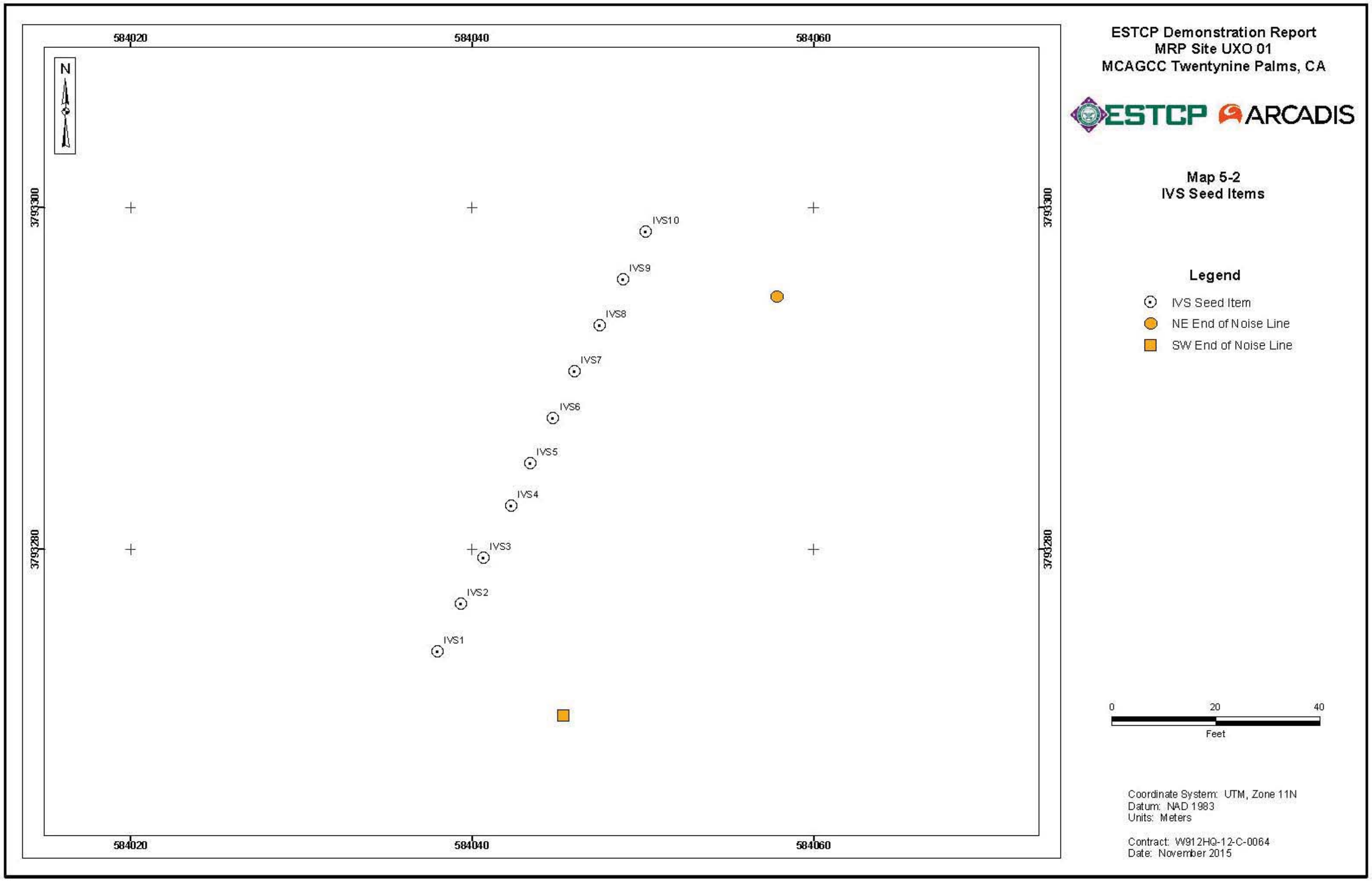

Table 5-1: IVS Construction Details

Item ID	Description	State Plane[1]		UTM[2]		Depth (cm)	Inclination	Orientation
		Northing (ft)	Easting (ft)	Northing (ft)	Easting (ft)			
T-001	Small ISO	1928775.38	7139537.75	3793274.02	584037.94	5	Vertical	NA
T-002	Small ISO	1928784.53	7139542.18	3793276.80	584039.32	10	Vertical	NA
T-003	Small ISO	1928793.46	7139546.50	3793279.51	584040.66	10	Horizontal	Along Track
T-004	Small ISO	1928803.51	7139551.68	3793282.55	584042.27	10	Horizontal	Across Track
T-005	60mm Practice Mortar	1928811.67	7139555.26	3793285.03	584043.39	17	Vertical	NA
T-006	Small ISO	1928820.44	7139559.62	3793287.69	584044.74	20	Vertical	NA
T-007	60mm Practice Mortar	1928829.40	7139563.66	3793290.41	584046.00	20	Horizontal	Across Track
T-008	Small ISO	1928838.25	7139568.28	3793293.09	584047.44	20	Vertical	NA
T-009	60mm Practice Mortar	1928847.20	7139572.71	3793295.80	584048.81	20	Horizontal	Along Track
T-010	Small ISO	1928856.43	7139577.08	3793298.60	584050.18	5	Vertical	NA

Notes:

1 – The State Plane coordinates are provided in CA State Plane Zone 5 North American Datum 1983 (NAD83) with units of U.S. survey ft.

2 – The Universal Transverse Mercator (UTM) coordinates are provided in UTM NAD83 Zone 11 North with units of m.

coordinates, depth to the center of mass, inclination and azimuth of each seed item. Coordinates are provided in both CA State Plane Zone V, NAD83 with units of U.S. survey ft and in UTM NAD83 with units of ms. The former was required for the RI being performed for the Navy and the latter was used for the ESTCP demonstration. Background measurements for the cued IVS surveys were conducted at the static test location that was approximately 15 ft away from the IVS line. The ends of the IVS lines, including the noise line, and the center of each of the IVS seed items were marked in the field with PVC pin flags. The seed items were distributed sufficiently apart (approximately 10 ft) to prevent overlapping signals. **Figure 5-2** shows the IVS layout. Each hole was dug following standard anomaly avoidance procedures.

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

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 cued TEMTADS data over known TOI at known depths, orientations, and locations to be used for algorithm training, as needed. The test pit and IVS data were used to establish dynamic detection thresholds for the dynamic surveys.

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 AGC performance with acceptable confidence bounds. To avoid this problem, Arcadis' UXO technicians emplaced BSIs in the demonstration area under the direction of the ESTCP Program Office.

The demonstration area was seeded with 75 QC and quality assurance (QA) seed items (*i.e.*, practice 81-mm mortars and small ISOs). All seeds were initially blind to Arcadis geophysicists involved in data collection, processing, analysis, and classification to allow for accurate evaluation of Arcadis' AGC performance. Arcadis seeded one small ISO80 within each of the DGM grids (38 total) to use as QC seeds and 37 QA seeds that were either a small ISO80 or an inert 80mm practice mortar. Arcadis' GIS specialist evaluated the QC and QA seeds for the ESTCP program office to determine that anomalies were detected with the anticipated response within the anticipated offset and that AGC results matched the seed item type.

If QC seed failures occurred, Arcadis was required to conduct a root-cause analysis. For this site, the BSI locations were only known to the Arcadis field personnel who emplaced the blind seed, the Arcadis GIS personnel, ESTCP Program Office, the LSAP surveyors, and the UXO technicians responsible for seeding the site. The locations and depth of these targets were unknown to the Arcadis Project Manager (PM) and geophysical team.

The exact (x, y) location, depth to the center of the target, and orientation were recorded for each emplaced BSI. The Arcadis UXO technicians and field personnel chose the BSI locations through coordination with the ESTCP Program Office.

5.3 SYSTEM SPECIFICATION

5.3.1 EM61-MK2

The Geonics EM61-MK2 EMI sensor was used to collect dynamic DGM data across 38 selected grids within the demonstration site, as well as for post-dig anomaly resolution to ensure that the source(s) of anomalies were recovered during intrusive investigation. **Figure 5-1** shows the location of the grids in which EM61-MK2 data was collected. 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 selected grids within the demonstration area totaling 3.44 acres. **Figure 5-1** shows the grids in which dynamic MetalMapper data was collected. Static data was not collected with the MetalMapper during this demonstration with the exception of the static background and spike tests to verify the instrument was functioning properly and static tests over test pit and IVS items.

Table 5-2 lists the data acquisition parameters that were used to collect data. 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. This data collection mode was only used for static testing and test pit measurements. The MetalMapper was not used to collect cued data within the production area due to safety concerns associated with the skid steer digging into the loose sands when sharp turns were made. This issue is further discussed in **Chapter 9** of this report.

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 in 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 (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 and dynamic data is not. Instead, dynamic data is leveled (*i.e.*, background and instrument drift are removed) in Geosoft Oasis Montaj©. Data processing of the dynamic data also included summing the z component of the inner five Rx coils for channels 2 (136 µs) through 9 (656 µs). All MetalMapper data was positioned with an RTK DGPS and an IMU that updated at a frequency of 1 Hz.

Table 5-2: MetalMapper Data Acquisition Parameters

Mode	Tx Coils	Window Width	Hold Off Time (µs)	Block Period (s)	Number of Repeats	Block Length	Number of Stacks	Decay Time (µs)	No. Gates	Repeat
Dynamic	Z Only	20%	100	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	Acquisition Mode	Gate Width	Block Period (s)	Hold Off Time (µs)	Number of Stacks	Stack Period (s)	Number of Repeats	Decay Time (ms)	Number of Gates
Static	Decimated	5%	0.90	50	18	0.9	9	25	121

Note:
ms - milliseconds

5.3.3 TEMTADS MP 2x2

Arcadis collected static TEMTADS data at 667 of the detected anomalies. Arcadis imported these files into Geosoft Oasis Montaj© for processing using the UX-Analyze Advanced module and performed QC, background corrections, and AGC for each of the anomalies.

Table 5-3 lists the data acquisition parameters that were used to collect cued TEMTADS data. 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. TEMTADS dynamic mode was not utilized at MRP Site UXO 01 as the sensor was only used to collect cued data.

5.4 CALIBRATION ACTIVITIES

Five types of calibration activities were performed at MRP Site UXO 01:

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 each geophysical sensor 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 either on a plastic jig placed on top of the bottom coil for the EM61-MK2 or underneath the coils for the advanced EMI sensors.

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 EM61-MK2 static data collected during this live site demonstration met these performance metrics. Performance metrics for the MetalMapper and TEMTADS are discussed in **Chapters 3** and **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** of this report. **Chapter 7** discusses the results of the static testing.

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. **Chapter 7** of this report discusses whether the performance metrics were met.

5.4.3 Background Measurements

Daily calibration efforts for the TEMTADS 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 dynamic EM61-MK2 and MetalMapper 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 (see **Appendix C**). **Chapter 7** of this report discusses whether the performance metrics were met.

5.4.4 Test Pit Calibration Measurements

Test pit measurements of TOIs were made with the MetalMapper and TEMTADS sensors. **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. Test pit data was collected in static mode for the TEMTADS and in both static and dynamic mode for the MetalMapper to enable the test pit data to be added to site-specific AGC libraries. **Appendix C** contains the test pit measurements for the MetalMapper and TEMTADS.

Table 5-4: Test Pit Calibration Data Measurement Summary

Test Pit Item	Approximate Depths (cm)	Dynamic MetalMapper Orientations	Cued TEMTADS Orientations
Small ISO	12.7	Horizontal, Across Track	Horizontal, Across Track, Vertical Up and Down
81-mm Mortar (M821/M889A1)	12.7	Horizontal, Across Track	Horizontal, Across Track, Vertical Up and Down
81mm Practice Mortar (M69)	12.7	Horizontal, Across Track	Horizontal, Across Track, Vertical Up and Down
60mm Mortar (M722)	12.7	Horizontal, Across Track	Horizontal, Across Track, Vertical Up and Down

Test Pit Item	Approximate Depths (cm)	Dynamic MetalMapper Orientations	Cued TEMTADS Orientations
60mm Mortar (M49A3)	12.7	Horizontal, Across Track	Horizontal, Across Track, Vertical Up and Down
60mm Practice Mortars (M69) – Full round; full, rusty round; and round with no tail boom	12.7	Horizontal, Across Track	Horizontal, Across Track, Vertical Up and Down

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. No data was collected during these instrument function tests.

5.5 DATA COLLECTION

5.5.1 Dynamic Data Collection

5.5.1.1. Scale

Arcadis performed the following amounts of dynamic surveys:

- <u>EM61-MK2</u>: 8.72 acres; and
- <u>MetalMapper on 0.5-m line spacing</u>: 3.44 acres.

Figure 5-1 shows the grids in which dynamic EM61-MK2 and MetalMapper data was collected. Arcadis collected dynamic DGM data within 38 100-ft x 100-ft grids (8.72 acres) across the 79-acre site using the commercially available EM61-MK2 positioned with a RTK DGPS. The EM61-MK2 data was collected as a requirement of the JV's RI at UXO 01 and was not required by the ESTCP demonstration; therefore, additional performance metrics are not discussed within this report.

Arcadis operated the MetalMapper in dynamic detection mode within 14 complete and 2 partial random, 100-ft x 100-ft grids (3.44 acres) across the site. Due to limitations on how long field activities could be conducted on site, the slower than expected production rates (see **Chapter 9** for details), and the terrain, MetalMapper data was not collected in all of the EM61-MK2 grids as was originally planned. Instead, dynamic MetalMapper data was collected within as many grids as possible spread around the site to provide enough spatial distribution to characterize the nature and extent of MEC within the site. See **Appendix D** for maps of the data, which are contained in **Appendix C**.

5.5.1.2. Sample Density

Two metrics defined the sample density during this demonstration: the across—track line spacing and the down-line data spacing. Arcadis collected dynamic MetalMapper data with an across-track line spacing of 0.5-m to ensure there was overlap of the Tx coil between adjacent lines. Down-line data was collected at a frequency of 10 Hz. The actual down-line data density varied as a function of the speed at which the instrument was moved across the site. The down-line data density results are shown on maps in **Appendix D** and are further discussed in **Chapter 7** of this report.

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 MetalMapper at the beginning and end of each day to ensure repeatability of response.
- Twice daily instrument function checks were performed at the IVS to verify the dynamic response and positioning repeatability of the complete geophysical system.

The results of quality checks and performance metrics are discussed in **Chapter 7** of this report.

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 file types as follows:

- **MetalMapper**
  - IVS: DIVSXXXXX.tem, where
    - XXXXX = Sequential number
  - QC (*i.e.*, static background and static spike): QCXXXXX.tem, where
    - XXXXX = Sequential number
  - Background: BKGXXXXX.tem, where
    - XXXXX = Sequential number
  - Dynamic production data: DYNXXXXX.tem, where
    - XXXXX = Sequential number

MetalMapper data were 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. Geophysical data and daily DGM data reports are contained in **Appendix C** and have been organized into raw and processed data folders. Each of the datasets is contained in a single .gdb file.

5.5.2 Static, Cued Survey Data Collection

5.5.2.1. Scale

Arcadis collected cued TEMTADS data at a total of 667 targets, which represented 46% of all 1,463 targets detected from the dynamic EM61-MK2 and MetalMapper surveys.

Figure 5-3 shows the targets at which cued data was collected. As further discussed in C**hapter 6** of this report, the final cued anomaly list consisted of targets from three target lists:

- EM61-MK2 Target List: 484 targets;
- MetalMapper Peak Picking (MMPP) Target List: 431 targets; and
- MetalMapper Dipole Response (MMDR) Target List: 548 targets.

Cued data was collected at all of the MMDR targets and at all of the EM61-MK2 and MMPP targets within grids A26, A28, and A29 as a verification of the MMDR Target List as outlined in the Anomaly Selection Technical Memorandum that was submitted to the ESTCP program office.

5.5.2.2. Sample Density

Static data was collected at an individual point with fixed Tx and Rx 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 AGC 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 AGC 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:

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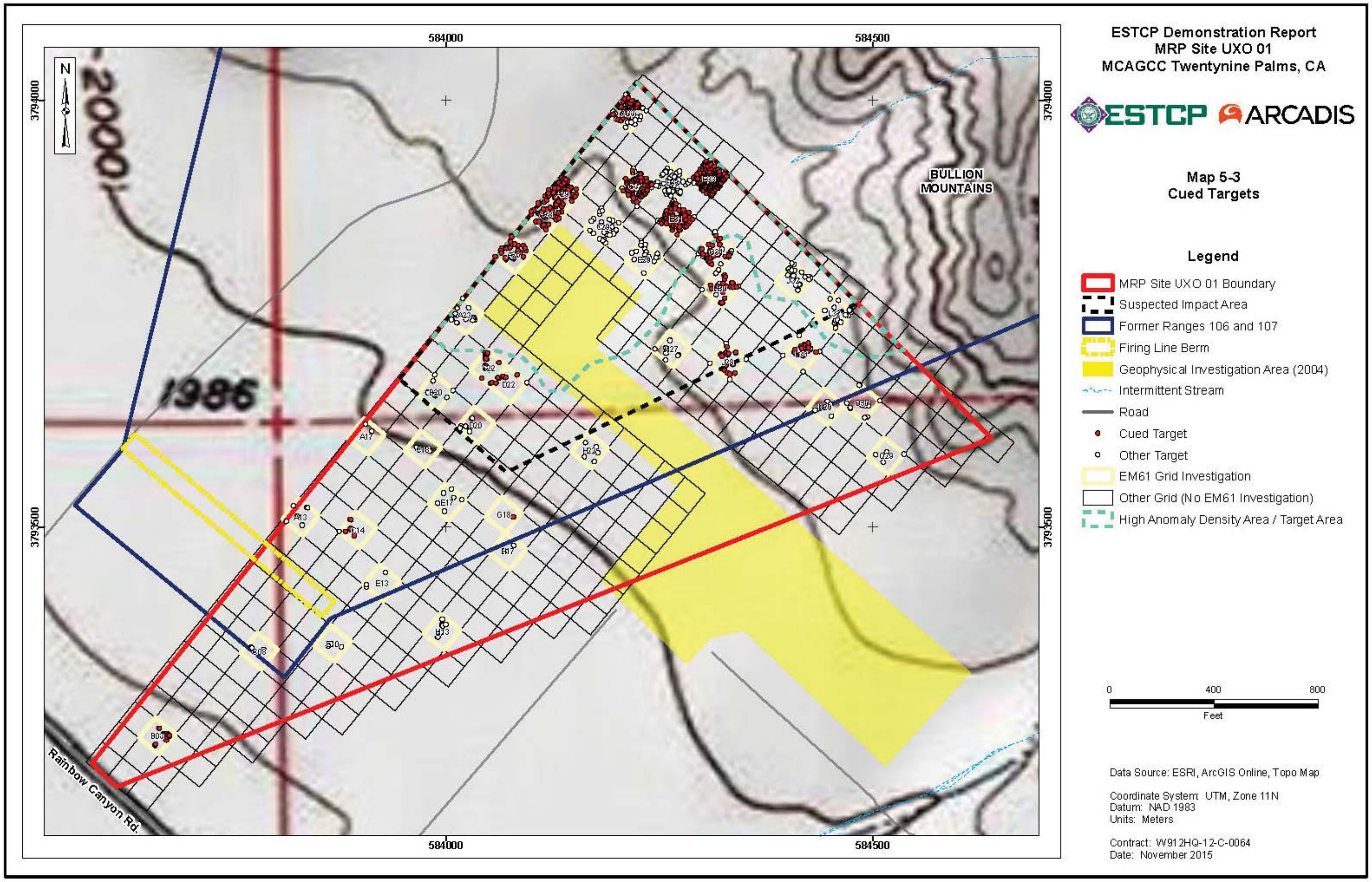
Figure 5-3: Cued Target Selections



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- IVS : 29P_IVS_XXX#.tem, where
    - XXX = Sequential number
    - # = b for background
    - # = sf for system function check
- Cued Target: 29P_Targets_XXXX#.tem, where
    - XXXX = ESTCP Target ID
    - # = b for background
    - # = sf for sensor function
    - # = QC for quality control point
    - # = r for redo point

The TEMTADS data were collected in binary .tem files. TEMTADS data were imported directly into a GDB for processing. Geophysical data is contained in **Appendix C** and has been organized into raw and processed data folders. Each of the datasets is contained in a single .gdb file.

5.6 VALIDATION

At the conclusion of data collection and processing activities, Arcadis selected 42 anomalies for intrusive investigation using the analysis procedures outlined in **Chapter 6** of this report. These anomalies were reacquired by the geophysical team, dug by the UXO team, and then resolved by the geophysical team. Arcadis' UXO Technicians 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 E** of this report.

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6.0 DATA ANALYSIS AND PRODUCTS

Two types of data were collected, processed, and analyzed during the Twentynine Palms live site 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 perform AGC of cued TEMTADS data.

Once the static data was pre-processed, Arcadis employed physics-based models to extract target parameters and then applied a library matching AGC algorithm 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 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 and correct the survey location point using attitude data for the MetalMapper platform (heading, pitch, and roll).

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

6.1.3 TEMTADS MP 2x2

The static TEMTADS data was collected in .tem files and the GPS data was collected in .gps files. These files were directly imported into a Geosoft Oasis Montaj© GDB using the UX-Analyze Advanced module. Geosoft databases were then background corrected 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

Three dynamic data target lists were generated during the live site demonstration and RI:

- EM61-MK2,
- MMPP, and
- MMDR.

Targets were selected for each target list based on the response for the anticipated UXO 01 TOI, which included the following:

- Small ISOs used as QC and QA blind seeds,
- 60mm mortars,
- 81mm mortars, and
- 2.36-inch rockets (which were found outside the MRS boundary near the MRS during the surface sweep).

Out of the above TOI, the small ISOs represent the smallest TOI. The following sections describe the data processing and target selection methods for each of the three target lists, while **Section 6.2.4** describes the final cued target list.

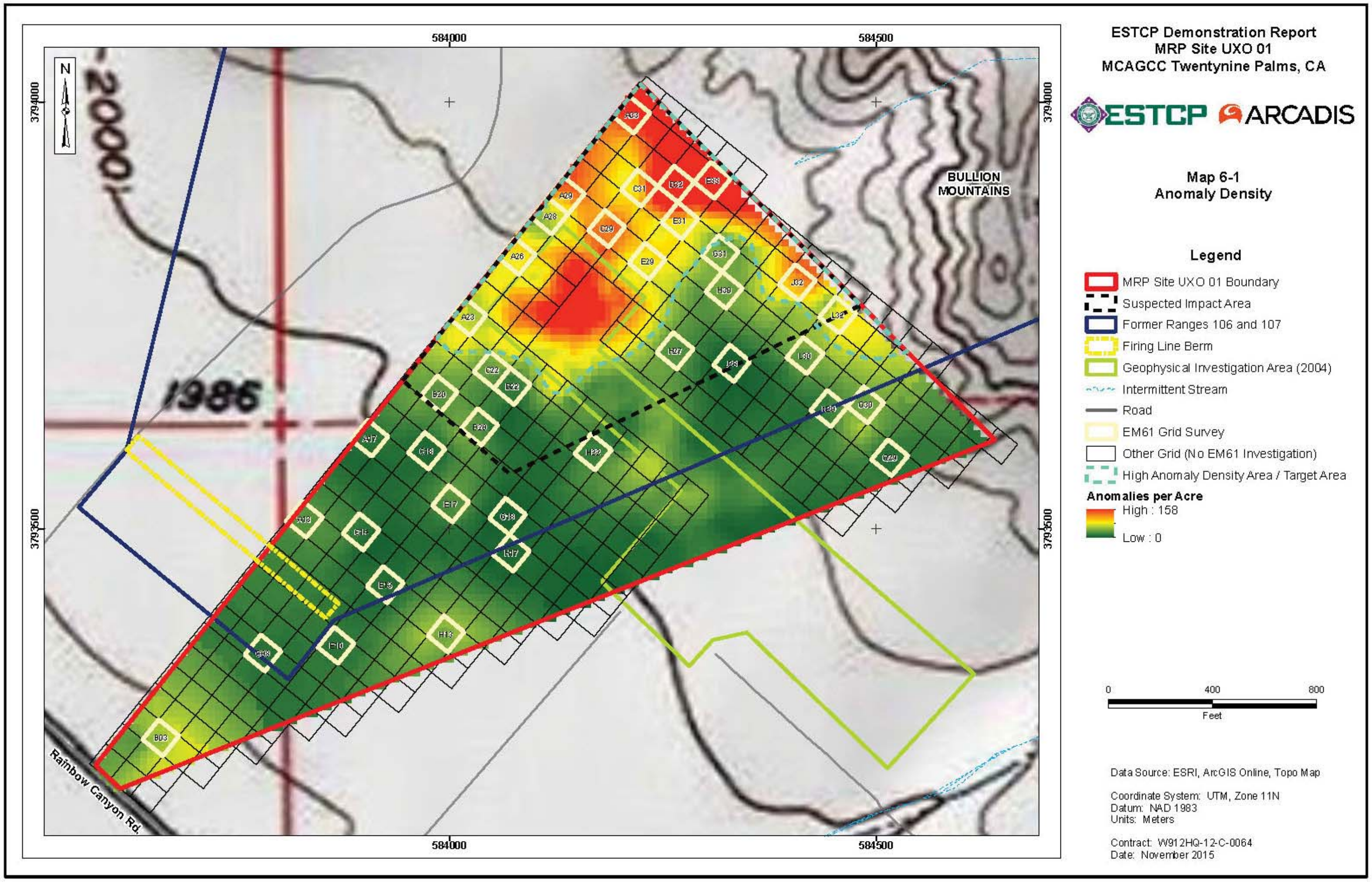
6.2.1 EM61-MK2

EM61-MK2 data was leveled, corrected for latency errors, and then channel 2 was gridded. Targets were selected from the gridded data for anomalies that had a channel 2 response greater than 7 mV, which was sufficient to detect 60mm and 81mm mortars in the least favorable orientation to 21.25 and 22.83 inches bgs, respectively. The EM61-MK2 survey maps are provided for each of the DGM survey grids in **Appendix D**. A total of 484 anomalies were identified in the 38 grids that were DGM surveyed. **Figure 6-1** shows the anomaly density and distribution across the using the EM61-MK2 data collected during the RI and during the 2004 DGM survey. A high anomaly density area is visible in the northwestern portion of the site and along the northern boundary of the site. Anomaly densities vary between 0 and approximately 160 anomalies/acre.

6.2.2 MetalMapper Peak Picking

Arcadis processed the dynamic MetalMapper data using a peak picking method similar to that used for the EM61-MK2 data. After pre-processing, dynamic MetalMapper data were imported into Geosoft Oasis Montaj©, a sum of time gates 2 (136 µs) through 9 (656 µs) was created for each of the 5 inner Z Rx cubes (Rx 2 through 6). Time gates 2 through 9 were chosen because they roughly match the time interval of time gates 1 through 3 of the EM61-MK2. The Z2 through Z6 sum channels were then leveled using a median filter, ignoring 0% of the lowest values and 50% of the highest values, and using a window length of 100 seconds. The levelled

Figure 6-1: EM61-MK2 Anomaly Density



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sum channels were then averaged. This averaged channel roughly mimics the EM61-MK2. The average channel was then corrected for minor latency errors based on IVS results and grid corner survey locations and the corrected data was then gridded using a kriging algorithm for target selection. Anomalies were selected for average, sum channel responses greater than 5 mV/A. A total of 431 MMPP targets were identified during this demonstration. Processed MetalMapper data is provided in **Appendix C**, while maps of the MMPP data and selected targets are presented in **Appendix D**.

6.2.3 MetalMapper Dipole Response

Acorn performed the MMDR data processing and target selection as a subcontractor to Arcadis. The MMDR target selection method takes advantage of all the measured data – not just the Z component – by employing an automated dipole inversion routine to estimate the source locations. The process involves:

1) At every 0.1-m grid node, the surrounding data (from a 1.6-m x 1.8-m box) were submitted to a dipole analysis inversion routine to determine the best match for a dipole located at that grid node. The match between the measured data and the derived dipole model (*i.e.* the fit coherence) was used to indicate the presence or absence of a discrete metal source at that location with a high match to a dipole indicating the presence of a metal source.

2) This fit coherence is mapped in the same manner as the amplitude response and peaks in this mapped detection metric indicate target locations. The peaks were initially selected using a custom peak detection routine in interactive data language (IDL) and compared to the Blakely peak detection routine embedded in Geosoft Oasis Montaj©. A detection threshold of 0.3 was used for both peak detection methods. All detected peaks regardless of detection method were passed on to the next step.

3) A subset of data around each peak was then subjected to a more computationally expensive process whereby the data were inverted in separate passes for one, two, or three dipole sources, enabling spatial resolution for multiple sources within the footprint of the original dipole response region.

4) Resulting sources were examined and culled (based upon size/decay/amplitude metrics) to only sources that could be a 37-mm projectile or larger. The size metric was calculated using polarizations from the 0.137 ms data and the decay metric was calculated by comparing the polarizations from the 0.137 ms data to the 1.022 ms data. The size and decay calculations were done using the routines in UX-Analyze. Any sources with a size less than -1 or decay less than 0.01 were removed from the final source list. Additionally any source with a size less than -0.5 and decay less than 0.05 were also removed.

5) Fit Easting (X) and Northing (Y) locations from the inversions were used as the source positions.

6) If the location of the source was greater than 0.4m from the original fit coherence peak an additional inversion was run using data centered on the fit position of the source. The results of additional inversion were also evaluated using the same size/decay/amplitude metrics described previously.

7) All the inversion results were then merged for all of the sources into one database and a target list was compiled based on the fit position of the sources. All sources that were within 0.2-m of one another were merged into one source and the final source list was generated.

The fit coherence peak threshold of 0.3 used in step 2 was derived by exercising the target selection algorithm on data that is comprised of modeled small ISO signatures superimposed on site specific noise measurements. **Figure 6-2** presents a comparison of the amplitude response signal relative to the noise (left panel) and the dipole filter metric signal relative to noise. Processed MMDR data is contained in **Appendix C**, while maps of the MMDR target selections are presented in **Appendix D**.

6.2.4 Final Cued Target List

A final cued target list was developed that merged the three target lists described above. The final target list consisted of 1,463 targets; however, a single piece of metal in the ground would likely have led to anomalies on all three target lists. **Figure 6-3** shows an example of target location variations for the three target lists. Cued data was collected at all of the MMDR targets because this target list had the best positioning accuracy as determined through analysis of their offsets relative to the QC blind seeds (see **Chapter 7** for performance assessments). In addition, cued data was collected at all of the EM61-MK2 and MMPP targets within grids A26, A28, and A29 to verify the accuracy of the MMDR target list.

6.3 PARAMETER ESTIMATES

Arcadis collected cued TEMTADS data over 667 of the 1,463 detected anomalies, including all of the MMDR anomalies. Each selected anomaly was analyzed using the multi-object solver algorithm in the UX-Analyze Advanced module within Geosoft 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. The static data was processed using UX-Analyze Advanced module to extract the three principal axis β curves for each target. Arcadis then matched the β curves for each target to a library of β curves to classify the target as either TOI or non-TOI.

6.4 CLASSIFIER

Arcadis' classifier 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 four scenarios:

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

Figure 6-2: MMDR Target Selection

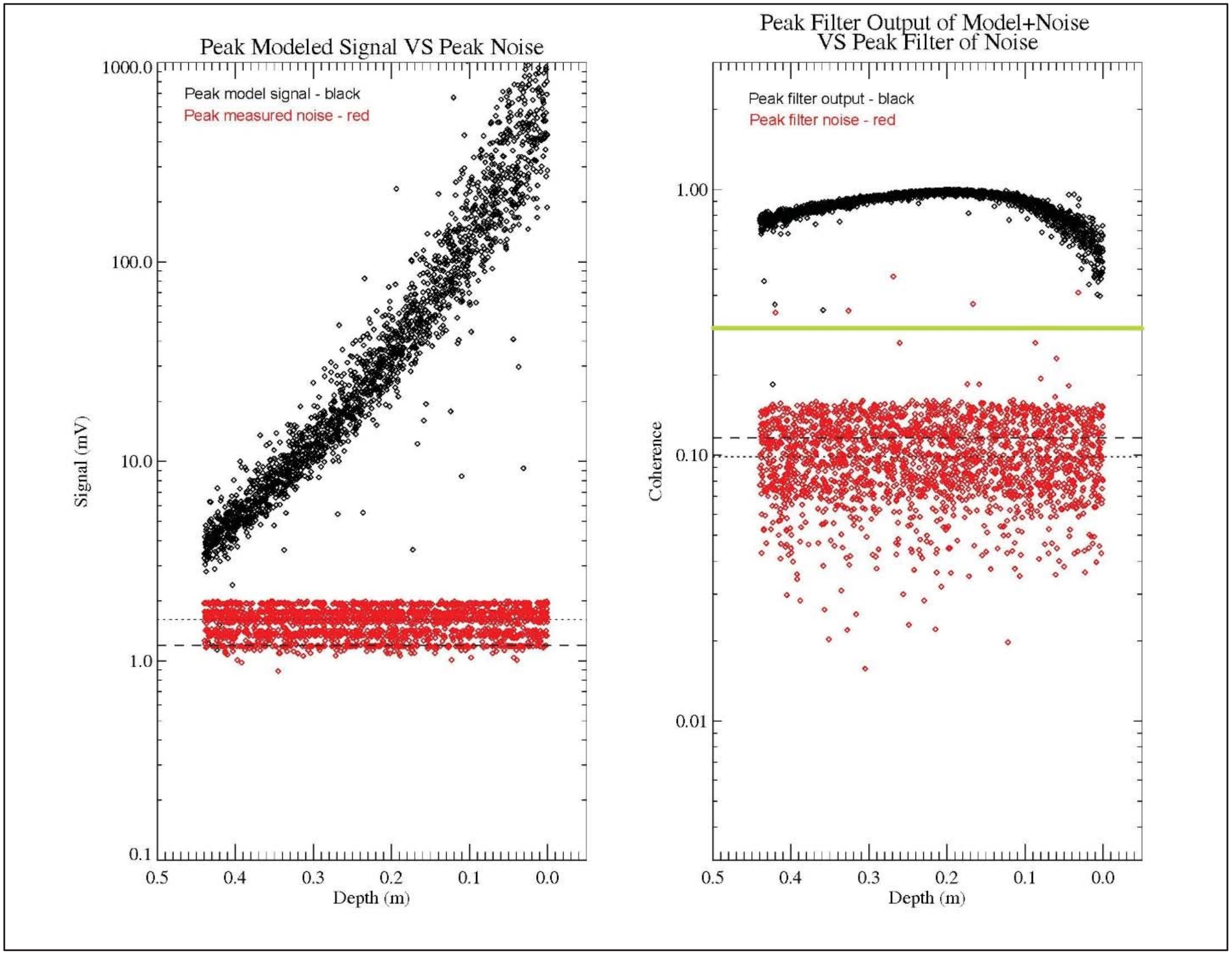

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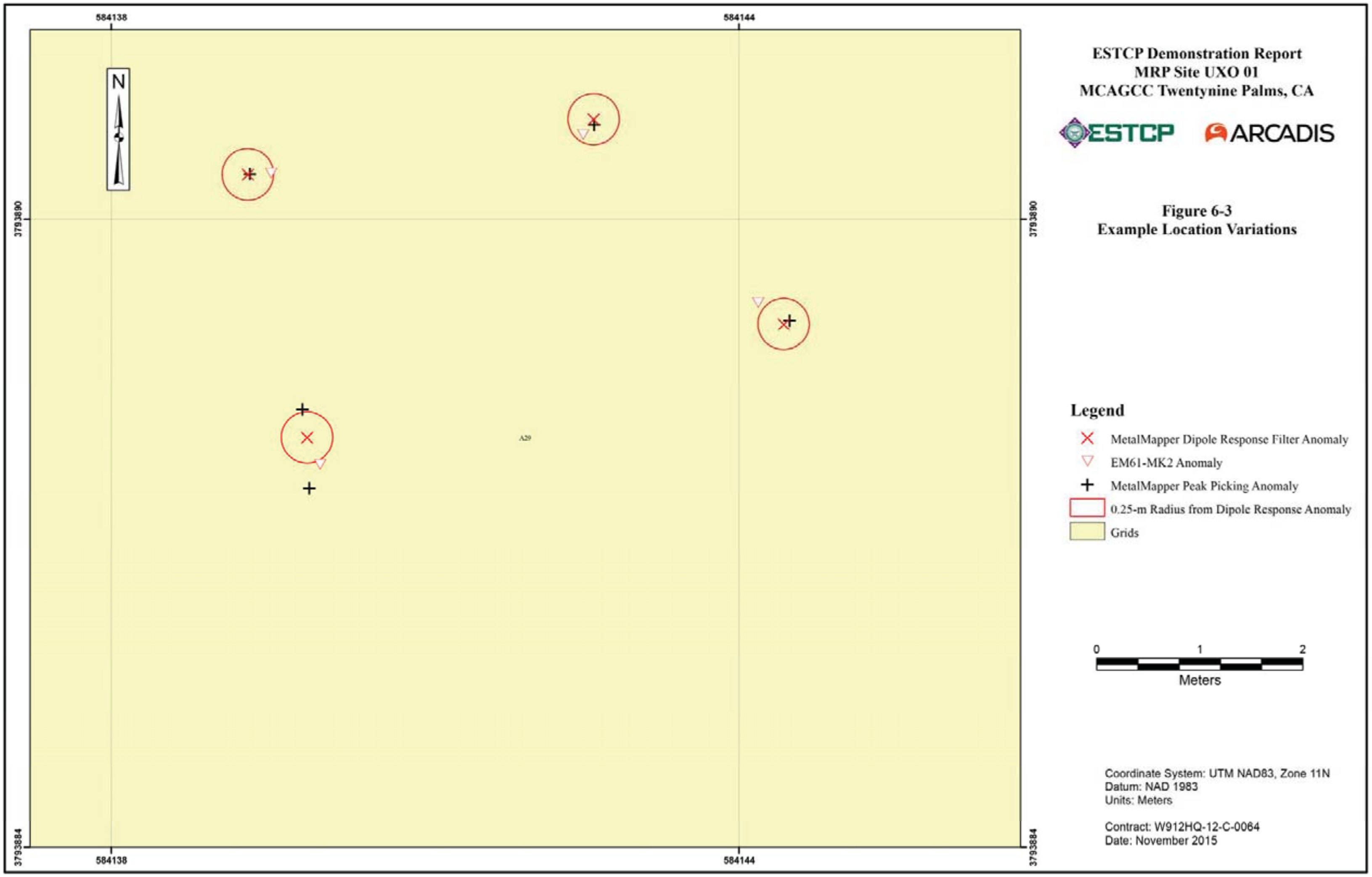
Figure 6-3: Example Target Location Variations



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

Arcadis then used these AGC results and size/decay feature space plots to identify clusters of anomalies that could have been potential UXO, as well as to verify that clusters suspected to be non-TOI were in fact due to non-TOI.

6.5 CLASSIFICATION

6.5.1 Initial Classification

The initial classification used the default weighted average in UX-Analyze Advanced to develop a decision metric. Each of the 667 targets was matched to the full library in UX-Analyze Advanced and a small, TOI-only library that included the following TOI:

- 60mm mortars
- 81mm mortars
- Small ISO80s,
- 2.36-inch rockets,
- Rifle grenades, and
- Fuze parts/components

The rifle grenades and 2.36-inch rockets were added to the TOI list because some were found outside of the MRS on operational area during the surface sweep. The targets were compared to the TOI to determine whether there were clusters of anticipated TOI at the site. After this calculation was made, the validate library tool within UX-Analyze was used to determine whether there were additional clusters of targets that weren't included in the TOI library.

Figure 6-4 shows the size/decay feature space for all targets, as well as an overlay of the TOI library items. Solid black circles indicate TOI clusters, while dashed circles indicate non-TOI clusters. A total of 19 clusters were identified: 1 small ISO80 cluster; 9 additional, potential TOI clusters; and 9 clusters that weren't known TOI clusters. **Table 6-1** presents a summary of the AGC and dig results for each cluster; however, the small ISO80 cluster is not included since it was excluded from consideration for intrusive investigations due to the limited number of investigations available to the team and the goal of this demonstration was to characterize the nature and extent of MEC. The small ISO80 cluster was, however, evaluated for QC performance, and is further discussed in **Section 7**.

Figure 6-4: Example Target Clusters. Solid circles indicate TOI clusters, while dashed black lines indicate non-TOI clusters.

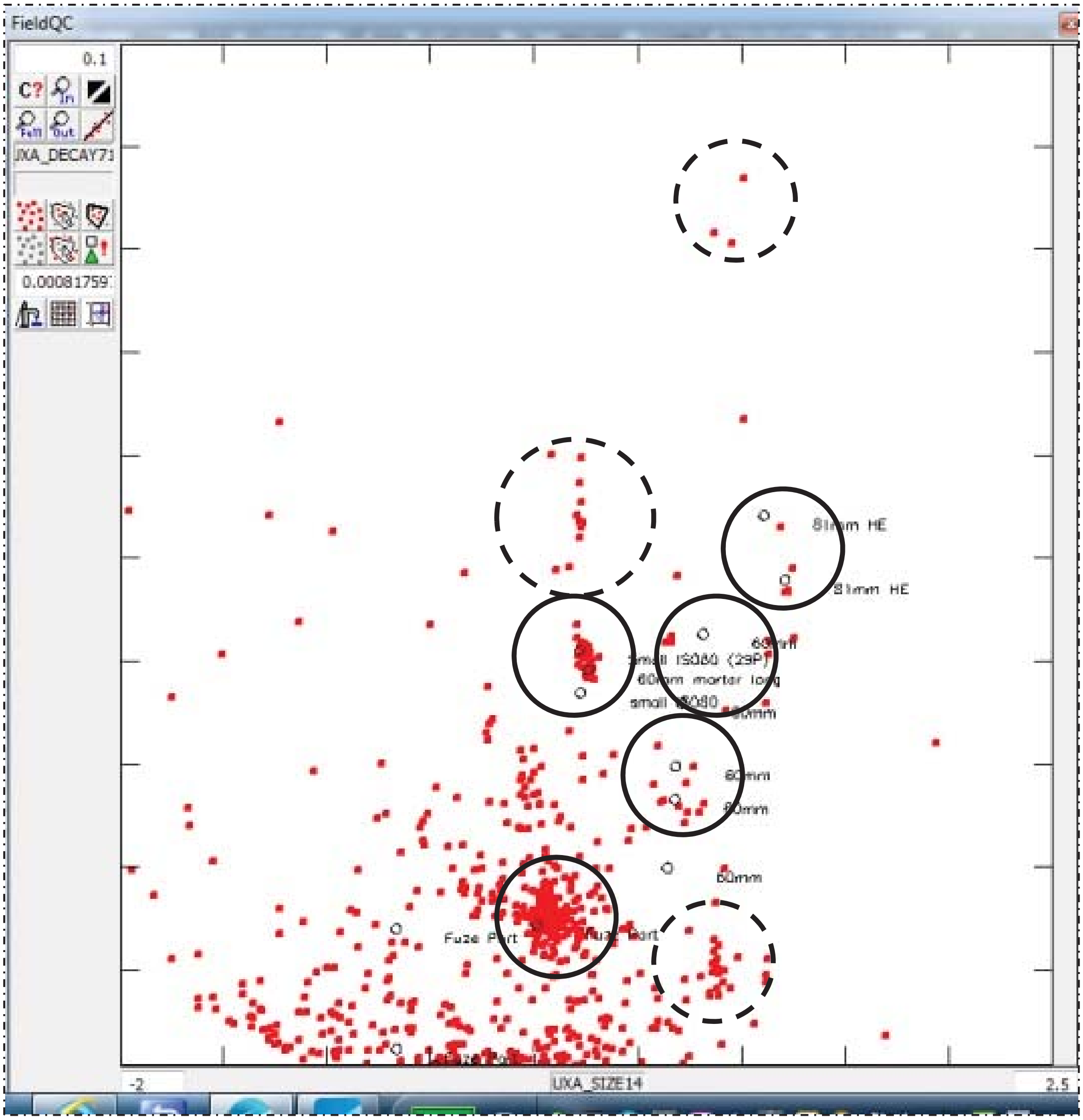


Table 6-1: AGC and Dig Result Summary

AGC Results				Dig Results	
Cluster	**Number of Anomalies in Cluster**	**Number of Anomalies Selected for Intrusive Investigation**	**Suspected UXO**	**Number of UXO Found**	**Dig Results**
1	4	1	Doesn't match library well	0	Illum disk
2	4	1		0	Mortar Tail Boom
3	4	1		0	Frag
4	2	1		0	No Contact
5	3	1		0	Tail boom part
6	10	1		0	Tail boom part
7	7	1		0	Frag and fuze parts
8	11	3		0	60mm mortar tail booms
9	10	1	Fuze Part	0	Fuze Parts
10	11	1	Fuze Part	0	Tail boom part
11	99	7	Fuze Part	0	60mm tail booms and fins
12	14	6	60mm Mortar	0	60mm Illumination Bodies
13	15	2	Fuze Part	0	60mm and 81mm Mortar Parachute Assemblies
14	4	1	Hand Grenade	0	Fuze shipping clip
15	6	2	Fuze Part	0	81mm Mortar parachute assembly and frag
16	10	3	81mm Mortar	1	81mm M374 HE Mortar; 81mm illum body; scrap metal

AGC Results				Dig Results	
Cluster	**Number of Anomalies in Cluster**	**Number of Anomalies Selected for Intrusive Investigation**	**Suspected UXO**	**Number of UXO Found**	**Dig Results**
17	13	8	60mm Mortar	4	4 60mm HE M49 Mortar; Mortar tail boom part; 60mm Illum body; frag
18	3	1	81mm Mortar	0	Drive Shaft
Totals:	**230**	**42**		**5**	

Each identified cluster was further evaluated to determine how many anomalies from that cluster would be selected for intrusive investigation to characterize the site. Targets were selected from each cluster to characterize that cluster as follows:

- Known TOI Cluster Characterization
  - **Nature:** At least 1 target within each anticipated TOI cluster was selected for intrusive investigation to confirm that the cluster was due to TOI.
  - **Extent:** Based on the initial dig results, additional digs were selected from TOI clusters with identified MEC to help determine what an appropriate stop-dig threshold might be.
- Unknown Cluster Characterization
  - **Nature:** At least 1 target within each cluster of unknown objects was selected for intrusive investigation to determine the nature of the cluster and to determine whether unanticipated TOI were present on the site.
  - **Nature and Extent of New TOI:** Additional digs were selected within newly identified TOI clusters to evaluate MEC hazard and determine stop-dig threshold.

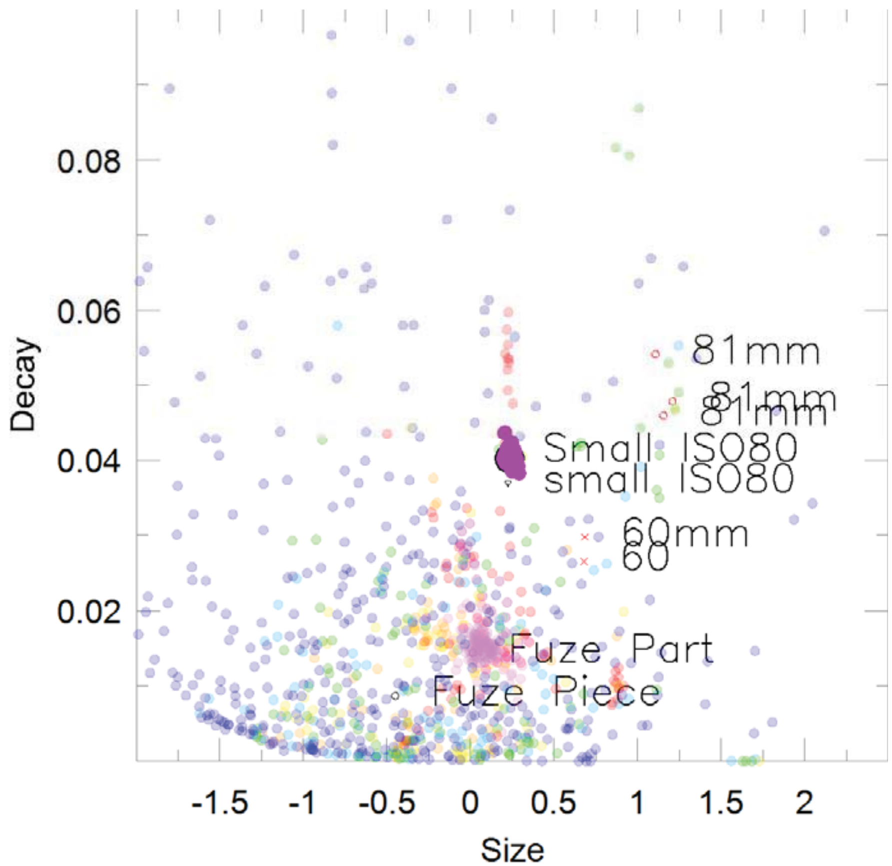
Figure 6-5 shows the small ISO80 target cluster, and the best matches within the cluster. In the best match figure, the red β curves represent the TOI library item, the blue β curves are for the particular target (target 628 in this example), and the gray curves represent the closest 15 matches to target 628 within the small ISO80 cluster. **Figure 6-6** shows the 60mm mortar cluster for cluster 17 (top left), best match (bottom), and an example 60mm MEC dig result from this cluster (top right). In the best match figure, the red β curves represent the TOI library item and the blue β curves are for the particular target (target 318). This particular target did not cluster with other 60mm targets; however, additional targets closely matched the 60mm curves. **Figure 6-7** shows another 60mm target cluster with the best matches within the cluster and dig results. In the best match figure, the red β curves represent the TOI library item, the blue β curves are for the particular target (target 508 in this example), and the gray curves represent the closest 15 matches to target 508 within the small ISO80 cluster.

Arcadis produced one ranked anomaly list that classified each anomaly as one of the following categories:

- *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 0.925. These anomalies were believed to have a high likelihood of being TOI.
- *Category 2:* Anomalies that had a combined metric match to TOI between 0.825. Arcadis was unsure whether these anomalies were TOI or non-TOI.
- *Category 3:* Anomalies that had a combined metric match to TOI less than 0.825. These anomalies had a high likelihood of being clutter items and/or a low likelihood of being TOI.

Note that there were no training data collected during this project, therefore there is no *Category -1* for this demonstration.

Figure 6-5: Small ISO Cluster (left) and best matches (right)



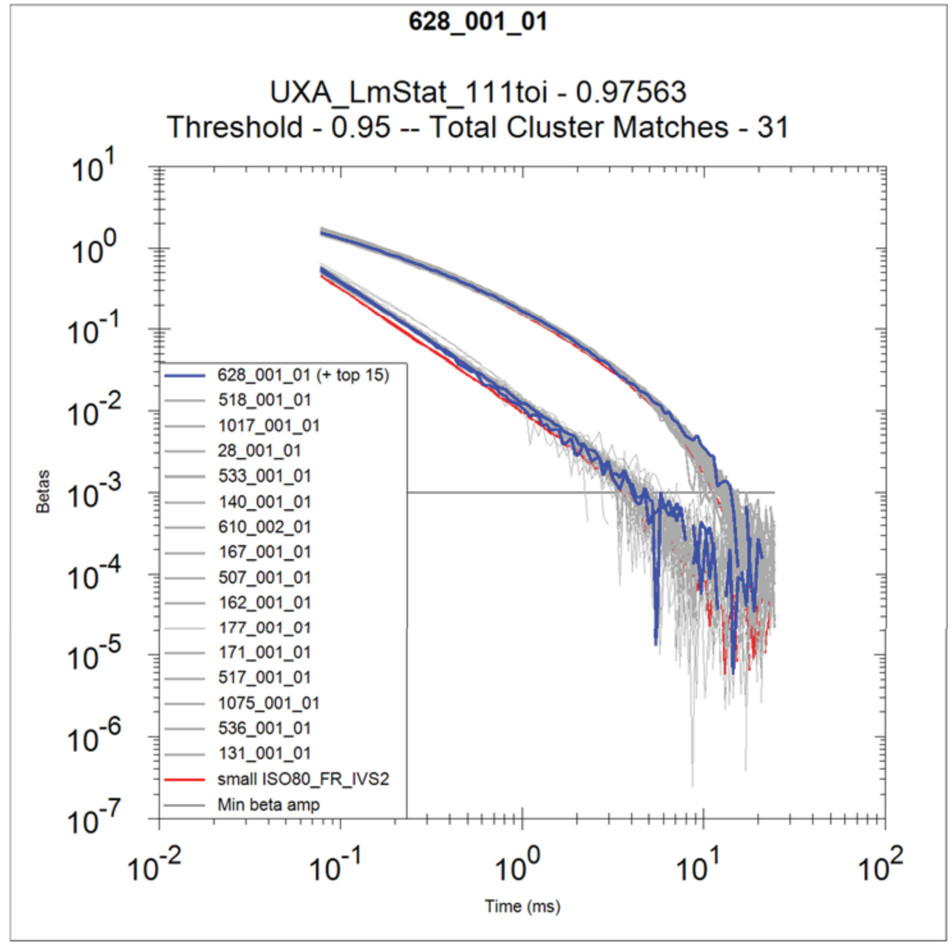


Figure 6-6: 60mm Mortar Cluster (top left), best match (bottom), and example 60mm dig result (top right)

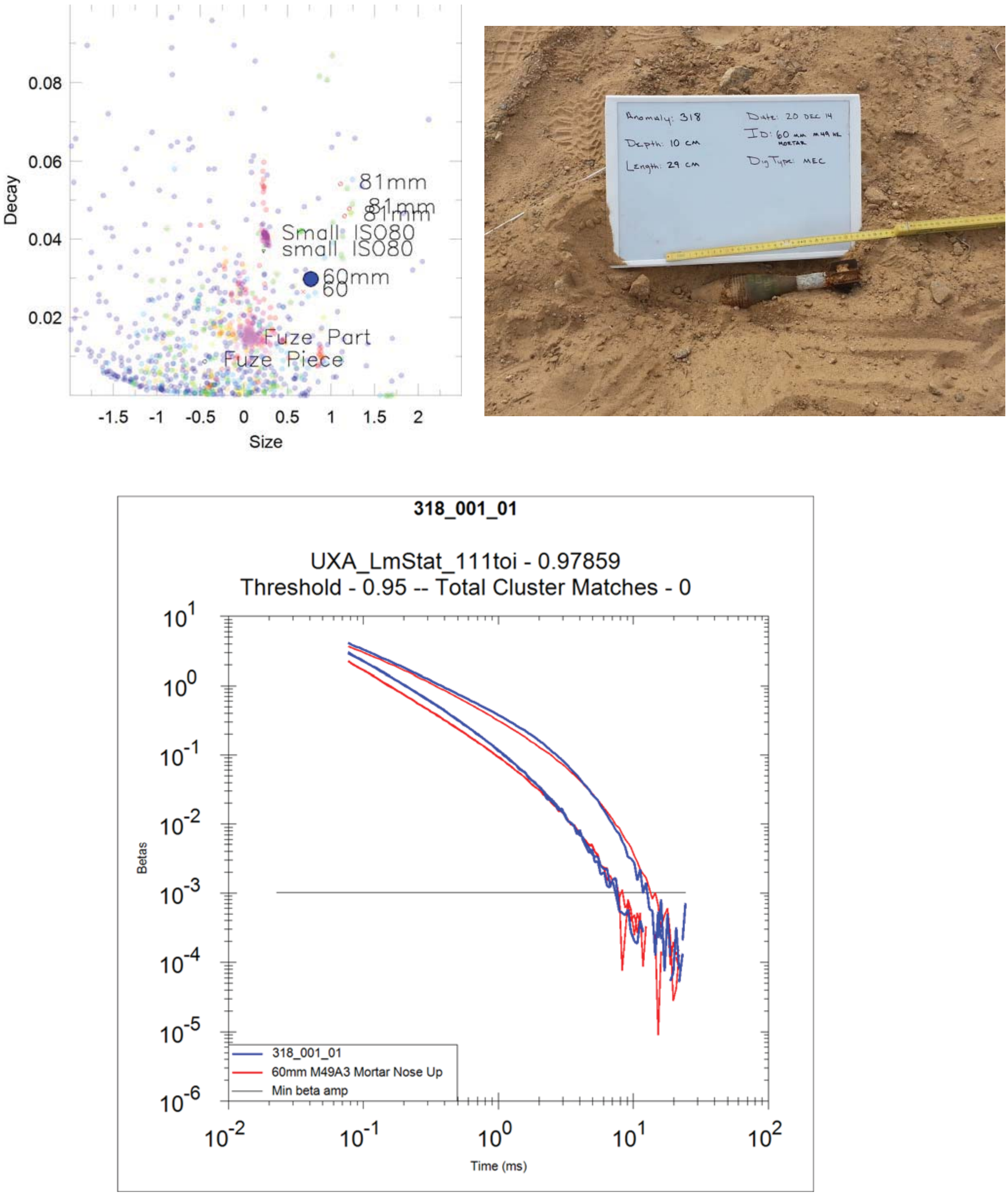


Figure 6-7: Example 60mm mortar cluster 12 matches (left) and example dig result (right)

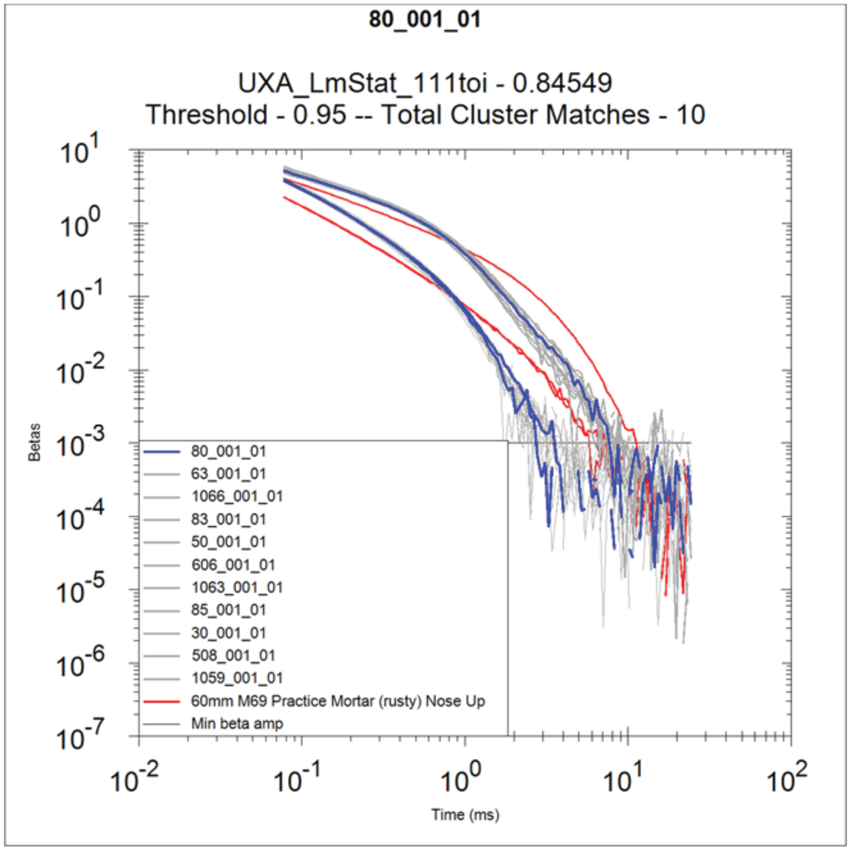


Table 6-2 shows an example of how Arcadis ordered our ranked anomaly list. Category 0, 1, 2 anomalies were placed above the dig threshold in descending order, while Category 3 anomalies were placed below the dig threshold. The first items on the ranked anomaly list were anomalies for which reliable parameters could not be extracted and therefore had to be dug. Next were the items that Arcadis was the most confident were "highly likely" to be TOI. The items were ranked according to decreasing confidence that the item were TOI. Any items that Arcadis was able to analyze, but were not able to definitively 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.

In addition, Arcadis provided an assignment to the 'Type' column, indicating the specific type of munition caliber (*i.e.*, 60mm). The final, ranked anomaly lists are provided in **Appendix F**.

Table 6-2: Example Ranked Anomaly List

Target ID	Category	Dig Decision (1=Dig; 0=Do Not Dig)	Type (mm)	Confidence Metric	Comment
29P-17	0	1	NA	9999	Can't Analyze
…	…	…	…	…	…
29P-862	0	1	NA	9999	Can't Analyze
29P -841	1	1	81	1	High Confidence Match to TOI
…	…	…	…	…	…
29P -562	1	1	60	0.925	High Confidence Match to TOI
29P -625	2	1	60	0.925	Cannot Decide
…	…	…	…	…	…
29P -167	2	1	60	0.825	Cannot Decide
29P -250	3	0	0	0.825	Low Confidence Match to TOI
…	…	…	…	…	Low Confidence Match to TOI
29P-008	3	0	0	0	Low Confidence Match to TOI

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. Arcadis used the QC seed items to modify our stop-dig threshold. Arcadis submitted Final Ranked Dig Lists (see **Appendix F**) to the Program Office for scoring against the QA BSIs.

6.6 DATA PRODUCTS

6.6.1 Ranked Anomaly Lists and Results

As discussed above, Arcadis submitted a cued anomaly list. Because not all anomalies were dug, a ROC curve could not be obtained. Instead, Arcadis evaluated performance based on correctly classifying QC and QA BSIs, which are further discussed in **Section 7**.

6.6.2 Intrusive Investigation Results

6.6.2.1. Intrusive Investigation Results

Arcadis UXO technicians dug each of the targets selected for intrusive investigation and recorded the type of item, its measured depth, its location 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 E** of this report and the photographs of recovered items are on file with the ESTCP Program Office. **Table 6-1** shows a summary of the dig results for each cluster, while **Table 6-3** presents a summary of the dig results for the investigation.

Table 6-3: Dig Result Summary

Type	Sub-Type	Count of Items	Depth Range (m)
MEC	60mm HE M49 Mortar	4	0.01-0.25
	81mm M374 HE Mortar	1	0.5
	Total:	**5**	**0.01 – 0.5**
MD	60mm mortar	13	0.01 - 0.19
	81mm mortar	3	0.03 - 0.19
	Frag	8	0.1 - 0.25
	Fuze Parts	7	0.1 - 0.25
	Illum Disk	1	0.01 - 0.01
	Mortar Tail	11	0.01 - 0.23
	Safety Pin	1	0.1 - 0.1
	Total:	**44**	**0.01 - 0.25**
NC	No Contact	1	NA
	Total:	**5**	**NA**
OD	Metal	4	0.01 - 0.115
	Total:	**4**	**0.01 - 0.115**
Grand Total:		**54**	**NA**

Notes:

NC – No Contact
OD – Other Debris

Figure 6-8 shows the results of the intrusive investigation for the RI/ESTCP demonstration and **Figure 6-9** shows the RI/ESTCP dig results as well as the dig results from the 2004 removal action. A total of 42 anomalies were selected for investigation during the demonstration and 54 items were recovered from those 42 anomaly locations. A total of 5 MEC were found during the investigation: four 60mm HE M49 mortars and one 81mm M374 HE mortar. An additional 60mm mortar was found lying on the surface while the geophysical travelled between investigation grids. One target (320) was a no contact, meaning the dig team couldn't find the particular item. **Figure 6-10** shows the reported intrusive investigation location for target 320. The offset between the fit location provided by the Senior Geophysicist and the dig result location is approximately 0.4-m.

Figure 6-11 shows the best 3-, 2-, and 1-component matches for target 320. The best matches are to a 20mm projectile and fuze components; however, the 2- and 3-component matches have low decision metrics. Given the small amplitude of the TEMTADS data, as well as the poor matches, it is likely that this is a small piece of metal that the dig team couldn't identify in the field and is not likely to be UXO.

6.6.2.2. Stop-Dig Threshold

As the second part of the anomaly selection process, Arcadis selected additional anomalies for intrusive investigation based on the initial dig results to determine the approximate stop-dig threshold for cluster 17, which consisted of 60mm mortars. **Table 6-4** presents a summary of the AGC and dig results for 8 targets investigated within Cluster 17. Four of the eight targets were UXO, while four of the targets were either MD or OD. All three of the targets that have decision statistics below 0.9425 weren't MEC. Any future removal actions might be able to use this decision statistic as a preliminary starting point for determining what targets are TOI and what targets are non-TOI. However, this decision statistic may not be correct because not all targets were dug and there is a possibility that another 60mm mortar may be present lower down the dig list. In addition, this threshold may not apply to 81mm mortars, which could not be evaluated because only one native 81mm mortar TOI was found. Finally, any decision statistic in future removal actions at the site should also factor in BSIs to ensure recovery of all ISOs.

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Figure 6-8: RI/ESTCP Demonstration Intrusive Investigation Results

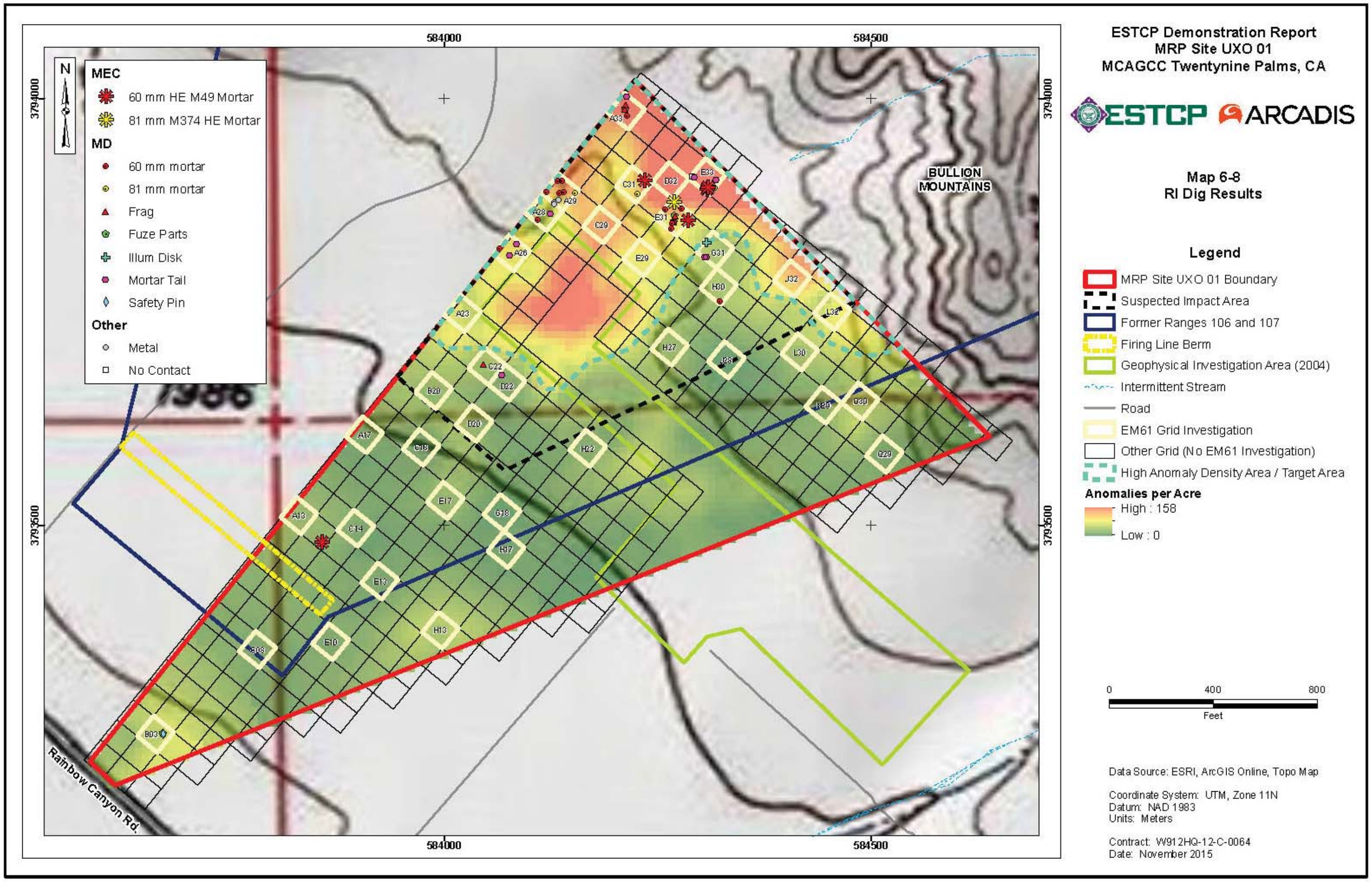


Figure 6-9: All Known Intrusive Investigation Results

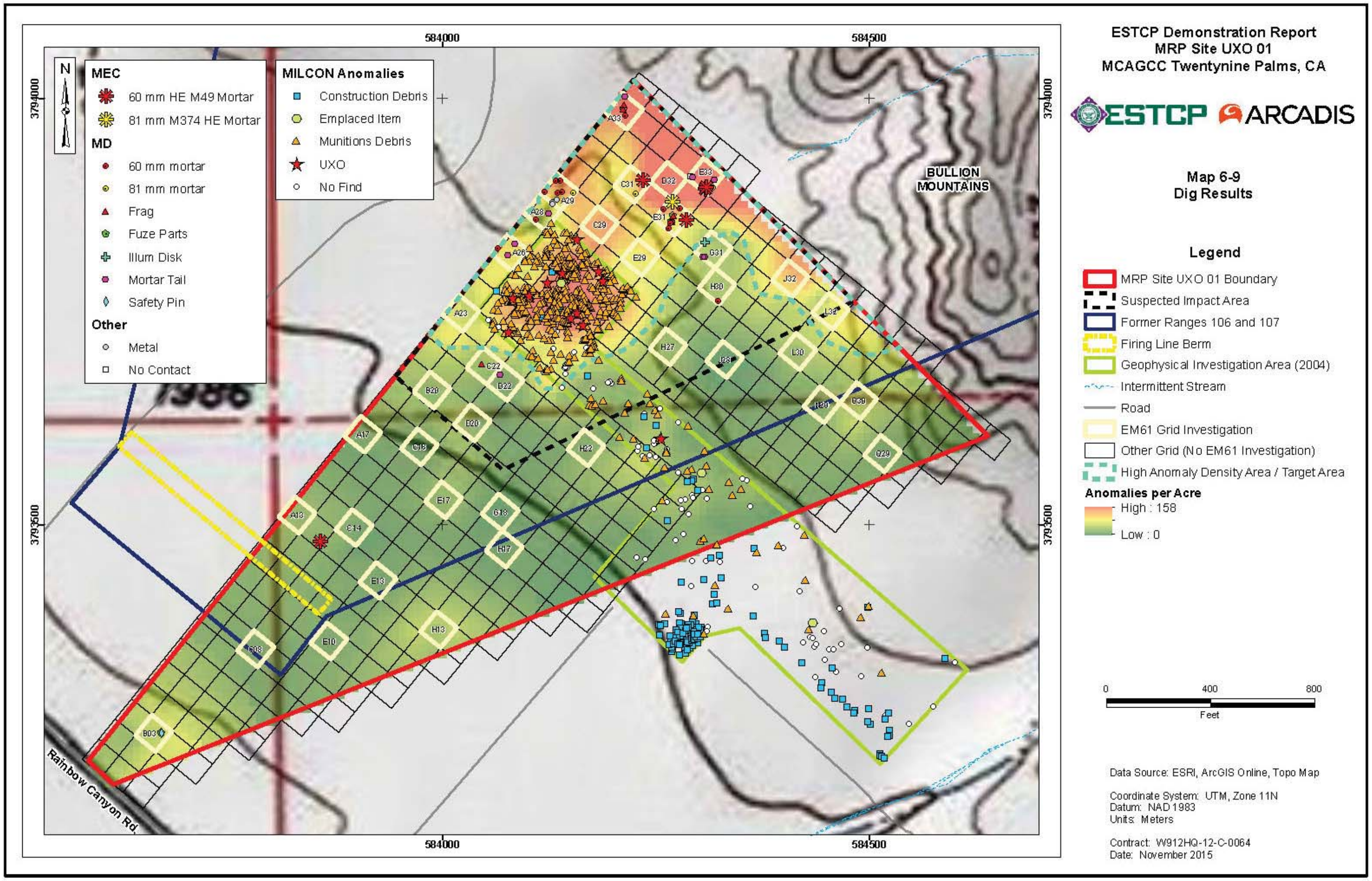


Figure 6-10: No contact dig location

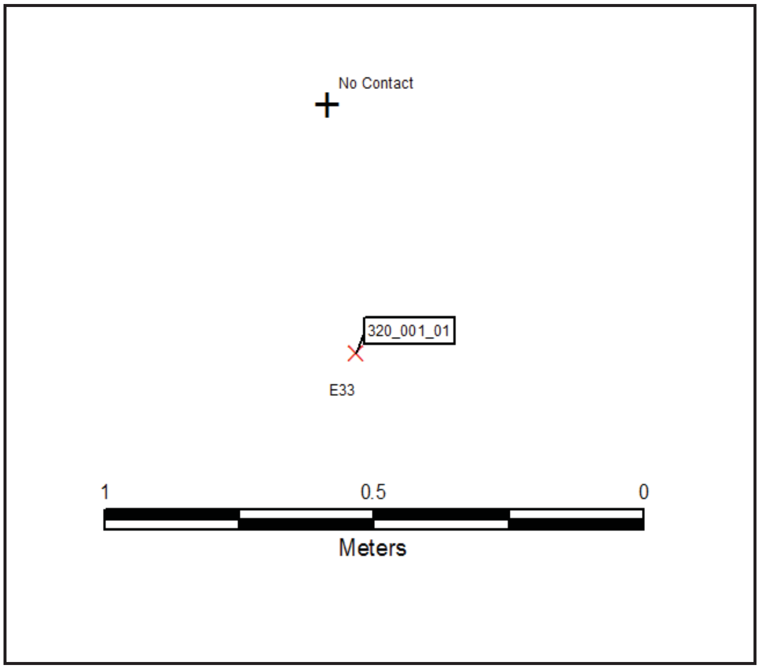


Figure 6-11: Target 320 3-, 2-, and 1-component matches.

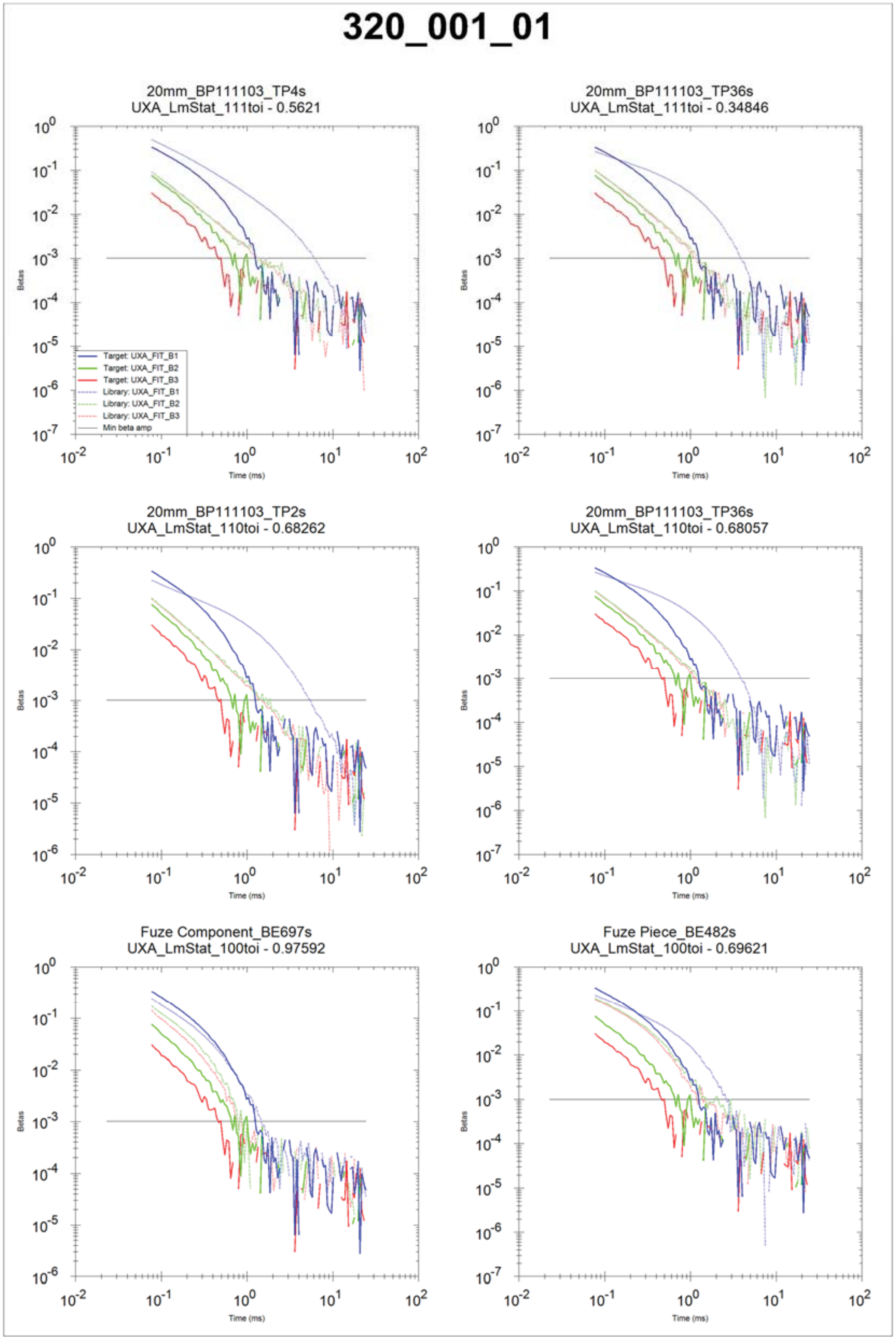


Table 6-4: Cluster 17 Dig Result Summary

<table>
<tr><th>Target ID</th><th>Decision Statistic</th><th>UXA_UXOTYPE</th><th>Dig Type</th><th>Dig Result</th></tr>
<tr><td>318</td><td>0.9807</td><td rowspan="5">60mm M49A3 Mortar</td><td>UXO</td><td>60mm HE M49 Mortar</td></tr>
<tr><td>370</td><td>0.9564</td><td>MD</td><td>Tail Boom Part</td></tr>
<tr><td>372</td><td>0.9483</td><td>UXO</td><td>60mm HE M49 Mortar</td></tr>
<tr><td>236</td><td>0.9453</td><td>UXO</td><td>60mm HE M49 Mortar</td></tr>
<tr><td>373</td><td>0.9427</td><td>UXO</td><td>60mm HE M49 Mortar</td></tr>
<tr><td colspan="5">Potential Stop-Dig Threshold for 60mm mortars.</td></tr>
<tr><td>64</td><td>0.9410</td><td>60mm M69 Practice Mortar (no tail boom) Nose Down</td><td>OD</td><td>Metal</td></tr>
<tr><td>118</td><td>0.9192</td><td>60mm M69 Practice Mortar</td><td>MD</td><td>60mm Illumination Body</td></tr>
<tr><td>169</td><td>0.8627</td><td>NA</td><td>MD</td><td>Frag</td></tr>
</table>

6.6.2.3. Residual MEC

As shown on **Figure 6-9**, the site can be broken down into high anomaly density and low anomaly density areas based on the Visual Sample Plan (VSP) geostatistical analysis of the EM61-MK2 data from the RI and the 2004 removal action. **Table 6-5** presents a summary of the estimated number of anomalies, the total number of anomalies dug, the number of MEC found, the percent of the items that were MEC and estimates of the residual number of anomalies and MEC at the site for both the high and low anomaly density areas. In order to be conservative, this analysis does not take into account those anomalies that weren't intrusively investigated, since these anomalies can't be confirmed to be non-TOI. Based on this analysis, Arcadis estimates that there are up to 40 MEC still remaining within the high anomaly density area and approximately 4 anomalies remaining within the low anomaly density area.

6.6.3 Raw and Processed Dynamic and Static Data

The dynamic and static QC, IVS, and production area data are included in **Appendix C** of this report and are on file with the ESTCP Program Office.

Table 6-5: Estimated Residual MEC

Anomaly Density Area	Total Number of Anomalies[1]	Number of Anomalies Dug[2]	Number of MEC Found[2]	Percent of Dug Targets that were MEC [2]	Total Remaining Number of Anomalies	Estimated Number of Residual MEC[3]
High	1440	414	16	3.9%	1026	40
Low	417	89	1	1.1%	328	4

Notes:

1 – Calculated based on VSP geostatistical analysis of EM61-MK2 data.

2 – Includes the anomalies dug in the ESTCP demonstration and the 2004 removal action.

3 – The estimated number of residual MEC does not account for those targets that were classified, yet were found unlikely to be TOI.

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. The following sections provide descriptions of the results of the performance objective evaluation. The dynamic performance metrics discussed below are strictly for the MetalMapper since the EM61-MK2 data was collected as part of the RI and was not collected as part of the ESTCP demonstration. The cued data collection objective results are strictly for the TEMTADS data.

7.1 DYNAMIC DATA COLLECTION OBJECTIVES

7.1.1 Objective: Initial Instrument Function Test

On October 21, Arcadis finished assembling the MetalMapper and collected a background measurement and a static test measurement using a small ISO80 to ensure that the sensor was properly functioning. Both files were imported into Geosoft Oasis Montaj©, the static measurement was background corrected, and anticipated response was compared to the small ISO80 in the target library. The initial instrument function test passed.

7.1.2 Objective: Spatial Coverage for Detection Results

The MetalMapper was used for the dynamic detection survey during this demonstration, although an EM61-MK2 survey was conducted as part of the RI. Success for the Spatial Coverage metric was that 100% coverage was achieved within accessible areas. 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. Although several of the grids did not achieve 100% coverage, this is due to variations in topography that were present at the site. The average coverage for all of the areas surveyed is 99.87% coverage. Figures showing the results of the UX-Detect calculation are provided in **Appendix D** of this report.

7.1.3 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 spacing less than 25 cm. All datasets exceeded this performance metric. Maps showing the sample separation were generated in Geosoft Oasis Montaj© using the sample separation executable and are provided in **Appendix D**.

Table 7-1: Dynamic Data Collection Performance Results

Performance Objective	Metric	Data Required	Success Criteria	Dynamic MetalMapper Results
Initial Instrument Function Test	Instrument Response Amplitude	Sensor function test (*i.e.*, static test)	Response (mean static spike minus mean static background) within 20% of predicted response for all Tx/Rx combinations	Pass
Spatial coverage in detection survey	Extended footprint coverage	Mapped survey data	100% at ≤0.5m cross-track measurement spacing excluding site-specific access limitations (*e.g.*, obstacles, unsafe terrain)	Pass
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	98% ≤ 0.25m between successive measurements	Pass
Dynamic detection performance	Percent detected of seeded items	Location of seeded items and anomaly list	100% of BSIs detected within 0.4-m halo	MMDR – Pass MMPP – 93% Pass (26 out of 28)
IVS Repeatability	Amplitude of anomaly and β	Twice-daily IVS survey data	Detection: Amplitude within 25%; Derived Position within 0.5-m	Position 94% (234 of 250) Amplitude 76% (191 of 250)
Sensor Tx Current	Per Dataset	Mapped survey data	Peak Tx current between 4.2 and 5 A	Pass
Acceptable Sensor Response	Response Amplitude within valid range	Mapped survey Data	MetalMapper Responses must be approximately between 0 and 10^3 mV/A	Pass
Valid position data (1)	GPS status	Mapped survey data	GPS status indicates RTK fix	Pass
Valid position data (2)	IMU Status	Mapped survey data	Valid orientation data	Pass

Table 7-2: Dynamic Data Coverage Results

Dataset ID	Coverage (%)
B03	99.72
C14	99.95
A2829	100.00
G18	99.88
C22 and D22	100.00
A33	99.13
E31	99.91
E33	99.88
C31	99.75
H30	100.00
G31	100.00
A26	100.00
L30	100.00
J28	100.00
Average:	99.87

7.1.4 Objective: Dynamic Detection Performance

Dynamic MetalMapper data was collected from 14 complete grids and two partial grids. 14 QC and 14 QA blind seeds were placed within the survey area. Arcadis' GIS personnel evaluated the performance of the MMDR and MMPP target lists in correctly locating blind seeds within -0.4-m of the surveyed BSI location. **Table 7-3** summarizes the results for the MMDR and MMPP target lists. The MMDR target list was the primary target list used during this demonstration and it detected 100% of the QA and QC seeds within the 0.4-m halo. The MMPP target detected 93% of the BSIs within the 0.4-m halo. The two missed targets were less than 0.42-m away from the surveyed BSI location.

Table 7-3: Dynamic Detection Offset Results

Target List		Number of BSIs	Number of BSIs that pass	% pass	Min Offset (m)	Max Offset (m)	Mean Offset (m)
MMDR	QC BSIs	14	14	100%	0.00	0.09	0.03
	QA BSIs	14	14	100%	0.00	0.14	0.05
	Total:	28	28	100%	0.00	0.14	0.04
MMPP	QC BSIs	14	14	100%	0.05	0.26	0.13
	QA BSIs	14	12	86%	0.05	0.42	0.12
	Total	28	26	93%	0.05	0.14	0.13

7.1.5 Objective: IVS Repeatability

IVS measurements were collected twice a day (one in the morning and one at night) unless weather and/or instrumentation difficulties prohibited data acquisition in the PM or if no dynamic data was collected within the production grids. In these cases, only one IVS measurement was collected. IVS data was collected to confirm proper instrument functionality and sensor system performance. The dynamic data from the MetalMapper in dynamic mode 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.

Dynamic MetalMapper data was collected over the ten IVS seed items twenty five times for a total of 250 IVS measurements. The positioning offset met the 0.25-m metric 234 out of the 250 times (94%). All of the failing offsets were from datasets where only a single line of data was collected down the centerline and where the MetalMapper didn't directly traverse the IVS seed item. These failures were largely seen in the datasets collected on October 29th and 30th. After these failures were noticed, the field team switched to collecting three lines of IVS data: the centerline and a single line on either side of the centerline at the planned line spacing. After switching to collecting data on three lines, all dynamic detection positions met the 0.25-m performance metric.

191 of the 250 measurements (76%) passed the ±25% response amplitude. There are at least two sources of error that were identified during the dynamic IVS surveys:

1) Only collecting data on the center line, IAW GSV guidance, often led to not collecting data directly over the IVS seed item. The variation in response due to this offset is not known because there aren't currently response curves to determine the variation in response to ISOs as a function of offset.
2) A marked increase in IVS seed item response was exhibited for all IVS seed items starting on November 17, 2014. The increased response is likely associated with the MetalMapper digging down into the loose sand at the site during the IVS survey in the morning or afternoon. Despite placing wooden boards across each of the IVS seed items to prevent scouring with the MetalMapper; some scouring of the loose sand appears to have occurred that resulted in an effective decrease in the distance between the MetalMapper and IVS seed items and corresponding increases in response.

7.1.6 Objective: Sensor Tx Current

The performance objective for this metric was that the sensor's Tx was transmitting current within the expected range. This value was evaluated for each of the datasets and each dataset passed.

7.1.7 Objective: Acceptable Sensor Response

The performance objective for this was that the sensor's Rx responses were within acceptable ranges. The response was evaluated for each of the datasets and each dataset passed.

7.1.8 Objective: Valid Position Data (1) – GPS

The GPS quality metric was used to evaluate whether the GPS metric was met. All data points had a GPS quality of 4, indicating that the data had an RTK fix.

7.1.9 Objective: Valid Position Data (2) – IMU

The IMU metric was evaluated to determine whether the IMU was collecting valid heading, pitch, and roll data. All data points had valid IMU data.

7.2 CUED TEMTADS DATA COLLECTION AND ANALYSIS OBJECTIVES

The following sections describe the performance of the TEMTADS relative to the performance metrics. **Table 7-4** contains a summary of the performance against each of the performance metrics.

7.2.1 Objective: Initial Sensor Function Test

On December 12, Arcadis finished assembling the TEMTADS and collected a background measurement and a sensor function test using a small ISO80 to ensure that the sensor was properly functioning. The sensor function test was compared to the expected response that was contained within the TEMTADS data logger and the initial sensor function test passed.

Table 7-4: Cued TEMTADS Data Collection Performance Results

Performance Objective	Metric	Data Required	Success Criteria	Results
Initial Sensor Function Test	Instrument Response Amplitude	Sensor function test (*i.e.*, static test)	Response (mean static spike minus mean static background) within 20% of predicted response for all Tx/Rx combinations	Pass
System Functionality	Polarizabilities	Five measurements over a small ISO80 target, 1 each directly under each of the Rx coils and 1 directly under center of array.	Match metric of ≥ 0.95 for each of the inverted polarizabilities	Pass
Initial IVS Background Measurement	Background Measurement Response	Five background measurements 1 centered at the flag and 1 offset 40cm in each cardinal direction	Amplitude Response curves were repeatable and indicated there were no metal objects at the background location.	Pass

Table 7-4: Cued TEMTADS Data Collection Performance Results

Performance Objective	Metric	Data Required	Success Criteria	Results
Initial IVS derived β accuracy	βs	Initial IVS test and surveyed seed item location	Library Match metric ≥ 0.95 for each set of inverted polarizabilities	97.5% Pass (39 of 40 measurements)
Derived IVS target position accuracy	Fit location	Initial IVS test and surveyed seed item location	All IVS item fit locations within 0.25m of ground truth locations	Pass
Ongoing IVS Background Measurements	Decay amplitudes	Twice daily IVS background measurements	Amplitude response curves were repeatable and indicated there were no metal objects at the background location	Pass
Ongoing derived IVS polarizabilities precision	Fit metric	Twice daily IVS tests	Library Match to initial polarizabilities metric ≥ 0.95 for each set of three inverted polarizabilities	Pass
Ongoing derived target position precision (IVS)	Fit location	Twice daily IVS tests	All IVS item fit locations within 0.25m of the known seed item location	Pass
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument was positioned within 40 cm of the BSI location	Pass
Initial measurement of production area background locations	Background Measurement Response	Five background measurements: 1 centered at the flag and 1 offset 40 cm in each cardinal direction)	Repeatable amplitude response curves indicated there were no metal objects at the background location.	Pass
Ongoing production area background measurements	Background Measurement Response	Background data nominally collected every 2 hours	Repeatable amplitude response curves indicated there were no metal objects at the background location.	Pass

Table 7-4: Cued TEMTADS Data Collection Performance Results

Performance Objective	Metric	Data Required	Success Criteria	Results
Ongoing instrument function tests	Sensor response	Static sensor function test with every background measurement	Response within 25% of predicted response for all Tx/Rx combinations	Pass
Tx current levels	Sensor response	Cued survey data	Peak Tx current between 5.5 and 9 A	Pass
Sensor response within valid range	Sensor response	Cued survey data	Values must be within ± 4.2V	Pass
Confirm all background measurements are valid	Sensor response	Background measurements	All decay amplitudes qualitatively agree with initial measurement	Pass
Confirm all measurements have an applicable background	Background measurements	Cued survey data	Time Separation between background measurement and anomaly measurement < 2 hours	Pass
Confirm GPS precision	GPS Position of control monument	Daily geodetic function tests	Control Monument positions repeatable to within 10 cm	Pass
Valid Position Data (1)	GPS status flag	Cued survey data	GPS status flag indicated RTK fix	Pass
Valid Position Data (2)	Orientation data	Cued survey data	Orientation data valid data input string checksum passes	Pass
Confirm inversion model supports AGC (1 of 2)	Fit Coherence	Cued survey data	Derived model response must fit the observed data with a fit coherence ≥ 0.8	636 of 667 targets pass (95.3%)
Confirm inversion model supports AGC (2 of 2)	Fit location	Cued survey data	Fit location estimate of item ≤ 0.4m from center of sensor	635 of 667 targets pass (95.2%)

Table 7-4: Cued TEMTADS Data Collection Performance Results

Performance Objective	Metric	Data Required	Success Criteria	Results
Confirm derived features match ground truth (1 of 2)	Fit Location	Prioritized AGC dig list and dig results	100% of recovered (excluding can't analyze category) item positions ≤ 0.25-m from predicted position (x, y).	Pass
Confirm derived features match ground truth (2 of 2)	AGC results	Prioritized AGC dig list and dig results	100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size	Pass
Validation of TOI/non-TOI thresholds	AGC results	Prioritized AGC dig list and dig results	100% of predicted non-TOI intrusively investigated are non-TOI	Pass

7.2.2 Objective: System Functionality

A systems functionality test was conducted to determine whether each Tx and Rx was functioning properly. Arcadis collected five measurements over a small ISO80 target: 1 each directly under each of the Rx Coils and 1 directly under the center of the TEMTADS 2x 2 sensors. During analysis of the test results the following day, the inverted polarizabilities were evaluated and the Arcadis data analyst determined that the inverted polarizabilities underneath Tx 3 and 4 did not meet the performance metric. Arcadis recollected the system functionality test collecting two measurements for each of the five locations: one each in the north-south and the east-west direction. The lowest 3-component match of this second round of tests was a 0.98 match to a small ISO80; therefore, the instrument passed this metric.

7.2.3 Objective: Initial IVS Background Measurement

The reliability of the IVS data required background measurements that were free of metallic objects that could adversely affect background corrections. Initial measurements were taken at the IVS background location and locations offset by approximately 40 cm in each of the cardinal directions. All IVS background locations collected on December 12 were determined to pass because the amplitude response curves were repeatable and indicated there were no metal objects at the background location.

7.2.4 Objective: Initial IVS Derived Polarizability Accuracy

Four sets of initial IVS data were collected over all 10 IVS seed items on 12/12/2014; one for each of the onsite crew that would potentially collect cued TEMTADS data. After the initial IVS datasets were collected, the derived polarizabilities were compared to the target library to determine whether the polarizabilities allowed the IVS seed items to be accurately classified. The objective was considered to be met if the Library Match metric was greater than or equal to 0.95 for each IVS seed item. Of the forty total measurements taken on the initial IVS, a single measurement taken over seed item 2 failed to meet the 0.95 library match. **Figure 7-1** shows the background corrected decay of the each Tx/Rx pair for the four cued datasets taken over seed item 2 on the initial day of data collection and

Figure 7-2 shows the polarizabilities for the failed data (IVS file 27) and the best two 3-, 2-, and 1-component matches. The curves shown on **Figure 7-1** indicate that the background corrected data from each of the have very similar decay; however, the failed IVS file 27, which is shown in light blue on **Figure 7-1** does have a lower response than the other 3 IVS measurements over seed item 2. This slight variation is also exhibited in the uncorrected background data, so the variation appears to be related to the cued measurement and not to the background.

As shown in **Figure 7-2**, the result of the measured response variation is that the β_3 curve decays much more rapidly for data file 27 than the other seed item 2 cued measurements (and the β_3 for the ISOs contained in the TEMTADS library) and a decreased fit metric. This failure was neither repeated by the other 3 cued measurements over the seed item on the initial IVS measurements nor on any ongoing IVS measurements taken at any seed items. **Figure 7-3** shows the flag location (*i.e.*, array center location) and fit locations for all four initial IVS datasets collected over seed item 2, as well as two cued flag locations that weren't properly positioned over the seed item (7_001_01 and 7_002_01) that were recollected. Based on this figure, it appears that all four of the initial cued datasets were collected on top of the seed item and that the resultant fit locations were within performance metrics. Based on this analysis, the particular cause of the failure to meet this performance metric is unknown; however, the variation in response was not repeated during the initial and/or ongoing IVS measurements. This suggests that this is a one-time response variation that does not indicate the TEMTADS was functioning improperly. Because the overarching goal of the initial IVS tests is to demonstrate that the instrument is functioning properly, 97.5% of the initial IVS measurements met the performance metric, there is no apparent explanation for the single failure, and the failure was not repeated during subsequent tests; the TEMTADS appears to have been functioning properly with the exception of this single data point and therefore, this performance metric is considered passed.

7.2.5 Objective: Derived IVS Target Position Accuracy

The reliability of the data also depends on the ability to accurately classify targets such that the location of TOI can be accurately determined. The IVS target positions for the four initial IVS tests all passed since the fit locations were all within 0.25m of the surveyed IVS seed item locations.

Figure 7-1: Decay of Initial IVS data collected over Seed Item 2

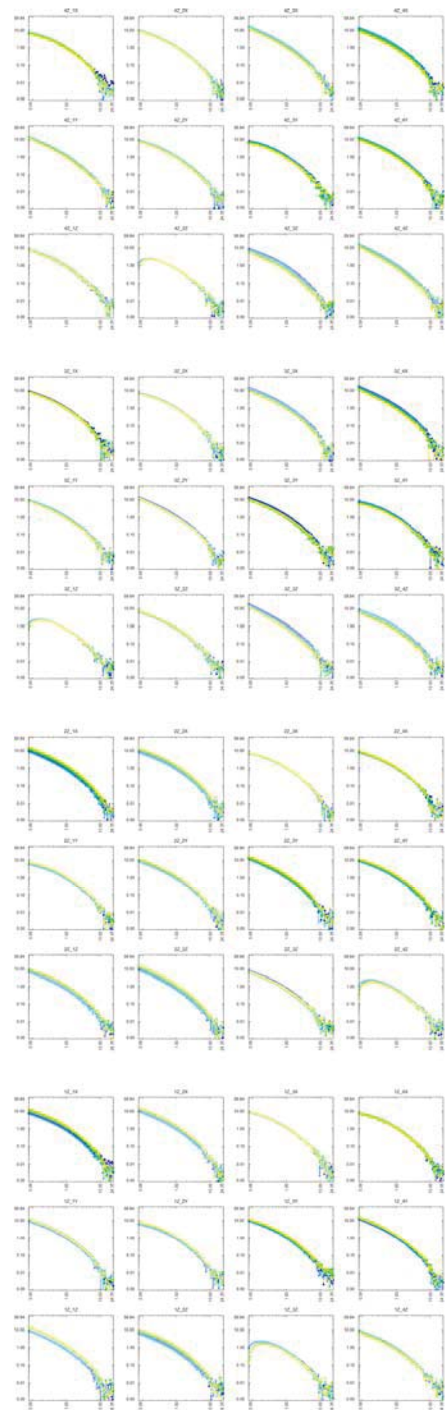


Figure 7-2: IVS data file 27 taken over Seed Item 2

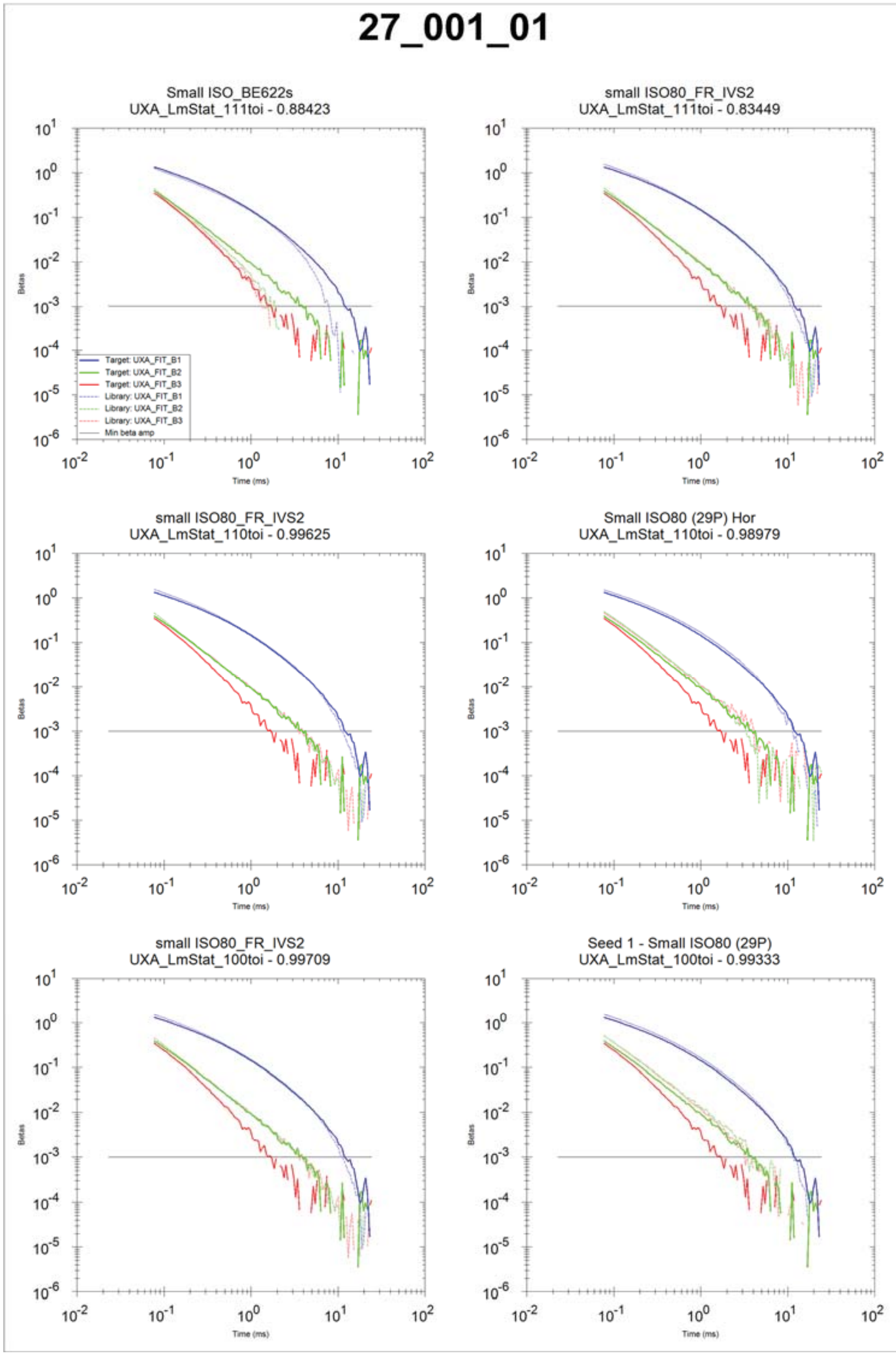
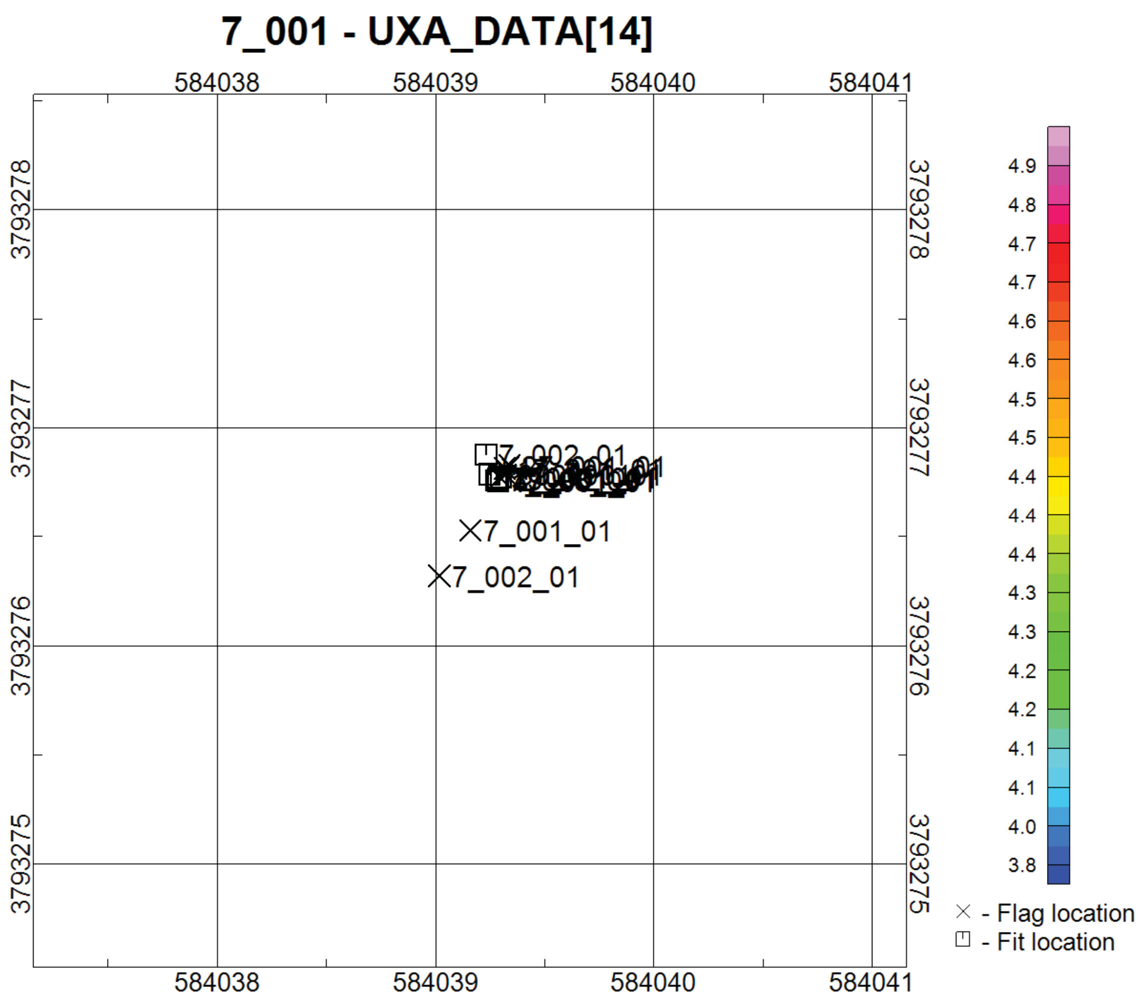


Figure 7-3: Initial IVS data collection locations over Seed Item 2



7.2.6 Objective: Ongoing IVS Background Measurements

The reliability of the IVS data required background measurements that were free of metallic objects that could adversely affect background corrections. Ongoing measurements were taken at the IVS background location. All IVS background locations were determined to pass because the amplitude response curves were repeatable and indicated there were no metal objects at the background location.

7.2.7 Objective: Ongoing derived IVS polarizabilities precision

Ongoing twice daily measurements were made at the IVS with the TEMTADS to verify the proper functioning of the equipment and the ability to correctly classify targets on a consistent basis. After the IVS datasets were collected, the derived polarizabilities were compared to the target library to determine whether the polarizabilities allowed the IVS seed items to be accurately classified. The objective was considered to be met if the Library Match metric was greater than or equal to 0.95 for each IVS seed item. All derived polarizabilities and the decision statistic for the matches for the ongoing IVS seed item tests were greater than 0.95 and therefore passed.

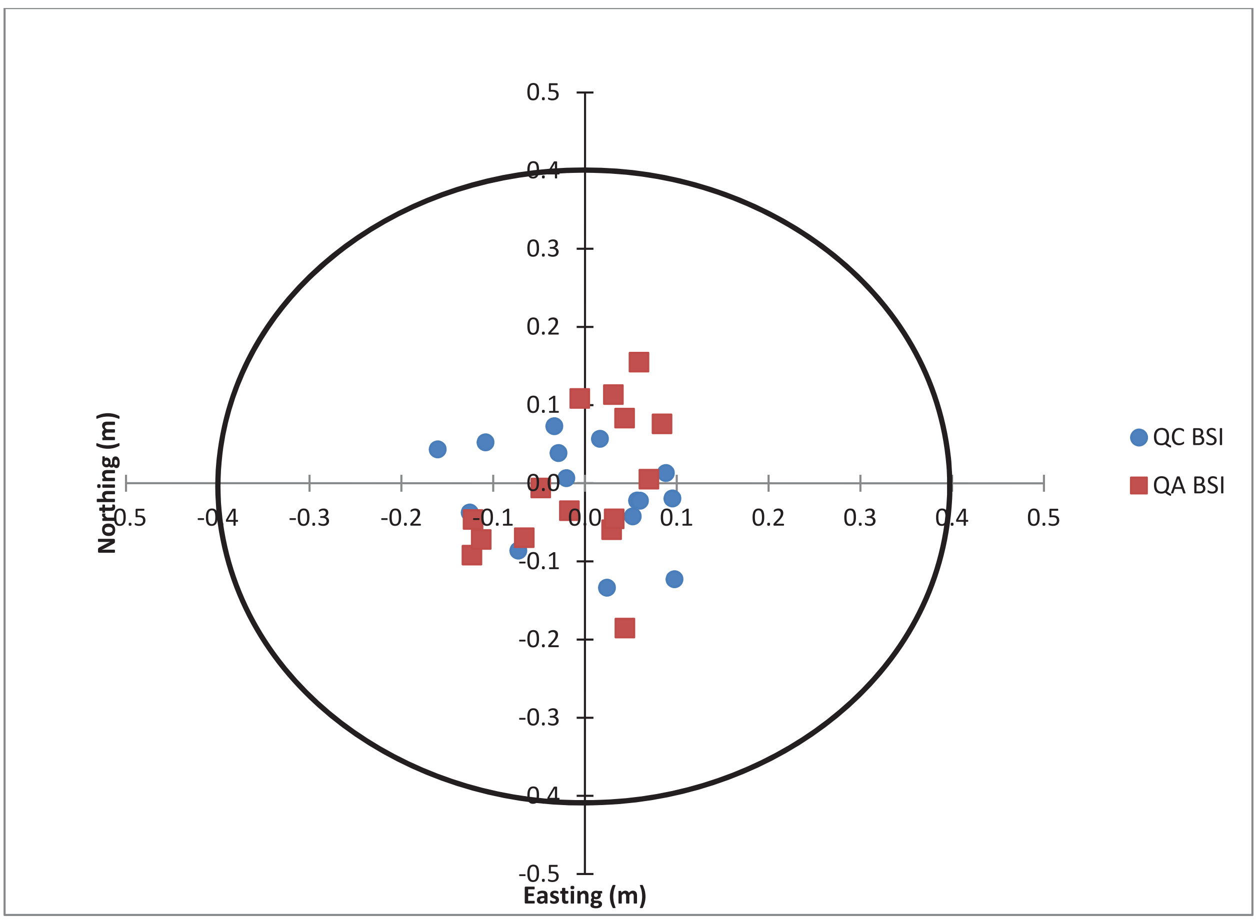
7.2.8 Objective: Ongoing IVS Target Position Precision

The reliability of the data also depends on the ability to accurately classify targets such that the location of TOI can be accurately determined. The IVS target positions for all IVS tests passed since the fit locations were all within 0.25m of the surveyed IVS seed item locations.

7.2.9 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. The objective was considered to be met if the center of the instrument was positioned within 40 cm of the actual anomaly location for 100% of the BSIs. **Figure 7-4** shows the offset between the center of the TEMTADS array and the BSI location for each of the QC and QA BSIs. All offsets are less than the 40 cm performance metric; therefore, the metric is considered to be met.

Figure 7-4: Offset between Array Center and BSI



7.2.10 Objective: Initial measurement of production area background locations

The reliability of the production data requires background measurements that are free of metallic objects that could adversely affect background corrections. Initial measurements were taken at each background location to demonstrate that no metallic objects that could interfere with background measurements were located near the background measurement location. Arcadis collected five background measurements at each background location: one centered at the proposed background location and one offset approximately 40 cm in each cardinal direction. The objective was considered to be met if amplitude response curves were repeatable and indicated there were no metal objects at the background location.

Table 7-5 presents a summary of the date, associated data files, and whether the background tests were passed. As shown on the table, all of the initial background measurements passed the performance criteria except the northern locations associated with the background locations in grids A33 and E31. These locations were not used as background locations once they were identified as not being suitable background locations on the following day. Although these were identified as bad background locations by the data analyst, the field team reviewed the background locations and performed sensor function tests at each one of these locations and felt they were suitable for use in the production grid prior to the data analyst receiving the files. Cued TEMTADS data that was collected on days where the A33 and E31 background locations were used were recollected later in the week using the A2829 background location to ensure that data quality met the project's performance criteria.

Table 7-5: Initial Background Measurement Locations

Background Location	Date Collected	Data Files	Pass/Fail
IVS	12/12/2014	29P_IVS_01_b through 29p_IVS_05_b	Pass
A2829	12/14/2014	29P_22_b through 29P_27_b	Pass
A33	12/15/2014	29P_28_b through 29P_33_b	28 failed and is to the north of the center of the background location
E31	12/15/2014	29P_34_b through 29P_38_b	34 failed and is to the north of the background location
B3	12/17/2014	29P_53_b through 29P_57_b	Pass
D22	12/17/2014	29P_59_b through 29P_63_b	Pass
J28	12/17/2014	29P_65_b through 29P_69_b	Pass

7.2.11 Objective: Ongoing production area background measurements

The reliability of the production data requires background measurements that are free of metallic objects that could adversely affect background corrections. Ongoing background measurements were required to minimize time-variable changes in background response. The objective was considered to be met if measurements were taken every 2 hours. Background measurements were taken within 2-hr intervals. All background measurements except those collected at the A33 and

E31 background locations passed this metric. Data that required the use of the background data at these two locations were re-collected at no cost to ESTCP using the A28A29 background location.

7.2.12 Objective: Ongoing instrument function tests

The reliability of the production data requires the TEMTADS, GPS, and IMU equipment to be functioning properly throughout the day. This test provided an in-field function test for the field team to determine whether there were instrument issues during data collection. Static sensor function tests were collected whenever a background measurement was collected. The results of the sensor function tests were field verified. The objective was considered to be met if the response was within 25% of predicted response for all Tx/Rx combinations. All sensor function tests passed the field verification.

7.2.13 Objective: Tx current levels

The instrument's detection depth capability and the ability to perform AGC were dependent on the instrument Tx functioning as intended. This metric was evaluated for each of the cued TEMTADS data points and data passed if the peak Tx current was between 5.5 and 9 A.

7.2.14 Objective: Sensor response within valid range

The reliability of AGC results depended on the instrument functioning properly and the instrument response being within the expected range. The objective was considered to be met if the response values were within plus or minus 4.2V. All recorded responses passed this metric.

7.2.15 Objective: Confirm all background measurements are valid

The reliability of the production data requires background measurements that were free of metallic objects that could adversely affect background corrections. Ongoing background measurements were required to minimize time-variable changes in background response. The objective was considered to be met if amplitude response curves were repeatable and indicated there were no metal objects at the background location. All background measurements except those collected at the A33 and E31 background locations passed this metric. Data that required the use of the background data at these two locations were re-collected at no cost to ESTCP using the A28A29 background location.

7.2.16 Objective: Confirm all measurements have an applicable background

The reliability of the production data required that background measurements were collected to record time-variable effects in background response to minimize their impact to the AGC results. The objective was considered met because the time separation between background measurement and anomaly measurement was less than 2 hours for all targets. This performance metric was met.

7.2.17 Objective: Confirm GPS precision

The reliability of the GPS positions required daily tests to document that the GPS was functioning properly. The objective was considered to be met if the control monument positions were repeatable to within 10 cm. The geodetic functionality tests passed on each day and the maximum offset was 0.48 cm.

7.2.18 Objective: Valid Position Data (1) – GPS

The GPS quality metric was used to evaluate whether the GPS metric was met. All cued data had a GPS quality of 4, indicating that the data had an RTK fix. All data passes this performance metric.

7.2.19 Objective: Valid Position Data (2) – IMU

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the IMU. Valid roll, pitch, and yaw data was collected for all data points and all data passes this performance metric.

7.2.20 Objective: Confirm inversion model supports AGC (1 of 2) – Fit Coherence

The reliability of the AGC results depends on collecting data that has a relatively high fit coherence to indicate the data could be modeled. Successful completion required that the derived model response fit the observed data with a fit coherence of greater than or equal to 0.8. A total of 636 of the 667 targets (or 95.3%) had a fit coherence greater than 0.8 and passed this metric.

7.2.21 Objective: Confirm inversion model supports AGC (2 of 2) – Fit Location

The reliability of the AGC results depended on collecting data where the sensor was above the subsurface metallic object. The objective was considered to be met if the fit location estimate of the subsurface item was less than or equal to 0.4-m from center of sensor. Based on the best multiple object fits, 635 of the 667 targets (or 95.2%) had a fit location offset from the array center of less than 0.4-m and passed this metric. Ten of these 32 targets that had differences between the array center and fit location greater than 0.4-m also did not pass the fit coherence test. Although the best match for 32 targets didn't pass the fit location test, the cued data for many of these targets included multiple fits and some of the secondary fits were within the metric. During the field QC process, the data QC personnel interpreted these targets as passing the fit location metric since there was at least one fit underneath the TEMTADS array.

7.2.22 Objective: Confirm derived features match ground truth (1 of 2)

The reliability of the AGC results depended on reliably being able to classify targets at their respective location. The objective was considered to be met if 100% of predicted seed positions were less than or equal to 0.25-m from known position (x, y, z). **Table 7-6** presents a summary of offsets between the fit locations of the inverted data and the seed item locations. All BSIs were found within the performance metric and this performance metric was passed.

Table 7-6: Cued TEMTADS BSI Fit Location Results

BSI Type	Number of BSIs	Number of BSIs that pass	% pass	Min Offset (m)	Max Offset (m)	Mean Offset (m)
QC BSIs	14	14	100%	0.01	0.03	0.02
QA BSIs	14	14	100%	0.00	0.03	0.02
Total:	28	28	100%	0.01	0.03	0.02

7.2.23 Objective: Confirm derived features match ground truth (2 of 2)

The reliability of the AGC results depended on reliably being able to classify targets. The prioritized AGC anomaly list and dig results were used to determine whether the AGC results matched the dig results for the targets that were intrusively investigated. **Table 7-7** presents a summary of the AGC and dig results for each target that was intrusively investigated. The table includes the UXO category for the item on the dig list. All targets qualitatively match the size of the dig results. In addition, 37 category 2 (*i.e.*, buffer targets) and category 3 targets (*i.e.*, unlikely to be TOI) were correctly classified as non-TOI dig results.

7.2.24 Objective: Validation of TOI/non-TOI thresholds

The data reliability depended on the AGC approach to correctly identify TOI and non-TOI. The objective was considered to be met if 100% of predicted non-TOI intrusively investigated were non-TOI. The preliminary ranked target list and the QC and QA BSIs, as well as the dig results for the anomalies that were intrusively investigated were used to evaluate this criterion. Arcadis used a threshold of 0.925 as a decision statistic for the TOI stop-dig threshold. All QC and QA BSIs, and all of the UXO recovered were above this threshold. Because not all targets were dug during this demonstration, this analysis is only qualitative (*i.e.*, TOI that weren't investigated could be present below this threshold).

Table 7-7: AGC Results vs. Dig Results

AGC Results				Dig Results			
Anomaly	UXO Category	UXA Decision Statistic	Best 3-Component Match	Dig Type	Identification	Depth (cm)	Length (cm)
8	3	0.6830125	60mm_BP110826_TP33m	MD	Tail Boom Part	3	14
38	3	0.6420675	Fuze Part_BE196s	MD	Tail Boom Part	23	5
45	1	0.928085	81mm M69 Practice Mortar Horizontal	OD	Drive Shaft	1	32.5
63	2	0.89312	60mm M69 Practice Mortar (rusty) Nose Up	MD	60mm Illum Body	8	21.5
64	1	0.9409925	60mm M69 Practice Mortar (no tail boom) Nose Down	OD	Metal	11.5	9
72	3	0.7810975	105mm heat_BP110826_TP57m	MD	60mm Tail Boom	3	15.5
80	2	0.892425	60mm M69 Practice Mortar (rusty) Nose Up	MD	60mm HE M49 Mortar	9.5	22
83	2	0.8842325	60mm_BP110826_TP29s	MD	60mm Illum Body	1	21.5
98	3	0.7776325	Fuze Component_BE697s	MD	81mm Parachute Assembly	19	21
112	2	0.864535	40mm_2011LSBP2913s	MD	Frag	22	3.5
112	2			MD	Frag	22	3.5
112	2			MD	Fuze Part	22	8
112	2			MD	Fuze Part	22	2.5
115	3	0.711465	20mm_BP111103_TP36s	MD	Frag	10	8
118	2	0.919235	60mm M69 Practice Mortar (rusty) Nose Up	MD	60mm Illum Body	3	21.5
122	1	0.9344375	Fuze Part_BE76s	MD	Mortar Tail Fins	15	9.5
147	2	0.8459	MK2 Hand grenade_FR_TP3s	MD	Fuze Shipping Clip	10	7
147	2			MD	Fuze Shipping Clip	10	7
147	2			MD	Safety Pin	10	5
169	2	0.862685	60mm M69 Practice Mortar (no tail boom) Nose Down	MD	Frag	14	11
180	1	0.92782	Fuze Part_BE76s	MD	Mortar Tail Fins	3	9
213	2	0.8741825	Fuze Part_BE76s	MD	81mm Parachute Assembly	11	75
236	1	0.9453375	60mm M49A3 Mortar Nose Down	MEC	60mm M49 HE	19	29

AGC Results				Dig Results			
Anomaly	**UXO Category**	**UXA Decision Statistic**	**Best 3-Component Match**	**Dig Type**	**Identification**	**Depth (cm)**	**Length (cm)**
256	2	0.843895	37mm_2011LSBP840s	MD	60mm Illum Body	6	21.5
270	1	0.9456725	Fuze Part_BE76s	MD	60mm Tail Boom	9	9.5
278	3	0.79302	105mm heat_BP110826_TP57m	MD	60mm Illum Tail Boom	1.5	16
282	2	0.8934525	Fuze Part_BE76s	MD	Frag	15	3
282	2			MD	Frag	15	3
282	2			MD	Frag	15	2
282	2			MD	Tail Boom	15	4
282	2			MD	Fuze Part	15	8
285	1	0.92762	81mm_BP110826_TP37s	MEC	81mm M374 HE	50	40
286	2	0.840865	Fuze Part_BE76s	MD	Frag	25	3
286	2			MD	Fuze Parts	25	4
286	2			MD	Fuze Parts	25	6
303	1	0.93611	Fuze Part_BE76s	MD	60mm Tail Boom	7	9
318	1	0.9807275	60mm M49A3 Mortar Nose Up	MEC	60mm M49 HE	10	29
320	3	0.7029925	20mm_BP111103_TP4s	NC	No Contact	123	
321	1	0.9275975	Fuze Part_BE76s	MD	Mortar Tail Fins	1	9.5
370	1	0.9564075	60mm M49A3 Mortar Nose Up	MD	Tail Boom Part	7	10
372	1	0.9482825	60mm M49A3 Mortar Nose Down	MEC	60mm HE M49 Mortar	15	32
373	1	0.942685	60mm M49A3 Mortar Nose Up	MEC	60mm HE M49 Mortar	25	32
415	1	0.98339	81mm HE M821A1/M889A1 Mortar Horizontal	MD	81mm Illum Body	3	25
428	1	0.934805	Fuze Part_BE76s	MD	Tail Boom Part	12	9
480	1	0.94906	Fuze Part_BE76s	MD	Mortar Tail Fins	1	9
485	1	0.9377475	Fuze Part_BE76s	MD	Mortar Tail Fins	3	9.5
487	3	0.7086825	Fuze Part_BE76s	MD	Illum Disk	1	7.5
508	2	0.88625	60mm M69 Practice Mortar (rusty) Nose Up	MD	60mm Illum	19	22

AGC Results				Dig Results			
Anomaly	UXO Category	UXA Decision Statistic	Best 3-Component Match	Dig Type	Identification	Depth (cm)	Length (cm)
554	3	0.7653025	Fuze Component_BE697s	MD	60mm Parachute Assembly	1	54
604	3	0.7793975	Fuze Part_BE76s	MD	60mm Mortar Tail Boom	1	16
607	2	0.867325	60mm M69 Practice Mortar (no tail boom) Nose Up	OD	Metal	2	12
607	2			OD	Metal	2	12
1007	3	0.705525	40mm gren_BP110427_TP20s	MD	Tail Boom Part	3	5
1066	2	0.8747	60mm M69 Practice Mortar (rusty) Nose Up	MD	60mm Illum Body	7	21.5

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 MCAGCC Twentynine Palms.

8.1 COST MODEL

Arcadis tracked costs throughout the ESTCP live site demonstration at the MCAGCC Twentynine Palms 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 MCAGCC Twentynine Palms live site demonstration including the data tracked during the demonstration. EM61-MK2 survey and intrusive investigation costs were not part of this demonstration. The intrusive investigation costs presented are an estimated cost based on the intrusive investigation costs at Camp Ellis, which was the last live site demonstration performed as part of this contract.

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 (doesn't include accident prevention plan, explosives siting plan or other plans. • General pre-planning activities	$17,690
Training	• Training in AGC data collection/processing	$13,167
Mobilization	• Mobilization of geophysical teams and equipment, including GPS, MetalMapper, and TEMTADS. • Costs include three total mobilizations. • UXO team mobilization costs covered under the RI costs separate from this demonstration.	$63,388 Average Mobilization: $21,129
Site Preparation	• Site Boundary Surveys • Blind Seeding • IVS setup	$15,430

Cost Element	Data Tracked During Demonstration	Estimated Costs
	• Test Pit Measurements	
MetalMapper Survey Data Collection		
Equipment Costs	• MetalMapper • RTK DGPS • Skid Steer	**Total Cost:** $30,031 for one month **Daily Rental Costs:** $1,500
Dynamic Survey	• Dynamic MetalMapper data collection, including MetalMapper, GPS, skid steer, and other equipment costs. • Daily IVS and QC tests • All equipment, including MetalMapper rental costs are included	**Total Cost:** $35,069 Cost per acre: $10,194
Total Dynamic Survey Costs	• All data collection and equipment costs (assumes 10 days of data collection)	**Total Cost:** $50,069 Cost per acre: $14,554 (non-contiguous RI grids of this demonstration) Cost per Acre: $6,479 (contiguous grids in previous demonstration including processing costs).
Dynamic MetalMapper Processing/QC	• MMPP Data Processing/QC • Grids and IVS/QC Processing	**Total Cost:** $10,883 Cost per acre: $3,163
	• MMDR Data Processing/QC • Grids and daily IVS processing	**Total Cost:** $25,041 Cost per acre: $7,279
TEMTADS Cued Data Collection		
Survey Costs	• Target reacquisition • Cued TEMTADS data collection • IVS and QC tests (TEMTADS rental costs are not included, but GPS and other equipment costs are included)	**Total Cost:** $32,238 (667 anomalies) Cost per Anomaly: $48.33
Analysis Costs	• Data Processing and QC • Target parameter extraction • Advanced anomaly AGC	**Total Cost:** $6,722 (667 anomalies) Cost per Anomaly: $10.08

Cost Element	Data Tracked During Demonstration	Estimated Costs
Validation Digging	• Costs were covered under the JV's RI outside of this demonstration. • Provided costs are estimated based on past ESTCP demonstrations and include reacquisition and intrusive investigation.	**Total Cost:** $110,989 (667 anomalies) Estimated Cost per Anomaly: $166.4
Final Report	• Develop project-specific final report	$25,000 (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 MetalMapper dynamic survey costs at MCAGCC were approximately double those costs for a dynamic MetalMapper survey where the survey acreage is contiguous. Additional time turning the MetalMapper and lining the instrument up significantly increased the costs to collect data on a per acre basis relative to previous, contiguous dynamic surveys. The costs encountered during this demonstration are applicable to an RI, while the costs to perform dynamic surveys on contiguous acreage are applicable to removal actions. The dynamic data collection costs for non-contiguous grids were at least twice the cost of performing dynamic surveys in contiguous grids. The dynamic processing costs are broken down for the MMPP target list and the MMDR target list. The MMDR data processing costs were more than twice as expensive as the MMPP; however, the MMDR target positions were much better, which could lead to cost savings in static data collection.
- **Static data collection:** TEMTADS data collection currently requires the reacquisition of target locations prior to cued data collection; therefore, it is generally more expensive to collect TEMTADS data than with the MetalMapper.
- **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 on a MR project. This demonstration was not a typical live site demonstration in that not all targets were dug; therefore, the amount of potential cost savings could not be determined. However, assuming that AGC could have led to a reduction of 70% of non-TOI digs, the total cost of AGC and intrusive investigation of 30% of the 667 targets is estimated at $69,000, which represents an approximate 38% reduction in the intrusive investigation costs.

8.3 COST BENEFIT

The primary driver for implementing AGC 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.

This demonstration was focused on applying the AGC process to RI sites where only a limited number of intrusive investigations could be performed; however, Arcadis has performed a cost evaluation to determine how the costs associated with this demonstration might apply to an RI where a more typical AGC approach is applied (*i.e.*, where all anomalies potential representative of TOI are dug). As shown above, the dynamic MetalMapper costs were significantly greater when the grids were not contiguous and therefore, this cost evaluation assumes that an EM61-MK2 is used to collect DGM data and that a TEMTADS is used to collect cued data. **Table 8-2** provides cost-benefit analyses for performing AGC using the costs listed in **Table 8-1** for the TEMTADS. 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 project that includes an EM61-MK2 survey and intrusive investigation of all anomalies.

Table 8-2 contains three scenarios:

- **Scenario 1:** Greatest cost savings associated within reducing the number of targets requiring intrusive investigation by 90%.
    - AGC Cost Savings: 46%
- **Scenario 2:** Intermediate cost savings associated within reducing the number of targets requiring intrusive investigation by 80%.
    - AGC Cost Savings: 36%
- **Scenario 3:** Lowest cost savings associated within reducing the number of targets requiring intrusive investigation by 70%.
    - AGC Cost Savings: 27%

Table 8-2: AGC Cost Evaluation

Cost Element	Cost per Unit	Unit	Quantity	Traditional MR Costs	AGC Costs
Scenario 1 – Greatest Cost Savings: 90% Anomaly Reduction					
EM61-MK2 Survey[1]	$4,000	Acres	5	$20,000	$20,000
TEMTADS Mobilization	$20,000	Lump Sum	1	$0	$22,000
Cued TEMTADS[2]	$48.33	Anomaly	2000	$0	$96,660
Classification	$10.08	Anomaly	2000	$0	$20,160
Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
Dig 10% of Anomalies	$166.4	Anomaly	200	$0	$33,280
			Total:	**$352,800**	**$192,100**
			Cost Savings ($):		**$160,700**
			Cost Savings (%)[3]		**46%**

Cost Element	Cost per Unit	Unit	Quantity	Traditional MR Costs	AGC Costs
Scenario 2 – Intermediate Cost Savings: 80% Anomaly Reduction					
EM61-MK2 Survey[1]	$4,000	Acres	5	$20,000	$20,000
TEMTADS Mobilization	$20,000	Lump Sum	1	$0	$22,000
Cued TEMTADS[2]	$48.33	Anomaly	2000	$0	$96,660
Classification	$10.08	Anomaly	2000	$0	$20,160
Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
Dig 20% of Anomalies	$166.4	Anomaly	400	$0	$66,560
			Total:	**$352,800**	**$225,380**
			Cost Savings ($):		**$127,420**
			Cost Savings (%)[3]		**36%**
Scenario 3 – Low Cost Savings: 70% Anomaly Reduction					
EM61-MK2 Survey[1]	$4,000	Acres	5	$20,000	$20,000
TEMTADS Mobilization	$20,000	Lump Sum	1	$0	$22,000
Cued TEMTADS[2]	$48.33	Anomaly	2000	$0	$96,660
Classification	$10.08	Anomaly	2000	$0	$20,160
Dig All Anomalies	$166.4	Anomaly	2000	$332,800	$0
Dig 30% of Anomalies	$166.4	Anomaly	600	$0	$99,840
			Total:	**$352,800**	**$258,660**
			Cost Savings ($):		**$94,140**
			Cost Savings (%)[3]		**27%**

Notes:

1 – EM61-MK2 survey costs are estimated from other projects.

2 – Assumes an additional $750/day rental costs for the TEMTADS that was not required at Twentynine Palms.

3 – The cost savings presented here do not include additional costs that are anticipated to be consistent between the traditional MR and AGC cost estimates. These include, but are not limited to EM61-MK2 and intrusive investigation team mobilization costs, project management costs, and MEC demolition costs.

9.0 IMPLEMENTATION ISSUES

The field conditions encountered at MRP Site UXO 01 presented unique challenges. Although vegetation removal was conducted, a variety of robust weed exists throughout the site that could not be entirely removed because removal would require digging out the dense root ball. The deep sand encountered across much of the site would easily give way, allowing the tracked skid steer that moved the MetalMapper to dig several inches into the sand when turning. Small dunes and arroyos also presented a challenge in keeping the MetalMapper sled fully in contact with the ground while traversing dunes, which required significant practice. Arcadis' lessons learned in implementing the advanced EMI sensors in the field are summarized below.

- **MetalMapper Data Acquisition**
  - The investigation site layout (checkerboard grid pattern as opposed to a solid area) resulted in a significant decrease from anticipated to the actual dynamic MetalMapper production rates resulting from the increased number of times the sensor had to be turned at the end of the line. Collecting dynamic data with the EM61-MK2 or the TEMTADS likely would not have the same reduction in production rates and are likely better instruments to use during RIs where investigation grids are not contiguous.
  - An in-depth site visit was not allowed prior to the investigation at MRP Site UXO 01 due to ongoing training activities at MCAGCC. Such a visit may have illuminated the loose, sandy terrain issues that were encountered. The loose sand ended up representing a safety hazard when the tracked skid steer that was used to maneuver the MetalMapper made sharp turns. A wheeled, boom forklift was used to move the MetalMapper; however, the tires on the forklift proved ineffective in maneuvering in the loose sand.
  - The MetalMapper was utilized in the sled configuration with a small skid steer. This arrangement provided a field of view benefit that is not available with vehicles utilizing a standard steering wheel setup. The skid steer uses two hand-held operating levers to control steering and front/back motion. This allowed for a full forward field of view, good screen view, and a useful place to mount a trackpad equipped keyboard (**Figure 9-1**).
  - Sandy terrain necessitated the use of a tracked 'tow' vehicle that induced severe vibration on the CPU. The CPU was isolated with foam padding, but still shook enough that the video card and various connections became intermittent by the conclusion of the dynamic acquisition. More internal vibration damping would certainly alleviate some vibration issues, but sand/dust protection may be even more vital in certain environments.

Figure 9-1: MCAGCC UXO 1 MetalMapper Equipment Operator Field of View

- **TEMTADS Data Acquisition**
  - Although the TEMTADS was used exclusively for cued acquisition, the instrument had to be moved across difficult dune type terrain with deep sand to move from anomaly to anomaly. The four wheel design worked well distributing weight in this environment and traversing effort was similar to the EM61-MK2.
  - The hot swap capability is an advantage because battery life is relatively short; however emplacing the batteries under the CPU can be difficult due to the tight space afforded. A design allowing side access to the battery compartments would be a benefit.
  - Develop a standard method or applications to field verify that a background location is free from metallic objects. The system function test is field user friendly and gives an element of security to the field team that they are conducting operations correctly. A similar feature for background locations could help field teams to identify background locations that are not suitable for use while in the field.

10.0 REFERENCES

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Appendix A: Points of Contact

QAPP Recipients	Title	Organization	Telephone Number (optional)	E-mail Address or Mailing Address
Dr. Anne Andrews	Acting Director	ESTCP	571-372-6379	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08, Alexandria, VA 22350-3605 anne.andrews@osd.mil
Dr. Herb Nelson	MR Program Manager	ESTCP	571-372-6400	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08, Alexandria, VA 22350-3605 Herb.nelson@nrl.navy.mil
Ms. Katherine Kaye	Special Projects Consultant, MR	HydroGeoLogic, Inc.	410-884-4447	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190 kkaye@hgl.com
Ms. Angela Wimberly	Remedial PM	NAVFAC Southwest	619-532-4168	NAVFAGC SW, Central IPT 937 Harbor Drive, Bldg. 1, 3rd Floor San Diego, California 92132 angela.wimberly@navy.mil
Ms. Diane Silva	Records Manager	NAVFAGC SW	619-556-1280	NAVFAGC SW 1220 Pacific Highway, Bldg. 3519 San Diego, California 92136 diane.silva@navy.mil
Mr. Plessie Ellitt	Activity Primary Point of Contact (POC)	MCAGCC Twentynine Palms	Not available	NREA Box 788110, Building 1451 MCAGCC Twentynine Palms, California 92278-8110
Ms. Margaret Sheatzley	Activity POC	MCAGCC Twentynine Palms	760-830-7722	Building 1418, Room 23 MCAGCC Twentynine Palms, California 92278-8110 margaret.m.sheatzley@usmc.mil
Ms. Rania Zabaneh	PM	DTSC	714-484-5479	DTSC, Cypress Field Office 5796 Corporate Avenue Cypress, California 90630 Rania.Zabaneh@dtsc.ca.gov

Mr. Roman Racca	Statewide Munitions Response Coordinator	DTSC	916-255-6407	DTSC 8800 Cal Center Drive Sacramento, CA. 95826 Roman.Racca@dtsc.ca.gov
Ms. Eileen Mananian	DTSC Supervisor	DTSC	714-484-5349	DTSC, Cypress Field Office 5796 Corporate Avenue Cypress, California 90630 Eileen.Mananian@dtsc.ca.gov
Ms. Phan Le	PM	RWQCB, Colorado River Basin Region	760-346-7491	RWQCB, Colorado River Basin Region 73-720 Fred Waring Drive, Suite 100 Palm Desert, California 92260 ple@waterboards.ca.gov
Ms. Susan Burtnett	PM	Arcadis and JV	813-857-0021	Arcadis 14025 Riveredge Drive, Suite 600 Tampa, FL 33637 Susan.burtnett@arcadis-us.com
Mr. Steve Stacy	Senior Geophysicist/Principal Investigator	Arcadis and JV	703-465-4234	Arcadis 3101 Wilson Blvd, Suite 550 Arlington, Virginia 22201 Steve.Stacy@arcadis-us.com
Mr. Greg Peterson	Senior UXO Supervisor	Arcadis and JV	760-602-3804	Arcadis 1525 Faraday Ave, Suite 290 Carlsbad, California, 92008 Gregory.Peterson@arcadis-us.com
Mr. Al Larkins	MEC Corporate QC Manager	Arcadis and JV	410-332-4814	Arcadis 300 East Lombard St., Suite 1510 Baltimore, Maryland 21202 Al.Larkins@arcadis-us.com

ADDENDUM TO:

ESTCP Munitions Response
Live Site Demonstration Report
Twentynine Palms
November 2015
Principal Investigator – Mr. Steve Stacy
ARCADIS-US, Inc.

Above mentioned Demonstration Report produced in support of requirements for Environmental Security Technology Certification Program (ESTCP) Project #201229, Comparative Demonstration and Evaluation of Classification Technologies.

This Addendum contains information regarding Appendices B through F of the ESTCP Munitions Response Live Site Demonstration Report detailing work conducted at Twentynine Palms 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. Contents of each appendix are detailed below:

Appendix	Content
Appendix B	GPS Control Point Data Sheets
Appendix C	Geophysical Data
Appendix D	Geophysical Data Maps
Appendix E	Extrusive Investigation Results
Appendix F	Ranked Anomaly List

These appendices are available for public release and unlimited distribution. If interested in requesting copies of these appendices, please contact the ESTCP Munitions Response Program Manager via email:

Dr. Herb Nelson
Munitions Response Program Manager
Environmental Security Technology Certification Program (ESTCP)
herb.nelson@nrl.navy.mil