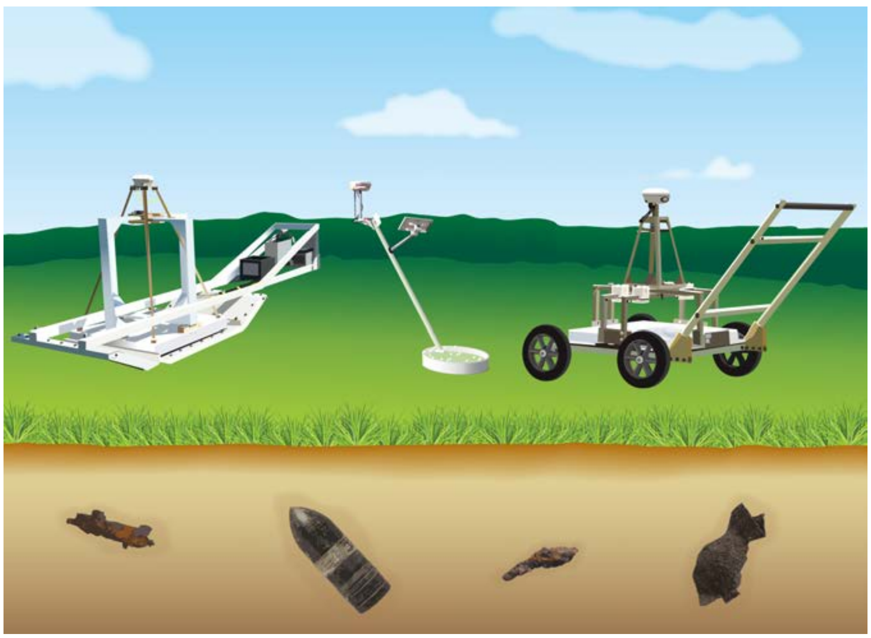
Guidance Document

Geophysical Classification for Munitions Response



August 2015

Prepared by
The Interstate Technology & Regulatory Council
Geophysical Classification for Munitions Response Team

ABOUT ITRC

The Interstate Technology and Regulatory Council (ITRC) is a public-private coalition working to reduce barriers to the use of innovative environmental technologies and approaches so that compliance costs are reduced and cleanup efficacy is maximized. ITRC produces documents and training that broaden and deepen technical knowledge and expedite quality regulatory decision making while protecting human health and the environment. With private- and public-sector members from all 50 states and the District of Columbia, ITRC truly provides a national perspective. More information on ITRC is available at http://www.itrcweb.org.

ITRC is a program of the Environmental Research Institute of the States (ERIS), a 501(c)(3) organization incorporated in the District of Columbia and managed by the Environmental Council of the States (ECOS). ECOS is the national, nonprofit, nonpartisan association representing the state and territorial environmental commissioners. Its mission is to serve as a champion for states; to provide a clearinghouse of information for state environmental commissioners; to promote coordination in environmental management; and to articulate state positions on environmental issues to Congress, federal agencies, and the public.

DISCLAIMER

GCMR-2

Geophysical Classification for Munitions Response

August 2015

Prepared by
The Interstate Technology & Regulatory Council
Geophysical Classification for Munitions Response

Interstate Technology & Regulatory Council (ITRC). 2015. *Geophysical Classification for Munitions Response* (GCMR-2). Washington, D.C.: Interstate Technology & Regulatory Council, Geophysical Classification for Munitions Response Team. http://www.itrcweb.org/

ACKNOWLEDGMENTS

The Interstate Technology & Regulatory Council (ITRC) Geophysical Classification for Munitions Response Team wishes to acknowledge the individuals, organizations, and agencies that contributed to this technical and regulatory guidance document.

As part of the broader ITRC effort, the Geophysical Classification for Munitions Response Team effort is funded by the U.S. Department of Defense, the U.S. Department of Energy, the U.S. Environmental Protection Agency, and ITRC's Industry Affiliates Program.

The Geophysical Classification for Munitions Response Team greatly appreciates the efforts of the team members who provided valuable written input in the development of this technical and regulatory guidance, as well as those who reviewed and commented on this document.

The team recognizes the efforts of the following state environmental personnel who contributed to the development of this guidance:

Team Leaders:

- Tracie White, Colorado Department of Public Health & Environment
- Roman Racca, California Department of Toxic Substances Control

State Team Members:

- Julie Ange, Alabama Department of Environmental Management
- Kim Churchill, Michigan Department of Environmental Quality
- William Harmon, Michigan Department of Environmental Quality
- Iver McLeod, Maine Department of Environmental Protection
- Abigail Power, Texas Commission on Environmental Quality
- Stephen Sterling, California Department of Toxic Substances Control
- Fred Vreeman, Alaska Department of Environmental Conservation
- Ed Walker, California Department of Toxic Substances Control

The team recognizes the contribution of the following community stakeholder representative:

- Lenny Siegel, Center for Public Environmental Oversight

The team also recognizes the contributions of the following federal agency representatives:

- Ed Corl, NAVSEA Laboratory Quality and Accreditation Office
- Jane Dolan, U.S. Environmental Protection Agency
- Bryan Harre, NAVFAC Engineering and Expeditionary Warfare Center
- Doug Maddox, U.S. Environmental Protection Agency
- Kari Meier, U.S. Army Corps of Engineers

- Herb Nelson, SERDP and ESTCP
- Andrew Schwartz, U.S. Army Corps of Engineers
- Amy Walker, U.S. Army Corps of Engineers

Finally, the team recognizes the contributions of the following consultants and industry representatives:

- Carla Gabarini, NAVSEA Laboratory Quality and Accreditation Office Support
- Dean Keiswetter, Acorn Science and Innovation, Inc.
- Tamir Klaff, CH2M HILL
- Lizanne Simmons, Kleinfelder
- Ryan Steigerwalt, Weston Solutions, Inc.

EXECUTIVE SUMMARY

For decades, the U.S. Department of Defense (DOD) has produced and used military munitions for live-fire testing and training to prepare the U.S. military for combat operations; as a result, unexploded ordnance (UXO) and discarded military munitions may be present at over 5,200 former ranges and former munitions operating facilities throughout the United States. Nearly half of these sites require a munitions response, at an estimated cost to complete of $14 billion and with a completion date of 2100.

To identify munitions for removal at these sites, DOD and its contractors have used various types of detection instruments to simply detect buried metal objects. This traditional technique requires the excavation and examination of most of the detected items, to determine whether they are military munitions; consequently, even highly trained UXO-qualified personnel typically excavate hundreds of metal items for each one munition recovered. Given this inefficiency, only limited acreage can be addressed with existing resources and budgets, and the time required for unnecessary excavations prolongs the munitions response process.

To improve the efficiency of munitions response, DOD's Environmental Security Technology Certification Program and its research partners in academia and industry have developed a new, advanced approach: geophysical classification. Geophysical classification is the process of using advanced sensor data to make principled decisions about whether buried metal objects are potentially hazardous munitions that should be excavated (that is, targets of interest) or items such as metal clutter and debris that can be left in the ground (non-targets of interest).

For geophysical classification, metallic items must initially be detected beneath the ground surface; however, this step is then followed by the use of advanced electromagnetic induction sensors to collect additional data. With the additional data, geophysicists can estimate the depth of each buried item, as well as intrinsic properties related to its size, material composition, wall thickness, and shape. Thus, by using the geophysical classification approach, a munitions response can focus on excavating only the buried metal items identified as potential munitions. Using this process, in combination with quality assurance investigations of other anomalies, results in a more efficient munitions response effort using more defensible data.

This document clearly explains the process of geophysical classification; describes its benefits and limitations, including site-specific characteristics that can impose limitations on its use; and most importantly discusses the information and data needed by regulators to monitor and evaluate the use of the technology. This document also emphasizes the use of a systematic planning process to develop data acquisition and decision strategies at the outset of a munitions response effort. Systematic approaches include the U.S. Environmental Protection Agency's Data Quality Objectives process and the Uniform Federal Policy for Quality Assurance Project Plans guidance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Geophysical classification is the process of making principled decisions, using data collected by geophysical sensors, to differentiate between buried metal items that are potentially hazardous and those that can be safely left in the ground (nonhazardous metallic items) during munitions response actions. This document provides technical and regulatory guidance for the application of geophysical classification using advanced sensors for munitions response projects. Elements of this document include the following:

- an overview of the science used to classify the source of a detected anomaly (that is, the metallic item that caused the anomalous geophysical response), as well as the benefits, limitations, and appropriate applications of the technology
- the data requirements necessary to successfully perform classification
- structured project planning guidance to ensure that classification is implemented correctly
- quality assurance (QA) and quality control (QC) procedures specific to classification that promote stakeholder and regulatory acceptance
- direction on integrating quality systems into a geophysical classification project, including specific references within the Geophysical Classification for Munitions Response, Quality Assurance Project Plan (AGC-QAPP) Template (IDQTF 2016)

The concepts presented in this document apply to all U.S. Department of Defense (DOD) Components (for example, U.S. Army) and all federal and state regulatory agencies.

As further described in Section 1.3, geophysical classification technology has been demonstrated on a number of terrestrial sites, with a range of complexities, across the United States. The technology demonstrations that have validated classification are referenced throughout this document to provide technology insight and lessons learned. Case studies of demonstrations and production projects are also provided to illustrate the process of geophysical classification at two representative sites (see Appendix A).

This document provides a sufficient level of detail to understand the applicability, benefits, and limitations of geophysical classification. It also presents adequate information to (1) evaluate whether classification is appropriate for use on a site; (2) establish realistic expectations of classification based on what has been demonstrated to date; and (3) assess whether classification is being implemented correctly.

This document assumes familiarity with conventional munitions response procedures and technologies as well as with the Comprehensive Environmental Response, Compensation, and Liability Act process; however, additional guidance resources are provided below in Section 1.5.

1.1 Target Audience

Those who understand current munitions response tools and procedures (for example, geophysical surveys, sensors, data analysis) will benefit most from this document. For federal and state environmental regulators, scientists, and engineers, as well as contractors, munitions response managers, technical staff, geophysicists, and stakeholders, this document adequately explains how geophysical classification can be used in munitions response. Stakeholders with an interest in a particular munitions response site (MRS) at which classification has been or may be proposed will also benefit from this document.

1.2 Purpose of Geophysical Classification

For decades, DOD has produced and used military munitions for live-fire testing and training to prepare the U.S. military for combat operations. As a result, unexploded ordnance (UXO) and discarded military munitions (DMMs) may be present at over 5,200 former ranges and former munitions operating facilities (such as production and disposal areas) throughout the U.S. Nearly half of these sites require a munitions response—at an estimated remediation cost of $14 billion and with a completion date of 2100.

To identify munitions for removal at these MRSs, DOD and its contractors have used various types of detection instruments to simply detect buried metal objects. Using this traditional technique requires the excavation and examination of most of the detected items to determine whether they are military munitions, and even highly trained UXO-qualified personnel typically excavate hundreds of metal items for each munition recovered. Whether the excavation sites are recreational areas, habitat, farmland, or private backyards, or are located within military installations, this inefficiency has many negative effects, as follows:

- With existing resources and budgets, only limited acreage can be addressed.
- The time required for unnecessary excavations prolongs the munitions response process.
- Extended area closures and evacuations disrupt communities and recreational areas because the public is prohibited from entering active excavation sites.
- The digging of unnecessary holes can disturb landscape, vegetation, and cultural resources at the sites.

To address these issues and improve the efficiency of munitions response actions, DOD's Environmental Security Technology Certification Program (ESTCP), Strategic Environmental Research and Development Program (SERDP), and research partners in academia and private industry have developed—and demonstrated (see Section 1.3)—geophysical classification for munitions response.

For geophysical classification, metallic items must first be detected beneath the ground surface; however, this initial step is followed by the use of advanced electromagnetic induction (EMI) sensors to collect additional data. With these additional data, geophysicists can also estimate the depth and the intrinsic properties related to the size, material composition, wall thickness, and shape of each buried item.

Through this process, a munitions response can focus on investigating anomalies identified as possible munitions, and, combined with required QA investigations of other anomalies (Figure 1-1), will result in a more efficient munitions response effort using more defensible data. Further, geophysical classification can be more cost-effective than traditional technologies. Employing a simple but realistic cost model shows that, if 75% of the detected anomalies can be confidently classified as nontargets of interest (non-TOIs) and left in the ground, the area that can be remediated for a fixed budget roughly doubles.

Figure 1-1. Examples of items detected.

The items above include a munition (left), suspected munition (second from left), munition fragment (second from right), and debris (right).

1.3 Technology Development

In response to the 2003 Defense Science Board report and U.S. Congressional interest, ESTCP initiated the Geophysical Classification Pilot Program in 2007. The pilot program consists of demonstrations at a number of sites to validate the application of advanced electromagnetic sensors in a comprehensive approach to munitions response. SERDP had previously initiated research and development supporting these electromagnetic sensor and analysis techniques.

The goal of the pilot program is to demonstrate that classification decisions can be made explicitly, based on principled physics-based analysis that is transparent and reproducible. The pilot program objectives are to test and validate detection and classification capabilities of available and emerging technologies

Geophysical Classification for Munitions Response at Camp Beale, California

At the former Camp Beale demonstration site, the use of geophysical classification would have reduced the estimated number of excavated debris items by 78%. Note that, because this was a technology demonstration, items deemed hazardous as well as identified nonmunitions items were excavated. This demonstration is detailed in Appendix A.

on real sites under operational conditions, and to investigate how classification technologies can be implemented in cleanup operations.

A Program Advisory Group composed of representatives from the DOD Components and state and federal regulatory agencies was established at the beginning of the pilot program and has been involved in site selection, program design, data review, and the development of conclusions.

Since the pilot program was initiated, demonstrations with increasing levels of site challenges (for example, terrain, geology, vegetation) have been conducted across the country. These demonstrations have shown that successful classification is possible under the conditions tested, but they have also indicated some limitations and challenges.

In 2012, the Interstate Technology & Regulatory Council (ITRC) established a technical team to evaluate geophysical classification for munitions response. The team convened national experts in geophysics and munitions response, state and federal regulators, contractors involved in technology demonstrations, industry representatives anticipating the use of geophysical classification on future projects, and stakeholders. Key efforts of the team included understanding the current status of the technology and its readiness for transition to production use, identifying the benefits and limitations as well as QA/QC measures to ensure successful use, and evaluating potential regulator and stakeholder concerns regarding implementation of the technology (see Chapter 5).

The geophysical classification process and equipment described in this document represent the current state of the technology at the time this document was written. As the technology advances, new or updated sensors and analytical software may be developed and become commercially available. As the number of demonstrations and production projects utilizing classification increase, the classification library is expected to expand and additional information regarding the benefits and limitations of the technology may become available.

The ITRC Geophysical Classification for Munitions Response Team has concluded that geophysical classification is now ready for production use on munitions response projects. Team members expect that classification will likely be proposed for use in the near future, even as additional demonstrations are ongoing and understanding of the capabilities and limitations evolves. The team hopes that this guidance will enhance familiarity with, and the ultimate use of, geophysical classification on munitions response projects.

1.4 Classification in the Munitions Response Process

DOD performs cleanup at munitions response sites under its Military Munitions Response Program (MMRP). DOD executes the MMRP in accordance with the processes outlined in the Defense Environmental Restoration Program Management manual (DOD 2012); these processes are based on applicable environmental laws, such as the Comprehensive Environmental Response, Compensation, and Liability Act. Geophysical classification will help DOD improve the efficiency of munitions cleanup and assist in moving MRSs through the cleanup process.

Note that, while classification will continue to evolve and the benefits of the technology may be realized for various stages of munitions response projects, the focus of this document is on implementation of geophysical classification following site characterization. At some sites, a small pilot study to demonstrate the applicability of geophysical classification to site conditions is performed as a component of the project feasibility study, or prior to beginning a munitions response (removal or remedial) action. At other sites, data collected from equivalent sites with similar site conditions can fulfill this purpose.

During the development of geophysical classification, it has become apparent that the technology's level of success at a given site is directly related to the quality of the site characterization performed. This includes determination of expected munitions types and well-defined targets of interest (TOIs). TOIs can range from intact munitions to partial rounds or components with residual explosive and/or chemical constituents. In addition, it is necessary to have a clear expectation from stakeholders regarding the remedial goal, as well as the input of munitions experts with knowledge of (1) munitions that are known or expected to be on site; (2) the site's operational history; and (3) hazardous components that might exist following deployment, function, or malfunction during operations.

1.5 Additional Resources

The Geophysical Classification for Munitions Response Team has published the following documents:

- Introductory Fact Sheet
- Technical Fact Sheet
- Regulatory Fact Sheet

The ITRC UXO Team has published a number of related documents, as well as internet-based training. Copies of these documents and archives of internet-based training sessions can be found on the UXO Team page. These products reflect the state of technology and processes at the time of publication and do not necessarily represent current practices:

- *Breaking Barriers to the Use of Innovative Technologies: State Regulatory Role in Unexploded Ordnance Detection and Characterization Technology Selection* (UXO-1)
- *Technical/Regulatory Guideline for Munitions Response Historical Records Review* (UXO-2)
- *Geophysical Prove-Outs for Munitions Response Projects* (UXO-3)
- *Survey of Munitions Response Technologies* (UXO-4)
- *Quality Considerations for Munitions Response Projects* (UXO-5)
- *Frequently Asked Questions About Wide-Area Assessment for Munitions Response Projects* (UXO-6)

Additional information on the ESTCP Geophysical Classification Pilot Program can be found at the SERDP/ESTCP Web site, Classification Applied to Munitions Response.

2.0 TECHNICAL OVERVIEW

This section provides an overview of the science and technology behind geophysical classification.

2.1 Introduction to Geophysical Classification

Geophysical classification as applied on a munitions response project consists of the following four steps:

1. Detection. Detection involves the initial mapping and identification of buried metal objects on the site. Often referred to as digital geophysical mapping (DGM), this step can be accomplished with traditional or advanced geophysical sensors. The detection process is discussed in detail in Survey of Munitions Response Technologies (UXO-4).
2. Cued data collection. In this step, a richer data set is collected by positioning an advanced EMI sensor over each buried metal object detected, and then collecting 60–120 seconds of data. As the technology develops, this step may be combined with the detection step, requiring the collection of fewer cued data and reducing data collection to one mobilization.
3. Parameter extraction. Software analysis of the advanced sensor data estimates the intrinsic characteristics of each metal object. These estimated characteristics relate to the objects' size, shape, symmetry, aspect ratio, wall thickness, and material composition.
4. Classification. In this final step, the estimated characteristics are used to classify each buried metal object as either a potential munition that must be removed from the site or a fragment or piece of debris that can be safely left on the site.

2.1.1 Sensor Basics

Although successful geophysical classification of munitions using advanced EMI sensors has only recently been demonstrated, the underlying physics governing the building blocks of EMI sensors were explored and understood almost 200 years ago.

In the case of a basic metal detector used by treasure hunters and other hobbyists, an electrical current is sent through a circular coil, which is swept near to the ground by the operator. If a metal object is in the immediate vicinity of the coil, electrical currents are set up, or induced, in the metal object. The induced electrical currents in the metal decay over time (milliseconds [ms] time scale) and, in turn, generate secondary magnetic fields. The secondary magnetic fields induce currents to flow in the receive coil. The receive coil currents are measured, and the presence of the buried metal is indicated to the operator by a visual or audible signal. If there is no metal in the vicinity of the sensor coil, no secondary magnetic fields are generated (Figure 2-1) and no currents are induced in the receive coil.

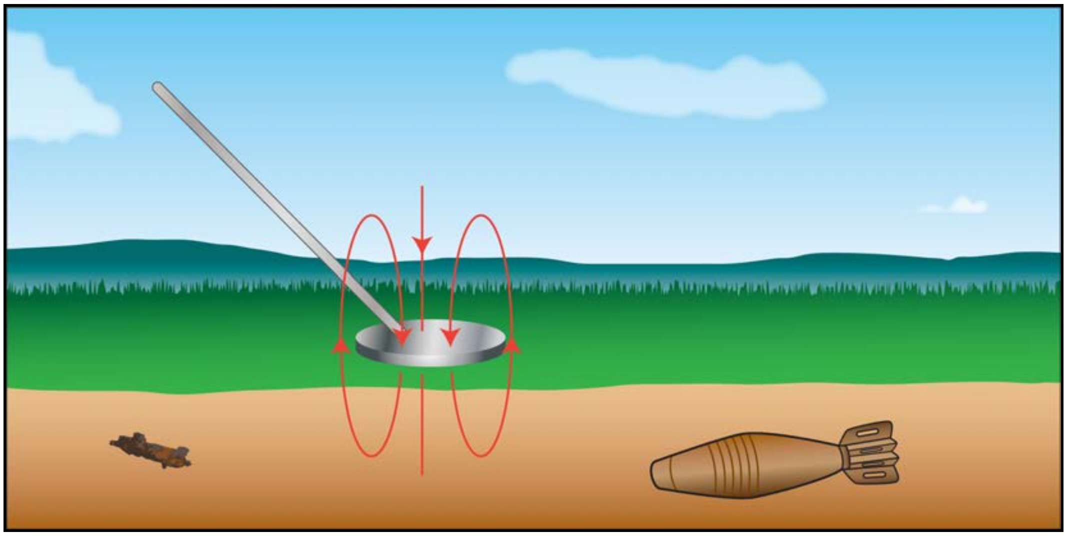


Figure 2-1. Operation of a basic metal detector.

EMI sensors can be configured for either continuous wave (frequency-domain) or pulsed induction (time-domain) operation (see Figure 2-2). Continuous wave sensors, such as the simple metal detector illustrated above, work by passing an alternating current through the transmit coil and analyzing the amplitude and phase delay of the received signal. Pulsed induction sensors use pulses of current through the transmit coil and only monitor the received current when the transmitter is turned off. The amplitude and decay properties of the received current are analyzed to estimate the objects' characteristics. All currently available advanced EMI sensors are pulsed induction sensors.

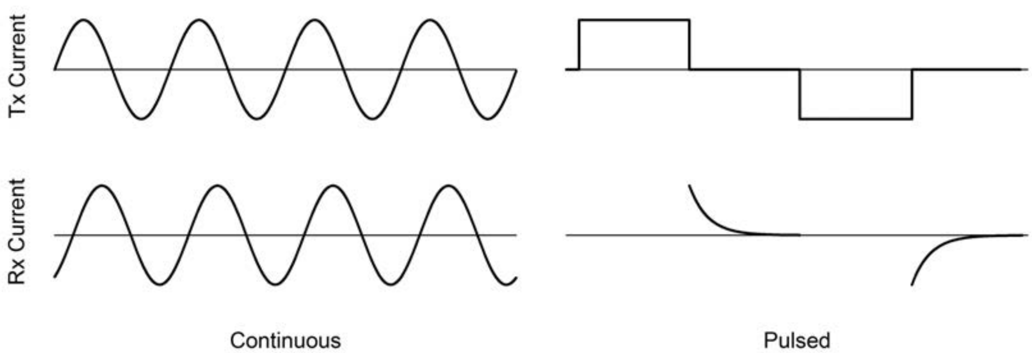


Figure 2-2. Comparison of continuous and pulsed induction.

Advanced EMI sensors that are designed to classify munitions vary in size and design, as shown later in this section, but are fundamentally simple and share the common components of the basic metal detector described above. The primary difference between basic metal detectors and the advanced EMI sensors used in classification involves the sophistication of the coil design. Basic metal detectors use a limited number of single-axis coils in a simple design; historically, the single axis EM61 cart was the most commonly used sensor to collect geophysical data on a conventional munitions response project. Advanced EMI sensors, on the other hand, make use of many transmit and receive coils that are rigidly assembled in a fixed-array configuration. The advanced sensors' coils also use low-noise digital electronics with large bandwidths to receive and record the induced currents.

The importance of multiple coils is illustrated in Figures 2-3 and 2-4. With a single-coil (single-axis) sensor (Figure 2-3), the orientation of the exciting field is one direction only and multiple measurements are required to excite all axes of the object being interrogated. A multiaxis sensor (Figure 2-4) can excite all axes of the object from a single measurement position without the need to stitch together the data from multiple measurements, each of which contains uncertainties in location and orientation.

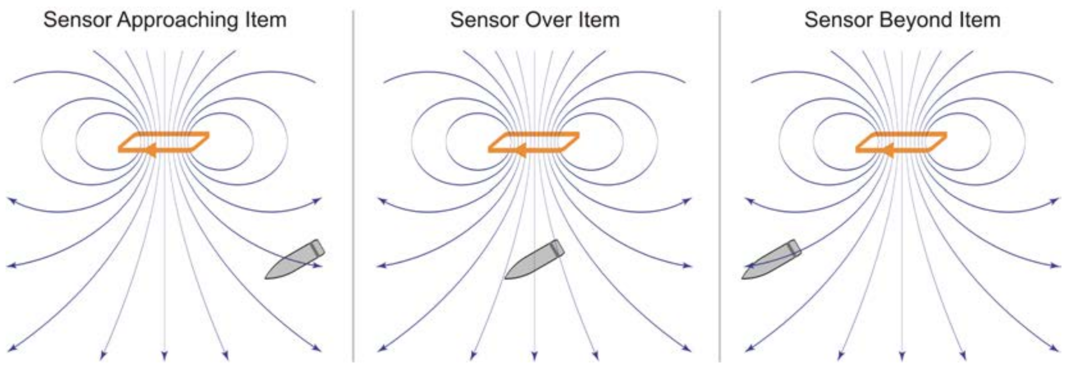


Figure 2-3. Single-axis sensor.
Multiple measurements are required to completely interrogate an object with a single-axis sensor.

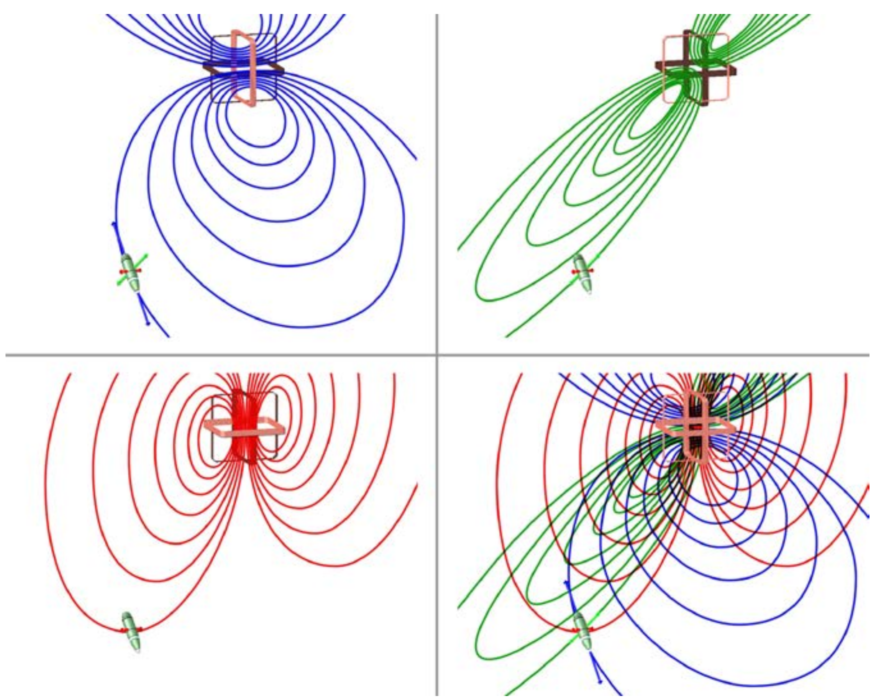


Figure 2-4. Multiaxis sensor.

A multiaxis sensor can completely characterize an object from a single measurement position.

The combination of the multiple receive coils, large bandwidth electronics, and supporting sensor data of the advanced EMI sensors results in the measurement of significantly more data than those collected with single-axis EM61 sensors. Figure 2-5 illustrates and compares the data volumes acquired at a single measurement point by both an advanced and traditional sensor.

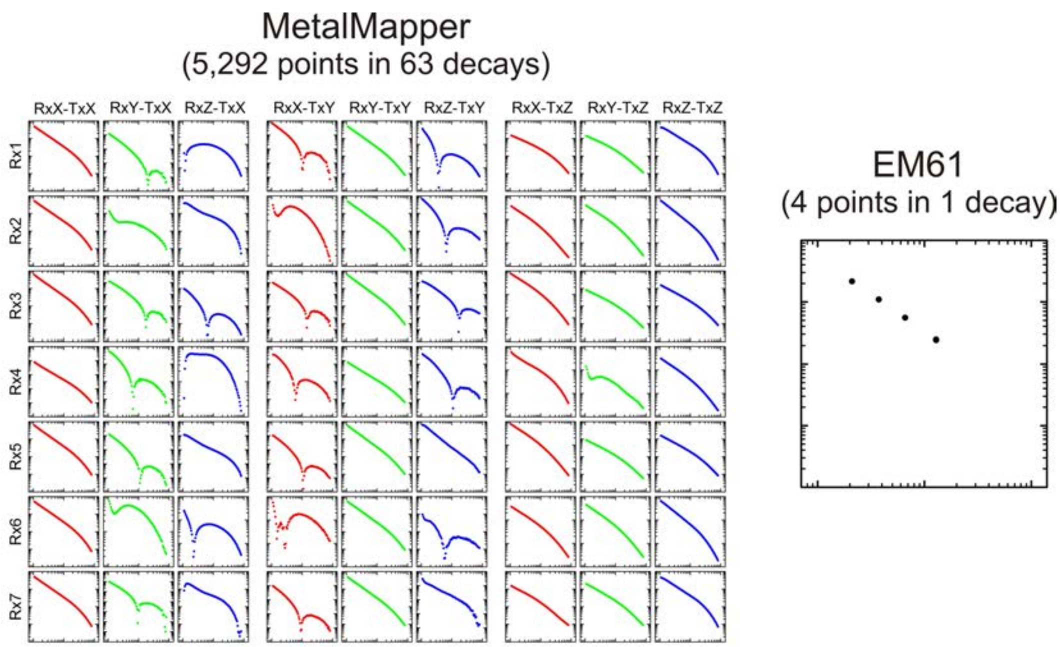


Figure 2-5. Data points collected at a single location.

For each location at which data are collected, an advanced sensor collects vastly more data points (all of the data points that make up the graphs shown on left) than does a traditional EM61 sensor (the four points shown on right).

2.1.2 Parameter Extraction

The measured decays from an EMI sensor are a function of the intrinsic properties of the object being interrogated as well as its orientation and distance from the sensor. In other words, a single item can produce a wide variety of signatures, depending on the way it is buried (Figure 2-6).

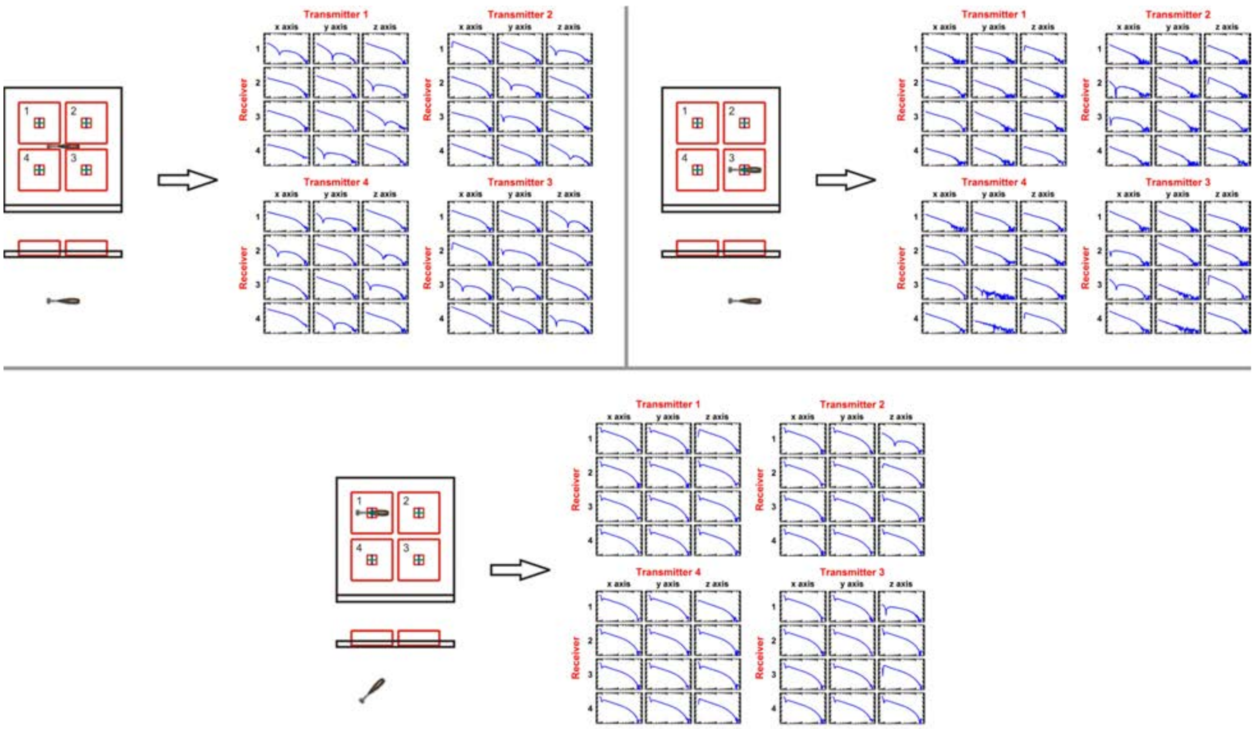


Figure 2-6. Measured decays from the TEMTADS 2x2 sensor based on location and orientation of the munition.

The decays resulting from the same object vary widely as the object is moved under the sensor.

To extract information that is intrinsic to the object, munitions classification using EMI data requires an analysis step that removes the effects of burial depth and object orientation and derives target response signatures that depend only on the object itself (intrinsic parameters). This is accomplished by fitting the observed data to an EMI response model (a process geophysicists refer to as inversion) to obtain the model parameters (the object's location and depth, the orientations of its principal axes, and its principal axis response functions) needed to reproduce the observed EMI data. This process is illustrated in Figure 2-7. The location, depth, and orientation parameters can be used to guide any subsequent excavation, while the principal axis polarizabilities (sometimes referred to as the object's EMI fingerprint) serve as the basis for the classification decision.

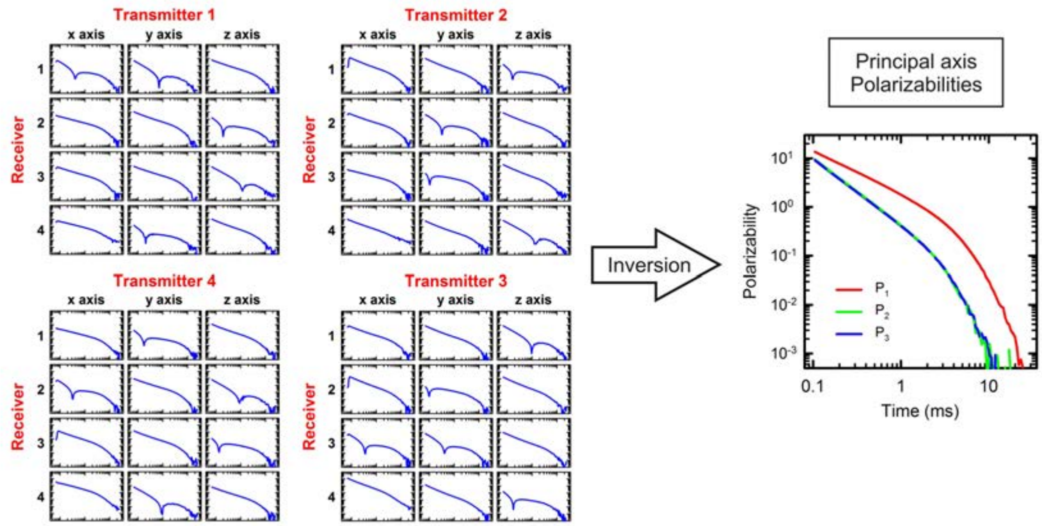


Figure 2-7. Principal axis polarizabilities.

The objective of the analysis process is reducing the sensor measurements, which are affected by the object's burial depth and orientation (on the left), to a single set of time-dependent signatures, which are invariant to the target's depth of burial and orientation (shown on the right). These reduced responses are referred to as the object's principal axis polarizabilities; they can reveal information about the object's size, shape, and wall thickness, and are used as the basis for subsequent classification decisions.

Inverting the data simply means working backward from the measured data using an EMI response model (commonly the dipole model) to obtain the object parameters (location, depth, orientation, intrinsic EMI response) most likely to have caused the measured anomaly.

At the onset, only the data collected over the target and the corresponding sensor location and orientation are available. The location, depth, and orientation of the buried object are unknown, as are the principal axis response functions. The inversion proceeds by systematically varying possible values for the object's parameters and using the dipole response model to calculate the expected sensor readings. As the parameters (location, depth, orientation, and principal axis responses) are systematically varied, the inversion process compares the set of calculated readings with the measured readings until the best match is found. Once completed, the inversion process has decoupled the depth of burial and orientation, which are extrinsic to the object, with the objects' intrinsic response coefficients, which form the basis of the classification decision. Extrinsic properties are not particularly useful for classification, but are still valuable information for field teams excavating the buried items.

Three principal axis responses are returned by the inversion process. Together, they are referred to as the objects' polarizabilities; although they may appear nondescript, they relate directly to physical attributes of the object under investigation. Information that can be inferred from the responses include size, shape, and wall thickness, as shown in Figure 2-8 and Table 2-1.

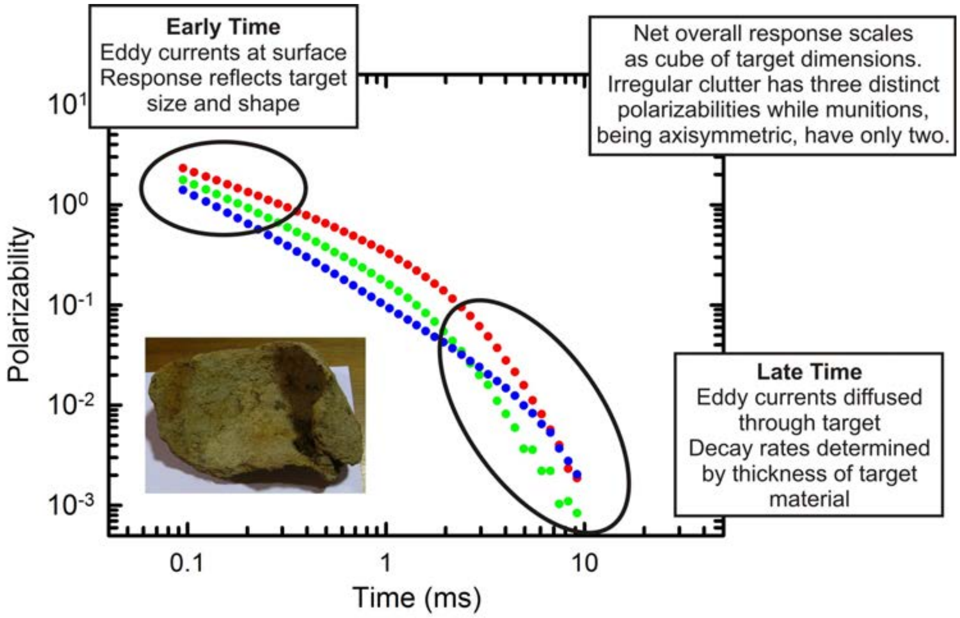


Figure 2-8. Polarizabilities for nonaxially symmetric clutter reveal three distinctly shaped responses.

Table 2-1. Basic relationship between properties of the polarizabilities and the source object

Polarizability Property	Object Property
Decay rate	Wall thickness and material property
Relative magnitude and shape of the three responses	Shape
Total magnitude	Size (volume)

Because munitions are inherently axially symmetric, the polarizabilities of munitions have the distinct characteristic of one large principal axis response and two smaller but equal responses; metallic objects that do not possess axial symmetry have three nonequal response curves. An example of polarizability responses for a munition and a fragment is presented in Figure 2-9.

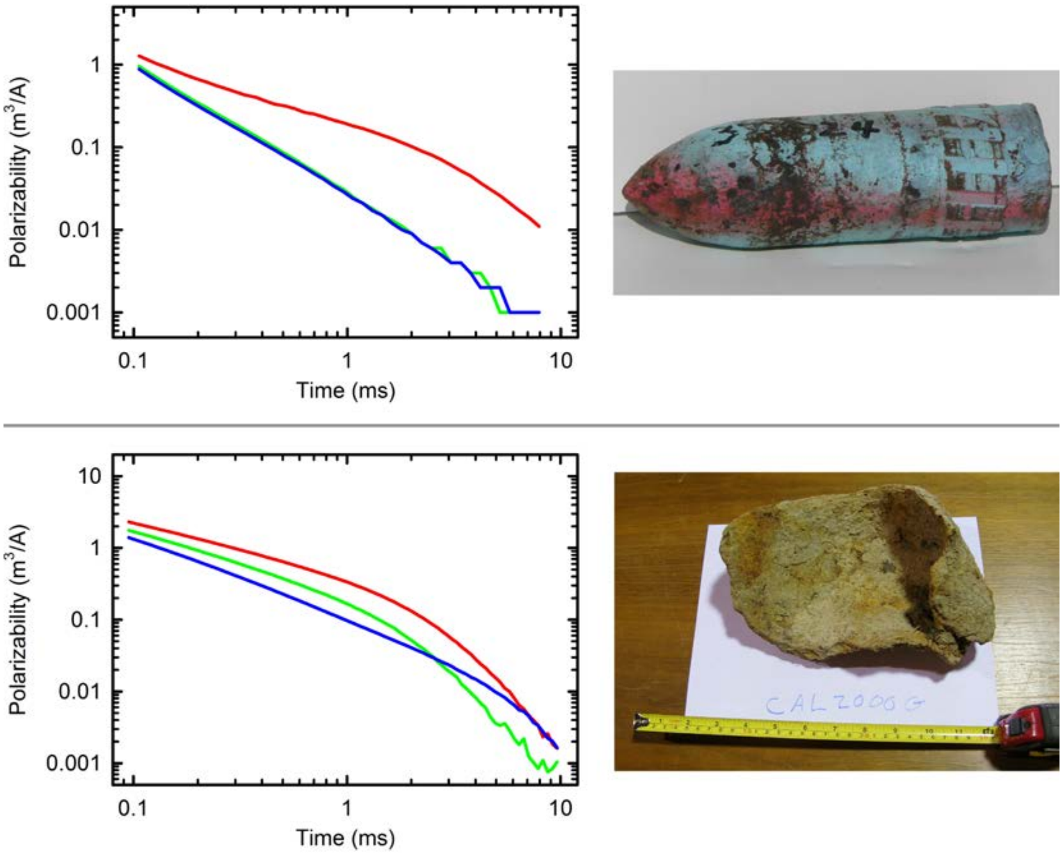


Figure 2-9. Polarizabilities of munition and fragment.

Polarizabilities for munitions are generally characterized by one large principal axis response and two smaller but equal responses (top pane). Polarizabilities for arbitrarily shaped metal items (bottom pane) do not possess this symmetry, and instead have three nonequal response coefficients.

The magnitude of the principal axis polarizabilities reflects the size of the object. Figure 2-10 shows that, while both of these objects are recognizable as symmetric munitions, the 75 millimeter (mm) projectile is larger than the 37 mm projectile by a factor of 6–8.

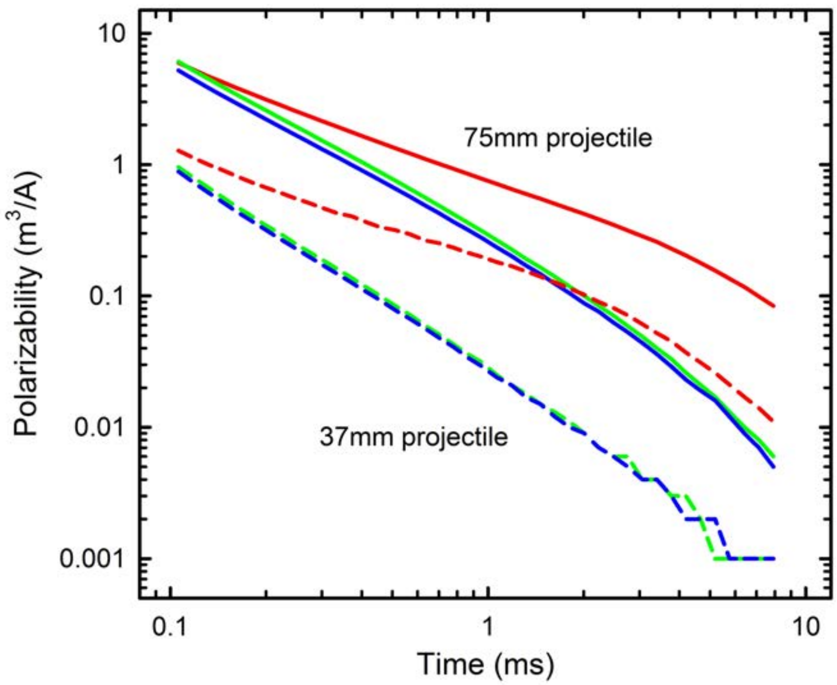


Figure 2-10. Polarizabilities as a function of size.
The principal axis polarizabilities scale with the size (volume) of the object.

2.1.3 Classification

The final step in this process involves making a classification decision for each detected metal object. This can be accomplished by comparing each object's polarizabilities to previously measured munitions' polarizabilities. Statistical classifier algorithms (using machine learning methods) and library-matching classification applications have progressed through the ESTCP Geophysical Classification Pilot Program (SERDP/ESTCP 2014a), and most practitioners now use a library-matching approach.

The library-matching process proceeds by quantifying the difference between the derived polarizabilities of each detected buried metal object with the polarizabilities of known munition items in a library. The objective is to specify how similar the polarizabilities of the unknown objects are to polarizabilities for known objects. There are multiple technical approaches for quantifying the similarities, but the essence of the classification process is to compare the amplitudes and shapes in a numerical and quantitative manner. In Figure 2-11, the polarizabilities of an unknown object (the colored lines) are compared to signatures of three different specific munitions items: 37 mm, 75 mm, and 105 mm projectiles (shown in gray). It is visually apparent that the signatures of the unknown buried metal object are similar to the 75 mm signatures. In this particular case, the unknown object was indeed later proved to be a 75 mm projectile. A screenshot of the library used for the comparison in Figure 2-11 is presented in Figure 2-12.

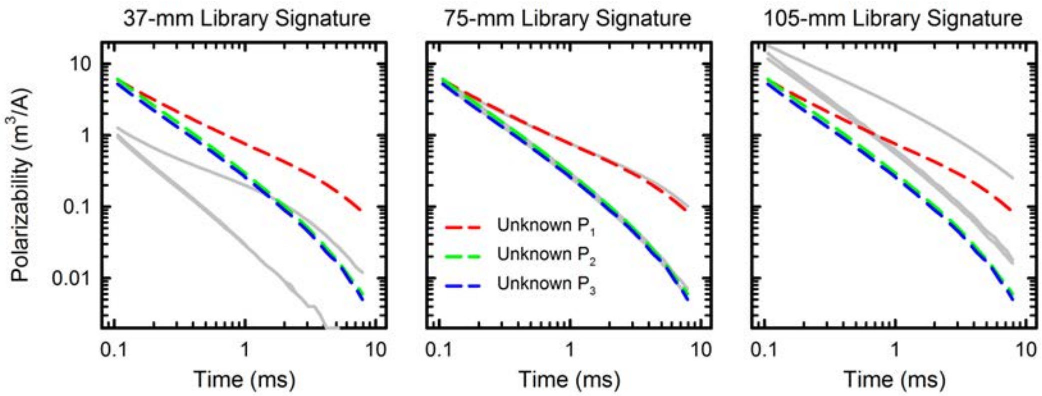


Figure 2-11. Library comparison.

Comparison of an unknown buried metal object, shown in color, with library signatures for 37 mm, 75 mm, and 105 mm projectiles. In this case, it is visually apparent that the unknown object is a 75 mm projectile.

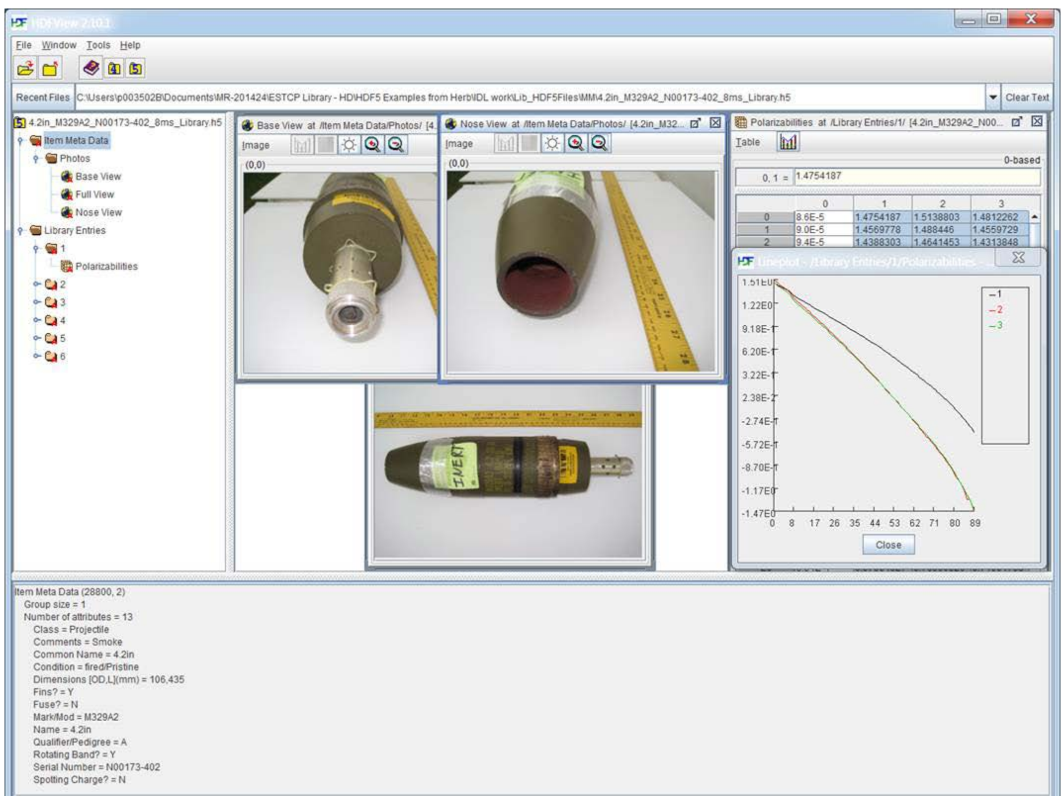


Figure 2-12. Collection of EMI signatures for various types of munitions.

As shown here, libraries often consist of not only the EMI signatures (shown in the middle portion of the figure), but also photographs and additional statistical attributes, such as decay rates, size estimates, and descriptions of the specific munitions items.

Comparisons can be made between the polarizabilities of each unknown object and those of the other unknown objects on the site, just as a numerical comparison can be made between the polarizabilities of the unknown objects and those in the project-specific library. This process, illustrated in Figure 2-13, identifies groups of objects (often termed clusters) with similar polarizabilities. A representative sample of objects in a cluster can be excavated to determine whether those objects are hazardous.

Munitions not in a project-specific library can still be identified as TOIs through either of the following means: (1) a large number of items have similar EMI characteristics; or (2) an item has characteristics that uniquely distinguish it as a TOI. The former, commonly referred to as a cluster, is identified by the analyst as a group of very similar sources for which there is no ground truth; these items cannot be confidently classified as non-TOIs. A small number of the cluster items must be excavated to reveal their identity, and if any are found to be TOIs, their EMI characteristics are added to the project-specific library and included in all future library-matching activities for that site. When the EMI characteristics of an unknown source suggest it is long and cylindrical (referred to as axially symmetric) and thick walled (even if there is only one such anomaly across the entire project site), that item should be identified for excavation because its characteristics are common to munitions. Although these characteristics are not measured directly by the EMI instrument, the intrinsic properties are determined through careful analysis of the EMI signature. As with cluster items, if a source having a munitions-like signature (in the EMI sense) is discovered to be a TOI, that signature is included in all future library-matching activities.

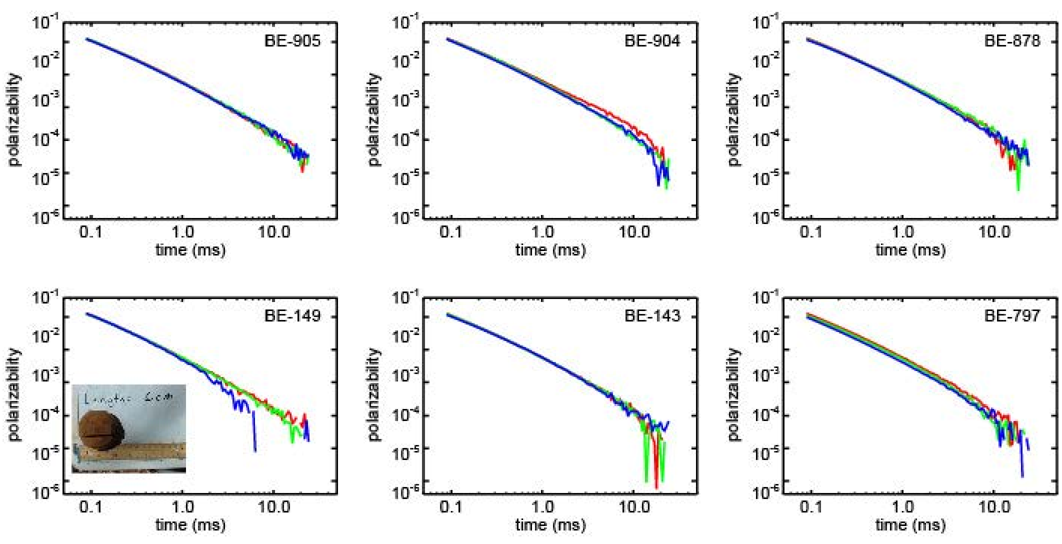


Figure 2-13. Cluster of unknown objects' polarizabilities.

These objects were detected during the ESTCP demonstration at former Camp Beale. One of the objects was excavated and determined to be an expended fuse.

Because the library is used as the point of comparison for identifying TOIs, the integrity and content of the library is important to the ultimate success of the classification project. In other words, if a particular type of munition is anticipated or known to be present on a site, the library should contain reference signatures for it. Site historical records and prior munitions response information should be reviewed to identify munition types.

A baseline master library of munition signature responses is being compiled by ESTCP. The master library will reside on a DOD-hosted website, and periodic updates to the library will be coordinated by DOD. The government project manager will be responsible for ensuring that the current version of the master library is obtained at the beginning of the project. The site team will construct a site-specific library by adding any unique munitions known to be at the site and, in some cases, removing small munitions that are known to not be present. This site-specific library can be modified during the course of the project as new information about the munitions on the site is obtained.

2.2 Advanced EMI Technologies

The most widely available advanced EMI sensor is the MetalMapper, developed by Geometrics (Geometrics 2015). As shown in Figure 2-14, this system is composed of three orthogonal 1 meter (m) x 1 m transmitters for target illumination, and seven three-axis receivers for recording the EMI response decay. Its sampling is electronically programmable, but it typically measures the decay out to 8 ms after the transmitters are turned off. The sensor is normally deployed in a sled configuration, mounted to a tractor or all-terrain forklift, although other schemes are possible. Centimeter (cm)-level-accuracy global positioning system (GPS) equipment is used for navigation and geolocation, and an inertial measurement unit (IMU) is used to measure platform orientation.

Figure 2-14. MetalMapper.

The drawing on the left shows the three orthogonal transmit coils and the seven three-axis receive cubes. The photo on the right shows the MetalMapper in its standard deployment mode on the back of a tractor.

The MetalMapper system is designed to be used in both survey and cued detection modes. In survey mode, only the z-axis transmitter is used for excitation, which results in a shorter measurement period. This allows higher survey speeds and more area coverage per hour. All three axes of all seven receive cubes are used to monitor the response decay. In cued mode, the MetalMapper is positioned over each buried item on its target list and collects the full suite of three-axis transmit, three-axis receive data while stationary.

> ***Survey mode****—a data collection scheme in which the user scans the ground with a sensor to accomplish 100% coverage (also referred to as a reconnaissance survey, dynamic survey, or detection survey)*
>
> ***Cued mode****—a data collection scheme in which the user positions the sensor at discrete XY locations previously identified by other means (also referred to as static or stationary measurement)*

Another commonly used sensor system is the "TEMTADS 2x2," which was developed by the Naval Research Laboratory. This sensor is composed of four individual EMI transmitters with three-axis receivers, arranged in a 2 x 2 array, as shown in Figure 2-15. The center-to-center distance between the individual sensors is 40 centimeters (cm), yielding an 80 x 80 cm array. The data acquisition (DAQ) computer is mounted on a backpack worn by one of the operators. A second operator controls the data collection using a tablet computer that wirelessly communicates with the DAQ computer. The second operator also manages field notes and team orienteering functions.

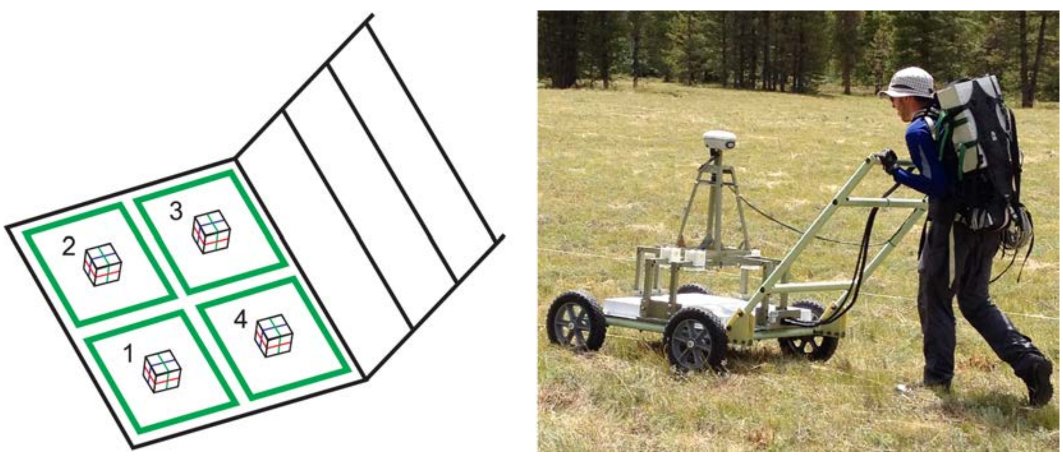


Figure 2-15. TEMTADS 2x2.
The drawing on the left shows the four individual sensors in the array, each comprising a z-axis transmit coil and a three-axis receive cube. The photograph on the right shows the TEMTADS 2x2 in survey mode.

In survey mode, each of the four TEMTADS sensors is energized sequentially, and the decay data from all 12 receive coils are recorded to 2.7 ms with minimal averaging. This allows for reasonable survey speeds. For cued measurements with the array static, the four transmitters are energized sequentially and the response is recorded for 25 ms after transmitter turnoff, resulting in 48 (4 x 4 x 3) transmit/receive pairs.

The man-portable vector (MPV), a handheld EMI sensor, has been designed to extend the classification performance of the latest vehicle-based geophysical platforms at the numerous MRSs where forest vegetation or challenging terrain limit access to these platforms. Because of its small size, the MPV has a lower areal coverage rate than larger units. It is composed of a single circular transmit coil and an array of five three-axis receive cubes, as shown in Figure 2-16. The MPV system is still under development and not yet commercialized.

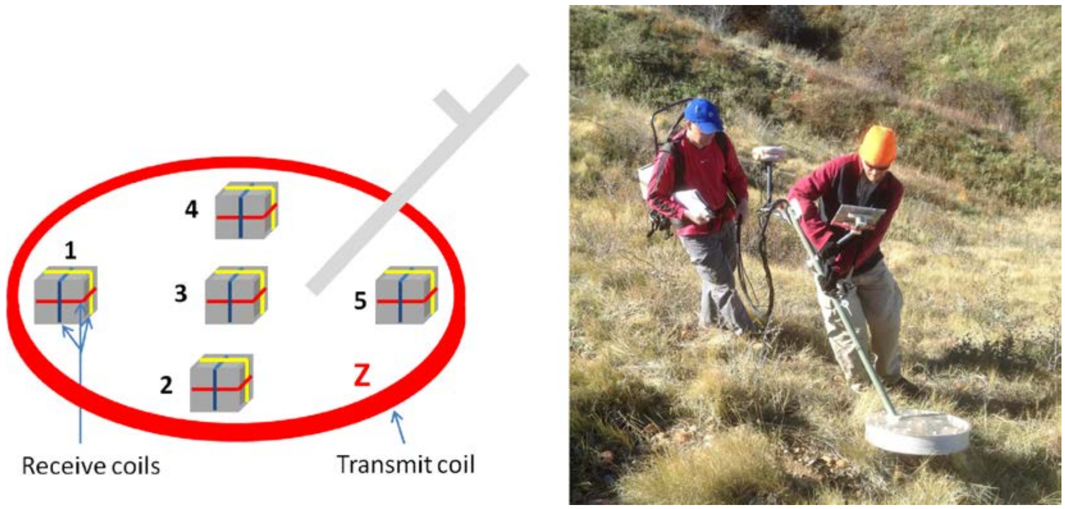


Figure 2-16. Man-portable vector.
The drawing on the left shows the MPV's transmit coil and the five three-axis receive cubes. The photograph on the right shows the MPV in survey mode.

The characteristics of these three sensors are summarized in Table 2-2.

Table 2-2. Summary of the characteristics of three advanced EMI sensors

Sensor	Description	Effectiveness	Implementation Issues	Availability
MetalMapper	• 1 m cube • Three-axis transmitter • Seven three-axis receive cubes • Sample to 8 ms after transmitter turnoff	• Near-perfect classification at demonstration sites • Good depth performance—large transmit moment	• Both survey and cued modes • Vehicular-borne, so some sites precluded • Requires GPS	Commercially available

Table 2-2. Summary of the characteristics of three advanced EMI sensors (continued)

Sensor	Description	Effectiveness	Implementation Issues	Availability
TEMTADS 2x2	• Mounted on a small cart, overall dimension 80 cm^2 • Backpack is 25 pounds (lbs.) • Four single-axis transmitters • Four three-axis receive cubes • Sample to 25 ms after transmitter turnoff	• Near-perfect classification at demonstration sites • Less depth capability—smaller transmit moment; best to 50 cm	• Both survey and cued modes • Cart-based deployment • Operation with or without GPS	Soon to be commercially available (five arrays currently available)
MPV	• Hand carried on wand, 12 lbs. • 50 cm single-axis transmitter • Five three-axis receive cubes • Sample to 8 ms after transmitter turnoff • Can be manipulated in three dimensions to obtain multiple looks at the target	• Near-perfect classification at demonstration sites • Less depth capability—smaller transmit moment; best to 50 cm	• Both survey and cued mode • Small and maneuverable for applications in wooded areas • Survey mode with GPS; cued mode with local beacon positioning	Developmental sensor

2.3 Benefits

Geophysical classification provides several benefits that make it worthy of consideration over current standard technology, as discussed below.

2.3.1 Decision Making

With standard technology, the geophysical sensor placed over a piece of metal produces a reading that simply indicates the presence of a metallic object somewhere beneath that sensor. Many things can affect the magnitude of this reading, such as the size and depth of the metallic object. Because traditional sensors only produce a reading in one plane, the only information known is the size of the reading, which could vary due to a wide variety of factors. For instance, the same reading could be the result of a large item buried deeply, a small item buried just below the ground surface, or even multiple small items buried close to one another; with traditional sensors, there is no way to know the difference. Thus, when single-axis EMI sensor technology is used, a dig/no-dig decision is typically derived from comparing the magnitude of an object's reading (usually in millivolts) to a threshold millivolt level defined through the Data Quality Objective (DQO) process.

The classification sensors provide substantially more data (both raw and derived) about the buried items, allowing for more accurate, defensible decision making. The sensors used for geophysical classification measure EMI responses at multiple points simultaneously, which provides a more complete sampling of the spatial field in three dimensions. EMI sensors provide a data set of responses that the classifier software can then use to essentially derive (invert) the attributes (for example, size, shape, wall thickness) and location of the item that created it. The software can then compare that set of attributes to a library of known items to find a match. Rather than using a threshold millivolt level to make dig/no-dig decisions, classification data allow for fine-tuning of the criteria to include or exclude items from the dig list. The additional data help in explaining to stakeholders or in legal proceedings why the particular selection criteria were used. They also provide information for project archives to inform future interest in the site. Further, each time an excavated item matches that predicted by the classifier, confidence in the system increases, and, conversely, instances of items not matching can indicate that the system is not working properly and requires reevaluation.

2.3.2 Economics

For many sites, geophysical classification provides a significant economic advantage over the standard detection process. The initial classification survey often costs more than traditional methods due to the required collection of higher quality data to precisely identify the locations of buried items (for later classification-grade data collection), as well as to the added cost of collecting and processing cued data over the reacquired targets. However, in most cases, the cost saving of reducing the number of buried items to be intrusively investigated exceeds the added initial expenses, thus lowering the overall cost of remediation per acre. This cost savings means that individual sites can be remediated less expensively, while maintaining or exceeding existing quality levels, and that a fixed budget can accommodate the surveying of many more sites.

An example of the shifting allocation of costs and potential overall cost reduction is presented in Figure 2-17, which is based on cost data from an ESTCP demonstration project. In current practice, most munitions response project costs are associated with excavating clutter, while excavating munitions (the main goal) accounts for less than 5% of each project. By comparison, with geophysical classification, data collection (detection survey and cued data) accounts for nearly half of the overall munitions response project cost, and only about a third of the project cost is spent on excavating clutter. For the ESTCP demonstration project, the classification process was able to reduce the amount of clutter to be excavated by approximately 80%, thus resulting in a total cost savings of 45%. Although additional spending for QC is required for classification to provide confidence in project results, the cost savings are large.

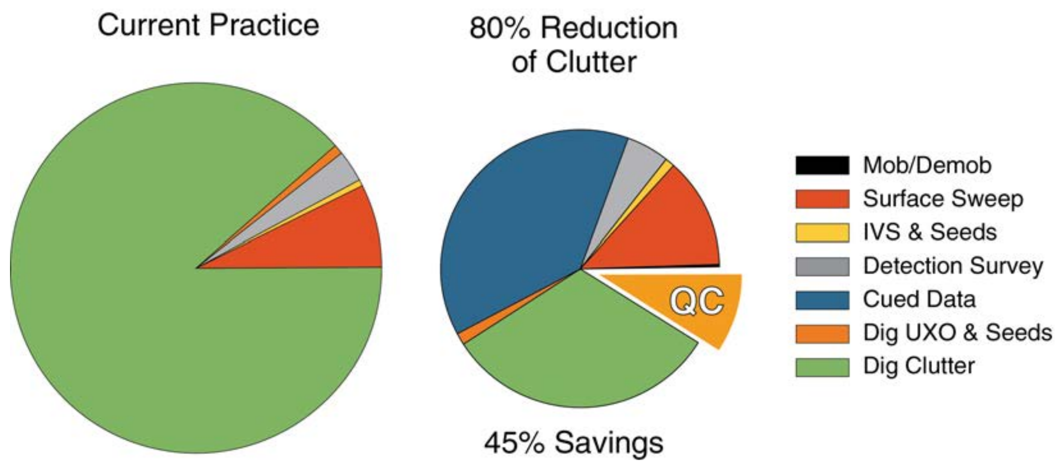


Figure 2-17. Cost allocation and savings.

2.3.3 Explosives Safety and Evacuation

In accordance with DOD Explosives Safety Board requirements, during intrusive excavation activities at areas known or suspected to contain munitions and explosives of concern (MEC), all nonessential personnel are prohibited from entering the area immediately surrounding the excavation (DOD 2010). The no-entry area surrounding the excavation is known as an exclusion zone (EZ). The size of an EZ is calculated based on the blast overpressure distance, or the fragmentation distance of the largest MEC item expected to be encountered.

Although an EZ surrounding manual operations is smaller in diameter than an EZ surrounding mechanized operations such as heavy equipment excavation, it could still obstruct residences, businesses, or public traffic routes. In such cases, buildings within EZs must be evacuated and, similarly, public traffic routes must be barricaded and drivers asked to stop during intrusive operations. If any nonessential personnel refuses to comply with these requirements, the excavation operation must cease.

The use of geophysical classification can significantly reduce impacts to a community surrounding an excavation site because the need to excavate fewer items should reduce the frequency and duration of EZ enforcement. Additionally, geophysical classification can reduce the time needed to complete the remediation of all identified sites, thereby reducing explosive risks to communities.

2.3.4 Cultural and Environmental Conservation

In cases where MEC contamination is present in culturally or environmentally sensitive areas, excavating fewer holes results in less disturbance because of the reduction in soil and vegetation disturbance and because fewer people are in the area, and for a shorter time. The compressed time to complete field work also makes it easier to work around important seasons for protected animals, such as mating or migratory periods. It can also more easily accommodate property owner conflicts, such as during hunting or farming seasons.

2.4 Limitations

Geophysical classification is not applicable in every situation. Some limitations for this approach involve the technology itself. Others involve site-specific characteristics that impose site access limitations, such as areas of dense vegetation; extremely rough, unstable, or steep terrain; or areas subject to electromagnetic interference. Further information on site-specific conditions that can impact or prevent geophysical data collection and classification is provided in Section 3.2.

2.4.1 Technological Limitations

Multiaxis EMI sensors do not consistently detect deeply buried, smaller munitions, and they do not consistently differentiate munitions in highly cluttered target areas (Section 3.2.4). While larger towed units have a depth range similar to standard EMI sensors, handheld advanced EMI sensors are lighter weight and less powerful; although they can sometimes detect deeper items, they are primarily useful in collecting advanced classification data on objects in the upper 1–2 feet of the subsurface. However, because 80%–90% of clutter is detected in the upper 2 feet, portable units should be sufficient to classify a buried item as a TOI (most likely a munition) or a non-TOI, or to determine that the item cannot be classified and thus must be added to the excavation list. Further, the limited depth of detection of the smaller units has not caused a difference in results with ESTCP demonstrations.

While these instruments are designed to be used outdoors, the lack of extreme ruggedization can limit performance in harsh environments, and they are subject to breakdowns. The frequency of such breakdowns depends on design and site conditions. The limited availability of parts for timely on-site repairs can be an issue. However, design improvements are ongoing, and as more instruments are put into use, the availability and distribution of parts should improve. In addition, advanced EMI sensors are not designed to work in extreme weather conditions and are not currently used on airborne or underwater platforms.

Although recent ESTCP demonstrations have shown success in classifying multiple overlapping objects, high-density overlapping objects can be difficult to differentiate. However, the greater the knowledge and experience with the software that analyzes overlapping signatures, the greater the success in classifying individual targets.

Even when target data are clear, a wide range of unknown items or various conditions of munitions (such as damaged or bent rounds) must still be added to the classification library of munitions. The library of EMI responses from various munitions continues to expand with each survey and has been used to detect a wide range of munitions types, including some in various states of damage. In addition, commonly occurring nonmunition items—such as horseshoes, mufflers, and gas cylinders—that possess consistent polarizabilities can also be readily recognized. ESTCP is replacing the library used by research developers with one that has carefully defined procedures for measuring responses and consistent metadata.

2.4.2 Site Limitations

Commercially available advanced EMI sensors are typically mounted on platforms that can be pushed or pulled across an area. This approach tends to preclude their use under difficult site conditions such as thick vegetation, rockiness, and extreme terrain, and in highly muddy areas or those covered by water (Section 3.2.3). Also, as with all EMI sensors, certain geologic conditions can interfere (for instance, in areas with primarily mafic or ultramafic rocks such as basalt). Sites where electromagnetic interference is an issue (such as sites near electrical substations or transmission equipment) or those adjacent to large aboveground or belowground metallic structures may not be conducive to EMI technologies.

2.4.3 Cost-effectiveness

As mentioned in Section 2.3.2, geophysical classification is cost-effective when the additional costs to perform enhanced geophysical investigation are offset by a reduction in the number of intrusive investigations. At most sites, the cost associated with the number of excavations that can be avoided by employing geophysical classification exceeds the extra cost of performing a better initial survey and cued interrogations.

For cued interrogations, typical production rates vary from 175 to over 300 cued measurements per day. Difficult terrain increases the difficulty of maneuvering the equipment, resulting in lower production rates. Higher production rates may be achieved when the terrain is not difficult and anomalies are of high amplitude and easier to locate.

Geophysically noisy sites, TOIs that are smaller than a large portion of the non-TOIs (clutter items), and high-anomaly densities all make classification of individual objects more difficult; consequently, such conditions increase the number of non-TOIs that must be excavated to ensure that all TOIs are removed.

If the ratio of TOIs to non-TOIs across a site is much higher than typical, the number of excavations avoided by using geophysical classification may not justify the additional cost of employing the process. This situation was observed on an air-to-ground gunnery range at New Boston Air Force Station, New Hampshire, but it is not commonly encountered at most MRSs.

Additionally, if a site is relatively small, the cost of acquiring and mobilizing advanced sensors would likely outweigh any cost savings that could be realized through a reduction in excavations.

3.0 PROJECT PLANNING

This section focuses on providing project planners and decision makers with sufficient information to participate in the planning and oversight of geophysical classification projects.

3.1 Introduction

Developing a geophysical classification work plan should involve a methodical planning process—that is, linking goals, cost and schedule, and quality criteria with the final outputs. Various government agencies and scientific disciplines have established and embraced such a systematic planning approach, which can vary depending on the specific application. The DQO process, developed by the U.S. Environmental Protection Agency (USEPA) (USEPA 2006), is the most commonly used application of systematic planning in the environmental community. DOD requires project planners to use the DQO process on all of its environmental projects.

Two key inputs are required in developing an effective project plan: a conceptual site model (CSM) and remedial action objectives (RAOs). These are discussed below.

3.1.1 Conceptual Site Model

The CSM is the primary planning and decision-making tool used to identify the key issues and data necessary to transition a project from characterization through postremedy. The CSM is an iterative representation of the project site that summarizes and helps project planners visualize and understand available information. The CSM is also a working tool used to perform the following:

- identify information or data deficiencies
- summarize, evaluate, and manage assumptions
- identify and document uncertainty
- document project decisions
- promote and support transparent and defensible decision making

The CSM is the starting point for (1) compiling and presenting information to support understanding and consensus; (2) identifying data gaps and uncertainties; and (3) determining subsequent data needs. Iterative improvement of the CSM occurs as new data become available through further investigation.

The progression of the CSM mirrors the common progression of the environmental cleanup process. Assumptions of the CSM are accepted or tested and refined to reduce uncertainty as the focus of the CSM shifts throughout the life of the project. The ongoing process of testing and confirming the CSM throughout the munitions response project lifecycle leads to confident decision making. An example of an MRS CSM is provided in Figure 3-1.

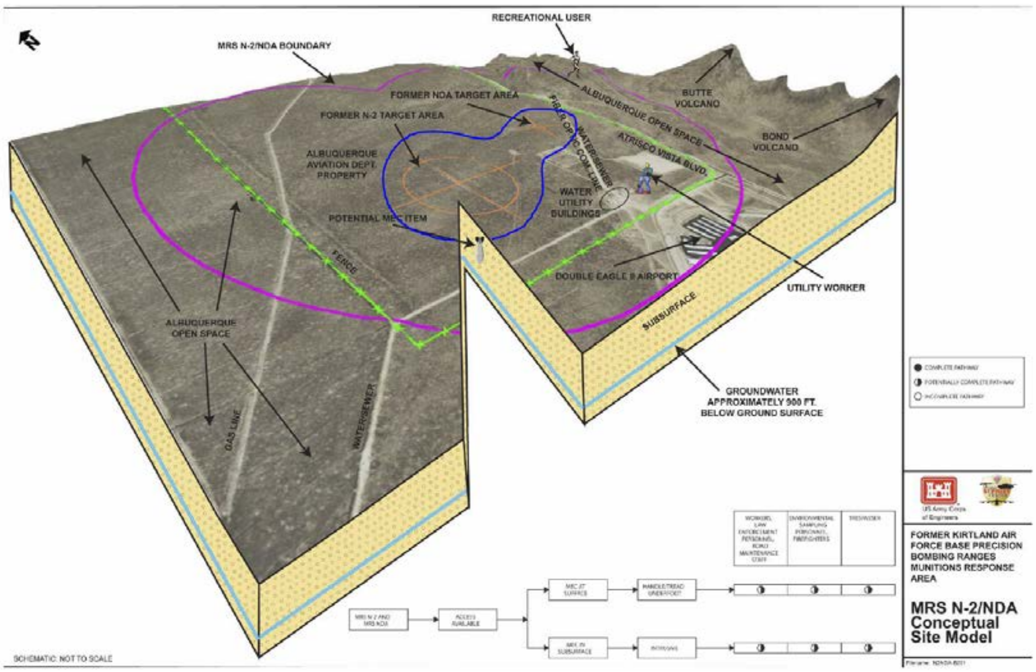


Figure 3-1. Example of an MRS CSM.

3.1.2 Remedial Action Objectives

RAOs are cleanup goals for a selected remedial action. Preliminary RAOs can be developed during the Preliminary Assessment/Site Investigation phase of a munitions response, and are refined into RAOs during the course of the Remedial Investigation/Feasibility Study process. Final RAOs are documented in the Record of Decision (ROD) or Decision Document (DD) (USEPA 1999). Remediation efforts are considered complete upon attainment of the RAOs.

During the scoping phase of the planning process, the project team reviews the RAOs and confirms that they are appropriate for the project and site conditions as further information about the site is gathered.

3.2 Preliminary Scoping—Site Suitability for Geophysical Classification

The decision as to whether geophysical classification is appropriate for an MRS is made in much the same manner as deciding the suitability of DGM using an EM61 vs. mag-and-flag for the site. Several interlocking factors must be considered, and each of these factors is discussed in more detail below.

Geophysical classification has been used successfully throughout the ESTCP Geophysical Classification Pilot Program (SERDP/ESTCP 2014a) at over 20 sites with vastly different types of terrain, vegetation, and mix of munitions. One of these demonstration sites may be a good model for a site in question, making the decision process somewhat easier.

3.2.1 Conceptual Site Model

The CSM should contain all current knowledge about the site, list the anticipated land uses, and include a record of all decisions that have been made about the site. The information in the CSM then leads to a ROD or DD that specifies the RAOs, which in turn drives the choice of sensor technology.

3.2.2 Types of Munitions and Area of Cleanup

The ROD or DD should specify the UXO or DMMs that will be the focus of the remediation as well as the area over which the cleanup is to be performed. If the particular MEC are not specified or information from the characterization phases conflicts with the ROD or DD, the project team should determine which UXO and DMMs to focus on.

The ROD or DD should also include a depth of concern based on anticipated land use. Given a depth of concern and a list of munitions anticipated on the site, sensor response curves for each munition can be consulted to verify that a particular advanced EMI sensor can achieve the RAOs. If no existing sensor can detect and classify the MEC to the depth of concern, the site team must assess the value of what can be achieved and determine whether additional protective measures will compensate for the limited depth of clearance.

3.2.3 Operational Environment

Vegetation, terrain, or structures/utilities within the site may impede the ability to use geophysical classification. The density of metallic items in the subsurface at the site or portions of the site may be so high that the sensors in use today are not able to resolve the individual buried items.

The EMI sensors used for classification must be positioned close to the ground (within a few decimeters) to properly interrogate buried munition objects. If local vegetation, such as trees, shrubs, bushes, or cacti, do not allow the sensors to be operated near the ground, geophysical classification may not be possible.

Differences in the nature and type of surface vegetation affect sensor selection and deployment schemes, as shown in Figure 3-2.

Figure 3-2. Influence of surface vegetation.

Similar limitations can be imposed by terrain. Rough terrain, rocky conditions, and steep slopes may also restrict the ability of the operator to position the sensor close enough to the object to be interrogated. Some examples of terrain limitations are shown in Figure 3-3. The left photograph depicts unchallenging terrain. The right photograph shows challenging terrain that requires a person-towed platform.

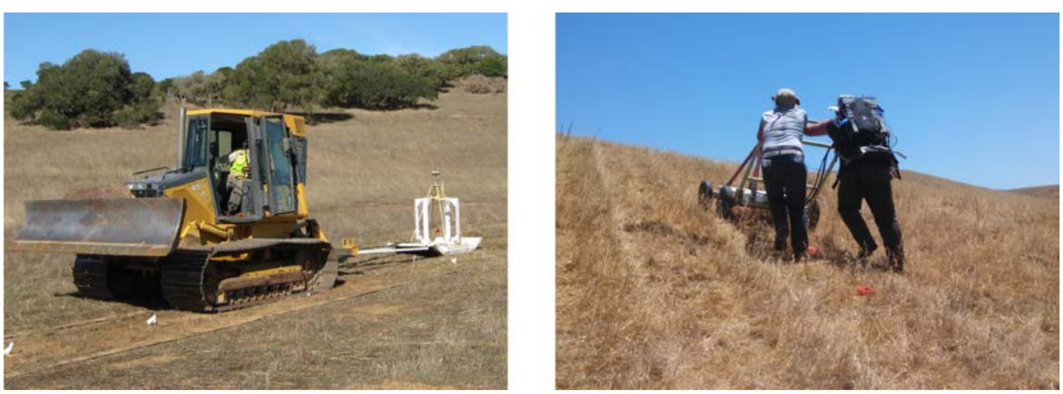


Figure 3-3. Effect of terrain on the geophysical classification process.

Variable and rough terrain impedes geophysical classification by hindering the ability to locate the sensor close to the buried item during data collection.

Potential structure and utility interferences are shown in Figure 3-4. The site in the top left photograph has minimal interference from structures. The MRS in the photo on the right contains the type of building and power lines that interfere with geophysical data collection for classification.

Figure 3-4. Negative effect of structures and utilities on EMI sensing for munitions.

The presence of structures and utilities can directly interfere with data collection or mask the native background response.

The project team should use range records, aerial photographs of the MRS if available, and site visit reports to confirm or identify areas expected to have high-anomaly density, such as target areas and burial pits. Examples of anomaly density data from a detection survey are presented in Figure 3-5. The top left panel shows an area of relatively low anomaly density for which no limitations should be anticipated. The top right panel shows an example of moderate anomaly densities where, again, no limitations are anticipated. Finally, the bottom panel shows challenging anomaly densities in the western portion of the area and decreasing eastward. Identifying the precise boundary where classification methods break down due to too many metallic items in the subsurface (and thus too many sources in the sensor's field of view) remains an active area of research.

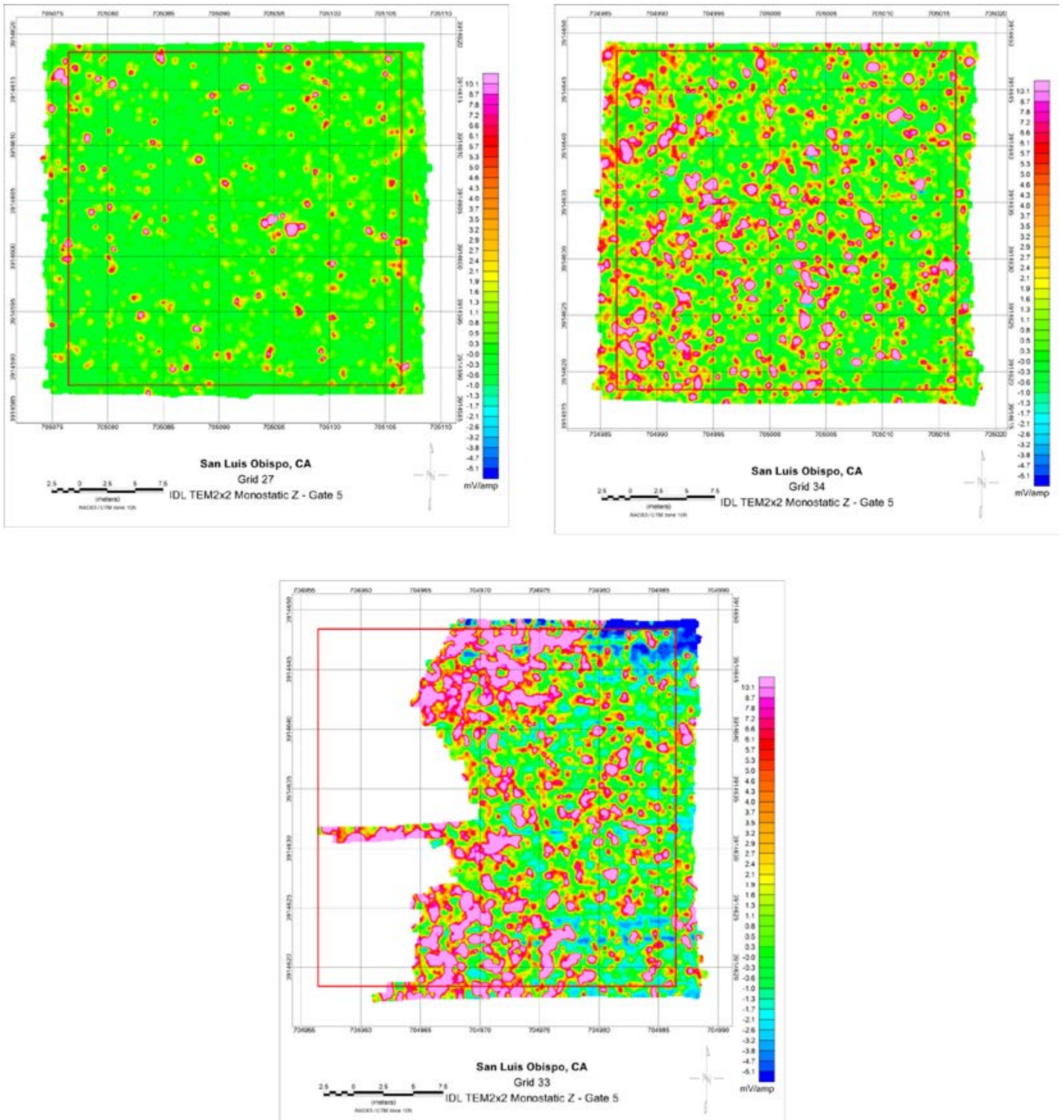


Figure 3-5. Detection survey data acquired at a single site show varying levels of anomaly densities.

3.2.4 Limitations of the Technology

One or another of the advanced EMI sensors is designed to be applicable on any area that traditional sensors can access. For example, the detection capabilities of the MetalMapper and TEMTADS sensors are analogous to the commonly used Geonics EM61 and Geometrics G-858 magnetometer for items in the top 60–100 cm. In the case of very deep munitions, such as large high-explosive bombs deeper than 4–5 feet, a magnetometer may be the only viable detection sensor. An advanced EMI sensor could be used to classify the majority of items found in the shallow subsurface with the deep magnetometer detections automatically added to the dig list.

3.3 Geophysical Classification Process

Once it has been determined that geophysical classification is appropriate for a site and objectives have been established, the project team proceeds with planning the data collection and analysis efforts to achieve the highest quality results. This section provides guidance on the planning process for each phase, including data requirements and data quality requirements.

3.3.1 Geophysical System Verification

Geophysical system verification (SERDP/ESTCP 2014b) is a simple but rigorous QC process used to confirm that a geophysical sensor is operating properly, and to provide ongoing monitoring of the quality of the geophysical data collection and target selection process. This process involves the following two key elements:

- an instrument verification strip (IVS), to confirm that the geophysical detection system is operating properly
- production area blind seeding, to provide ongoing monitoring of the quality of the geophysical data collection and analysis as it is performed in the production survey throughout the project

Both of these concepts apply to projects using geophysical classification. Some planning considerations for the use of geophysical system verification are discussed below.

3.3.1.1 Instrument Verification Strip

An IVS is used to verify on a daily basis that the geophysical sensor system can deliver the expected detection and classification performance. It is not intended to determine limits of detection or classification ability against a particular target; these performance parameters have been established in a series of demonstrations conducted by ESTCP (SERDP/ESTCP 2014a).

The IVS is constructed of one or more buried inert munitions or industry standard objects (ISOs) spaced approximately 5 m apart. A convenient area that is representative of the production site should be chosen for the IVS. The area should be free of discrete anomalies that would meet the anomaly selection criteria, but should contain representative local geology and perhaps small metallic clutter if that is expected at the production site. In some circumstances, multiple IVS locations are preferred. If the site is very large, additional locations save undue travel time for daily checks.

The contents of the IVS can, in principle, consist of any well-characterized objects, although ISOs are often the most convenient. Strictly speaking, only one item is necessary to provide the data required for physics-based confirmation of performance—that is, to ensure that the sensor system is recording the expected signal at the correct location. However, multiple items may be desired to provide a range of signals or to aid in project team communication. In addition to the buried items, an IVS often has an adjacent lane dedicated to measuring site noise (Figure 3-6). These background noise measurements can be used both initially to verify that RAOs are achievable and, in follow-up surveys, to measure any drift in sensor response.

The objective of the IVS is to verify correct operation of the sensor (not to test its maximum performance, which can be calculated). Thus, items in the IVS should be buried deep enough to provide signals well above the sensor noise level so that measurements of sensor signal level is not contaminated by significant noise. This condition is easily satisfied if the items are buried at depths corresponding to three to seven times their diameter. The items are buried in a straight row and are not intended to be blind to the sensor operator. Rather, the lane to be surveyed should be well marked, so the sensor passes directly over the targets in dynamic mode, providing an accurate measure of the peak signal, and it is easily positioned over each target in cued mode to collect classification data.

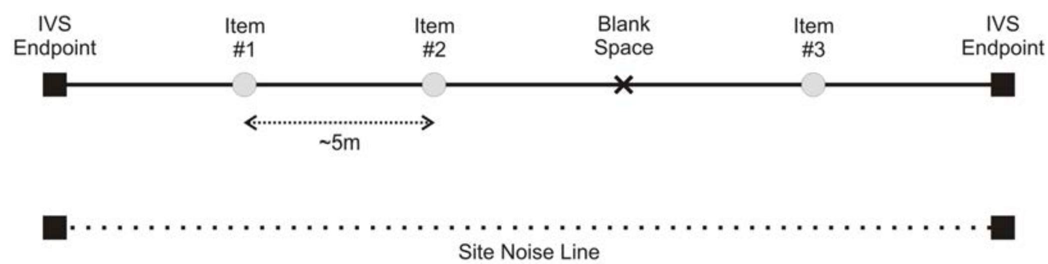


Figure 3-6. A typical IVS plan.

The IVS plan identifies the minimum frequency at which each instrument must be operated over the IVS and specifies the necessary criteria to demonstrate that the instrument is fully functional. Frequency is usually limited to a single pass over an IVS line before the start of production work and one after work is completed at the end of the day.

Performance criteria are expressed in terms of either signal response (the only option for dynamic surveys, although they can be used for cued surveys) or inversion results (for cued surveys.) Dynamic criteria are usually expressed in two terms: initial measurement requirements and follow-on requirements (see below for further information on the need for these terms). Initial requirements are expressed as absolute percent difference in measured peak responses from predicted values, and should be stated in the IVS plan. Relative percent difference in measured peak responses, as compared to the initial measurements, is used for all subsequent dynamic IVS measurements.

For cued surveys, IVS results demonstrate instrument functionality either as relative percent difference in measured signals (usually compared to an initial measurement, although they could be compared to predicted responses) or as comparisons of inversion results to an IVS library. The former necessitates criteria for each channel of each of the advanced sensor's receivers. This approach is cumbersome to manage because the sensor has 12–21 receivers and each receiver has up to 50 channels. Thus, comparing inversion results to an IVS library is more common where very high match metrics (90% minimum is typical) are used to prove functionality.

Many IVS plans have initial and follow-on performance criteria—because subtle variations between the design and as-built characteristics in the IVS can lead to relatively large variations between predicted responses (in the design phase) and actual responses (as measured in the field). Thus, initial measurement criteria demonstrate that the instrument is indeed functioning once it is fully assembled, and the criteria factor in variations that may occur during IVS construction. Once the initial measurements confirm proper operation, those measurements become the baseline for demonstrating site-specific functionality for all subsequent IVS measurements. This approach is often needed to allow for the removal of any allowances from the follow-on criteria that were added solely to account for differences between planned and as-built IVS characteristics. This two-step approach results in meaningful IVS criteria that confirms proper operation at the start of field work and continued functionality for the duration of the project.

3.3.1.2 Quality Control and Validation Seeding Program

QC (production team) and QA validation (government or third-party) blind seeds provide an opportunity for ongoing monitoring to ensure that each step leading to the product is working—from the selection of buried items through to classification. The failure to detect or properly classify a QC seed target allows the production team to recognize that problems exist, and provides a means of identifying root causes so that corrective action (CA) can be undertaken while still in the field. The government validation seeds provide ultimate confidence to the entire project team and stakeholders that the data collected in the project are usable for their intended purpose.

Decisions on the specifics of the QC and validation seed plans—including seed selection, density, and depth—are based on site-specific conditions. Performance requirements are established during the DQO phase of project development and are used to guide the design parameters selected for the production area seeding. The specific objectives depend on the types of munitions expected and the cleanup standard for the anticipated use. Other considerations, such as ensuring contract compliance, may also drive aspects of the seed plan.

The items chosen for seeding must be representative of munitions expected to be encountered on the site. They should meet the anomaly selection and TOI classification criteria and have a signature with a magnitude and spatial extent that is close to the munition of interest. On most sites, there is more than one munition type of interest; therefore, seeds are generally selected based on the most stressing target(s). For example, the site team might choose the object of interest with the smallest spatial signature, as this object is likely to drive the DQO on lane spacing. Choosing seeds with smaller detection signatures and that are more difficult to classify than any munition expected on the site is not recommended as it only leads to unnecessary detections and clutter digs.

ISOs and inert munitions may be chosen as seeds. Although the use of inert munitions is not required for the main objective of the seed program—to confirm that the detection and classification system is working and that TOIs will be detected and classified as expected based on prior tests—the use of some inert munitions may be necessary to satisfy the public or aid in communication. As with the ISOs, the munitions-like objects used for seeding should be selected with a specific objective in mind.

On average, at least one seed should be encountered per day per crew for both the detection and cueing crews; that is, the seeding frequency is designed for the operation that covers the lowest number of acres or lowest number of anomalies per day. For the detection phase and a field crew using a cart-based sensor, the daily coverage might be 1 acre, and one seed per acre would be appropriate. For a towed array system, the production rate may be 5–10 acres per day and, assuming the higher production rate, one seed per 5 acres would be appropriate. When cued data are being collected, a typical production rate may be 150–200 cued anomalies a day. If the site has on average 1,500 anomalies per acre, using the lower production rate, 10 seeds per acre would be appropriate. If a project is using all three of the above techniques, the seeding rate is designed for the activity with the lowest production rate; in this case, the cued data collection and the entire site would be seeded at a rate of 10 seeds per acre.

Seeds should be buried at depths where they are expected to be detected. It is difficult to interpret a failure if items are buried at their most stressing depths, such that their expected probability of detection is not 100%. Seeds may be buried in any variety of orientations. Keeping the above principle in mind, the depth distribution of seeds depends on whether they are QC seeds emplaced by the contractor or validation seeds emplaced by the government. It is in the contractor's best interest to bury its QC seeds over the full depth range at which the particular item is expected to be encountered and, in most cases, down to the RAO depth (presuming that depth is within the detection capability of the technology). At a recent site in California, the detection threshold was set to detect and classify the smallest munition of interest to a depth of 30 cm. The contractor emplaced seeds evenly in depths down to 30 cm, allowing for the discovery of any process issues that would interfere with achieving the stated objective. The validation seeds normally serve as contract enforcement mechanisms. Thus, the government may choose to emplace validation seeds at depths that more closely mimic the depth distribution of UXO or DMMs known at the time (so long as they are also relatively easy to classify), as well as smaller numbers of seeds at depths that would serve to confirm performance down to the RAO depth. Having greater numbers of easy-to-classify validation seeds facilitates contract enforcement because any failure to detect or correctly classify one is an unambiguous indication of a significant breakdown of the contractor's QC program.

Evaluation of the QC blind seeds is, in most cases, performed by the QC arm of the production contractor. Most important is to maintain the integrity of the blind seeds, which requires that appropriate corporate firewalls are in place between the planning and evaluation of seeds and the data collection and analysis sides of the contractor. The validation seeds are evaluated by the government or its representative.

3.3.2 Anomaly Identification Survey

Digital geophysical survey data from within the MRS is required to detect and select anomalies for further classification. The project team uses the geophysical data to determine whether the anomaly density supports classification and whether the preliminary anomaly selection criteria will achieve project RAOs.

Four primary planning activities are conducted in preparation for the dynamic (or anomaly detection) survey: (1) ensuring 100% coverage of the survey area and proper sampling intervals to achieve the data density for the geophysical survey; (2) navigating, locating, and mapping anomalies to ensure 100% coverage; (3) establishing anomaly density above which classification is not attempted; and (4) performing the preliminary anomaly selection. All of these planning activities arise from the RAOs for the munitions response.

3.3.2.1 Geophysical Survey Data Density Requirements

In all cases, the collection of digital geophysical data over 100% of the survey area is required. The size and depth of munitions expected to be encountered on the site drives the design of the dynamic survey. Small shallow munitions require a detection survey with tighter cross-track spacing of the survey lines and smaller down-track sampling intervals to achieve 100% detection of the TOIs. Conversely, larger deep targets allow these parameters to be relaxed. These same considerations drive the design of the QC and QA seed plans and detection of all blind seeds and, coupled with proof of achieving 100% coverage, are the ultimate performance check of the dynamic survey.

3.3.2.2 Navigating, Locating, and Mapping

Collection of survey data implies that the location of each geophysical measurement has been obtained. At sites with good sky view, this can be easily accomplished with modern GPS equipment. For most applications, cm-level GPS (location precision of about 3–5 cm) should be used if possible, which requires a second GPS receiver located over a known survey point. For sites with tree cover or other obstructions, the choices are more limited. If the vegetation density is moderate, robotic total stations can give single point precision equal to GPS, but will result in data gaps that must be filled in via dead-reckoning. In extremely dense vegetation, these data gaps dominate, and more traditional methods involving survey tapes and spooling thread are required. These methods do not achieve the precision required for 100% coverage with tight lane spacing that makes for optimal survey practice.

3.3.2.3 Anomaly Data Density Requirements

Planning for the dynamic survey requires establishing the local anomaly density above which classification will not be attempted. Factors that limit the use of classification technology at high-anomaly densities include the inability to identify individual anomalies in the detection survey and the inability to perform reliable classification because there are too many individual large pieces of metal beneath the footprint of the sensor during an individual measurement. The specific threshold density depends on the expected munitions at the site, and the value chosen should be documented. Development of data analysis methods to address high-anomaly densities is an active area of research in SERDP (MR-1637, MR-1662, and MR-2318).

3.3.2.4 Preliminary Anomaly Selection Requirements

The final presurvey parameters to be determined are the preliminary anomaly selection criteria. These criteria can be amplitude-based, as in the case of a traditional EM61 survey, or based on the greater amount of information available by using the advanced EMI sensors. In either case, these preliminary selection criteria are derived from the specific munitions to be detected and the depths to which they must be detected. Small munitions expected relatively deeply require low-anomaly selection thresholds that likely also select large numbers of small fragments. If the targets are large munitions and the soil conditions are such that they have not penetrated very far, higher selection criteria can be employed to reduce the number of fragments selected.

The anomaly selection criteria cannot be chosen without considering site noise. If the RAOs lead to anomaly selection criteria that are within the expected site noise, the wrong sensor has been selected or an RAO requires modification. In many cases, site noise levels will have been determined during the characterization phases of the project and can be used to confirm the validity of the preliminary anomaly selection criteria. In all cases, this should be confirmed after the initial IVS survey and continually throughout the project as new areas of the site are surveyed

3.3.3 Cued Data

Cued data collection produces high-quality data to support geophysical classification. Cued data are collected over buried item locations selected from the anomaly detection survey to support RAOs. The two main planning issues in preparation for the cued surveys are detected anomaly location accuracy and background measurement needs.

3.3.3.1 Anomaly Location Accuracy

Anomaly location accuracy flows directly from the detection survey performance, depending on the accuracy of the locations of detected seed items. This requirement can be tailored for the types of munitions at the site. For all except fairly large munitions, such as 100 lb. bombs and larger, the detection accuracy should be approximately 25 cm. The more accurate the detection survey locations, the less time it takes to position the cued sensor over the intended location and the easier it is to confirm that the proper location was indeed occupied. Actual detection accuracies are proven through the QC and validation seed detection accuracy results.

3.3.3.2 Background Measurements

The second planning activity in preparing for the cued survey involves establishing background locations and the intervals required between background measurements throughout the production day. The detection survey map can be used to locate areas throughout the project area that appear free of metal. Critical in selecting locations is determining the minimum distance to nearby anomalies that might produce a measurable response. Then, when any background location is first sited, measurements should be taken in a pattern circling that location, as well as the location itself, to prove that no metal objects are present within sensing range of the instrument. Different sensor configurations have different lateral sensing capabilities, and a background that might have first been established with a TEMTADS cannot necessarily be assumed to also be free of nearby metal for use by MetalMapper instruments.

There is no limit to the number of background locations that can be used. Experience has shown that occupying at least one location on repeated occasions throughout the project (or throughout the day) helps to identify whether the site is prone to minor upward or downward trends in background response, which might adversely affect inversions of low signal-to-noise ratio anomalies. Soil moisture content is the most frequently cited potential cause for these trends when they are observed, although research has yet to establish the true cause. Nonetheless, until it is established that there are no upward or downward trends to the background response, background measurements should be taken at fairly short intervals (typically two hours). It is also wise to require repeat background measurements at the same location if conditions change from dry to wet, at least at the first occurrence, if only to confirm that the site background is not prone to this possible influence.

3.3.4 Classification Analysis

As described in Section 2.1.3, a library-matching process, comparing each item's principal axis polarizabilities to a library of munitions expected on the site, is at the heart of most classification schemes. During project planning, the team should ensure that suspected and known munitions are contained in the library. If not, they will be added to the project-specific library. The contractor should develop a data analysis plan to define the decision metrics that serve as the foundation for classification decisions. Decision metrics are thresholds for which items are identified as TOIs or non-TOIs or items that cannot be analyzed. This metric is a measure of the fit correlation between data for a buried item and the library entry that best fits that item, with higher values indicating a better fit between the buried item and the corresponding item in the library.

3.3.5 Validation Plan

The project team should develop a validation plan before fieldwork begins. In addition to items identified as TOIs and those that cannot be classified, the validation plan should include the excavation of a number of items classified as non-TOIs to verify the dig/no-dig threshold recommended by the analyst and validate the overall classification process. After the data have been collected and analyzed, the validation plan should be reassessed to assure that it is still applicable.

The dig/no-dig threshold is easily verified by digging a number of items past the recommended threshold. During the later ESTCP demonstrations, this part of the plan was structured as a defined number of digs past the last TOI found. In this manner, the analyst is not penalized for setting a conservative threshold, and the site team can be confident that the correct threshold was used. Obviously, any TOIs discovered during these digs will reset the threshold and require more digs.

Validation of the method is more difficult. On most sites, it is generally rare to find UXO at all, and even more unlikely after project completion. Thus, random searching for remaining UXO is unlikely to be fruitful. In the past few years, ESTCP has settled on a validation method that illustrates the accurate basis for dig/no-dig decisions. Every item classified as a TOI has already been excavated, and the analyst should have verified that each recovered item matched the predictions from the analysis. The only remaining requirement is to assure that any items classified as non-TOIs were classified correctly. The site team selects a number of non-TOIs for use in this validation. The anomaly numbers are furnished to the analyst who answers the following question for each item: Why was this classified as a non-TOI? In most cases, the answer will be simple (for example, it was too small, too flat, or too asymmetric to be a TOI; it was recognized as a clutter item such as a fins set, baseplate, horseshoe, or barbed wire). Each selected item is then excavated and compared to the analyst's predictions. Agreement in all cases should assure the site team that the correct decisions were made and that the results are accurate.

4.0 QUALITY CONSIDERATIONS

This section discusses the integration of quality systems (also known as management systems) into a geophysical classification project. As defined in *Quality Systems for Environmental Data and Technology Programs—Requirements with Guidance for Use* (ANSI/ASQ 2004), a quality system is

> a structured and documented management system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization for ensuring quality in its work processes, products (items), and services. The quality system provides the framework for planning, implementing, and assessing the work performed by an organization and for carrying out required QA and QC activities.

For organizations conducting geophysical classification, a quality system is documented at an organizational level in a Quality Systems Manual and at a project level in a Quality Assurance Project Plan (QAPP). The format and key elements of these documents for geophysical classification projects is generally the same as for any other projects involving the collection and use of environmental data.

The goals of quality systems on a geophysical classification project are to ensure the following:

- Geophysical classification data are of known and documented quality, suitable for their intended uses.
- Geophysical classification technology and programs meet stated requirements.

The requirements and guidelines for documenting a quality system for organizations conducting geophysical classification are based on the Uniform Federal Policy for Implementing Environmental Quality Systems: Evaluating, Assessing, and Documenting Environmental Data Collection/Use and Technology Programs (UFP-QS) (IDQTF 2005)—a high-level policy developed by the Intergovernmental Data Quality Task Force (IDQTF) based on Part A of ANSI/ASQ E4-2004. They are supplemented by the more specific requirements and guidelines contained in the international standard ISO/IEC 17025, General requirements for the Competence of testing and calibration laboratories (ISO/IEC 2005) Note that the term "laboratory" refers to any organization that conducts testing or calibrations; it therefore applies to public or private organizations conducting geophysical classification.

Requirements and guidelines for documenting a project-specific QAPP for geophysical classification projects are contained in the AGC-QAPP (IDQTF 2016). The AGC-QAPP is based on the Uniform Federal Policy for Quality Assurance Project Plans (IDQTF 2014) (UFP-QAPP), developed by IDQTF and based on Part B of ANSI/ASQ E4-2004. Appropriate use of this format is approved and endorsed by DOD and USEPA.

As explained in the introduction to the UFP-QS, providing consistent intergovernmental policy for the implementation of quality systems has several benefits. As applied to geophysical classification for munitions response, these benefits include the following:

- improved effectiveness of geophysical classification technology by focusing on results, quality of data and services, and stakeholder requirements and expectations
- clarification of roles and responsibilities for managing and overseeing the use of geophysical classification for munitions response
- increased stakeholder confidence in the capability of geophysical classification technology and processes, such that duplication of oversight activities are minimized
- enhanced accountability by lead organizations, and public confidence in decisions, based on the results of geophysical classification

These benefits are especially relevant to the implementation of new technology, such as the use of geophysical classification on a production basis, where there is a great deal of stakeholder interest. The remainder of this section discusses important considerations for developing and implementing quality systems specifically for geophysical classification projects. Section 4.1 presents the Quality Systems Manual; Section 4.2 addresses personnel qualifications; Section 4.3 covers the quality considerations contained in the AGC-QAPP(including the processes and procedures that occur during planning, collection, and processing of data, and the ultimate data usability requirements); Section 4.4 describes the DOD Advanced Geophysical Classification Accreditation Program (DAGCAP); and Section 4.5 discusses government oversight.

4.1 Organizational Quality—Quality Systems Manual

Organizations wishing to perform geophysical classification must develop and document a quality system that addresses all applicable requirements contained in ISO/IEC 17025. A documented Quality Systems Manual provides evidence of the following:

- management's commitment to and accountability for quality
- independent oversight of quality
- provision of resources commensurate with quality objectives
- commitment to regular internal assessments and continual improvement of the quality system

The organization's Quality Systems Manual also provides the basis for accreditation in accordance with the DAGCAP, as discussed in Section 4.4.

4.2 Personnel Qualifications

Project teams should carefully consider the necessary qualifications for contractor personnel performing geophysical classification tasks—including the QC geophysicist, the project geophysicist, the field team leader, and data processors/analysts. The roles, responsibilities, and qualifications for these and other key project team members are determined during initial project scoping and documented in the QAPP. Factors that should be considered are education, experience, and general qualifications, which should be commensurate with the assigned roles and responsibilities.

The project geophysicist/analyst qualifications should focus on learning experiences with the geophysical classification tools defined for the project. Other factors might include 10–15 years of experience in performing digital geophysics on munitions response projects, as well as a degree in geophysics (or a closely related field) or other equivalent professional experience. The QC geophysicist should have qualifications similar to those of the project geophysicist/analyst. Specific geophysical classification experience should include developing quality systems to assess raw data usability and inversion output usability, and designing and implementing classification systems. The ESTCP Geophysical Classification Pilot Program provides evidence that all good analysts acquired their skills by working through difficult geophysical classification problems. Learning experiences stemming from investigations at complex sites using critical quality tests—such as not detecting a TOI or misclassifying a TOI and then conducting an appropriate CA—should be viewed as desirable elements of the individual's base of experience.

The DAGCAP provides guidance on the roles and responsibilities for key personnel and requires an organizational demonstration of capability, as well as individual demonstrations of capability, before they may perform geophysical classification. Section 4.4 below provides more information about DAGCAP. The project-specific AGC-QAPP documents personnel qualifications. DOD Quality Systems Requirements Section 4.1.5(i), established as the underlying standard for the geophysical accreditation program, provides guidance on the roles and responsibilities of the Quality Manager.

DOD Quality Systems Requirements Section 5.2.2 lists minimum skills that must be demonstrated by field personnel, including the Project Geophysicist, QC Geophysicist, and personnel performing data processing.

4.3 Project-Specific Quality—The AGC-QAPP

The AGC-QAPP template was developed by the IDQTF to assist project teams in planning for the use of geophysical classification on munitions response projects. It was written specifically for those with expertise in the application of this technology. The template is based on extensive research and development of the technology and initial guidance established under the ESTCP. It promotes consistent implementation of the geophysical classification technology in a performance-based approach—that is, by providing flexible guidance on the process and specific minimum recommended requirements, where appropriate.

The AGC-QAPP template follows the requirements and format of the UFP-QAPP. Use of this template will ensure the development of a complete QAPP—that is, a stand-alone document (work plan) addressing all of the necessary QA and QC elements. A complete AGC-QAPP contains all required content normally found in a Sampling and Analysis Plan, Work Plan, and/or Field Sampling Plan, including copies of all standard operating procedures (SOPs). Thus, a AGC-QAPP integrates all technical and quality aspects for the life cycle of the project, including planning, implementation, quality assessment, and the ultimate data usability assessment (DUA).

The AGC-QAPP template follows the format of the 28 worksheets contained in the Optimized UFP-QAPP Worksheets (IDQTF 2012); however, use of the original 37 UFP-QAPP worksheets is also acceptable. Regardless of which format is used, the QAPP worksheets are divided into four main categories, as follows:

1. Project management and objectives [Worksheets 1–16]
2. Measurement and data acquisition [Worksheets 17–30]
3. Assessment and oversight [Worksheets 31–33]
4. Data review [Worksheets 34–37]

Note that the same numbering system is used for the 28 optimized worksheets and the 37 original worksheets.

There are distinct differences between quality systems elements needed for geophysical classification and those captured in the UFP-QAPP worksheets for typical environmental investigations. Given that many steps in the geophysical classification process are performed dynamically, a more structured process for evaluating data quality and subsequent dynamic decision-making is vital to the success of meeting geophysical classification project objectives. The AGC-QAPP template provides a decision tree (Worksheet 17, Figure 17-1) that describes this structured decision-making process. In addition, because geophysical classification data are collected in the field and environmental media samples are not sent off site for analysis, the UFP-QAPP worksheets and elements pertaining to sample collection and sample handling are not applicable and therefore not included in the AGC-QAPP.

The information and examples in the template are intended to augment the systematic planning process (see Chapter 3), not to replace it. The AGC-QAPP template includes (1) specific instructions and guidance on completing each worksheet [in green text]; (2) examples of the types of information typically needed [in blue text]; and (3) baseline minimum requirements and specifications [in black text]. The minimum recommended requirements are based on the extensive research and demonstrated experience of ESTCP field work activities, and therefore should meet the needs of most geophysical classification for munitions responses. The project-specific AGC-QAPP should specifically document if/when the black-text recommendations are not used and justify any deviations from minimum recommended requirements.

4.3.1 QAPP Development Process

The process for developing a project-specific QAPP using the AGC-QAPP template begins with a series of planning meetings. Project planning must involve key members of the project team (identified on AGC-QAPP Worksheets 4, 7, and 8). It is not necessary for all members to participate in all meetings; however, each meeting must involve the members representing the particular skill set and stakeholder interests necessary to accomplish the objectives of that meeting. AGC-QAPP Worksheet 9 provides a template for documenting project planning meetings, including participants present, decisions reached, and action items. See Chapter 3 for guidance and considerations to be addressed during project planning.

Using the site-specific CSM (documented on AGC-QAPP Worksheet 10) as foundational input, the project team develops project-specific DQOs, which are documented on AGC-QAPP Worksheet 11. Once the project DQOs are established, the minimum data quality required for specific activities are listed. Data quality is assured by defining measurement performance criteria (MPC) for each specific measurement activity throughout each phase of the project (that is, detection survey, cued survey, and intrusive investigation). The MPC are expressed in terms of data quality indicators (DQIs), which include precision, accuracy, representativeness, comparability, completeness, and sensitivity. The DQIs and associated MPC are listed in AGC-QAPP Worksheet 12. Ultimately, the MPC are used to assess whether and how well the project objectives have been met.

Project-specific MPC drive the development of the sample design (documented in AGC-QAPP Worksheet 17), which contains detailed procedures for implementing the selected technology. Specific equipment testing, inspection, and QC criteria designed to control the data collection process such that MPC can be met are described in AGC-QAPP Worksheet 22. The remaining worksheets address requirements for documentation, assessments, and data review (verification, validation, and the DUA). The following sections summarize key QA and QC measures that should be documented in the AGC-QAPP for the detection survey, cued survey, and intrusive investigation, respectively.

Data Quality Indicators

The DQIs for the purposes of this document are as follows:

Precision*—Precision indicates mutual agreement (random error) among individual measurements of the same property, usually under prescribed and similar conditions.*

Example: During the intrusive investigation, reacquisition of GPS benchmark positions must be repeatable to within 10 cm.

Accuracy*—Accuracy indicates the overall agreement of a measurement to a known or accepted reference value. Accuracy includes a combination of random error (precision) and systematic error (bias) components that are due to sampling and analytical operations.*

Example: During the intrusive investigation, 100% of the predicted non-TOIs that are intrusively investigated are confirmed to be non-TOIs.

Representativeness*—Representativeness is the degree to which collected data are characteristic of the whole medium for which they are being used to make inferences.*

Example: During the cued survey, background locations will be selected such that background data are representative of the various subsurface conditions expected to be encountered within each survey unit at the site.

Completeness*—Completeness is the amount of valid data obtained compared to the planned amount, usually expressed as a percentage (that is, the quantity of data successfully collected with respect to the amount intended in the experimental design).*

Example: During the detection survey, 100% of the spatial area will be completely surveyed for the presence of anomalies.

Comparability*—Comparability measures the confidence with which one data set or method can be compared to another (that is, the ability to describe likenesses and differences in the quality and relevance of two or more data sets).*

Example: During the cued survey, the library must include signatures for all munitions known or suspected to be present at the site, as listed in the CSM.

Sensitivity*—Sensitivity is the capability of a method or instrument to discriminate between small differences in the characteristic being measured.*

Example (based on TEMTADS): During the detection survey, a detection threshold of 1.7 millivolts per ampere and signal-to-noise ratio of 5 is required to detect a horizontal 37 mm projectile at a depth of 0.3 m.

4.3.2 Detection (Dynamic) Survey QA/QC

As noted above, AGC-QAPP Worksheet 12 lists recommended minimum project-specific MPC that must be met by the data collected during the detection survey to satisfy the DQOs. AGC-

QAPP Worksheet 22 lists recommended minimum inspection and QC procedures designed to keep the data acquisition process in a state of control such that MPC will be met. Minimum recommended requirements are discussed below.

4.3.2.1 Placement of Contractor Blind QC Seeds and Validation Seeds [Representativeness]

The project-specific AGC-QAPP must describe procedures for the contractor's placement of blind QC seeds. (The government's placement of blind validation seeds is usually covered in the government's Quality Assurance Surveillance Plan [QASP].) AGC-QAPP Worksheet 12 must specify the number of QC seeds to be placed as well as the spatial distribution of seeds (both horizontal and vertical). It must describe and justify the types of seeds to be used. Blind QC seeds must be distributed such that each field team can expect to encounter an average of one to three seeds per day. The placement of the QC seeds should be sufficiently challenging. At least a portion of the seeds should be representative of the TOIs expected to be the most difficult to detect and classify. The exact number and placement of QC seeds are "blind" to the field team and must be known only to the QC geophysicist. The ability to detect QC seeds is part of the contractor's internal QC. Failure to detect a QC seed triggers a root cause analysis (RCA) to identify the source of the problem such that a CA can be implemented.

4.3.2.2 Survey Coverage, Including Inline and Crossline Spacing [Completeness]

Survey coverage is also a key quality component in the detection survey. As specified in AGC-QAPP Worksheet 12, 100% of the investigated area must be surveyed. Project-specific requirements for inline and crossline spacing will be developed during project planning and documented in AGC-QAPP Worksheet 22 to ensure 100% coverage.

4.3.2.3 Detection Threshold and Signal-to-Noise Ratio [Sensitivity]

As discussed in Section 3.2, interferences can have a significant impact on the ability of the detection technology to achieve the project-specific MPC. Certain geologic conditions can generate severe interference (for example, areas of primarily mafic or ultramafic rocks such as basalt), as can certain locations (for example, areas situated beneath high-tension power transmission lines). Thus, it is important to know the types of munitions expected and anticipated depth, density of anomalies, clutter environment, geology, and other interference factors when planning the detection threshold. Knowledge of these factors is also required when deciding which types of items are appropriate for QC seeds and how deeply they should be buried. Determining these factors after the detection survey is complete is vital in understanding the actual detection performance and in assessing detection performance against the MPC. Worksheet 11 of the QAPP describes how the detection threshold is defined so that it meets the project's DQOs. Worksheet 12 of the QAPP describes the project-specific detection threshold, which is a function of the types of munitions expected to be present, the depths of distribution, and geology. The detection threshold is expressed in terms of signal strength (millivolts per ampere) and signal-to-noise ratio.

4.3.2.4 Seed Detection Requirements [Accuracy and Completeness]

The detection of blind QC seeds is an ongoing, internal process QC check described in AGC-QAPP Worksheet 22. If the field team fails to detect any QC seeds, an RCA must be performed and a CA implemented. Performance criteria for QC seed detection are usually set at some specified distance from the initial planted ground truth location. To ensure a successful project, it is in the contractor's best interest to self-test by placing some seeds near the limits of the target-specific detection thresholds. This helps to ensure that no validation seeds are missed. The detection of validation seeds is a measure of overall project success. As specified in AGC-QAPP Worksheet 12, the project team must detect 100% of validation seeds to meet the DQOs. Failure to detect a validation seed is a serious flaw and has a negative impact on data usability. In such cases, the project team must consider which data may have been affected and determine an appropriate response based on the specific conditions.

4.3.2.5 Instrument Assembly, Operation, and Proper Function [Accuracy]

Before being used in the field, equipment must be inspected and tested to verify that it is properly assembled and functioning. SOPs containing detailed procedures for assembling, operating, and verifying the correct functioning of sensors and other equipment used during the detection survey must be contained in an appendix to the AGC-QAPP. However, specifications or measurement quality objectives (MQOs) for these procedures must be summarized in AGC-QAPP Worksheet 22. MQOs must address verification of correct assembly, initial and ongoing function tests, initial and ongoing dynamic positioning accuracy, operation at the IVS, and sensor response. The AGC-QAPP template provides recommended minimum procedures and MQOs for all inspection and QC procedures.

The initial and ongoing instrument function tests are performed to verify system operation and sensitivity capabilities. As described in Section 3.3.1, the IVS is used at the beginning and end of each day to verify correct operation of the detection system. The initial derived position of seed targets placed in the IVS must be within stated limits relative to ground truth, while the ongoing position requirement is evaluated relative to the average. The initial minimum response amplitudes should be within an established percentage of predicted values, while the ongoing amplitude requirements are relative to the initial response. If these criteria are not met, the field team must make any necessary adjustments and re-verify. These actions must be documented in the field notes, and verification must be completed before the instruments are used in the field for data collection.

To ensure complete coverage during the detection survey, the operator must verify that all equipment used for positional measurement is operating properly. Procedures and checks are critical in verifying that IMUs and GPS instrumentation are operating within specifications. Where site conditions prevent the use of GPS (for example, dense tree canopy), procedures to ensure the accuracy of fiducial positioning must be documented. If multiple advanced sensor instruments are being used in the field, a minimum distance of separation between the instruments must be established and maintained to avoid potential interferences.

4.3.3 Cued Survey QA/QC

The following sections discuss the recommended minimum QA/QC requirements for the cued survey.

4.3.3.1 Target Characteristics and Library Matching [Completeness and Comparability]

Matching the intrinsic responses of buried items to known library signatures is a key step in the classification process; on most sites, more than 95% of TOIs are identified via library matching. For library matching on any project, it is important to document that an up-to-date master library is used as a reference point, and that appropriate additions are made to the project-specific library. ESTCP is completing a baseline master library of munition signatures. This library will reside on a DOD-hosted website, and DOD will periodically update it. The government project manager will be responsible for downloading the current version of that master library for use in developing a project-specific library. Further information on library matching is presented in Section 2.1.3.

As a check of both completeness and comparability, Worksheet 12 of the QAPP requires that the site-specific library include signatures for all munitions known or suspected to be present at the site, as specifically identified during project planning and documented in the QAPP on Worksheet 10 (CSM). If site-specific additions to the project library are required, it is the responsibility of the project team to verify that these additional responses are determined in accordance with the SOP and QC procedures published with the master library.

4.3.3.2 Procedures and Frequency for Collecting Background Data [Representativeness and Accuracy]

As discussed previously, background influences can have an effect on classification. Appropriate background locations must be initially selected based on environmental conditions and geological heterogeneity and then checked at specified intervals during the cued survey. Background data are typically collected at least once every two hours of cued survey data collection. Background locations must be representative of the various subsurface conditions expected to be encountered at the site. AGC-QAPP Worksheet 22 provides recommended minimum acceptance criteria for background measurements.

4.3.3.3 Determination and Verification of the Dig/No-dig Threshold [Accuracy and Completeness]

Following data processing, all anomalies must be classified as one of the following: TOI, non TOI, or "inconclusive." They are then listed in order from highest likelihood to be a TOI to highest likelihood to be a non-TOI, and dig/no-dig decisions are made on each. TOIs and items deemed inconclusive are automatically included on the dig list. The last item included on the dig list denotes the dig/no-dig threshold. As provided on AGC-QAPP Worksheet 22, to confirm correct placement of this threshold, an additional 200 threshold verification digs (predicted non-TOI) are identified in the ranked list. These are investigated during the intrusive investigation. 100% of the threshold verification digs must be confirmed to be non-TOIs; otherwise, the threshold must be readjusted. The number 200 is a regulatory compromise reached by the members of the IDQTF Advanced Classification Subgroup. The threshold verification digs are a process control check on the ranked list, designed to foster further confidence in the technology and ensure that the list was created correctly. (Note: The 200 threshold verification digs combined with the 200 validation digs [see Section 4.3.4] equal roughly one week's worth of digging, and the IDQTF subgroup agreed that this additional level of effort was reasonable, appropriate, and sufficient for providing assurance to regulators and the public).

4.3.3.4 Requirements for Seed Classification [Accuracy and Completeness]

As with detection, the correct classification of blind QC seeds is also an ongoing process QC check. As specified in AGC-QAPP Worksheet 22, if the field team fails to correctly classify any QC seeds, an RCA must be performed and a CA implemented. The correct classification of validation seeds is a measure of overall project success. AGC-QAPP Worksheet 12 requires that the project team correctly classify 100% of validation seeds to meet the DQOs. Failure to correctly classify a validation seed reflects a serious flaw in either the sample design or its execution, and it has a negative impact on data usability. In such a case, the project teams must determine a response based on the specific conditions.

4.3.3.5 Instrument Assembly, Operation, and Proper Function [Accuracy]

SOPs containing detailed procedures for assembling, operating, and verifying the correct functioning of sensors used during the cued survey must be contained in an appendix to the AGC-QAPP, and specifications (the MQOs) for these procedures must be summarized in Worksheet 22. MQOs must address verification of correct assembly, initial and ongoing function tests (including sensor response and library match metrics), transmit current levels, initial and ongoing target positioning accuracy, and operation at the IVS. Reacquisition of designated GPS locations must meet specified limits, as also documented on Worksheet 22.

4.3.3.6 Data Processing [Accuracy]

The AGC-QAPP template, Worksheet 22, contains recommended minimum specifications for selecting background measurements and confirming that the results obtained from the inversion model support a classification decision. Target parameters obtained from an inversion are only reliable if the model accurately reproduces the measured data. If there is not good agreement between the model and the data, the target item is classified as "inconclusive" and is added to the dig list. Similarly, if the target location estimate from the inversion is too far from the measurement location, the inversion parameters are considered unreliable. All QC seeds must be detected within the specified tolerance for location and depth and then appropriately classified as a TOI. If any seed is not detected within tolerance, or is incorrectly classified, an RCA must be performed with a potential CA. Because the field team does not know the locations of the seed items, conformance to MQOs is not evaluated until data processing is complete. This delay may result in the collection of additional field data being acquired after the missed QC seed, in which case the RCA and CA must account for these data and determine whether the root cause and corrective action should be applied to any affected data.

4.3.4 Intrusive Investigation

The AGC-QAPP does not address procedures for recovering targets. Worksheet 36, however, addresses the verification of the dig/no-dig threshold and evaluation of the items following excavation. Key requirements include the following tasks:

- For the TOIs on the dig list, a prediction of the identity or characteristics of each item should be included. A comparison of the items removed to the predictions made on the dig list may be helpful in building greater confidence in the geophysical classification implementation at the site; it may also alert the project team to issues that require resolution.
- To verify correct placement of the dig/no-dig threshold, an additional 200 non-TOI targets, below the threshold, must be dug. If the verification excavations uncover any TOIs, the threshold will be adjusted accordingly.
- To validate performance of the overall study, an additional 200 randomly selected "validation digs" (that is, non-TOI targets) not including the threshold verification targets, must be intrusively investigated to qualitatively evaluate how well the physical properties of the recovered non-TOI targets match predictions.

4.3.5 Data Management and Reporting

AGC-QAPP Worksheet 29 provides minimum specifications for data management tasks; interim and final deliverables; and procedures for controlling project documents, records, and databases. Its purpose is to ensure data completeness, data integrity, and ease of retrieval. Part 1 of Worksheet 29 outlines project-specific requirements for data management. This section should describe specifications for geographic information systems, including the standards and formats to be used for storing and presenting data. It should also describe required electronic format specifications for computer files and other digital data, including photographs.

During planning, project teams should decide how, when, and to whom specific project records will be distributed. It is important for all stakeholders to understand and agree upon the content and distribution of interim and final project deliverables. If a project website is being used to facilitate information exchange among project team members, Worksheet 29 should provide the URL as well as instructions for uploading and downloading files.

Part 2 of AGC-QAPP Worksheet 29 lists project-specific requirements for distributing and controlling documents, records, and databases, including field records, deliverables (for example, plans, technical memoranda, reports, and databases), and project assessment checklists and reports. For each type of record, Worksheet 29 identifies the parties responsible for generating and verifying the record, as well as requirements for format, interim storage, and final archiving.

It is critical that Worksheet 29 describe all computerized and manual procedures that date from generation to final use and storage. Applicable SOPs on data handling/management should be attached to the AGC-QAPP. The following data management steps should be addressed:

- Data Recording and Retention
- Data Transformations and Data Reduction
    - Describe when and how data conversion procedures are performed, how they are checked, the documentation generated, and responsible personnel.
    - Describe all data manipulations involved and responsible personnel.
    - Provide references to specific software documentation for automated data processing.
    - Describe internal checks to detect errors, the documentation generated, and responsible personnel. Provide examples of all verification checklists and forms.
- Data Transfer and Transmittal
    - Identify electronic data transfer software.
    - Describe electronic transmittal procedures, the documentation generated, and responsible personnel.
    - Describe internal checks to detect errors, the documentation generated, and responsible personnel. Provide examples of all verification checklists and forms.
- Data Analysis
    - Identify and describe the computer hardware and software that will be used to process, compile, and analyze project data (for example, Excel, UX-Analyze).

4.3.6 Data Review

Data review is addressed in AGC-QAPP Worksheets 34–37. Data review is conducted in three phases: data verification, data validation, and DUA. Data verification is a check that all specified data collection and processing activities have been completed and documented and that the necessary records are available for proceeding to data validation. Data validation is the evaluation of conformance to stated requirements documented in the SOPs and QAPP. Because geophysical classification is a dynamic process, data verification and validation procedures must be incorporated into the process and conducted daily. Many of the verification steps occur in the software itself. Data validation is conducted on an ongoing basis by the project or QC geophysicist. Results of validation are documented in daily and weekly QC reports, which are usually contained in the electronic records. The DUA is conducted at the end of data collection, to confirm that the data can be used as intended with an acceptable level of uncertainty. The geophysical process also incorporates process validation, which consists of the use of blind QC seeds and validation seeds, verification of the TOI/non-TOI threshold, and the use of validation digs. AGC-QAPP Worksheet 34 lists all project records that are subject to verification, validation, and the DUA. Additional details on each phase of data review are provided in the following sections.

4.3.6.1 Data Verification and Validation

Data verification and validation are integrated into the geophysical data collection and data processing steps and conducted concurrently, on an ongoing (daily) basis, by the project and QC geophysicists. AGC-QAPP Worksheet 34 provides a checklist of the inputs used in performing verification and validation. Worksheet 35 describes the procedures for conducting data verification and validation based on the checklist inputs from Worksheet 34. Inputs include all required documents (for example, contracts, SOPs, planning documents), field records (both hard-copy and electronic), and interim and final reports. Data verification is a check that all records are documented and the specified activities documented in those records have been completed and recorded. These records represent objective evidence that the quality review can proceed to data validation.

Data validation is the evaluation of conformance to stated requirements. AGC-QAPP Worksheet 35 lists the activities and records reviewed, the sources of the specifications against which the activities and records are evaluated, the responsible party, and the manner in which verification/validation will be documented. Worksheet 36 documents data verification and validation procedures that are implemented during field work for geophysical classification projects; this worksheet documents the specific validation approach, which involves testing the thresholds for both anomaly detection and anomaly classification.

4.3.6.2 Process Validation

AGC-QAPP Worksheet 36 documents procedures used to validate the overall anomaly detection and classification approach as it is implemented at a specific site. Process validation provides added confidence in the ability of the sample design to detect anomalies meeting the project-specific detection threshold and correctly classify anomalies as TOIs or non-TOIs. Process validation tests the overall approach in the following four ways: (1) placing blind validation seeds (the locations of which are known only to the government); (2) comparing recovered items to the predictions contained on the dig list; (3) excavating an additional 200 objects (threshold verification digs) beyond last TOI to verify correct placement of the threshold; and (4) conducting validation digs of 200 randomly selected non-TOIs at the end of the project to provide added confidence that anomalies classified as non-TOIs are, in fact, non-TOIs.

4.3.6.3 Data Usability Assessment

AGC-QAPP Worksheet 37 documents procedures to be used in performing the DUA. The DUA is performed at the conclusion of data collection activities, using the outputs from data verification and data validation. It involves a qualitative and quantitative evaluation of environmental data to determine whether the project data (geophysical classification results) are of the right type, quality, and quantity to support the MPC and DQOs. It is a retrospective review of the systematic planning process to evaluate whether underlying assumptions are supported, sources of uncertainty have been managed appropriately, data are representative of the population of interest (that is, the type and distribution of munitions present are accurately reflected in the CSM), and the results can be used as intended with an acceptable level of confidence. Worksheet 37 documents the personnel responsible for participating in the DUA and identifies which documents and data will be used as input.

For geophysical classification projects, a DUA is conducted at the end of each major investigative phase: detection, cued, and intrusive phases. The first phase occurs at the conclusion of the detection survey, because items cannot be classified until/unless they are correctly detected. The second phase occurs at the end of the cued investigation because an assessment of data usability is required before the intrusive investigation can be initiated. The third DUA occurs at the end of the intrusive investigation to evaluate how well the overall sampling design performed with respect to correctly classifying TOIs and non-TOIs and meeting the MPC defined on Worksheet 12.

4.4 DOD Advanced Geophysical Classification Accreditation Program

The DOD Environmental Data Quality Workgroup (EDQW) is developing the DAGCAP to provide a unified DOD program through which organizations implementing the advanced geophysical classification technology at MRSs can demonstrate competency and document conformance to the international standard, ISO/IEC 17025. Among other things, ISO/IEC 17025 requires each organization to be accountable for establishing minimum qualifications and training requirements for its personnel, and requiring demonstrations of capability for key personnel. For the DAGCAP, ongoing demonstrations of capability will be demonstrated (and maintained) through the organization’s continued ability to correctly detect and classify validation (blind) seed items.

ISO/IEC 17025 is divided into two principal sections: management requirements and technical requirements. Documentation of management requirements must include detailed specifications for the following:

- description of the organization, including roles, responsibilities, accountability, and lines of authority
- general management system requirements
- document control
- contracting
- subcontracting
- purchasing services and supplies
- customer service
- complaint handling
- control of nonconformances
- continual improvement
- corrective action
- preventive action
- control of records
- internal audits
- management reviews

Documentation of technical requirements must include detailed specifications for the following:

- factors affecting data quality
- personnel qualifications
- facilities and environmental conditions (in which testing is conducted)
- test methods and method validation

The DAGCAP will use third-party accreditation bodies (ABs) to assess and accredit organizations wishing to use advanced geophysical classification at DOD MRSs. The DAGCAP will apply to organizations wishing to do business with DOD, regardless of their size or volume of business. It will apply to the use of advanced geophysical classification at all DOD MRSs. Participation by both organizations and ABs will be voluntary. ABs wishing to participate in the program must be formally recognized by DOD. To be recognized, an AB must fulfill the following requirements:

- be a U.S.-based signatory in good standing to the International Laboratory Accreditation Cooperation Mutual Recognition Arrangement
- submit a documented management system conforming to the international standard ISO/IEC 17011, Conformity assessment—General requirements for accreditation bodies accrediting conformity assessment bodies (ISO/IEC 2004)
- accept specific DOD conditions and criteria for recognition
- complete assessor training

Each AB will establish and administer its accreditation program in accordance with its internal quality systems requirements. It will conduct assessments, issue assessment reports, monitor implementation of CA responses, and issue accreditation certificates. Each AB will publish a list of organizations that hold current accreditation. Published information will include the specific advanced geophysical classification technology for which the organization is accredited. Project teams will be responsible for verifying that selected organizations are capable of meeting all requirements contained in a project-specific AGC-QAPP. The DOD EDQW will provide management and oversight of the DAGCAP. On behalf of DOD, the EDQW will evaluate and recognize ABs. Where contractual, regulatory, and/or programmatic requirements specify that geophysical classification will be performed, documentation of the selected organization's accreditation should be included as an attachment to the AGC-QAPP.

4.5 Government Quality Assurance Oversight

Government QA oversight is an essential component in the successful implementation of advanced geophysical classification. This oversight occurs on several levels. Certain aspects of QA—those intended to objectively verify the adequacy of the contractor's QC and the contractor's response actions—should be independent of the contractor or lead agency executing the action. Because the different phases of geophysical classification (detection survey, cued survey, and intrusive investigation) are implemented in a continuous, dynamic, and labor-intensive process, it is essential that the government QA oversight be integrated into that process in a seamless manner. Once field activities begin, any interruptions or time delays will result in less efficiency and lower cost-effectiveness.

> ***Quality Assurance***
>
> *QA is an integrated system of policies and procedures for planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or activity is of the type and quality required for a process and products (USEPA/DOD/DOE 2005).*

For the purposes of this document, responsibilities for government oversight will be divided between the activities conducted by the lead agency (DOD oversight) and those conducted by state and federal regulators (regulatory oversight). Specific roles, responsibilities, and activities involved in government oversight should be agreed upon during project planning and accommodated in the project schedule. They should also be documented in relevant AGC-QAPP worksheets (for example: Worksheets 3 and 5—Project Organization; Worksheet 6—Communication Pathways; Worksheet 9—Project Planning; Worksheets 14 and 16—Project Tasks and Schedule; Worksheets 31, 32, and 33—Assessments and CA; and Worksheet 37—Data Usability Assessment).

4.5.1 DOD Oversight

DOD oversight occurs on several levels, which are usually described in the government's QASP. Oversight activities typically include contract compliance monitoring, project planning, DAGCAP oversight, QA seeding, on-site observation and assessments, data validation, and DUA.

4.5.1.1 Contract Compliance Monitoring

Each DOD component has its own set of requirements for contract compliance monitoring. This is an effective form of oversight because payment for contracted services is typically linked to the achievement of specific objectives and milestones. Providing guidance on specific contract compliance monitoring activities is outside the scope of this document; however, DOD has established policy and guidance for acquisitions involving the collection and use of environmental data, and contracted organizations conducting geophysical classification for munitions response are subject to those guidelines (OUSD(AT&L) 2007).

4.5.1.2 Project Planning

Project planning occurs during a series of meetings, which may involve different subsets of the project team, depending on the phase of the planning. At a minimum, the DOD project manager will participate in all planning meetings (Chapter 3 discusses project planning in more detail). AGC-QAPP Worksheet 9 provides a concise summary of all project planning meetings, including participants, topics discussed, decisions reached, and action items.

4.5.1.3 DAGCAP Oversight

The DOD EDQW provides oversight for the DAGCAP (see Section 4.4 for further detail).

4.5.1.4 Validation Seeding

DOD documents its planned QA seeding program in the QASP.

4.5.1.5 On-site Observation and Assessments

The level of DOD oversight during field activities should be discussed and agreed upon during project planning and built into the project schedule (AGC-QAPP Worksheets 14 and 16). Specific assessment activities should also be documented in Worksheets 31, 32, and 33, and time for the contractor to respond to assessment findings should be accommodated by the project schedule. The government QASP (however named) should also describe DOD's planned on-site observation and assessment activities.

4.5.1.6 Data Validation

The contractor (project or QC geophysicist) conducts data validation on an ongoing basis; however, there are critical points in data acquisition and processing at which DOD must review and accept the data validation results. These decision points are shown on AGC-QAPP Worksheet 17, Figure 17-1.

4.5.1.7 Data Usability Assessment

A DUA is conducted by key members of the project team at the end of the detection and cued surveys, and also following the intrusive investigation. The DUA evaluates conformance to the MPC documented on AGC-QAPP Worksheet 12, considers how well the investigation achieved the DQOs documented on Worksheet 11, and evaluates the impact of any nonconformances on data usability. The procedures and participants involved in conducting the DUA are documented on Worksheet 37. Section 4.3.6.3 provides additional information about conducting the DUA.

4.5.2 Regulatory Oversight

Regulatory participation in project planning activities is critical in ensuring regulatory acceptance of the final decisions. Key agreements and decisions reached among the lead agency, contractor, and regulators are documented on AGC-QAPP Worksheet 9. Regulatory review and acceptance of the QAPP is usually required before field activities begin. The level of involvement by the regulatory agency during field activities and data processing efforts varies across agencies and is dictated largely by resource constraints. Thus, ongoing communication with regulators is extremely important; the timing, frequency, responsibilities, and format of regulatory communication should be agreed upon during project planning, built into the schedule, and documented in the QAPP (Worksheets 3 and 5—Project Organization, Worksheet 6—Communication Pathways, Worksheet 9—Project Planning Session Summary, Worksheets 14 and 16—Project Schedule, and Worksheet 29—Project Documents and Records). The regulatory agency has the opportunity to review and accept the DUA, as described on AGC-QAPP Worksheet 37, before the final report is submitted.

5.0 STAKEHOLDER PERSPECTIVES

At MRSs throughout the U.S., the stakeholders are the "ultimate customers," whose health, safety, interests, and even livelihood may be impacted by the quality of a munitions response. These stakeholders include (1) owners of land or businesses located on former military facilities; (2) developers that plan to build on such property; (3) Native Americans on tribal lands formerly used for military purposes; and (4) anyone who lives, works, travels, worships, attends school, or enjoys recreational activities in these areas (DOD 2008).

In addition to the diversity in types of stakeholders, there are differing perspectives regarding risk. In particular, explosive risk is viewed differently than toxic risk. While most people take a conservative, precautionary approach to explosive risk because of the potential immediate effects, some stakeholders, such as souvenir hunters, tend to minimize such risk; others show concern at the mere appearance of munitions-related items. Thus, it is essential that munitions response projects be understood by the people they are designed to protect. It is also important to make stakeholders aware that, no matter what munitions response technology is used, there is no way to ensure 100% removal of hazardous munitions from a site.

Often, munitions response projects depend entirely on rights of entry; consequently, for practical reasons, it is crucial that public and tribal stakeholders are informed and consulted about munitions response activities. Without access agreements signed by private property owners or representatives of local agencies (depending on the specific site), a munitions response cannot be initiated. Additionally, where institutional controls are required to prevent contact with munitions—either before, during, or after the munitions response is conducted—public cooperation is key to implementing limitations on access and use. Finally, because most accidents involving munitions occur during movement of or tampering with munitions, stakeholders should be fully informed about and comfortable with the three R's of explosives safety: recognize, retreat, and report.

5.1 Trust

Stakeholders may have doubts or even be skeptical about geophysical classification for reasons that have nothing to do with the technology itself. Those who lack technical knowledge or experience or who do not understand environmental industry nomenclature may be reticent to trust the professionals involved in the cleanup. Many are reluctant to trust project teams who downplay potential risks, particularly if subsequent investigations uncover additional hazards. In some cases, munitions response projects face opposition because of uncertainty about the effects on the property itself or due to concerns that munitions response will lead to development. With tribal stakeholders, in particular, who believe their lands have been damaged enough by past military activities, it is important to convey the benefits of geophysical classification as a far less intrusive technology than previous methods. Therefore, before introducing geophysical classification, community attitudes and concerns must be understood by the project team, and efforts to inform and engage the public should be made long before project plans are finalized.

Public and tribal stakeholders should be viewed as partners in the overall munitions response effort, and it is crucial for DOD and the regulators to establish trust with these impacted communities. Trust building should involve education and open communication with stakeholders on issues such as how munitions response investigations are carried out, how advanced geophysical classification works, and what can be expected when the technology is implemented successfully. Some concerns can be allayed by (1) informally engaging with stakeholders; (2) conducting public meetings, or providing other means by which stakeholders can voice their concerns; and (3) engaging an established restoration advisory board, or seeking interest in forming such a board if one does not already exist. In addition, DOD's Technical Assistance for Public Participation Program or USEPA's Technical Assistance Grants may enhance public understanding of the technology and encourage a positive perspective.

In the case of Native Americans, mistrust can go much deeper, predating the project by decades or even centuries; however, by understanding local tribal concerns, creative solutions can be developed and implemented by the project team. Tribal stakeholders generally feel more comfortable when they are considered part of the solution, working alongside the government agencies and contracting firms. When contractors hire workers from the tribes whose lands are being remediated, it may be easier to establish trust between those involved.

> ***Stakeholder Involvement at the Pine Ridge Munitions Site***
>
> *At the Pine Ridge Lakota (Sioux) reservation, which includes the Badlands Bombing Range, the tribe wished to have the bombing range cleared of munitions, but did not want the U.S. Army to once again encroach on its territory. This reservation is one of the most impoverished areas of the country with a high unemployment rate. To address these issues, the tribe and DOD developed a solution that satisfied and benefited both sides: tribal members who were U.S. Army veterans were trained to become munitions response technicians and were then able to take an active role in the cleanup.*

In any case, mutual trust is the key to cooperation between impacted stakeholders and the project team responsible for the cleanup. Stakeholder communities that trust the project team are more likely to play a productive role in the process. This, in turn encourages the project team to be more open to input from stakeholders and to hear their concerns. Thus empowered, the impacted communities continue to offer constructive feedback. Trust drives a continual feedback loop, and once such trust is established, stakeholders are more likely to be proponents of geophysical classification.

5.2 Acceptance

During the initial geophysical classification field demonstrations, there was concern that community stakeholders would be uncomfortable with decisions to excavate fewer items than was routinely done with older technologies. However, interviews and workshops thus far have shown that stakeholders prefer more selective excavation if they can be assured that decision-makers are competent and accountable, and that the process is transparent.

In November 2012, a forum was convened by the Center for Public Environmental Oversight with support from ESTCP. The forum participants generally consisted of stakeholders with long-standing experience in monitoring and providing input on environmental cleanups, including munitions response, in their communities. Following a brief presentation on geophysical classification by DOD, the forum participants offered the following input:

- Geophysical classification is appropriate under certain circumstances and at particular sites, taking into consideration that the success of EMI surveys depend on conditions such as terrain and geology as well as the size and depth of the buried munitions.
- Selective excavation may be preferred at sites where lands such as deserts, prairie, and tundra take decades or longer to restore, or in populated areas where fewer excavations result in less disruptive evacuations or area closures.
- Selective excavation may not be desirable at some sites, where nonexplosive fragmentation from munitions poses a physical hazard.
- Geophysical classification is acceptable based on assurances that the analysis will be properly conducted.
- The accuracy of excavation lists varies according to the expertise of the geophysicist doing the work; therefore, some form of certification of qualifications is preferred.
- Dig/no-dig rationale should be collaboratively agreed upon by the project team and should be clearly communicated to stakeholders.
- There should be independent verification of those decisions, perhaps by geophysicists working for regulatory agencies, with local stakeholders as witnesses to the verification.

The November 2012 forum participants had prior experience with munitions response actions. Stakeholders who are newer to the process may require more detailed explanations or additional training. Furthermore, as mentioned above, stakeholders tend to be more receptive to geophysical classification when it is presented in lay terms (that is, not containing a great deal of calculations, technical terminology, and complex graphics).

Once they understand the capability and reliability of the technology, many stakeholders look favorably upon geophysical classification because it is less intrusive to the landscape, less disruptive to their lives and livelihood, and more cost-effective.

5.3 Assurances

In the final analysis, acceptance of geophysical classification is based on its reliability in reducing explosive risk. There is no guarantee that any munitions response strategy will ensure the location and removal of all explosive hazards. Cued classification only helps determine which items, already identified, should be excavated.

It is essential that all communities in which geophysical classification is applied understand this limitation, because at some point one or more pieces of munitions may be encountered after project completion. Particularly if the discovery is associated with an injury, even at just one site, it could undermine the use of geophysical classification on a broad scale. However, if affected stakeholders are engaged in munitions response projects from start to finish, and if their concerns about the proper use of the technology are addressed, they are unlikely to question the practice of selective excavation. In fact, they may end up being among the strongest proponents of the new technology.

6.0 REFERENCES

ANSI/ASQ. (American National Standards Institute and American Society for Quality). 2004. Quality Systems for Environmental Data and Technology Programs – Requirements with Guidance for Use. American National Standard for quality management systems for environmental sector applications.

DOD (Department of Defense). 2008. Department of Defense Instruction. Explosives Safety Management Program. http://www.dtic.mil/whs/directives/corres/pdf/605516p.pdf.

DOD. 2010. Department of Defense Manual. DOD Ammunition and Explosives Safety Standards: Criteria for Munitions Response, Waste Military Munitions, and Material Potentially Presenting an Explosive Hazard. http://www.dtic.mil/whs/-directives/corres/pdf/605509m/605509-M-V7.pdf.

DOD. 2012. Department of Defense Manual: Defense Environmental Restoration Program (DERP) Management. http://www.denix.osd.mil/references/upload/DoDDODM_471520_DERP-Manual_9March2012.pdf.

Geometrics, Inc. 2015. MetalMapper. cliometrics-products/geometrics-electro-magnetic-products/metal-mapper/.

IDQTF (Intergovernmental Data Quality Task Force). 2005. Uniform Federal Policy for Implementing Environmental Quality Systems: Evaluating, Assessing, and Documenting Environmental Data Collection/Use and Technology Programs, Version 2.0. Intergovernmental Data Quality Task Force. EPA-505-F-03-001. DTIC ADA 395303. DOE/EH-0667. (UFP-QS). http://www.denix.osd.mil/edqw/upload/UFP.PDF.

IDQTF. 2012. Uniform Federal Policy for Quality Assurance Project Plans. Optimized UFP-QAPP Worksheets. http://www2.epa.gov/sites/production/files/documents/ufp_qapp_worksheets.pdf

IDQTF. 2014. Uniform Federal Policy for Quality Assurance Project Plans. Intergovernmental Data Quality Task Force (UFP-QAPP).

IDQTF. 2016. Uniform Federal Policy for Quality Assurance Project Plans Template: Advanced Geophysical Classification for Munitions Response (AGC-QAPP). https://www.epa.gov-/fedfac/uniform-federal-policy-quality-assurance-project-plans-template-advanced-geophysical .

ISO/IEC (International Organization for Standardization and International Electrotechnical Commission). 2004. ISO/IEC 17011, Conformity assessment – General requirements for accreditation bodies accrediting conformity assessment bodies. (ISO/IEC 17011).

ISO/IEC. 2005. ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories. (ISO/IEC 17025)

ITRC (Interstate Technology and Regulatory Council). 2000. *Breaking Barriers to the Use of Innovative Technologies: State Regulatory Role in Unexploded Ordnance Detection and Characterization Technology Selection*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/GuidanceDocuments/UXO-1.pdf.

ITRC. 2003. *Technical/Regulatory Guideline for Munitions Response Historical Records Review*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/GuidanceDocuments/UXO-2.pdf.

ITRC. 2004. *Geophysical Prove-Outs for Munitions Response Projects*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/GuidanceDocuments/UXO-3.pdf.

ITRC. 2006. *Survey of Munitions Response Technologies*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/GuidanceDocuments/UXO-4.pdf.

ITRC. 2008. *Quality Considerations for Munitions Response Projects*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/GuidanceDocuments/UXO-5.pdf

ITRC. 2010. *Frequently Asked Questions about Wide-Area Assessment for Munitions Response Projects*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/GuidanceDocuments/UXO-6.pdf.

ITRC. 2012. *Geophysical Classification for Munitions Response: Introductory Fact Sheet*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/Documents/Team-Resources-GCMR/GCMR_FactSheet1.pdf.

ITRC. 2013. *Geophysical Classification for Munitions Response: Technical Fact Sheet*. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/Documents/Team-Resources-GCMR/ITRC-MR-technical-fact-sheet-June-2013-FINAL.pdf.

ITRC. 2014. Geophysical Classification for Munitions Response: Regulatory Fact Sheet. Washington, D.C.: Interstate Technology and Regulatory Council, Geophysical Classification for Munitions Response Team. http://itrcweb.org/Documents/Team-Resources-GCMR/ITRC-GCMR-Team-Regulatory-Fact-Sheet-Final-10-10-2014.pdf.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD (AT&L)). 2003. *Report of the Defense Science Board Task Force on Unexploded Ordnance*. Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Defense Science Board. Washington D.C. http://www.denix.osd.mil/mmrp/upload/uxo.pdf.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD (AT&L)). 2007. *Department of Defense Policy and Guidelines for Acquisitions Involving Environmental Sampling or Testing*. Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Washington D.C. http://www.denix.osd.mil/mmrp/upload/uxo.pdf.

SERDP/ESTCP (Strategic Environmental Research and Development Program/Environmental Security Technology Certification Program). 2014a. "Classification Applied to Munitions

Response." http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response.

SERDP/ESTCP. 2014b. "Geophysical System Verification." http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Geophysical-System-Verification.

USEPA (United States Environmental Protection Agency). 1999. Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents. http://www2.epa.gov/sites/production/files/2015-02/documents/rod_guidance.pdf.

USEPA. 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process*. EPA QA/G-4.

USEPA, DOD, and United States Department of Energy. 2005. Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP), Intergovernmental Data Quality Task Force, EPA-505-B-04-900A. http://www2.epa.gov/sites/production/files/documents/ufp_qapp_v1_0305.pdf.

APPENDIX A. CASE STUDIES

Over the past several years, the U.S. Department of Defense (DOD) Environmental Security Technology Certification Program (ESTCP) has successfully demonstrated the capabilities of geophysical classification technologies at munitions response sites (MRSs) around the country. Until recently, however, the technology had not been taken beyond the demonstration phase and used as part of a removal action on an active remediation site.

This appendix presents two geophysical classification case studies at former DOD training installations. Section A.1 describes the classification demonstration conducted at the former Camp Beale in California. Section A.2 discusses the use of geophysical classification as part of an active munitions response at former Camp Sibert in Alabama.

A.1 Former Camp Beale

In 2011, geophysical classification was formally demonstrated at the Former Camp Beale in northern California. The site is located 45 miles north of Sacramento and immediately east of the current Beale Air Force Base.

A.1.1 Demonstration Overview

The demonstration was conducted in an area located within the historical bombing Target 4 and the Proposed Toss Bomb target area.

The following four technologies were demonstrated: (1) the vehicular-borne MetalMapper; (2) the man-portable TEMTADS 2x2; (3) the Man-Portable Vector (MPV); and (4) the portable Berkeley UXO Discriminator (BUD). The MetalMapper was demonstrated in an open area at the demonstration site amenable to maneuvering the vehicle. An adjacent treed site was used to demonstrate the portable sensors; this constituted the first test of smaller man-portable advanced electromagnetic induction (EMI) sensors intended for use where terrain or vegetation demand a more maneuverable option. In this demonstration, the MetalMapper results provided a point of comparison for the performance of the portable sensors. The geophysical data collected during the demonstration were analyzed by eight different teams using multiple classification approaches. All detected targets were excavated to provide complete accuracy in performance for this demonstration.

A.1.2 Demonstration Objectives

This demonstration was designed to investigate geophysical classification technology at a site that is more challenging and that contains a greater diversity of buried munitions than in previous demonstrations. The site included moderately challenging slopes, trees obstructing the acquisition of global positioning system (GPS) signals, and significant variety in types of munitions. The demonstration teams were composed of both developers and commercial digital geophysical mapping (DGM) contractors.

One of the objectives of the demonstration was to determine the ability of the commercial contractors to operate the advanced sensors and to adequately process the data and classify anomalies. The teams collected cued classification data over anomalies identified from a baseline geophysical survey. They then processed the data and categorized the anomalies as either targets of interest (TOIs), non-TOIs, or "can't analyze." After the data collection was completed, all of the identified anomalies were excavated and identified to determine the success of the classification. Note that some of the commercial contractors participating in the demonstration were first-time operators of the EMI sensors; therefore, an accurate range of results—from beginner to experienced performer—was obtained.

A.1.3 Conceptual Site Model

A.1.3.1 Site History and Status

DOD purchased the property in 1942 and used it as a full-service military training facility; combat training included tank maneuvers, mortar firing, aerial bombing, and chemical warfare. From 1959 to 1964, the former Camp Beale was sold off in portions following an inspection and removal program for surface munitions and explosives of concern (MEC). The remaining MEC hazards are being addressed by the U.S. Army Corps of Engineers (USACE) under the Formerly Used Defense Sites (FUDS) program.

A.1.3.2 Land Use

The former Camp Beale now consists of approximately 60,000 acres with multiple land use areas. Some areas are undeveloped and used for cattle grazing, wildlife, and recreation, while other areas are rural residential. Local residents believe that their property values are adversely affected by the potential for subsurface MEC and that the potential MEC hazards may hinder land transactions and future development.

A.1.3.3 Munitions

As stated above in Section A.1.1, the geophysical classification demonstration was conducted at Bombing Target 4 and the Proposed Toss Bomb target area. It was believed that this part of the former Camp Beale contained 37-millimeter (mm), 75 mm, and 105 mm projectiles, and 60 mm and 81 mm mortars.

A.1.3.4 Terrain and Vegetation

The former Camp Beale lies along the foothills of the Sierra Nevada mountain range. From west to east, the topography transitions from a grassland valley into rolling foothills of the Sierra Nevada. Vegetation consists largely of grasslands, with trees in low-lying areas that accumulate water (Figures A-1, A-2, and A-3).

Figure A-1. Treed area at the former Camp Beale demonstration site required the use of man-portable systems to conduct classification surveys.

Figure A-2. Treed areas can obstruct the acquisition of GPS satellite signals.

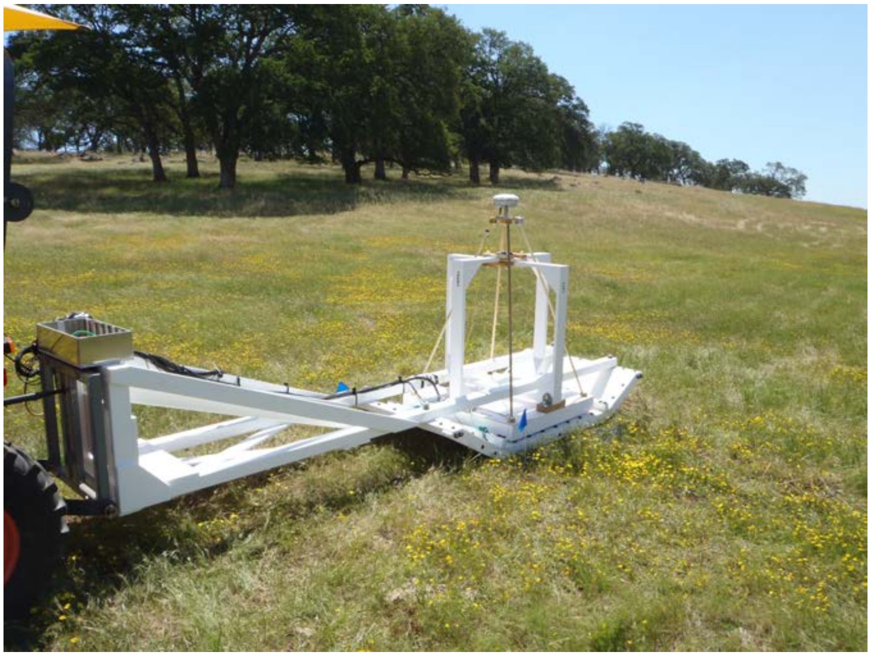


Figure A-3. Grasslands at the former Camp Beale demonstration site allowed for the maneuvering of vehicular-towed sensor systems.

A.1.3.5 Geology

The predominant geologic formations within the project area include Jurassic pyroclastic rocks and flows, and metavolcanic rocks ranging from andesite to rhyolite. The volcanic rocks consist of poorly to well-consolidated volcanic breccia, tuff breccia, and tuff. Minor igneous formations within the central and eastern region of the project site include a granitic dike, several intrusions of Jurassic-age granite, and intrusions of diabase and gabbro. The western region of the project site is underlain by both Laguna and Riverbank Formations. The Laguna Formation is a sequence of predominantly fine-grained, poorly bedded, and slightly compacted alluvial clays, sands, and gravels. The Riverbank Formation is an alluvial gravel fan.

During the demonstration, it was determined that the sensor data displayed moderate geologic interference. Such interference typically arises from the conductivity of ferrous minerals contained in the geologic formations.

A.1.4 Demonstration Activities

A.1.4.1 Field-Related Activities

The field-related demonstration activities included the following:

- selection of survey areas
- clearance of surface metal
- placement of seed items

- establishment of the instrument verification strip (IVS)
- baseline geophysical survey
- placement of survey markers at anomalies
- cued data collection
- intrusive investigation of anomalies

Selection of survey areas

The selected demonstration area, which covered approximately 10 acres, was divided into sub-areas: treed areas where each portable system was demonstrated, open areas where the Geometrics' MetalMapper was demonstrated, and an open area where the MetalMapper and all of the portable systems were demonstrated. Figure A-4 shows the subareas within the demonstration area.

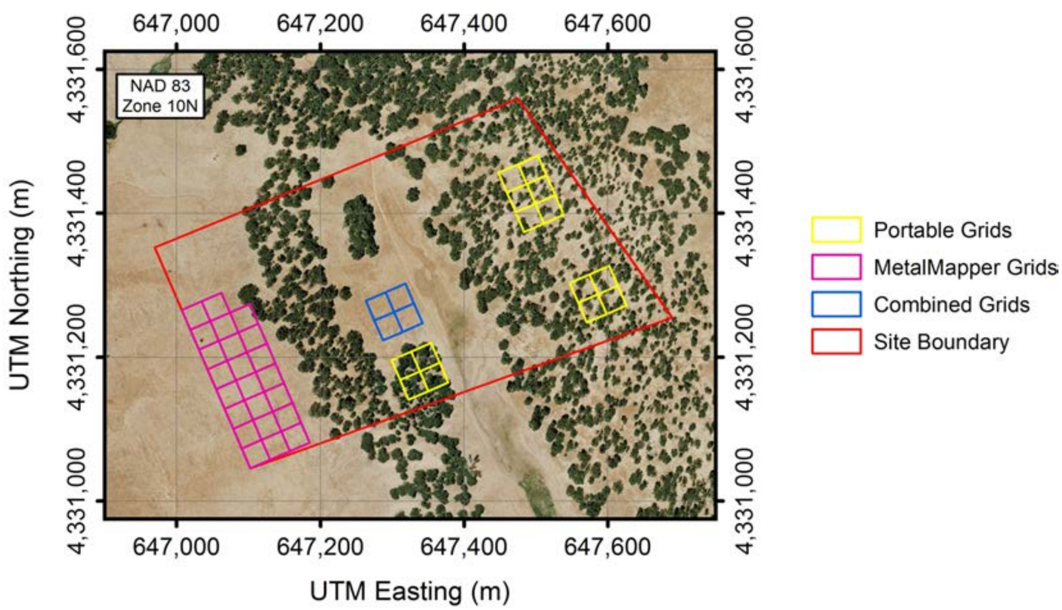


Figure A-4. The 50-acre demonstration site with the MetalMapper grids, portable system grids, and combined grids delineated.

Clearance of surface metal

A team of qualified unexploded ordnance (UXO) technicians removed all visible metal items from the surface. The main objective of the surface clearance was to ensure that no hazardous items would be encountered in the demonstration area during the nonintrusive phases and to remove metallic surface debris from the grids. In addition to the surface clearance in the demonstration area, a minor amount of brush was cleared and low branches and fallen trees removed. Most of the items found on the surface sweeps consisted of barbed wire with small fragments of munitions. Two notable items identified during the surface clearance were an empty 75 mm projectile and a large pile of barbed wire that was eventually moved out of the survey area.

Placement of seed items

At a live site, the amount of MEC items is not substantial enough to determine any demonstrator's classification performance with acceptable statistical confidence. In fact, on the Camp Beale demonstration site, only four munitions were recovered in the intrusive investigation. Therefore, the site was seeded with enough TOIs to ensure statistical validity on measures of TOI classification. These seeds are listed in Table A-1. At this demonstration, for the first time, the seeds included not only inert munitions, but also industry standard objects (ISOs). The ISOs were also considered TOIs and expected to be both detected and correctly classified.

Table A-1. Emplaced seeds for the Camp Beale demonstration

Item	Number	Depth Range (cm)*
ISO small, Schedule 40	65	10–25
37 mm projectile	59	10–32
60 mm mortar	34	15–40
81 mm mortar	33	15–50
105 mm projectile	9	15–60
* Depths are to the center of the object below ground level.		

Establishment of the instrument verification strip

A geophysically quiet area near the portable grids was located to establish an IVS to be used for daily verification of proper sensor operation and a training pit to be used to collect sensor data for algorithm training. The contents of the IVS are detailed in Table A-2.

Table A-2. Instrument verification strip details

Item ID	Description	Depth (meters)	Inclination	Azimuth
T-001	Shotput	0.30	N/A	N/A
T-002	105-HEAT	0.45	Horizontal	Across track
T-003	37 mm projectile	0.15	Horizontal	Across track
T-004	60 mm mortar	0.15	Horizontal	Across track
T-005	Small ISO	0.15	Horizontal	Across track

Baseline Geophysical Survey

Because the primary objective of the study was to evaluate classification, as opposed to detection, only a single geophysical system was required for detection. To compare different classification approaches in a straightforward manner, a common set of detections for each data set is required. A Geonics EM61-MK2 cart system (which detects both ferrous and nonferrous metal, and is the most commonly used detector in the industry) was used to survey all three subareas at 100% coverage to provide a baseline for the demonstration and determine the locations of the anomalies for the cued interrogation.

Placement of survey markers at anomalies

A real-time kinematic (RTK) GPS and conventional survey equipment were used to reacquire the locations of geophysical anomalies selected from the EM61-MK2 data. Nonmetallic survey flags were placed at each location.

Cued data collection

Four advanced EMI systems were demonstrated at the site. The MetalMapper was used for cued interrogation of anomalies in the open areas, and the three developmental EMI systems—the Naval Research Laboratory's TEMTADS 2x2 array, the Lawrence Berkeley National Laboratory's man-portable BUD, and the Sky Research MPV handheld system—were used to perform cued interrogation in the treed areas.

Intrusive investigation of anomalies

After the cued data collection was completed, all of the targets on the anomaly list were dug and each was assigned a ground truth label designating whether it was a TOI. These labeled data, including the seeded targets, were available to be used as training data or test data.

A.1.4.2 Data Analysis

Classification demonstrators could analyze the survey data, the cued data, or a mix of the two. For some anomalies under some analysis schemes, decisions could be made from the survey data so there was no need to bear the cost of a cued measurement.

Demonstrators could choose to perform their classification based on no site-specific training data or on a demonstrator-requested training data set. If requested, all truth information for the training data was provided to the processors and used to adjust their algorithms. The ground truths for the remaining data were not shared with the demonstrators and were used for blind testing. The processors were required to provide their assessment of the TOI/non-TOI labels for each item in the test data part of the detection list. The labels were compared to truth by an independent third party to score performance.

The data corresponding to each buried item were analyzed by the processing teams to extract parameters by fitting the data to a geophysical model. This had the effect of separating the intrinsic target parameters from extrinsic variables such as the distance and orientation between the sensor and the target. All except one of the processing approaches relied on the dipole model (see Section 2.1.2). Intrinsic parameters that were considered include the following:

- electromagnetic polarizabilities, which relate to the object's physical size and aspect ratio
- electromagnetic decay constants, which relate to the object's material properties and wall thickness

A.1.4.3 Classifiers

Once parameters have been estimated, a mechanism is necessary for deciding whether the corresponding object is a TOI. For this demonstration, several types of classification processing schemes were evaluated, including both statistical classification and library-matching classification. See Section 2.1.3 for descriptions of classification methods.

The analysts had the choice of using training data from one of the following three sources:

- previously collected data from other sites only
- on-site training data supplemented with data from the IVS and training pit at the demonstration site
- additional training data obtained from the excavation of a limited number of anomalies from the demonstration site

For the demonstrators who chose to use on-site training data, the anomaly list was divided into training and blind testing sets. For those who did not choose on-site training, the test set consisted of all anomalies. After training, the decision process for each algorithm was finalized and documented and the demonstrators provided ranked dig lists for the blind test set.

The final step in classification is delineating TOIs from non-TOIs. All anomalies are ordered by the likelihood that they are TOIs; the likelihood values do not represent a yes/no answer, but rather a continuum within which a dividing line or threshold must be specified. Depending on the application, the threshold may be set to try to avoid false positives, which may come at the expense of missing some TOIs, or it may be set to try to avoid false negatives, which may lead to a greater number of non-TOIs being intrusively investigated. For this demonstration, where missing a TOI represented the most serious failure, demonstrators selected thresholds that would retain all of the detected munitions.

A.1.5 Demonstration Results

A number of the demonstrators investigated multiple methods for training, parameter estimation, and classification during this demonstration. As a result, a total of 19 dig lists were scored in the blind phase of the demonstration, representing the various combinations of sensor data collection systems and processing approaches used.

Although there were varying results—depending on the system used, the contractor, and the analyst—the classification process was extremely successful. Both production contractor geophysicists and the developers of classification methods were successful in using these data to achieve substantial classification. Figures A-5 and A-6 show the classification results of the same data set, the first by one of the developers of the classification methods and the second by a contractor.

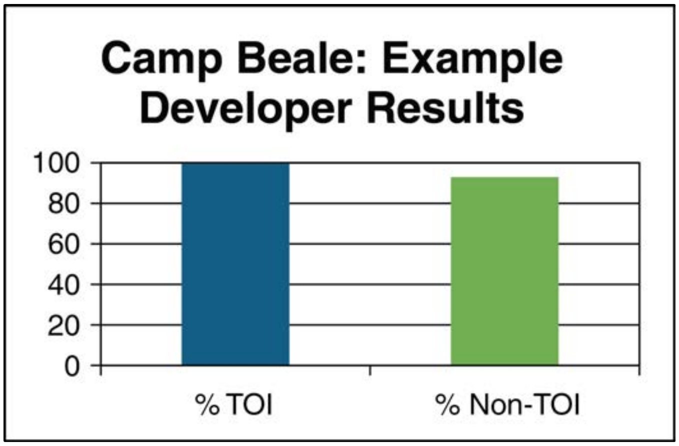


Figure A-5.Percentage correctly classified as TOIs (blue) and percentage correctly classified as non-TOIs (gray) from analysis of MetalMapper cued data by one of the developers of the classification methods.

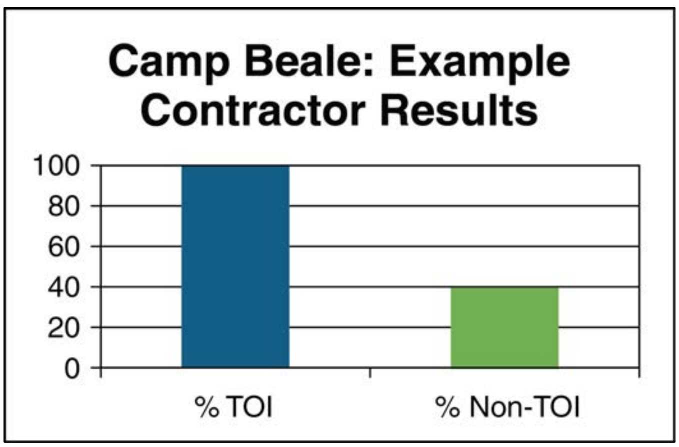


Figure A-6. Percentage correctly classified as TOI (blue) and percentage correctly classified as non-TOI (gray) from analysis of MetalMapper cued data by one of the novice contractor analysts.

The results from all analyses of the advanced sensor data collected during this demonstration are presented in Figure A-7. All 16 analysts were able to correctly identify 100% of the TOIs. The blue bars represent the number of clutter items excavated at each analyst's operating threshold. The worst performer was able to correctly classify approximately 40% of the clutter correctly. The best analysts were able to reject more than 75% of the clutter using data from any of the three sensors. The orange bars show the amount of excavated clutter items necessary to arrive at 100% correct classification of the TOIs, regardless of where the threshold was placed—that is, the best the analyst could have done by putting the threshold in the optimum place where the last TOI is found in the ranked list.

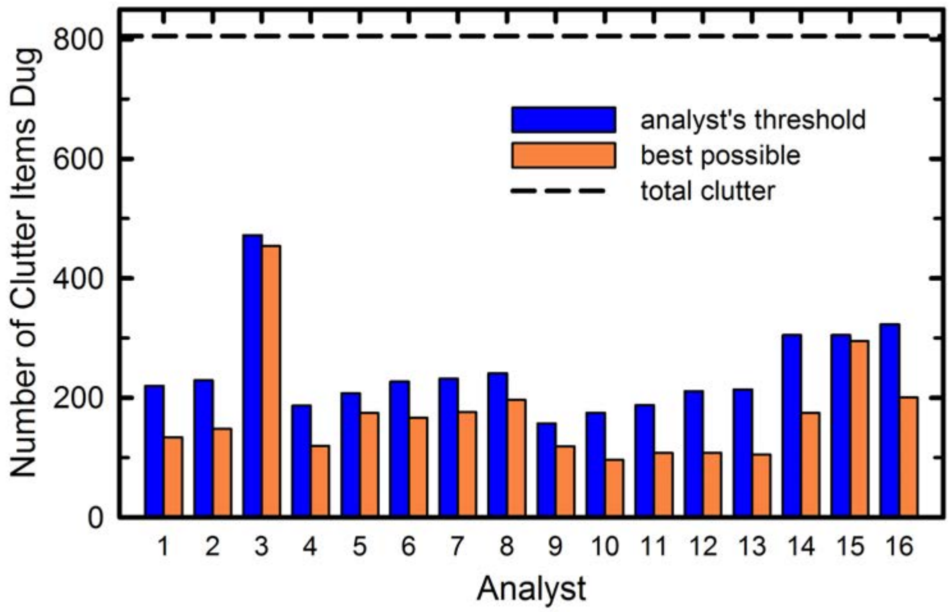


Figure A-7. Overview of the performance of all analyses of the cued data from the advanced portable sensors.

Considerable variations in performance were achieved among the production geophysicists, but this was determined to be due to the need for additional training as opposed to insufficient data to make appropriate dig decisions.

A cost comparison between the classification technique and the 100% intrusive investigation showed a cost savings of 48%–55% with the classification technique.

Although all of the anomalies were intrusively investigated to gather the accuracy needed to score the demonstrators, an additional benefit of using the classification technique would have been a significantly reduced environmental impact on the project site because of the up-to-75% reduction of required intrusive investigations.

A.1.6 Discussion

A.1.6.1 Challenges and Successes

Camp Beale was specifically selected as a classification demonstration site because it presented new challenges for the equipment and demonstrators as well as a wide array of target munitions. These challenges are as follows:

- Camp Beale's geology provided moderate soil responses that affected the data analysis.
- Features of the terrain, including slope and large rock outcrops, presented conditions that the tractor-mounted sensor could not navigate.
- Moderately dense trees presented challenges to the sensor positioning accuracy.
- The transition from research-based equipment to field-ready production equipment presented several challenges.
- The current equipment is not suitable for all weather conditions.
- The equipment has limited field time and may require upgrades to communication links, data acquisition, and data formatting.
- Limited quality assurance (QA) and quality control (QC) procedures have been established.

A.1.6.2 Contractor Experience and Variability

Camp Beale demonstrators included production geophysics contractors, classification researchers, and USACE geophysicists, some of whom were collecting and analyzing advanced sensor data for the first time. The significant range in performance achieved at Camp Beale could be attributed to the experience of the individual demonstrators. Most demonstrators significantly reduced the clutter items from dig sheets, while others showed insignificant reductions in excavations. Demonstrators with prior experience generally performed better. Overall, the demonstrators proved to be quite competent in including TOIs on the dig lists.

A.1.7 Conclusions

The demonstration showed sequential improvements to the techniques and results in the application of geophysical classification. The demonstrators achieved consistent reductions in dig requirements, eliminating 70%–85% of the clutter. The relatively new introduction of this technology and the limited experience of demonstrators having produced extraordinary results with advanced sensors show that significant reductions can be made in unnecessary excavations of nonhazardous munitions debris. Such reductions in the number of excavations could lead to significant cost reductions and more expeditious remediation of more sites than is currently achieved.

A.2 Former Camp Sibert

In spring and summer 2013, geophysical classification was used during a removal action at former Camp Sibert in Alabama. The project was conducted by a commercial contractor under contract to USACE with regulatory oversight from the Alabama Department of Environmental Management (ADEM).

A.2.1 Demonstration Overview

At former Camp Sibert, Site 18 and Range 28 Area A were originally scheduled for a removal action, consisting of an EM61 survey and intrusive investigation, during field work in 2013. The sites each had large sections of open field, flat topography, and a single suspected munition, making them ideal candidates for geophysical classification using the MetalMapper. The project team determined that, based on the site characteristics, results from previously conducted ESTCP demonstrations at Site 18, and proven contractor capability, classification could be successfully implemented at Camp Sibert in support of a removal action. The opportunity to shorten the time frame of the removal action also played a role in the decision to try classification on these sites. Because the property owners use these areas heavily for hunting, it was important for the field crews to avoid site work during hunting season; using traditional technology, it would have taken a period of two years to complete the work.

To conduct the classification, static cued MetalMapper data were collected on geophysical targets identified in EM61 DGM data collected in the open areas of Range 28 Area A and Site 18. The collected data were processed and analyzed off site to categorize the targets based on electromagnetic signatures and to determine which would require intrusive investigation. Those targets were added to the dig list, then excavated and removed from the site following normal procedures, while the items not meeting the dig criteria were left in the ground. QA excavations were then conducted on some of the remaining targets to validate the process.

While advanced classification was used for the removal actions in the open areas of both Site 18 and Range 28 Area A, the intrusive work at Range 28 Area A is ongoing; therefore, this case study focuses on Site 18 only, although the results are expected to be similar for both sites

A.2.2 Conceptual Site Model

A.2.2.1 Site History and Status

Former Camp Sibert is a FUDS located in north-central Alabama between the cities of Gadsden, Attalla, and Rainbow City; these cities are growing toward the former camp boundaries. When it was operational, the camp encompassed approximately 37,035 acres in a tract approximately 14 miles long and 5.5 miles wide.

In spring 1942, the area that would become Camp Sibert was selected for use in the development of a Replacement Training Center for the Army Chemical Warfare Service. From late 1942 to early 1945, units and individual replacements were trained in aspects of both basic military training and the use of chemical weapons, decontamination procedures, and smoke operations. Several types and calibers of conventional weapons were fired at former Camp Sibert. Among these, the 4.2-inch (in.) mortar was the heavy weapon used most often in training.

Site 18 is in the southwest portion of former Camp Sibert. The available historical information indicates that Site 18 was used for training in pillbox assault tactics. During training, troops would bombard the pillboxes with 4.2 in. mortars containing white phosphorous and high explosive, then move forward. Once close enough to the bunkers, the troops would use flamethrowers and other weapons directly. The open area at Site 18 covers approximately 118 acres (Figure A-8).

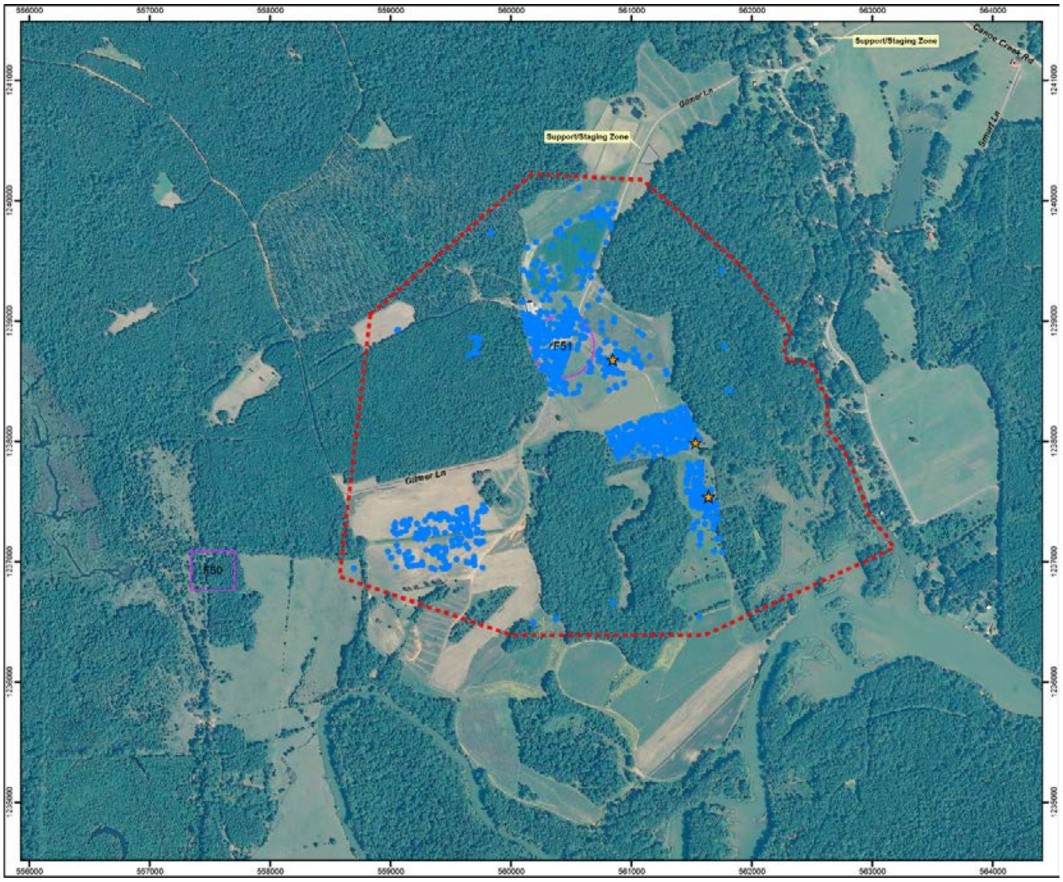


Figure A-8. Camp Sibert Site 18.

Blue dots show the location of excavations from prior efforts; stars represent previously recovered 4.2 in. mortars.

A.2.2.2 Land Use

Site 18 contains a mix of open fields, wooded areas, and residences. The current property owner uses the area that comprises the majority of Site 18 as a managed wildlife and hunting area, and this land use is expected to remain unchanged in the near term. However, with the continuing expansion of the surrounding cities, increased development is likely at some point.

A.2.2.3 Munitions

The only suspected munition at Site 18 was the 4.2 in. mortar. However, given their presence at other locations at Camp Sibert and due to project team concern, 2.36 in. rockets and Livens projectiles (8 in. drum-type mortars typically filled with flammable or toxic chemicals) were also considered to be potential contaminants.

A.2.2.4 Terrain and Vegetation

Former Camp Sibert lies in the foothills of the southern Appalachian Mountains. The general topography within former Camp Sibert is dissected by rolling, hilly uplands and flat lowlands. Etowah County, in which the site is located, is approximately 68% timberland, much of which is in nonindustrial private or corporate ownership. Most of the timberland is composed of oak-hickory forest. The former Camp Sibert area is now mostly rural—approximately 40% forest and 60% open field and pasture. The portion of Site 18 in which geophysical classification took place is open field and relatively flat.

A.2.2.5 Geology

Former Camp Sibert lies in the southern portion of the Valley and Ridge Physiographic Province. Locally, the bedrock geology of the Canoe Creek Valley consists of the Cambrian Conasauga Formation, which is a medium-blue-gray, fine-grained argillaceous limestone interbedded with dark gray shale. According to the Soil Survey of St. Clair and Etowah Counties, Alabama, former Camp Sibert lies within the Limestone Valleys and Uplands soil area of Alabama. Soils in this area were formed mainly in residuum weathered from limestone. Soils of the Tennessee River and Coosa River valleys were weathered from pure limestone and are mainly red clayey soils with silt loam surface textures. Most of the soils of the uplands are derived from cherty limestone. Bodine and Fullerton soils are extensive in many of these landscapes. They typically have a gravelly loam and gravelly clay subsoil and a gravelly, silt loam surface layer.

A.2.3 Objective

The Decision Document stated that the goal of the removal action was to “remove all material potentially presenting an explosive hazard to depth of detection.” The classification objective, therefore, was to provide sufficient data to ensure the removal of all TOIs to the depth of detection. The objective of the MetalMapper data collection and analysis was to accurately classify each of the collected targets as either a TOI or a non-TOI. For the purposes of this project, the TOI designation covered all seed items (blind and QC), native munitions, and intact native munitions with or without explosive hazard.

A.2.4 Project Design

A.2.4.1 Equipment

The Geometrics MetalMapper (Figure A-9) was used for data acquisition for the geophysical classification. A description of the MetalMapper and introduction to its use are provided in Section 2.2. MetalMapper was chosen for this project because (1) it has been demonstrated to be a reliable and capable instrument in this type of application; (2) the contractor had prior experience collecting and analyzing MetalMapper data in multiple ESTCP demonstrations; and (3) it was available for use when needed.

Figure A-9. MetalMapper in use at Camp Sibert Site 18.

A.2.4.2 Targets of Interest

There was a great deal of information about the expected types and density of munitions, based on the previously conducted Phase II Engineering Evaluation/Cost Analysis, Remedial Investigation, and ESTCP demonstration. Only 4.2 in. mortars had been found on the sites, and all but one MEC item were at depths of less than 2 feet below ground. The one deeper item was recovered at 40 in. in a swampy area at a separate MRS. Based on these previous efforts, the investigation of approximately 8,000 targets was expected to be required at Site 18.

A.2.4.3 Performance Objectives

The performance objectives developed for the MetalMapper survey and data analysis at former Camp Sibert are summarized in Table A-3. These performance objectives were either standard for the ESTCP Live Site Demonstration Program or developed in response to lessons learned during the program. Data that successfully pass these performance indicators are considered high quality, adequate for use in classification.

Table A-3. Performance objectives

Performance Objective	Metric	Success Level
Correctly identify seed items in IVS	Percentage of IVS items identified correctly	98% of IVS items identified correctly with confidence metric of >0.90
Correctly position MetalMapper relative to source	Distance between collection location and inverted target location	100% of inverted locations within 40 cm of collection point unless reshot also outside radius[a]
Correctly position MetalMapper relative to EM61 target	Distance between MetalMapper collection location and EM61 target location	100% of collection points within 65 cm of EM61 target location[b]
Maximize TOIs retained on dig list	Percentage of TOIs identified as dig targets	100% of TOIs identified as dig targets[c]
Minimize non-TOIs retained on dig list	Percentage of false alarms eliminated	75% of non-TOIs left in ground
Correctly identify type of TOI	Percentage of TOIs correctly identified by group[d]	75% of TOIs identified correctly
Classify type of non-TOI	Percentage of non-TOIs correctly classified by size and shape[e]	75% of non-TOIs classified correctly with regard to size and shape[f]
Correctly estimate target location	Accuracy of estimated target parameters for dig list targets marked as "dig"	X, Y< 30 cm (1σ) Z <15 cm (1σ)

Notes:

[a]In addition to targets with both initial and reshot inverted locations greater than 40 cm from the collection point, targets collected specifically to be within 65 cm of an EM61 pick location will not negatively affect this objective if inverted locations are >40 cm from the collection point.
[b]Points with no identified problems (for instance, inversion offset or noise) and no other targets within 1.5 m of the target in question will not be re-collected.
[c]The validation digs described in Section A.2.12 will provide the data for testing this objective for in situ TOIs. The rest of the digs, by definition, can only be tested against the blind QA seeds, as the other anomaly sources will remain unknown in the ground.
[d]The only expected TOI groups will be munitions (4.2 in. mortars and associated simulants) and large items identified as dig targets that do not appear to be munitions based on library matching.
[e]Groups for non-TOIs are expected to be as follows: small and cylindrical, large and cylindrical, small and plate-like, and large and plate-like.
[f]Shape will only be considered for objects with a library match to a cylindrical (that is, ISO, rebar) or plate-like (that is, horseshoe object) with a confidence metric of >0.75.

A.2.5 Data Collection Procedures

The MetalMapper system was calibrated before the start of data collection for the project and twice daily as part of testing at the IVS. This was done to ensure that the equipment was functioning properly and to allow the field crew to resolve any failures before wasting time and effort collecting unusable data.

The MetalMapper data were collected in static mode by a field team of at least two geophysicists who took turns driving the tractor and collecting data. The target position was generally reacquired using GPS, along with visual feedback from the data acquisition (DAQ) computer (Panasonic touch-screen terminal). Once the platform was positioned approximately over the target, a single data point was acquired. During the static survey, each target point was associated with a background point that best represented the local background. Background data were collected at least every two hours, and were used to correct all associated target points prior to inversion.

A.2.6 Data Handling

Data were recorded in binary format as files on the hard disk of the MetalMapper DAQ and then offloaded to other media at least once a day. The data file names acquired each day were cataloged in a Microsoft Access database and integrated with any notes or comments the operator had provided in his field book.

A.2.7 Data Analysis

A.2.7.1 Preprocessing

Once collected, data were preprocessed using TEM2CSV software to convert the GPS-supplied latitude/longitude data to UTM coordinates and to correct the survey location point using attitude data for the MetalMapper platform (heading, pitch, and roll).

The background field was removed from all receiver transients using the Geosoft Oasis montaj UX-Analyze module following a review of all background points. Any significant outliers identified during this review were considered poor options for use in background correction and were not used to correct data.

The offsets between the MetalMapper sensor position and the original EM61 target location were calculated following initial data processing. Targets for which the sensor-to-EM61 target offset was greater than 65 cm were set for re-collection.

A.2.7.2 Parameter Estimation

Parameters were estimated using the UX-Analyze module in Oasis montaj software. All targets were inverted using single-source and multisource dipole response models to estimate various parameters for each target. The principal parameters for use in classification of the targets are the three estimated polarizabilities (β1, β2, and β3). In addition to estimates for the three βs for each target, an estimated location and depth was also developed for each target during inversion. Other parameters estimated by UX-Analyze include the inclination and rotation of the source object, a measure of the error between the modeled anomaly results and the actual anomaly results, the signal amplitude for each shot, and two noise measures for each shot.

A.2.7.3 Inverted Data Quality Control

To determine the usability of each collected point, the following analyses were conducted for each target as part of the data QC process:

- The estimated locations were compared to the location of the MetalMapper during collection. Targets with offsets greater than 40 cm were noted for re-collection.
- The estimated polarizabilities for each target were analyzed by examining the comparison maps generated for each. Targets with notably poor curves were identified in the comments section of the Geosoft database (generally, targets with at least a good β1 curve can be used). Targets with three poor curves or no identifiable β1 curve were classified as can't analyze targets unless it was deemed likely that no source object was present at the collection location.
- Targets deemed too small to be TOIs by the analyst—based on an examination of the EM61 data (for example, single data point spike)—as well as targets that appeared to be due to geology rather than subsurface metal were considered for removal from consideration as can't analyze targets because it was possible that no source objects were present at the chosen location (that is, a "no contact").
- In addition to the analyses described above, the decay and size characteristics of all targets were examined using a parameter space plot to determine their characteristics compared to the other targets at the site. Because data collected over no metal object can sometimes be inverted to resemble large munitions at depth, depending on the geology of a given site, a final determination of whether to include items plotting as large objects on the space plot but not matching the classification library particularly well as dig targets was made using the EM61 data. Actual large items at depth produce responses across multiple lines in the EM61 data and look markedly different than actual no contacts.

A.2.7.4 Training Data

Training data were primarily derived from previous testing of the MetalMapper using various inert MEC items and test stand data collected prior to this project. These data were used to create a library of polarizabilities for standard munitions types, although most were various examples of 4.2 in. mortars. In addition to the library comparison, the target locations within the parameter space plot generated using the decay vs. size comparison were examined (see Figure A-10). To select potential training data, this plot was used to identify groups of targets that might indicate a munition that was not expected at the site. A clustered group of unknown targets at Camp Sibert would have been grounds for requesting training data for a subset of the group.

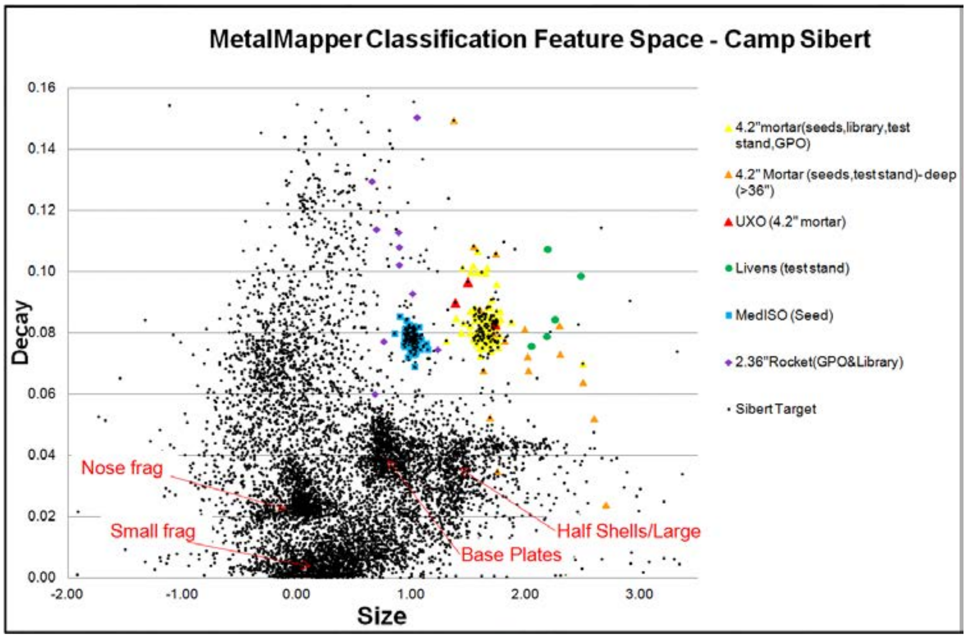


Figure A-10. Feature space plot showing size versus decay calculated from βs.

A.2.8 Classification

The classifier used to create the ranked dig list for the Camp Sibert targets was based primarily on the confidence metrics generated by UX-Analyze during comparisons of the β values estimated for each target surveyed at Camp Sibert and the β values in the munitions library developed for the project. Confidence metrics indicate the degree of match between a target and its corresponding item in the library, with higher metrics indicating a better match between the two. The library used for the Camp Sibert project was limited to the 4.2 in. mortars expected at the site, including the ISOs to be used as simulants, and items known to be used elsewhere at Camp Sibert, such as 2.36 in. rockets and Livens projectiles.

The target data were compared to the library using the Advanced Target Classification function of UX-Analyze, which allows the user to weigh the importance of each of the three polarizability curves for comparison. Four comparisons were generated for each target, with the various comparisons using (1) an equal weight for all three curves (3-curve metric); (2) a zero weight for β3 (2-curve metric); (3) a zero weight for β2 and β3 (1-curve metric); and (4) weights of 1 for β1 and 0.5 for β2 and β3 (weighted metric).

The classifier used for this project, which has also been used successfully on a number of previous projects, is defined as follows:

- Category 1 targets (dig)
  - weighted or 3-curve confidence metric >0.575
  - 2-curve confidence metric >0.7

   - 1-curve confidence metric >0.8
- Category 2 targets (dig)
   - β3 curve identified as poor by analyst
   - 2-curve confidence metric >0.7
   - 1-curve confidence metric >0.8
- Category 3 targets (dig)
   - β2 and β3 curves identified as poor by analyst
   - 1-curve confidence metric >0.8
- Category 4 targets (dig)
   - targets added at the discretion of the analyst, as for noisy data with confidence metrics close to the thresholds described above or targets added based on location within a space plot
- Category 5 targets (dig): can't analyze targets
- Category 6 targets (dig): validation digs
- Category 7 targets (no-dig): targets not meeting the above criteria

All targets were ranked from high (category 1: most likely TOI) to low (category 7: most likely clutter) based on the classifier. In addition to identifying each target as a dig or no-dig, each was also assigned a group primarily related to its size. Likely TOI targets (categories 1–4) were assigned to one of the following three groups:

- 4.2 in. mortars
- non-4.2 in. mortar munitions
- large items that do not match library items particularly well

A.2.9 Classification Results

The removal action at Camp Sibert Site 18 successfully used advanced classification to remove munitions and safely leave a high percentage of metal in the ground. Cued MetalMapper data were collected from over 6,055 anomalies selected from the EM61 data. All seeds and three 4.2 in. mortars were correctly classified, while 84% of the targets were left in the ground. A total of 91% were classified as no-dig by the contractor, with 7% additional digs for validation. Of the targets classified as dig by the contractor, 26% were munitions or seeds (see Figures A-11 and A-12).

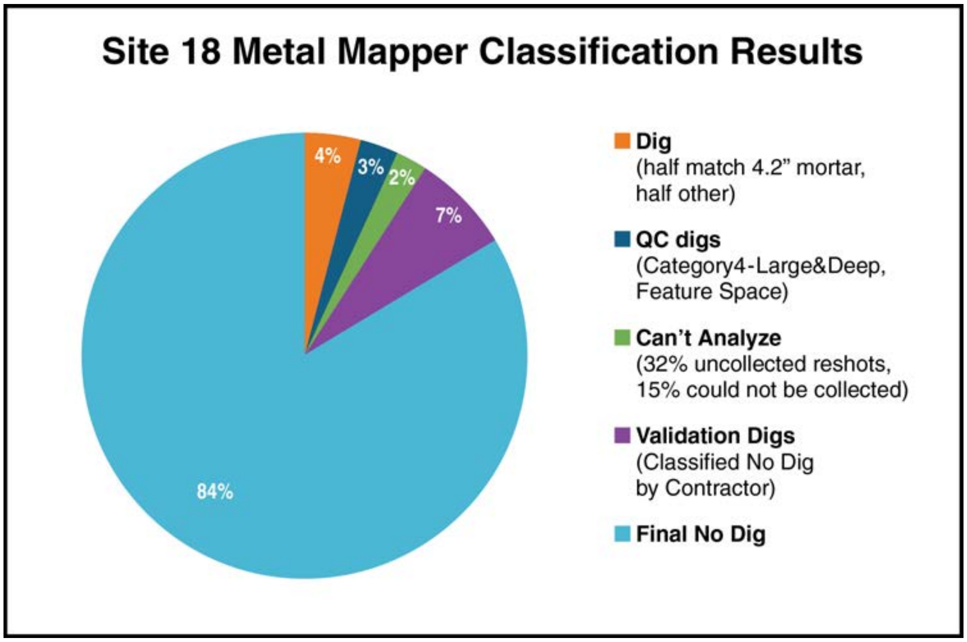


Figure A-11. Results of classification by category.

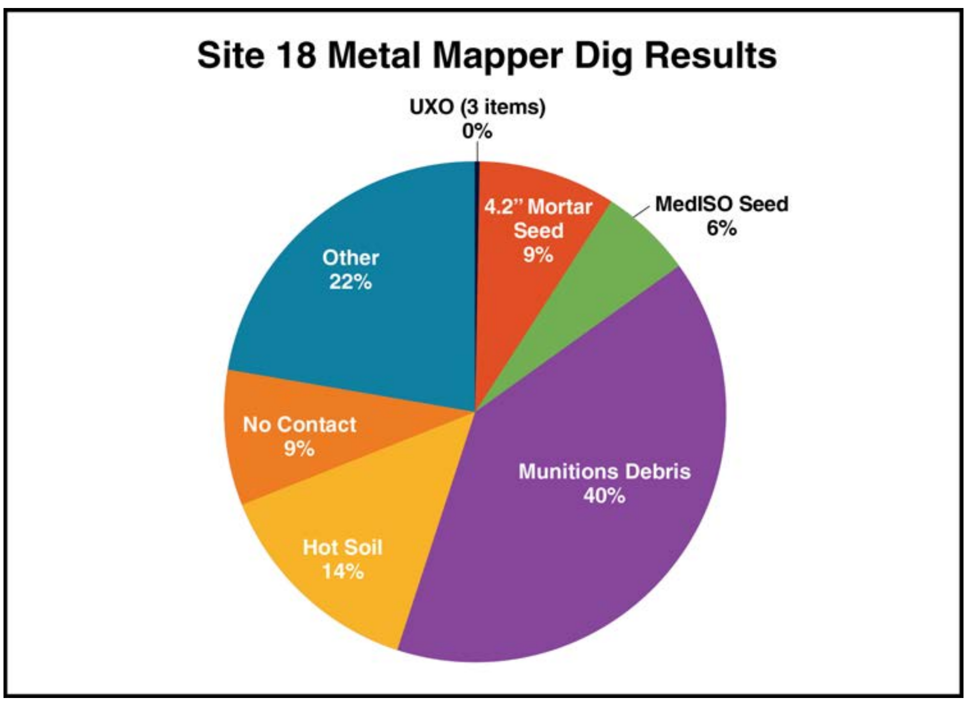


Figure A-12. Intrusive results by category.

The three recovered munition items were excellent library matches (0.99) to mortars, and were some of the highest ranked digs (see Figure A-13 below).

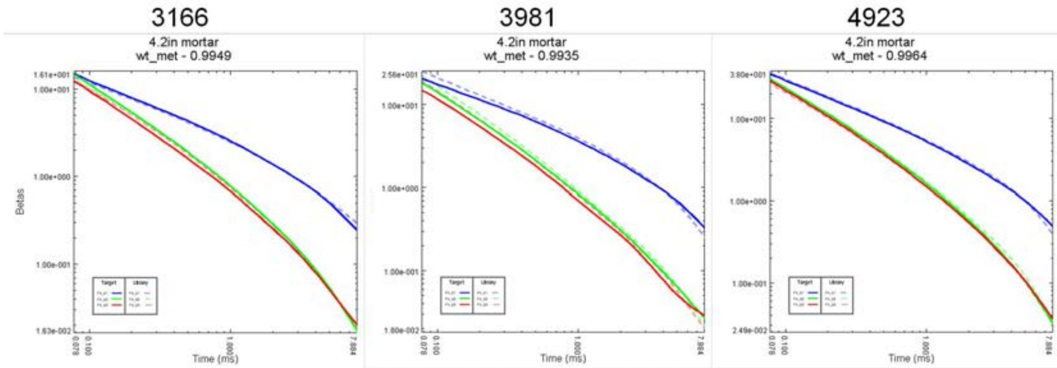


Figure A-13. All three recovered munitions (4.2 in. mortars) had a library match of 0.99.

The relatively high number of no contacts and "hot soil" digs resulted mostly from category 4/QC digs, which were added in an attempt to recover very deep mortars. As seen in the test stand data, when 4.2 in. mortars are deeper than approximately 1 m, the library match degrades; however, they are still of a large size. When no metal or hot soil is present, the results can appear similar to very deep items.

As illustrated in Figure A-14, the majority of metallic items were recovered in the upper 1 foot, with munitions recovered from 12–24 in. (center of mass). This result confirms the conceptual site model, which was based on previous investigations. Inert 4.2 in. mortar blind seeds were placed at depths up to 43 in., which represented a much more difficult classification problem than the munitions, but were nevertheless all classified to dig.

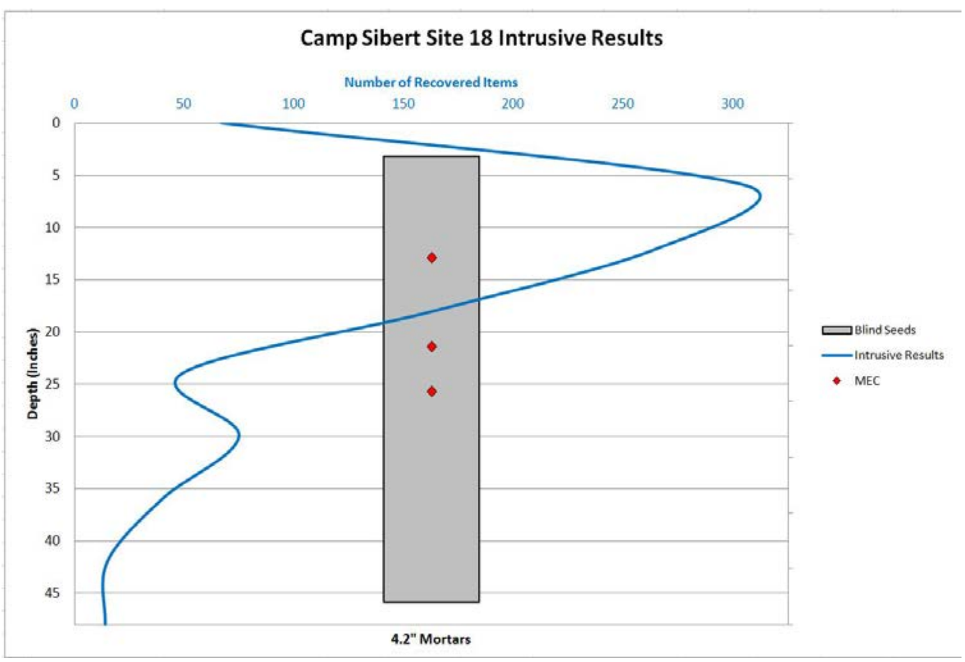


Figure A-14. Intrusive results depth summary.

Intrusive results numbers (blue line) do not include no contacts, hot soil, or seeds, but do include multiple items from the same anomaly.

Camp Sibert data show excellent separation between TOIs and clutter, with evident clusters due to common 4.2 in. mortar munitions debris. Targets (black dots) in 4.2 in. mortar cluster without corresponding mortar are due to multiple picks on the same items or large nonmunitions debris (for example, fencepost).

A.2.10 Quality Control/Quality Assurance

A.2.10.1 Instrument Verification Strip

Data collectors visited the IVS twice daily (at the start and end of each day) to verify equipment function. All IVS results met the project-defined performance metrics for library match, position offset, and depth offset, with the exception of one positioning test. This offset was determined to be caused by a faulty inertial measurement unit, which was corrected.

A.2.10.2 Cued Data Positioning

The fit location of the data (the metal location according to the model) was compared to the location of the MetalMapper array. When this value was greater than 40 cm, data were re-collected at the fit location. This was done to ensure that the metal source was fully illuminated by the sensor and that the resulting data were reliable. In some cases, the result for a high offset was already classified as dig; therefore, no reshot was collected (for example, one blind seed—see Figure A-15). Additionally, several anomalies requiring reshots were dug as can't analyze targets, due to field scheduling constraints (that is, it is more cost-effective to dig than to remobilize a MetalMapper crew).

A.2.10.3 Seeds

Two types of seeds were used to evaluate the classification: inert 4.2 in. mortars and medium ISOs (see Figure A-16). The inert 4.2 in. mortars were blind seeds unknown to the contractor. The medium ISOs were QC seeds used by the contractor for ongoing feedback on the MetalMapper functionality and the classification results. All seeds were classified by the contractor as digs, and most had very high library matches. The lower matches were expected based on test stand data for deeper items, and were accounted for in the classification methodology.

Figure A-15. Seed results (Site 18 and Range 28 Area A).

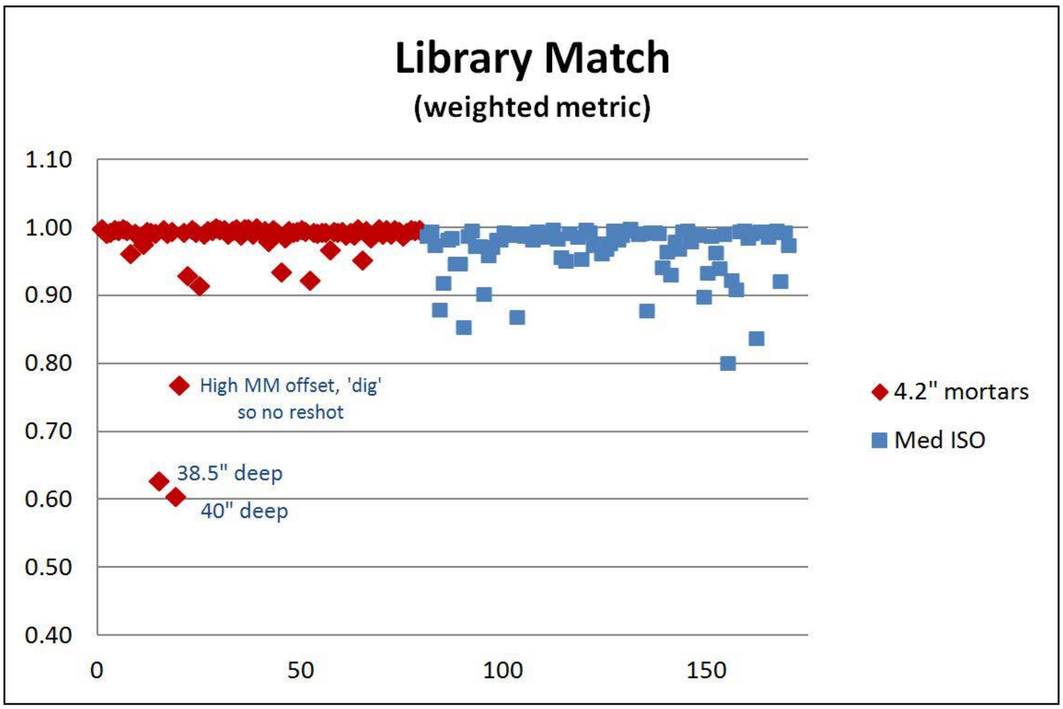


Figure A-16. Blind (left) and QC (right) seeds.

A.2.11 Validation Digging

In the planning stages of the work, the project team agreed that 500 validation digs would be selected by USACE and ADEM, split between Site 18 and Range 28 Area A. This was broken out into two primary methods.

First, 200 targets were dug to fully investigate a contiguous area early in the data collection and analysis process. The results were presented to ADEM, including correct classification of seeds (no munitions were found), as well as an analysis showing that the size and shape of the items classified as no-dig were reasonable.

Second, the remainder of the validation digs were selected based on their location in feature space, proximity to contractor dig thresholds, and location in large anomalous features where classification may be more difficult. The final validation digs were selected by USACE and ADEM concurrently, while the data were reviewed in UX-Analyze. The contractor's selection method was conservative, so none of the validation digs were expected to result in TOIs; they did not.

Results of these digs further validated the classifier by matching the predicted results (for example, high number of hot soil results for potentially large/deep items in feature space, half-shells correctly labeled).

A.2.12 Documentation and Data Delivery

Data were delivered to USACE throughout the project, and were reviewed by the project QA geophysicist to ensure that the performance metrics were being met, including correct classification of blind seed items. All decisions were fully documented in a Microsoft Access database that includes tables for tracking all aspects of the project (IVS results, background data, single- and multi-object solver parameters, final classification decisions, and intrusive results). The database includes extensive notes by the processor for individual cued targets, which were quite helpful in the QA review and in selecting validation digs (for example, "same as target X, which is already dig" and "fence post").

A.2.13 Project Team Review and Coordination

Project team coordination was essential in making this a successful project. Prior to the final decision to pursue classification, several meetings were held between the contractor, USACE, and ADEM to discuss the proposed approach. The work plan and seed plan were reviewed by ADEM, with comments incorporated. A meeting was held to present the results of the initial 200 validation digs and overall data quality; the team agreed that the approach was acceptable and, assuming project metrics continued to be met, no-dig targets would be left undug. A working meeting was held between USACE and ADEM to review the final data analysis and select remaining validation digs. This coordination was essential in allowing the project to meet the landowner's schedule for completion of field work. Final project reporting is ongoing.

A.2.14 Discussion

A.2.14.1 Challenges and Successes

1. Some areas had saturated EM61 response and did not allow for selection of individual anomalies. For these cases, MetalMapper data were not collected, polygons were drawn around the areas and they were cleared by traditional mag and dig methods.
2. After analyzing the classification results, including seeds, USACE was able to inform the field team of a high likelihood munition item. This information was especially useful to the team because the 4.2 in. mortars at Site 18 are potentially liquid filled (likely tearing agent), which requires a series of notifications and additional security measures, including scheduling of explosive ordnance disposal. Knowing in advance that the item might be a suspect liquid-

filled item, the team was able to check with the explosive ordnance disposal program ahead of time and schedule the dig based on technician availability. This helped to minimize exposure to the item, impacts to the property owner, and costs associated with security.

3. Site 18 is used as a hunting preserve with fields planted to attract wildlife. This required scheduling considerations, and less intrusive activity allowed for faster completion as well as less impact on the land, which was important to the landowner.

A.2.14.2 Conclusions

Using MetalMapper data, advanced classification was successfully applied at the Camp Sibert Site 18 removal action to excavate the munitions and safely leave 84% of the targets in the ground. This was not a challenging site for classification using an advanced EMI sensor. There is a single, large TOI and low anomaly density. A production contractor field crew collected high-quality cued MetalMapper data and successfully analyzed the data to achieve substantial classification. All seeds and three munition items were successfully classified and dug. The munitions were all highly ranked with library matches of 0.99. Given that this was the first attempt to apply advanced classification to leave buried metal items at an MRS, the classification approach was quite conservative. The approach involved (1) digging targets that matched items found elsewhere at Camp Sibert, but not expected at Site 18; (2) using low-library-match thresholds; (3) setting dig criteria to include deep mortars (not expected at Site 18), which caused a high percentage of no contact and geology/hot soil dig results; and (4) digging 500 validation digs (which represent nearly half of the digs). The project team (the contractor, DOD, and state regulators) worked together in ensuring acceptable QA/QC processes to provide confidence that the classification system was working properly; they agreed to leave 84% of the metallic items in the ground. While there is no guarantee that all MEC was removed, given the data quality and the results of the intrusive investigation, it is considered highly unlikely that any MEC remain. At the conclusion of this investigation, the project team considers the removal action complete for the area covered, and believes that utilizing advanced classification resulted in no increased risk of munitions remaining than if the traditional approach of digging all selected EM61 anomalies has been followed.

APPENDIX B. TEAM CONTACTS

Roman Racca, Team Leader
California Department of Toxic Substances Control
916-255-6407
roman.racca@dtsc.ca.gov

Tracie White, Team Leader
Colorado Department of Public Health & Environment
303-692-3452
tracie.white@state.co.us

Katherine Kaye, ITRC
Program Advisor
HydroGeoLogic, Inc.
301-829-1801
kkaye@hgl.com

Julie Ange
Alabama Department of Environmental Management
334-270-5646
jange@adem.state.al.us

Kim Churchill
Michigan Department of Environmental Quality
586-753-3816
churchillk1@michigan.gov

Ed Corl
NAVSEA Laboratory Quality and Accreditation Office
757-396-2227
william.corl@navy.mil

Jane Dolan
U.S. Environmental Protection Agency
617-918-1272
dolan.jane@epa.gov

William Harmon
Michigan Department of Environmental Quality
517-284-5110
harmonw@michigan.gov

Bryan Harre
NAVFAC Engineering and Expeditionary Warfare Center
805-982-1795
bryan.harre@navy.mil

Dean Keiswetter
Acorn Science and Innovation, Inc.
919-454-4774
dkeiswetter@acornsi.com

Tamir Klaff
CH2MHill
202-596-1199
tamir.klaff@ch2m.com

Iver McLeod
Maine Department of Environmental Protection
207-287-8010
iver.j.mcleod@maine.gov

Doug Maddox
U.S. Environmental Protection Agency
703-603-0087
maddox.doug@epa.gov

Kari Meier
U.S. Army Corps of Engineers
502-315-6316
kari.l.meier@us.army.mil

Herb Nelson
SERDP/ESTCP
571-372-6400
herb.nelson@nrl.navy.mil

Abigail Power
Texas Commission on Environmental Quality
210-403-4060
abigail.power@tceq.texas.gov

Andrew Schwartz
U.S. Army Corps of Engineers
256-895-1644
andrew.b.schwartz@us.army.mil

Lenny Siegel
Center for Public Environmental Oversight
650-961-8918
lsiegel@cpeo.org

Lizanne Simmons
Kleinfelder
619-831-4521
lsimmons@kleinfelder.com

Ryan Steigerwalt
Weston Solutions, Inc.
267-258-2672
Ryan.Steigerwalt@WestonSolutions.com

Stephen Sterling
California Department of Toxic Substances Control
916-255-3739
Stephen.Sterling@dtsc.ca.gov

Fred Vreeman
Alaska Department of Environmental Conservation
907-451-2181
fred.vreeman@alaska.gov

Amy Walker
U.S. Army Corps of Engineers
256-895-1604
amy.n.walker@usace.army.mil

Ed Walker
California Department of Toxic Substances Control
916-255-4988
ed.walker@dtsc.ca.gov

APPENDIX C. ACRONYMS

AB	accreditation body
ADEM	Alabama Department of Environmental Management
AGC-QAPP	Uniform Federal Policy for Quality Assurance Project Plans Template: Advanced Geophysical Classification for Munitions Response
ANSI/ASQ E4-2004	Quality Systems for Environmental Data and Technology Programs—Requirements with Guidance for Use
BUD	Berkeley UXO Discriminator
CA	corrective action
CSM	conceptual site model
DAGCAP	DOD Advanced Geophysical Classification Accreditation Program
DAQ	data acquisition
DD	Decision Document
DGM	digital geophysical mapping
DMM	discarded military munition
DOD	United States Department of Defense
DQI	data quality indicator
DQO	Data Quality Objective
DUA	data usability assessment
ECOS	Environmental Council of the States
EDQW	DOD Environmental Data Quality Workgroup
EMI	electromagnetic induction
EOD	explosive ordnance disposal
ERIS	Environmental Research Institute of the States
ESTCP	Environmental Security Technology Certification Program
EZ	exclusion zone
FUDS	formerly used defense sites
GPS	global positioning system
IDQTF	Intergovernmental Data Quality Task Force
IMU	inertial measurement unit
ISO	industry standard object
ITRC	Interstate Technology and Regulatory Council
IVS	instrument verification strip
MEC	munitions and explosives of concern

MMRP	Military Munitions Response Program
MPC	measurement performance criteria
MPV	man-portable vector
MQO	measurement quality objective
MRS	munitions response site
non-TOI	non-target of interest
QA	quality assurance
QAPP	Quality Assurance Project Plan
QASP	quality assurance surveillance plan
QC	quality control
RAO	remedial action objective
RCA	root cause analysis
ROD	Record of Decision
RTK	real-time kinematic
SERDP	Strategic Environmental Research and Development Program
SOP	standard operating procedure
TOI	target of interest
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UFP-QS	Uniform Federal Policy for Implementing Environmental Quality Systems
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UXO	unexploded ordnance

APPENDIX D. GLOSSARY

A

advanced sensors

Munitions-classifying sensors that are designed with many transmit and receive coils rigidly assembled in a fixed-array configuration. The combination of multiple receive coils, large bandwidth electronics, and supporting sensor data results in the collection of significantly more data than can be collected with single-axis EM61 sensors.

C

conceptual site model

Iterative representation of the site that summarizes and helps project planners visualize and understand available information. The CSM is the primary planning and decision making tool used to identify the key issues and the data necessary to transition a project from characterization through post-remedy.

cued mode

A data collection scheme in which the user positions the sensor at discrete XY locations previously identified by other means (also referred to as static or stationary measurement).

D

data quality objective

A qualitative and quantitative statement developed to clarify study objectives, define the type of data needed, and specify the tolerable levels of potential decision errors. A DQO is used as the basis for establishing the type, quality, and quantity of data needed to support decisions.

digital geophysical mapping

Mapping data generated from a geophysical system that digitally records geophysical and positioning information to support initial mapping and identification of buried metal objects on a site.

E

electromagnetic induction

Physical process by which a secondary electromagnetic field is induced in an object by a primary electromagnetic field source.

G

geophysical classification

The process of making principled decisions, using data collected by geophysical sensors, to differentiate between buried items that are potentially hazardous and those that can be safely left in the ground during munitions response actions.

geophysical system verification

The quality control (QC) process used to verify that a geophysical sensor is operating properly, and to provide ongoing monitoring of the quality of the geophysical data collection and target selection process as it is performed in the production survey. The process includes daily measurements of an instrument verification strip and production area blind seeding.

I

industry standard object
Commonly available pipe sections that have been characterized and can be used as munition surrogates in the geophysical system verification process.
instrument verification strip
One or more buried inert munitions or industry standard objects spaced approximately 5 meters apart. Data are collected over the IVS twice daily to verify that the geophysical sensor system can deliver the expected detection and classification performance.
inversion
Fitting measured sensor data to an EMI response model (commonly the dipole model) to obtain the model parameters, including the object's location and depth, orientations of its principal axes, and its principal axis response functions.
L
library matching
Comparing the derived polarizabilities of each detected buried metal object with the polarizabilities of a collection of known munition items in a library. The objective is to classify the unknown objects based on the similarity of their polarizabilities to an entry in the library.
M
multiaxis sensor
Advanced EMI sensor with excitation and receive coils arranged to interrogate a buried object along multiple axes from one measurement location.
P
parameters
Intrinsic characteristics of a buried metal object, including size, shape, symmetry, aspect ratio, wall thickness, and material composition.
polarizabilities
Three principal axis responses returned by the inversion process, which relate directly to physical attributes of the object under investigation. Information inferred from the responses—including the object's size, shape, and wall thickness—forms the basis for classification decisions.
Q
quality assurance validation blind seeding
Seeds emplaced by the government (or its representative) and blind to the production team to provide confidence to the entire project team and stakeholders that the data collected in the project are usable for their intended purpose.
quality control blind seeding
Inert munition or munitions surrogate buried on the site to serve as a process QC check. Surrogates are selected to correspond with munitions of interest on the site. QC blind seeds allow the production team to recognize that problems exist, and provides a means of identifying root causes so that corrective action can be undertaken while still in the field.
quality system
A structured and documented management system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization to ensure quality in work processes, products (items), and

services. The quality system provides the framework for planning, implementing, and assessing the work performed by an organization and for carrying out required quality assurance and QC activities.

R

remedial action objectives

Cleanup goals for a selected remedial action. Preliminary RAOs are often developed during the Preliminary Assessment/Site Investigation phase of a munitions response, and are refined into definitive RAOs during the course of the Remedial Investigation/Feasibility Study process. Final RAOs are documented in the Record of Decision or Decision Document. Remediation efforts are considered complete upon attainment of the RAOs.

S

survey mode

A data collection scheme in which the user scans the ground with a sensor to accomplish 100% coverage (also referred to as a reconnaissance survey, dynamic survey, or detection survey).

T

target-of-interest

Items that must be correctly classified and excavated to accomplish site remediation goals. All munitions, QC and QA seeds, and other items designated by the site team, such as significant pieces of munitions, are targets of interest. Some site teams may even include selected fuzes and other components to the TOI list. Munitions do not have to contain high-explosive filler to be classified as TOI; anything that must be excavated and examined to determine whether it is hazardous should be included in the definition of TOI.