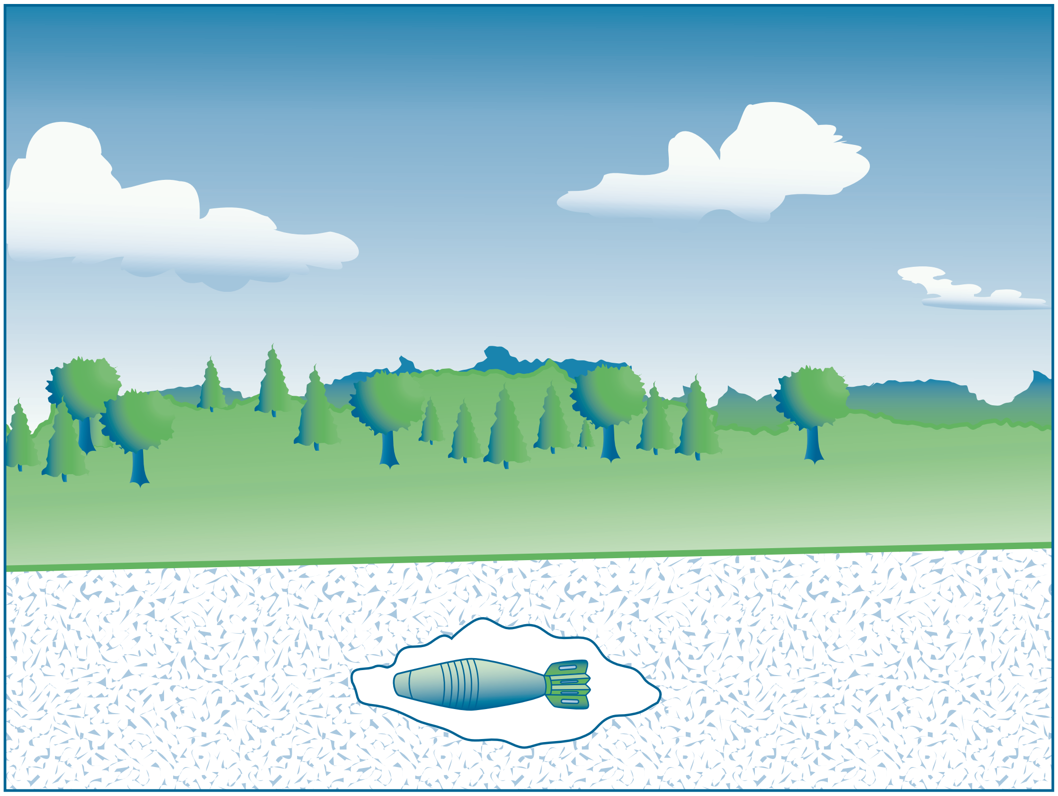
Technology Overview

Frequently Asked Questions about Wide-Area Assessment for Munitions Response Projects



May 2010

Prepared by
The Interstate Technology & Regulatory Council
Unexploded Ordnance Team

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UXO-6

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EXECUTIVE SUMMARY

The intent of this frequently asked questions (FAQ) technology overview document is to provide state regulators, project managers, and stakeholders with a ready source of information about the wide-area assessment (WAA) process and a description of the tools currently available to conduct WAA within a munitions response area (MRA).

The majority of munitions and explosives of concern within an MRA are often concentrated in or around predictable munitions response sites (MRSs, e.g., targets, aiming circles, etc.). Once the MRSs are identified, the project team can focus resources on those that present the greatest potential hazard.

WAA is a reconnaissance process designed to provide data to assist the project team in selecting MRSs for response action. WAA uses specific tools, either singularly or in combination, to efficiently provide reliable evidence of munitions-related features, such as bomb craters or concentrations of geophysical anomalies. The project team then uses the data generated by WAA to identify, delineate, and prioritize MRSs within the MRA for response action.

This FAQ document will help project teams determine whether WAA is appropriate for their projects and, if appropriate, which tools or technologies are most suitable for conducting WAA at each site. The Unexploded Ordnance Team encourages readers to learn more about WAA by referring to *ESTCP Pilot Project Wide Area Assessment for Munitions Response* (ESTCP 2008) and the other resources listed in this document.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

FREQUENTLY ASKED QUESTIONS ABOUT WIDE-AREA ASSESSMENT FOR MUNITIONS RESPONSE PROJECTS

1. INTRODUCTION

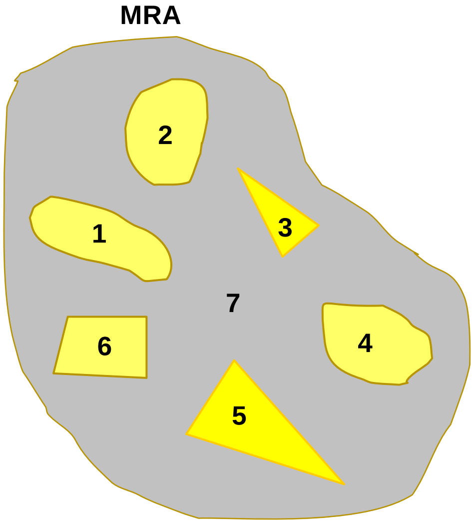
The characterization and remediation of munitions response areas (MRAs) is a subject of intense interest to the U.S. Department of Defense (DOD), which has identified millions of acres across the United States and its territories as MRAs. MRAs vary in size from tens to thousands of acres; some exceed 10,000 acres (Defense Science Board Task Force 2003).

When evaluating an MRA, DOD may subdivide the MRA into multiple munitions response sites (MRSs, Figure 1-1). If DOD is unable to divide the MRA into multiple MRSs, the entire MRA is identified as one MRS. The area of the MRA must equal the sum of the area of all MRSs. DOD implements a munitions response (MR) at the MRS level.

A Note on Terminology: MRA and MRS

A “munitions response area” is any area on a defense site that is known or suspected to contain unexploded ordnance, discarded military munitions, or munitions constituents. Examples are former ranges and munitions burial areas. An MRA comprises one or more munitions response sites (32 CFR §179).

A “munitions response site” is a discrete location within an MRA that is known to require a munitions response (32 CFR §179).



MRS 1–6: six discrete MRSs (e.g., bombing targets, impact areas, and munitions disposed areas)

MRS 7 (remaining area): no evidence of concentrated munitions use

MRSs 1–6
\+ MRS 7 (remaining area)
7 MRSs = Total MRA

Figure 1-1. Relationship between munitions response sites and a munitions response area.

The majority of munitions and explosives of concern (MEC) within an MRA are often concentrated in or around predictable MRSs (e.g., targets, aiming circles, etc.). By some estimates, up to 80% of the larger MRAs are essentially free of MEC (Defense Science Board Task Force 2003). Therefore, a reconnaissance process that can reliably, quickly, and efficiently provide evidence to identify and delineate MRSs for response action (i.e., evidence of concentrated munitions use vs. no evidence of concentrated munitions use) would be of great value to DOD.

Research conducted by the Environmental Security Technology Certification Program (ESTCP) and others has verified that wide-area assessment (WAA) is such a reconnaissance process. Data generated by WAA can provide DOD with sufficient evidence to identify and prioritize MRSs within an MRA, allowing DOD to focus limited resources on the MRSs that present the highest potential hazard to the public. Ultimately, determining what areas require an MR is a decision made by the project team (including DOD representatives, regulatory agencies, stakeholders, etc.) based on current and reasonably anticipated future land use, munitions (type, sensitivity, distribution, density, etc.), regulatory requirements, site conditions, and other factors.

A Note on Terminology: MEC

32 CFR §179 provides the following definition:

> "Munitions and explosives of concern" distinguishes specific categories of military munitions that may pose unique explosives safety risks, such as UXO, as defined in 10 U.S.C. 101(e)(5); discarded military munitions, as defined in 10 U.S.C. 2710(e)(2); or munitions constituents (e.g., TNT, RDX), as defined in 10 U.S.C. 2710(e)(3), present in high enough concentrations to pose an explosive hazard.

WAA technologies are not capable of the direct detection of munitions constituents in environmental media. Therefore, this document uses the collective term "unexploded ordnance/discarded military munitions" to refer to the specific components of MEC to which WAA is applicable.

1.1 What is wide-area assessment?

WAA is a reconnaissance process that uses various technologies, either singularly or in combination, to detect munitions-related features (MRFs) and/or concentrations of geophysical anomalies within an MRA or MRS. MRFs provide a physical indication that a discrete area may have been used for munitions activities. These physical indications include craters, aiming circles, firing points, access roads, land scarring, etc. Changes in vegetation patterns or species may also provide indirect indications of munitions use. WAA is not a process for locating and mapping individual anomalies for classification and removal (see ITRC 2006).

The decision to use WAA is based on the expectation that MRFs or geophysical anomalies exist within the MRA, are not obscured, and are of sufficient density or size to be detected by the technology the project team selects. Using data generated by a WAA process, the project team can potentially do the following:

- delineate an MRA into one or more MRSs
- identify MRSs with no evidence of concentrated munitions use
- prioritize MRSs for MR
- validate or update the conceptual site model (CSM)
- provide anomaly density estimates for alternatives analysis during the feasibility study

WAA is most valuable when implemented during the site inspection or remedial investigation phase of the project. By conducting WAA early in the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) process, the project team can delineate areas of concentrated munitions use, thereby focusing resources for follow-on investigations of the MRSs.

Depending on the terrain and vegetation, the WAA process may use one or several technologies to investigate the MRA. Tools used to conduct WAA may be deployed from fixed-wing aircraft, helicopter, land-based, or water-based platforms. Light detection and ranging (LiDAR) and orthophotography are deployed from fixed-wing aircraft or helicopters. Geophysical sensors such as magnetometers and electromagnetic induction (EMI) sensors are deployed from helicopter, land-based, or water-based platforms.

LiDAR and orthophotography can survey and map thousands of acres per day. LiDAR can detect MRFs such as crater fields and target circles. Geophysical sensors mounted on helicopters can survey hundreds of acres per day, and geophysical sensors mounted on land-based platforms can survey up to tens of acres per day. Geophysical sensors detect metallic objects on or under the ground surface that may include unexploded ordnance/discarded military munitions (UXO/DMM), munitions debris (MD), and other debris (e.g., fence posts, construction debris, etc.).

Depending on the data needs of the project (see ITRC 2008), certain technologies used for WAA may be applied in a layered approach. For example, orthophotography or LiDAR may be followed with helicopter-deployed or land-based technologies (e.g., land-based, statistically derived geophysical transects). The specific technologies selected and their sequence for use is determined by the project team.

1.2 How does the objective of wide-area assessment differ from the objective of a remedial/removal action?

The objective of performing WAA is to identify areas of concentrated munitions use, while the objective of a remedial/removal action is to detect, map, and remove individual geophysical anomalies across 100% of an MRS. Remedial/removal actions require more stringent survey and sampling requirements than those used for WAA. For example, the probability of detection required for a remedial/removal action is usually 95% or greater, while the probability of detection for WAA does not need to be as stringent because the objective is not to identify every anomaly. Also, positional accuracy for WAA does not need to be as precise as that required for a remedial/removal action, where the objective is to return to specific anomalies.

1.3 How does wide-area assessment supplement historical information?

Historical research is a necessary precursor to performing WAA. ITRC 2003 provides additional information on performing historical records reviews (HRRs).[1] Historical research is used to identify MRAs and possibly assist in delineating MRSs within the MRA. WAA or other site-characterization methods can then be used to confirm or refute historical information, fill in data gaps, and produce sufficient data for a project team to delineate the MRSs and help focus follow-on investigatory activities.

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[1] For DOD’s Military Munitions Response Program, historical information is gathered and presented in the Preliminary Assessment.

2. COMMONLY USED WAA TECHNOLOGIES

The technologies discussed in this section are commercially available technologies with proven performance criteria sufficient for conducting WAA at MRAs. Demonstration reports are available for these technologies and may be accessed through the Strategic Environmental Research and Development Program (SERDP)/ESTCP website.

Key performance criteria for most of the technologies discussed in this section are data density, sensor sensitivity and noise level, transect spacing (if applicable), and positional and navigation accuracy:

- ***Data density*** is the number of sensor measurements per unit area. Data density requirements are based on the size of the object the sensor must detect (resolve). Generally, higher data density results in greater image resolution. Data density is affected by the distance from the sensor to the target, the speed the sensor passes over the target, and the sampling rate of the sensor. The greater the distance and the faster the sensor passes over the target, the lower the data density.
- ***Sensitivity*** is the minimum signal a sensor can detect. Noise refers to all signals not related to a target. Sensitivity, noise levels, and data density determine the smallest target that can be detected. Data density and sensor noise levels are described in detail in ITRC 2006.
- ***Transect spacing*** is the distance between adjacent survey lines. Transect spacing determines the size of the target area that can be detected and is a critical element in Visual Sample Plan (VSP). An in-depth discussion of transect design is provided in section 2.4 of this document.
- ***Positional accuracy*** refers to how close a measurement is to a known location on the earth's surface; ***navigation accuracy*** establishes how well planned transects are followed. Technology-specific considerations are presented below.

Finally, when evaluating the use of any technology for WAA, there must be a reasonable expectation that munitions use at a site would have created MRFs or left concentrations of geophysical anomalies that are discernable today.

2.1 What is LiDAR?

Light detection and ranging has become an established method for collecting very dense and accurate elevation values. It is analogous to radar (radio detection and ranging), except that it is based on discrete light pulses and measured travel times. The location and elevation of the reflecting surface are derived from (a) the time difference between the laser pulse being emitted and returned, (b) the angle at which the pulse was "fired," and (c) the location and height of the aircraft (i.e., the sensor location) (NOAA 2008).

For application to WAA, LiDAR is often deployed from fixed-wing aircraft, though helicopters are also used, flying at an altitude of 350–800 m (1,000–2,500 feet) and measures elevation differences on the ground surface. The position and orientation of the aircraft are precisely measured using the Global Positioning System (GPS) and an inertial navigation system. A laser pulse sent from the aircraft to the ground surface is reflected to the aircraft. The time of return of each laser "point" is used to measure ground surface elevation. This process is repeated many times in swaths 300–400 m wide as the aircraft flies forward (Figure 2-1). A ground surface contour is developed from the sequential measurements. LiDAR can survey thousands of acres per day. LiDAR and orthophotography are typically collected simultaneously from the aerial platform.

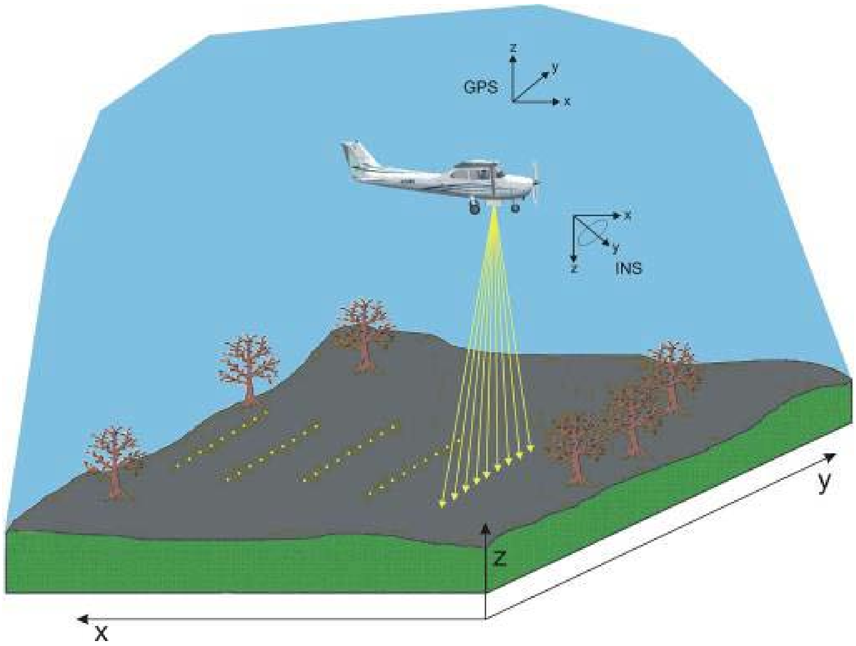

Figure 2-1. LiDAR data collection.

2.1.1 What does LiDAR measure or detect, and how much of the MRA is covered?

LiDAR data are typically collected over 100% of the MRA to detect and measure subtle differences in ground surface elevation that may be indicative of munitions-related activities (i.e., MRFs). Modern LiDAR systems can be configured to reliably detect MRFs with elevation differences on the order of 10 cm and a horizontal dimension of 1 m or greater.

2.1.2 What is the data product?

LiDAR produces a digital ground surface contour map. The data set is processed and displayed using a geographic information system (GIS) by a trained analyst. Figure 2-2 is an example LiDAR image from Pueblo Precision Bombing Range (PBR) #2 in Colorado.

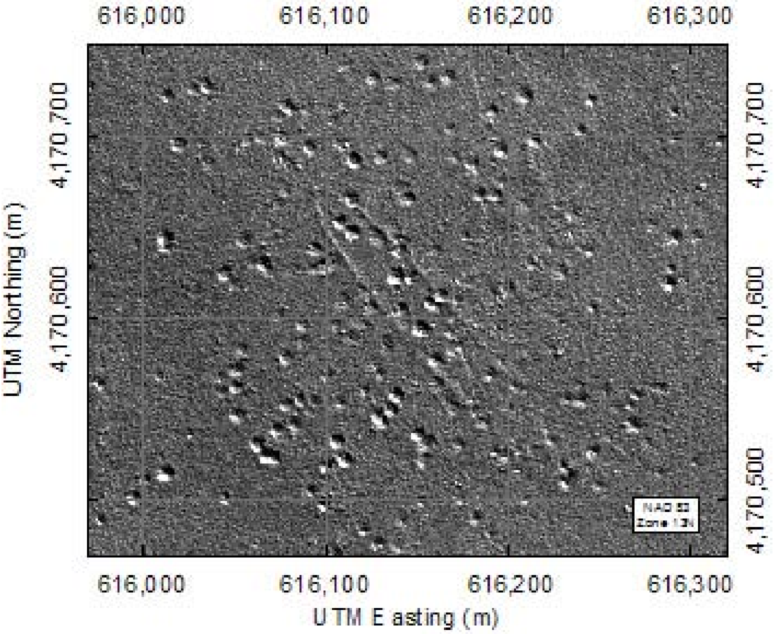

Figure 2-2. LiDAR data from Pueblo PBR #2 showing a ship-shaped target berm and numerous bomb craters.

2.1.3 What site conditions affect the applicability of LiDAR?

LiDAR is suitable for sites free of surface obstructions that may obscure MRFs. It can be used in forested areas where tree canopy is not too dense or layered; however, dense grass and low shrubs obscure the surface features that LiDAR is designed to map. LiDAR is not suitable for areas where changes in landscape (e.g., erosion) have eliminated surface features.

2.1.4 What are the data requirements to identify MRFs?

LiDAR image quality depends on three factors: point density on the ground, vertical resolution, and horizontal positional accuracy. Density of four points per square meter has been shown to reliably detect craters as small as 1 m across; higher point density is required to detect smaller features. Vertical resolution determines the elevation difference that can be measured. Horizontal positional accuracy determines the image quality and the ability to accurately locate features of interest. Commercial systems can routinely provide a vertical resolution of 15 cm and a horizontal positional accuracy of 60 cm, which is sufficient for identifying MRFs.

2.2 What is orthophotography?

Orthophotography is the collection of high-resolution aerial photographs which are geometrically corrected (orthorectified) such that the scale is uniform and the photo lacks distortion, similar to a map. Orthophotographs can be black and white, color, or color-infrared. Orthophotography does not necessarily have to be developed from recent aerial photography; historical aerial photography can also be orthorectified. Orthophotographs and LiDAR are typically collected at the same time from an aerial platform.

2.2.1 What does orthophotography detect, and how much of the MRA is covered?

Orthophotography can detect MRFs if they are visible to the camera. If an MRF is captured in the orthophotograph, its location can be determined with a high degree of accuracy. Orthophotography cannot detect individual UXO/DMM. Orthophotographs are typically collected over 100% of the site.

2.2.2 What is the data product?

The data product is a digital image that can be used in GIS for interpretation by a trained analyst to identify MRFs. Though it is possible to automatically scan the images using feature recognition tools, no such systems are known to be programmed for the types of features common to MRSs. Figure 2-3 shows an overlay identifying MRFs. The figure shows the crosshairs and circle used to designate a target at the former Kirtland Air Force Base bombing range. Individual craters are marked with red circles.

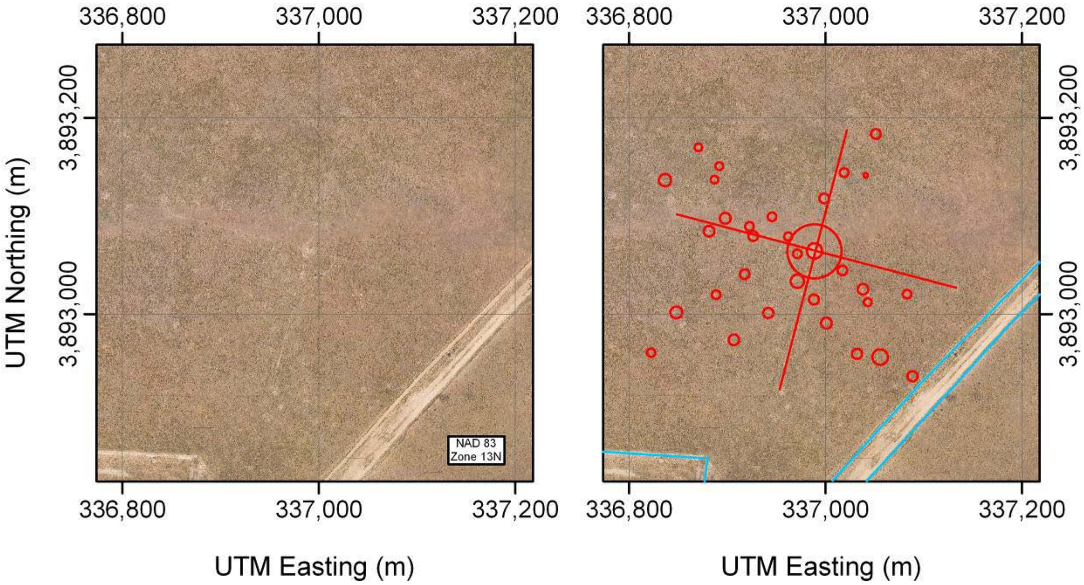

Figure 2-3. Orthophotograph of the New Demolitions Impact Area of the Former Kirtland Bombing Range. The crosshairs, circle, and craters (red) used to designate the target are seen easily. A nearby roadway (blue) is also visible.

2.2.3 What site conditions affect the applicability of orthophotography?

Orthophotography is suitable for most MRAs. However, dense or seasonal vegetation, forest canopy, cloud cover, and snow cover can obstruct MRFs, making the features "invisible" to the camera. Also, changes in landscape (e.g., erosion) or land use can obscure MRFs entirely or reduce their dimensions below the detection capabilities of the imaging system. Orthophotography is not suitable for underwater munitions sites.

2.2.4 What are the data requirements to identify MRFs?

Orthophotography image quality depends on resolution and horizontal positional accuracy, both of which can affect the information extracted. The resolution is determined by the height of the platform and the number of pixels in the image. Each pixel represents a discrete area on the ground. Commercial systems typically correlate each pixel to an area of 10–20 cm on a side with a horizontal positional accuracy of approximately 0.5 m. These requirements are suitable for most WAA applications.

2.3 What geophysical sensors are applicable to wide-area assessment?

Geophysical sensors applicable to WAA include magnetometers and EMI instruments. For a detailed discussion of the different geophysical sensors and their capabilities, see ITRC 2006.

2.3.1 When performing wide-area assessment, how are geophysical sensors deployed?

Geophysical sensors used for WAA can be deployed on helicopter, land-based, or water-based platforms. The geophysical sensors are deployed as single sensors, arrays of sensors, or a combination of the two sensor types.

Helicopters rather than fixed-wing aircraft are used for deploying airborne geophysical sensors. The signals from geophysical sensors fall off quickly with distance from the anomaly. In most cases, geophysical survey altitudes cannot exceed 3 m. Therefore, helicopters are used because they can fly low to the ground. In addition, helicopters can maintain the slow speed over ground that is required to obtain the desired data density along the flight lines. Figure 2-4 shows a helicopter-borne magnetometer array.

Figure 2-4. A helicopter-deployed magnetometer array during a geophysical survey.

Land-based geophysical systems (magnetometers, EMI sensors, or a combination of the two) are deployed as handheld devices, man-portable devices (Figure 2-5), cart-mounted instruments, or vehicle-towed platforms (ITRC 2006). The type of terrain encountered dictates the choice of sensor platform.

Figure 2-5. A man-portable EMI array during a geophysical survey of statistically based transects.

Figure 2-6. Cable-towed underwater array.

Underwater geophysical sensors, configured individually or as arrays, are typically towed behind boats (Figure 2-6). Underwater geophysical sensors are the same as those used for helicopter-deployed and land-based geophysics (magnetometers and EMI) except they are designed for use in the underwater environment. Underwater geophysical sensors must maintain a consistent distance from the sea, lake, or stream bed to achieve a consistent probability of detection.

2.3.2 What do geophysical instruments detect, and how much of the MRA is covered?

Geophysical instruments measure variations in the local magnetic field or electromagnetic response caused by surface and buried metallic objects (e.g., UXO, DMM, MD, other debris, etc.). High anomaly densities suggest an area of concentrated munitions use within an MRA.

For the purposes of land-based and underwater WAA, geophysical instruments are deployed along statistically based transects designed to ensure the area sampled accurately reflects the entire site. Survey coverage is dictated by the objectives of the statistically based transect program. For example, in the ESTCP Pilot Project, the area sampled was only 1%–5% of the entire MRA. The UXO modules of VSP are often used by investigators to develop statistically based surveys and to post-process the data to identify areas with high concentrations of anomalies. See section 2.4 for a further discussion of VSP.

Helicopter-deployed geophysical surveys are conducted either along statistically guided transects or over 100% of the MRA. Practical considerations as well as data quality/quantity issues make it worth considering performing 100% coverage with a helicopter system. For example, helicopter surveys can cover the site quickly compared to man-portable or vehicle-towed units and in some cases cost-effectively. In situations where smaller areas of concentrated anomalies (e.g., burial or disposal pits) are expected, 100% coverage may be the only way to reliably identify them. Site-specific conditions and data quality objectives (DQOs) determine the platform and whether statistically guided transects or 100% coverage are required.

2.3.3 What is the data product?

Data from statistically based transect or 100% coverage surveys are used to produce maps showing the location of anomalies detected by the instrument. A statistically based transect geophysical survey results in a map depicting transect paths and the anomalies detected along them (see Figure 2-7). Transect data and geophysical anomaly locations can be used as input into VSP (see section 2.4) or other GIS-based software to perform anomaly density mapping, geostatistical density modeling, and target area delineation.

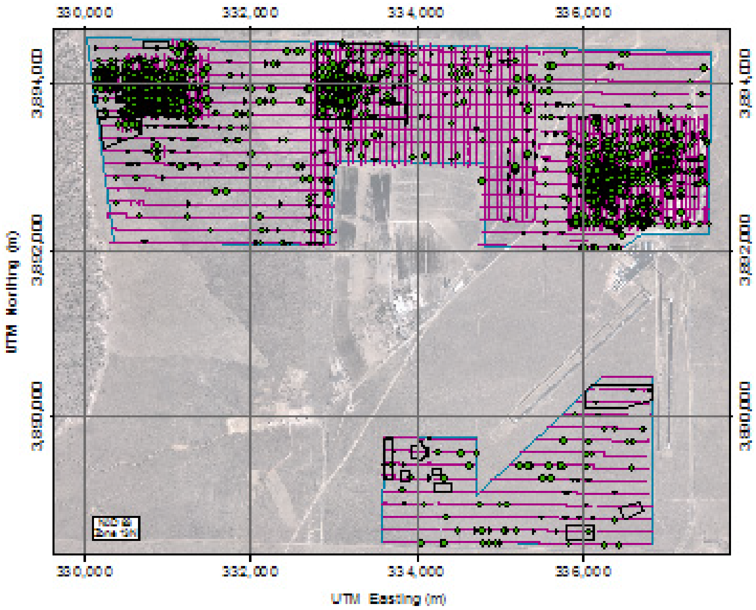

Figure 2-7. Ground transects and anomaly locations overlain on an aerial photograph of the Kirtland site. The transects, as driven, are shown in pink and the anomalies as green dots. The original transect plan included only the east-west transects. After analysis of these data, the north-south transects were added in areas of greater anomaly density to better define the areas of concentrated munitions use.

Data from 100% coverage surveys are also used to generate color-coded maps. Experienced geophysicists are required to interpret these maps to select anomalies. Areas of concentrated anomalies may be indicative of concentrated munitions use in an MRA. Figure 2-8 shows example magnetic anomalies identified during a helicopter magnetometer survey from Pueblo PBR #2 in Colorado.

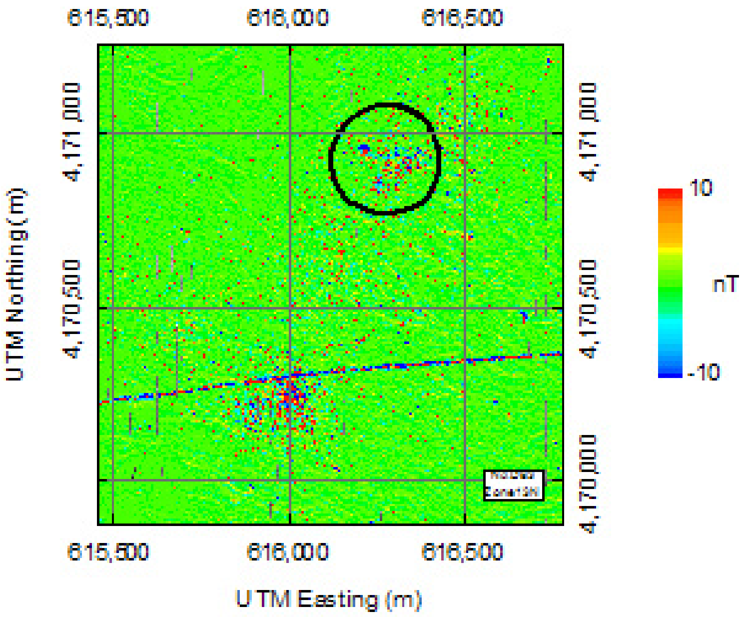

Figure 2-8. Magnetic anomaly image (nano-tesla) constructed using data collected by a helicopter-deployed magnetometer array at Pueblo PBR #2. There is a concentration of anomalies near the target circle (black) and extending to the southwest. The linear feature in the image running east-west is a fence. A second (previously unknown) concentration of anomalies is present south of the fence.

2.3.4 What site conditions affect the deployment of geophysics?

Geophysical instruments are limited by magnetic geology, rough terrain, and dense vegetation. Regardless of the platform used, deployment of magnetometers for WAA is not very successful in areas with substantial interference from magnetic geology (“hot rocks”).

Helicopter-deployed geophysical sensors are best suited for MRAs with UXO/DMM that can be detected at the operational sensor height. Helicopter-deployed geophysical sensors are less appropriate for MRAs with low anomaly density or munitions smaller than a 60 mm mortar. Helicopter-deployed geophysics is best suited for arid and semiarid regions where vegetation is low and the MRA is relatively free of objects that may impede low-altitude (2–3 m) flight. Helicopter-deployed geophysical sensors can be used in areas with shallow water, such as marshes and tidal areas.

Land-based geophysics can be deployed on a variety of platforms, making it suitable for most terrain and site conditions. However, the terrain encountered dictates the choice of sensor platforms. Vehicle-towed arrays are best used on large, flat, open areas, while man-portable or handheld devices may be necessary in steep or heavily forested terrain.

Underwater geophysics is suitable for sites where UXO/DMM are present on or beneath the sea, lake, or stream bed. As with airborne and land-based geophysics, the sensors should be deployed at a range sufficient to ensure detection, which for the smallest objects will be as close as possible. For shallow water, both cable-towed systems and pole-mounted systems have been successfully deployed.

2.3.5 What are the performance requirements for geophysical instruments when conducting wide-area assessment?

The performance of helicopter-deployed geophysics is affected by several factors, including sensor height, sensor sensitivity, data density, positional accuracy, and coverage. The operational height for helicopter-deployed geophysics is typically 2–3 m. Surveys conducted above this height have decreased likelihood of detecting items of interest. Current sensor technologies deployed at 2–3 m above the ground are sufficiently sensitive to detect medium to large munitions (see ITRC 2006). Data density is determined by flight speed and sensor sampling rate. Commercial systems based on this technology provide sufficient data density at safe operating speeds and height. Positional accuracy requirements are determined based on the type of survey. Total (100%) coverage surveys require higher positional accuracy than transect surveys to ensure that excessive data gaps do not exist (see discussion of positional accuracy required for transect surveys at the beginning of section 2).

Performance of land-based geophysical transects used for WAA is based on several factors, including transect spacing design, sensor type, positional accuracy, navigational accuracy, data density, and sensor noise level. Section 2.4 provides an in-depth discussion of transect spacing design. ITRC 2006 discusses in detail the benefits and limitations of the geophysical sensors (magnetometer vs. EMI). The follow-on MR activities subsequent to WAA determine the positional accuracy required for the survey. Acceptable navigational accuracy depends on transect spacing, but accuracies on the order of 5–10 m are achievable and should be acceptable.

Data density and sensor noise levels, which determine the sensitivity of detection, are common quality elements in MR projects and are described in detail in ITRC 2006.

The performance of underwater geophysical sensors, while affected by those factors identified above and at the beginning of section 2, is primarily limited by the platform used to deploy and control the sensors. The geophysical sensors themselves are not limited by water depth but must be controlled to maintain a depth close enough to the sea, lake, or stream bed to optimize detection while also avoiding underwater obstacles. Underwater magnetometers are commercially available, configured in pressure vessels with integrated depth and altimeter controls, for cable-towed deployment to depths up to 9,000 feet. However, such products are designed for applications with increased bottom standoff (e.g., shipwreck hunting). The long tow cables required to reach great depths increase the possibility of entanglement and decrease positional accuracy. These factors generally limit usage to maximum depths of tens of meters. Remotely operated vehicle (ROV)–based geophysical sensors are being developed, but the motor and actuators produce interference that can be problematic. Heavy near-shore wave action, large tidal swings, and strong currents are not technological limitations but nonetheless pose significant survey challenges.

2.4 What is Visual Sample Plan?

VSP is a software tool that supports the development of statistically defensible sampling plans for site characterization and analysis of the resulting data. VSP has many sampling design and statistical analysis modules that focus on soils, sediments, surface water, streams, groundwater, buildings, and geophysical anomalies at sites. The UXO modules within VSP are designed to plan statistically guided transect sampling, as well as perform target area detection and delineation and anomaly density mapping and estimation from sparsely spaced transects.

2.4.1 What is statistically guided transect sampling?

Statistically guided transect sampling collects data over a small percentage of the survey area (transects) to produce a data set that statistically represents the survey area. The pattern of transects is usually equally spaced, parallel lines across the MRA (see Figure 2-9). Transect spacing is based on a user-defined probability of detecting the target area with an associated confidence level. Sampling of transects can be conducted with any of the standard geophysical sensors or platforms.

2.4.2 How can VSP be used to plan statistically guided transects?

The VSP user specifies the transect width, anomaly detection efficiency, background anomaly density, target area density, target area size expected, and the required probability of traversing and detecting that target. In cases where limited information is available, the VSP user can focus solely on traversal of the target. Determining the size of the target area of interest is challenging. Many factors (e.g., fragmentation radius, firing direction, trajectory, expected munitions type and size) are evaluated to determine an appropriate value for the target size. VSP computes the required transect spacing, calculates the probability of detecting the target area as a function of anomaly density in the target area, and displays the proposed transects on a site map. The user can then conduct a sensitivity analysis by evaluating the effects of varying the input parameters. These methods and tools allow a project team to evaluate different input parameters against costs and other constraints.

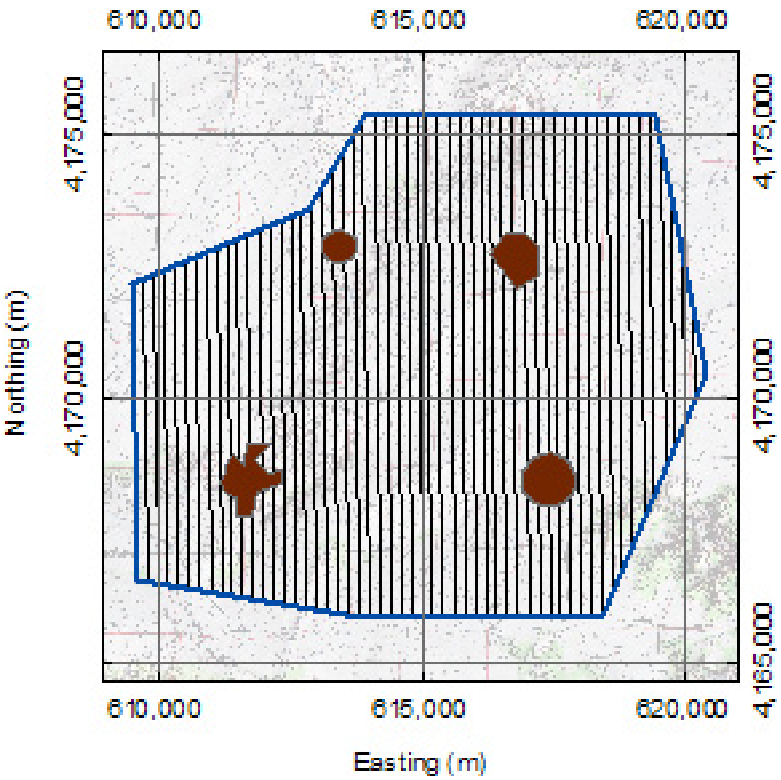

Figure 2-9. Example of planned transects resulting from the use of Visual Sample Plan. Example target shapes (red) are included to assist in visualizing the relationship between target area size and transect spacing.

In the example shown in Figure 2-9, VSP has been used to define transect spacing on the MRA shown outlined in blue. The suspected targets, along with an estimate of their size, were inputs to VSP, which calculated the spacing of transects across the MRA. VSP determines the transect spacing required to meet the user-specified probabilities of traversing and detecting the various targets.

2.4.3 What is the data product?

After collecting survey data, VSP's target area identification algorithm systematically moves along each transect surveyed and identifies areas with greater anomaly density than would be expected for background. A component of the UXO module within VSP interpolates anomaly densities between transects. Figure 2-10 shows an example of the anomaly density estimated for and around a target area on Pueblo PBR #2 in Colorado.

2.4.4 For what types of sites is VSP suitable?

VSP statistically guided transect sampling is suitable for any MRA that can be traversed with a geophysical sensor.

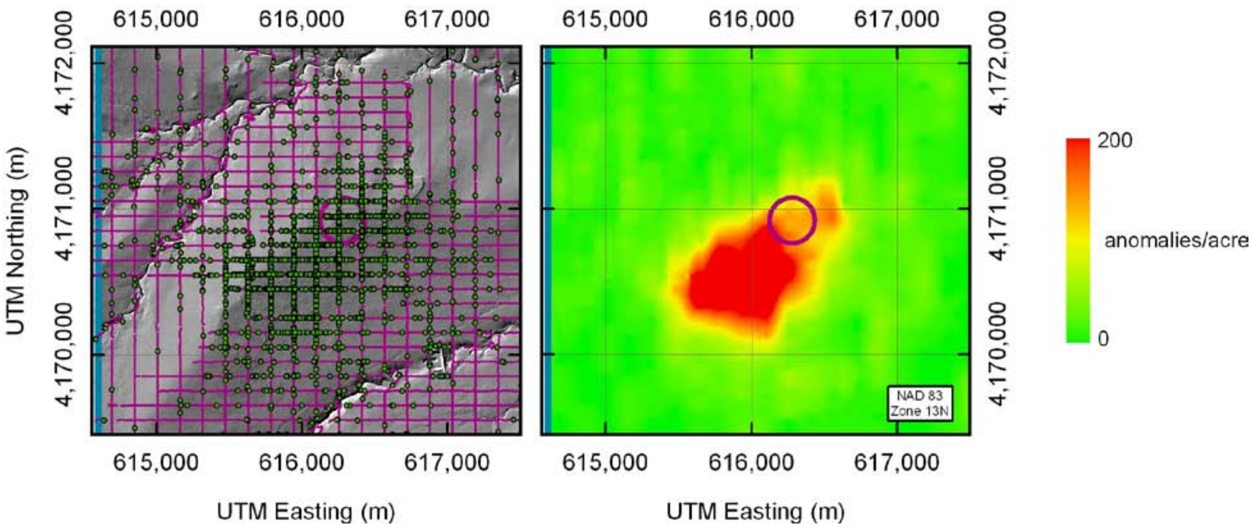

Figure 2-10. Anomaly density estimated using the results of a towed-array transect survey over Pueblo PBR #2 Target 4. The left image shows the transect locations and the individual anomalies. The image on the right shows the resulting anomaly density. The circle (right) represents the target location identified through historical research.

2.4.5 What are the VSP data requirements to identify MRSs?

VSP requires knowledge of, or assumptions about, target characteristics suspected to be present within the MRA. These characteristics are captured within three primary inputs:

- ***Target area size and orientation***—The target area size is largely a function of the fragmentation range of the munitions of interest. Additional factors that influence target area size include firing direction, trajectory, delivery system, range probable error, and number of munitions fired. The project team should evaluate these factors in combination when selecting a target area size and orientation.
- ***Background anomaly density***—This value is the density associated with non-munitions-related activity (e.g., geological or anthropomorphic anomalies) within the survey area. Work from a similar site or survey results from a small portion of the MRA are used to estimate this value.
- ***Expected anomaly density and distribution in the target area***—VSP allows users to assume the distribution of anomalies within the target area to be uniform or to decrease with distance from target center. As the target area density is often unknown and varies, VSP allows the user to evaluate traversal and detection probabilities over a range of target area densities above background.

Additional inputs (e.g., confidence level, probability of detection) are user-defined. The minimum size of target area should be appropriately selected to ensure that the transect design results are representative. As discussed previously, determining the size of the target area can be challenging.

When using VSP to plan transects, the first step is to define the decision that will be resolved using the data generated through this process (i.e., systematic planning and DQOs). For example, if the geophysical survey is used to locate a target area, the acceptable levels of probability and confidence levels can be evaluated by employing a range of inputs and assumptions. VSP is based on well-understood and documented statistical methods. VSP and the associated documentation are free and available to download from http://vsp.pnl.gov. Demonstrations of the use of VSP at MRAs (funded through ESTCP and SERDP) can be found by searching for "0325" using the SERDP/ESTCP online document library system (http://docs.serdp-estcp.org/index.cfm).

2.5 What technologies other than geophysical sensors are available for conducting WAA at an underwater site?

Geophysical sensors available for use on underwater platforms are discussed in section 2.3. LiDAR and orthophotography used in WAA on a terrestrial site have direct counterparts in the underwater environment. Side-scan sonar, multibeam sonar, and laser-line scan systems provide a bottom map analogous to the result of a LiDAR survey, while towed cameras provide an image of the water bottom that can be interpreted in the same way as orthophotography.

2.5.1 What does sonar measure and how is it used?

Active sonar is the process of emitting a pulse of sound waves (ping) into water and analyzing the time it takes for the sound waves to be reflected off an object and return to a receiver (echo). The distance (range) to the object is calculated using this measured time and the speed of sound in the water. The sound pulse can be either a narrow beam that is rastered across the bottom to create a map of the bottom or a fan-shaped beam that covers the bottom as the vehicle moves through the water (see Figure 2-11).

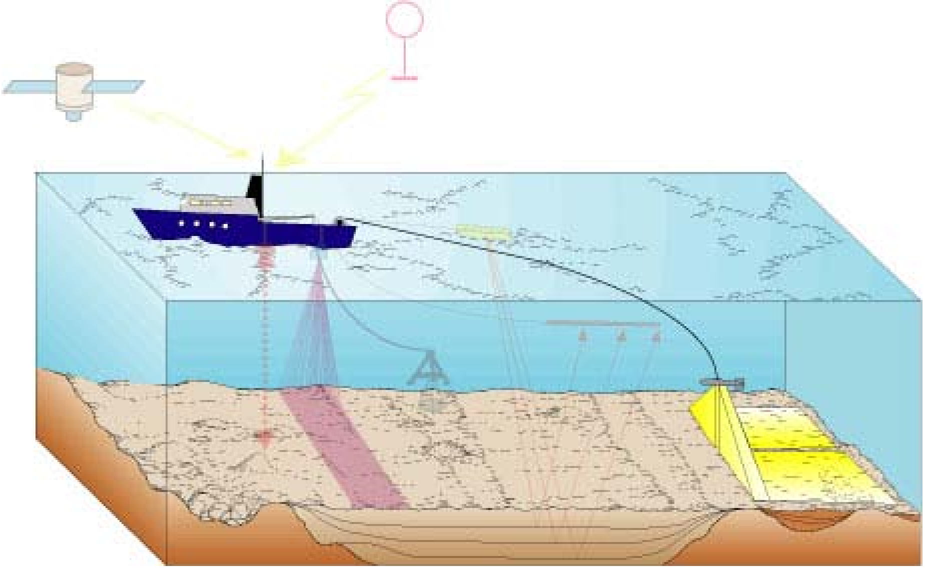

Figure 2-11. Side-scan sonar data collection.

Sonar operating at sufficiently high frequencies to give good definition of munitions-sized objects has very little bottom penetration ability. These systems, which include most commercial systems in use today, therefore detect only objects that are proud of the surface or partially buried. Some research systems operating at oblique angles to the bottom are able to detect buried objects the size of munitions, but these systems have not yet been validated for WAA.

2.5.2 What do underwater optical sensors measure, and how are they used?

There are two types of underwater optical systems that can be used for WAA: camera (video and still) and laser line-scan. Cameras use ambient or strobe light to capture a photograph of the water bottom, analogous to orthophotography. Laser line-scan systems record the time of return and reflected intensity from a laser pulse that is rastered across the bottom. Similar to LiDAR, laser line-scan systems measure range to the bottom, obtain a measure of reflectance from every laser pulse, and produce an image built up from thousands of successive laser pulses.

Like orthophotography, underwater optical sensors provide an image of the bottom surface. They have no ability to penetrate the bottom, and the usefulness for WAA can be degraded by vegetation. Heavy biofouling may make it difficult to recognize targets of interest in an underwater photograph; the three-dimensional information available from a laser-line scan image may help with this problem. At present, laser line-scan systems are not common in the commercial market.

2.5.3 How are these other underwater sensors deployed?

In shallow water (up to 50 m) all of these sensors can be mounted directly to survey vessels. Water clarity limits the maximum offset at which optical sensors are useful. Unlike the geophysical sensors, these sensors do not need to be as close to the bottom to detect underwater UXO/DMM. However the imaging capability of acoustic and optical sensors does degrade as distance from the sensor to the object of interest increases. When trying to detect objects in deeper water, optical sensors can be mounted to a “fish” and towed by cable from the survey vessel or mounted to an ROV to keep the sensor at the desired distance from the bottom.

2.5.4 What is the data product?

Sonar imaging systems (e.g., side-scan sonar, subbottom sonar, and multibeam bathymetry) produce sonograms of the water bottom, which are interpreted to identify features of interest that may be associated with munitions-related activities. These products are analogous to those produced from orthophotography and LiDAR in that an experienced interpreter analyzes the sonograms to identify features of interest and describe their location on a site map.

The optical sensors produce images or video of the water bottom (Figure 2-12). These are also usually interpreted by trained analysts. Though it is possible to automatically scan the images or video using feature recognition tools, no such systems are known to be programmed for the types of features common to MRSs.

In both cases, the resulting products include maps or GIS data layers of the surveyed areas identifying and locating features that may be munitions related.

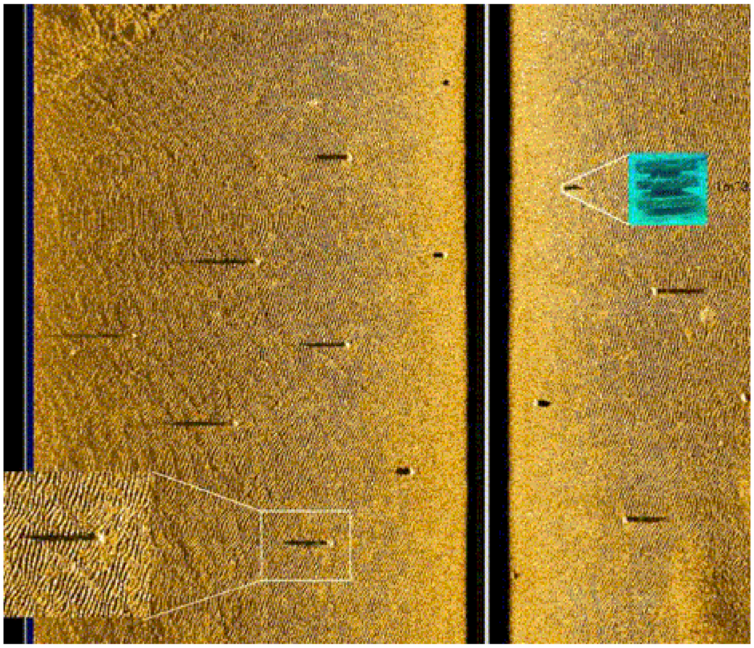

Figure 2-12. Side-scan sonar data showing "mine-like" targets. Data collected by 4200 series side-scan sonar system with a frequency of 600 kHz.

2.5.5 What site conditions affect the deployment of underwater optical and acoustic sensors?

As discussed above, these sensors are currently applicable only to sites with targets proud of the bottom or partially buried. Sonar is suitable for most underwater environments; water clarity is not an issue. Optical systems require sufficient water clarity for light to reflect off the water bottom and be captured by the imaging system. As in the case of orthophotography, heavy underwater vegetation can obscure the bottom. Experience using underwater optical and acoustic sensors in the MR industry is limited. Technology experts should be consulted to determine whether these technologies are appropriate for a particular MRA.

2.5.6 What are the performance requirements for optical and acoustic sensors when using these sensors to conduct wide-area assessment?

Data density, transect spacing, positional accuracy, navigation accuracy, and sensor stability are key performance components for surveys using optical or acoustic sensors. Image quality is highly dependent on sensor stability. The project team sets and monitors requirements for each of these components to ensure the survey meets project objectives. Typically, the project team first determines what survey coverage (i.e., total coverage or statistically derived transects) is necessary to achieve project objectives. Once coverage requirements are established, data density requirements, transect spacing, survey vessel speed, etc. can be set for the sensor. Next, the project team evaluates the required sensor "swath" (i.e., the cross track coverage expected from the sensor). The swath depends on the standoff distance of the sensor from the sea, lake, or river bed needed to achieve the required data density/resolution. Once the required coverage, data density, and the sensor "swath" are determined, the project team can set the transect spacing to achieve project objectives.

Since the sampling swath is generally wider for underwater optical and acoustic sensors than for geophysical sensors, positional and navigation accuracy does not have to be as precise. Typical underwater positional and navigation accuracies of 10 m are sufficient for these sensors. In total-coverage (100%) surveys, low positional accuracy can be overcome by collecting tighter transects to ensure overlap between swaths or photographs.

3. OTHER TECHNOLOGIES POTENTIALLY APPLICABLE TO WIDE-AREA ASSESSMENT

Several other technologies or technical disciplines may be applicable to WAA; however, because of certain limitations, complexity, or the significant computational resources required for their use, they are not commonly used. Advances in these technologies or their applications may make their use more common in the future.

3.1 What is spectral imaging?

Spectral imaging is often referred to as “multispectral” or “hyperspectral” imaging. Multispectral remote sensors produce images with a few (tens to hundreds) relatively broad wavelength bands. Hyperspectral remote sensors, on the other hand, collect image data simultaneously in hundreds or thousands of narrow, adjacent spectral bands to produce a hyperspectral image.

Although hyperspectral imaging has been an area of active research and development over the past several years and shows greater potential for use during WAA than multispectral imagery, it is less likely to be used due to the complexity and cost associated with managing hyperspectral data. With the recent appearance of commercial airborne hyperspectral imaging systems, the technology could be poised to enter the mainstream of remote sensing.

The idea that drives hyperspectral imaging for WAA is that it draws information from such a large portion of the light spectrum that any given object (e.g., MRF, debris) should have a unique spectral signature in at least a few of the many bands that are scanned. Also, researchers are using hyperspectral imaging to monitor the development and health of vegetation. Using hyperspectral imaging in this manner could prove useful when analyzing the effects of concentrated munitions use on vegetation in an MRA (see section 3.4).

In summary, using hyperspectral remote imaging to detect MRFs, although possible, is not currently practical. The primary disadvantages are cost and complexity. Fast computers, sensitive detectors, and large data storage capacities are needed for analyzing hyperspectral data. Moreover, highly trained and experienced individuals are required to plan and acquire the data necessary to capture and match the spectral signatures to MRFs. As a relatively new analytical technique, the full potential of hyperspectral imaging has not yet been realized. However, this may change as the technology matures and becomes more available to the public.

3.2 What is satellite imagery?

Imagery taken from orbiting satellite platforms is available and has been used for many environmental and earth resources management activities. Most readily available satellite photos have 1 m pixels, with the best only as small as 30 cm. Usually, pixel sizes of 10–20 cm are required to resolve many of the existing MRFs at the MRAs. Figure 3-1 illustrates the problem with pixel size. The left panel shows a portion of the former Camp Beale site in the 10 cm pixel orthophotograph collected in the pilot project. The target circles are clearly visible in the photograph. The right panel shows a standard 30 cm (1-foot) pixel photo of the same area in which the surface features are much less obvious and might not be noticed by an analyst. Until resolution of commercially available satellite imagery meets these requirements, it will not be very useful for purposes of WAA.

Figure 3-1. Comparison of 10 cm pixel orthophotograph of a portion of the former Camp Beale (left) with a conventional 30 cm pixel aerial photo (right).

3.3 What is synthetic aperture radar?

Synthetic aperture radar (SAR) is an airborne side-looking radar system that uses the flight path of the platform to simulate an extremely large antenna (Figure 3-2). The multiple radar images produced by the moving system are processed to yield higher-resolution images than would be possible by a conventional radar system.

SAR works best in areas with dry homogenous soil, smooth topography, and little vegetation. Under ideal circumstances, the dry soil may permit some penetration of the radar energy, and the lack of vegetation may reduce the number of false alarms that can be quite high in a SAR measurement. Unfortunately, the ground is a complex medium, and variations in soil, moisture content, and microtopography and the presence of vegetation can cause SAR to produce large numbers of false alarms. In addition, SAR's data acquisition requirements are substantial. Multiple passes over the MRA are required to allow the detection of objects of interest. Finally, formation of SAR images requires intensive post-processing, and automated tools for target detection are not robust. For these reasons, SAR is not routinely employed for WAA.

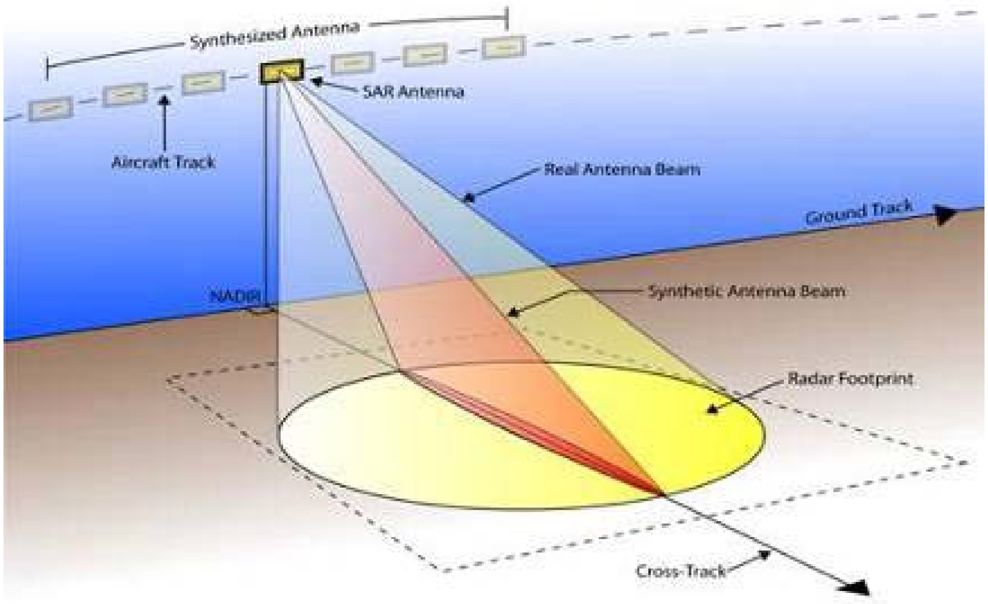

Figure 3-2. Diagram of SAR processing to generate a long synthetic antenna and hence a very narrow cross-track synthetic beam.

3.4 What is vegetation analysis?

Vegetation analysis, more a technical discipline than a technology, is a visual assessment of the type, distribution, development, and health of vegetation in an MRA. The utility of vegetation analysis as a WAA technology is based on the premise that concentrated munitions use has an observable long-term affect on the distribution, development, or type of vegetation present. Observed variations in plant development or unexpected plant types in a specific location may indicate an area of concentrated munitions use within an MRA. Vegetation analysis requires highly trained individuals using information from a variety of sources such as local knowledge, field observations, color or color-infrared aerial orthophotography, or other remote sensor images (e.g., hyperspectral images) to identify vegetation “anomalies” that may be related to MRFs within an MRA. Even observant investigators not specifically trained in vegetation analysis may notice variations in plant type or development that could provide important information on the location of MRFs. The level of expertise notwithstanding, areas identified as potential MRFs using vegetation analysis require further investigation (ground-truthing) or additional lines of evidence to confirm the observations.

An Example of Vegetation Analysis

In the arid desert areas of Arizona, a hard caliche layer often forms at a depth of 3–12 inches below the ground surface and affects both the infiltration of rain water and the types of plants that are able to establish root systems. However, where the surface layer has been broken up or disturbed, cholla-type cactus are known to colonize and out-compete other native species. At one former Air Force WWII bomb and aerial rocket target, site inspection team noticed that a certain species of cholla-type cactus overwhelmingly dominated both the target and abandoned dirt access roads. This local knowledge about cholla-type cacti colonizing broken caliche soils was used the following year to identify a previously unknown 30-year-old mortar firing position on an unrelated range survey at a nearby National Guard facility.

4. APPLICATIONS

WAA technologies are not intended to support detection of individual munitions. However, some WAA technologies can detect individual munitions (see ITRC 2006 for more information on this topic). Instead, its purpose is to provide data that can be used to delineate MRSs (areas of significant MRFs or geophysical anomalies). The success of WAA is not dependent on detecting the smallest or deepest munitions. The following sections provide information on the use of the previously mentioned technologies.

4.1 What are the considerations when selecting wide-area assessment technologies?

Historical information assists the project team in estimating the size of the MRA; the type of MRA; expected munitions; location of firing points, impact areas, and burial areas; and the time span the range was in use. This information is collected early in the CERCLA process and is captured in the CSM. Based on the information available and the uncertainty in the CSM, the project team then determines what, if any, additional information is required to delineate the MRA into one or more MRSs.

The project team evaluates the data gaps in the CSM, identifies decisions to be made, and assesses the technologies (discussed in sections 2 and 3) that are available to fill these needs. The project team should also evaluate the potential uncertainty that the data from each technology will accurately represent conditions on the ground. The project team must ensure they select technologies that will support defensible decision making.

For example, historical information confirms a bombing range within an MRA, but there is insufficient information regarding its exact location. If there is a reasonable expectation that MRFs are still present, then LiDAR would be an appropriate WAA technology. If the project team identifies the target areas using LiDAR, then geophysical mapping using airborne or land-based platforms may be an appropriate follow-on to begin characterizing the MRS. If LiDAR does not detect the target area and the weight of evidence in the archival record is strong enough to indicate that a target was in fact present, then geophysical surveys on statistically based transects would be an appropriate WAA technology to verify or refute the use of the range.

In situations where there is no reasonable expectation that the MRFs would still be detectable today, then the project team should consider geophysics using statistically based transects as the appropriate WAA technology.

If the project team identifies an impact area through historical documentation, aerial photos, etc. and confirms the location by observations on the ground, the project team may decide there are sufficient data, without using WAA, to begin characterizing the MRS.

4.2 What does orthophotography/LiDAR show that historical photos do not?

Orthophotographs/LiDAR images obtained for the purpose of identifying MRFs can provide several advantages over historical photos. An orthophotograph is an aerial photograph geometrically corrected such that the scale is uniform (i.e., the photo has the same lack of distortion as a map). Orthophotographs are adjusted for topographic relief, lens distortion, and camera tilt. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances because it is an accurate representation of the earth's surface.

LiDAR can detect MRFs roughly 1 m in size with 5–10 cm elevation difference. It can penetrate vegetation to produce high-resolution, vegetation-free images of the earth's surface. The images can reveal MRFs often obscured by vegetation in historical aerial photos or orthophotographs.

Depending on site conditions, orthophotography and LiDAR combined can produce high-resolution images of the earth's surface with accurate range and spatial information. Orthophotography/LiDAR can be used to validate and/or update a preliminary CSM.

Historical photographs include both land-based and aerial photos. Although land-based photos can provide important historical information, they often lack relevant spatial information and might not provide full coverage of the MRA. Aerial photos are generally more useful than land-based photos. Aerial photos can be spatially rectified and can cover wide areas if not the entire site. In addition, aerial photos from successive years can provide a record of changing land use and—if taken during the time the site was operational—help identify MRFs. Historical photos are a vital source of information when developing the initial CSM of the MRA. Historical photos provide information about past activities; while orthophotography/LiDAR provide information about current conditions.

Historical photo archives typically do not contain photographs from every year. In addition, photos may be damaged, or MRFs may be obscured by vegetative growth or cloud cover. Both land-based and aerial photos are also affected by lens distortion, geometric distortion, and camera tilt. These inherent distortions can present a false or inaccurate representation of ground features which may lead to false interpretations or data gaps.

4.3 Can wide-area assessment be used in mountainous areas?

Some WAA technologies are appropriate for use in mountainous areas, and some are not. High-airborne LiDAR and orthophotography can be used in mountainous areas. However, steep slopes and rock overhangs may limit the ability of the sensor to sample the ground surface. Using helicopter magnetometer systems in mountainous areas is dangerous. The final decision on whether or not the conditions are suitable is made by the pilot in command of the aircraft. Ground transects necessary for land-based geophysics may be difficult to conduct on very steep hillsides and mountainous terrain. In many cases, land-based geophysics is the only way to collect geophysical data in mountainous areas.

4.4 Can wide-area assessment be used in forested areas?

WAA can be used in forested areas if the appropriate system is used. High-airborne LiDAR can be used in forested areas where tree canopy is not too dense or layered; however, dense grass and low shrubs obscure the surface features that LiDAR is designed to map. Orthophotographs quickly lose their value for detecting ground features as the canopy density increases. However, orthophotography and LiDAR methods can remain useful to the extent that past munitions-related activities are reflected in the forest density or species distribution. Significant tree cover affects the ability of the helicopter system to fly at the 2–3 m altitude necessary to obtain reasonable detection performance. The conditions dictate the appropriate sensor and platform. Vehicular systems can be used through lightly forested areas, but only man-portable or handheld versions are useful as the trees become very dense. Further, dense tree cover degrades the ability to use GPS for high-accuracy location, but this limitation can often be tolerated for the purposes of WAA.

4.5 What are the smallest and largest areas for which wide-area assessment is appropriate?

WAA is a process that takes advantage of many different technologies either singularly or in combination and, therefore, is likely applicable to almost any size site. The key to selecting the most appropriate WAA technology is to identify the most efficient and cost-effective alternative that it will collect the desired data to support decision making.

Generally, collecting airborne data is not cost-effective on small MRAs because there is not enough acreage to allow the increased efficiency per acre to cover the mobilization and operation cost of the aircraft. The costs for mobilization and operation should be calculated and compared to alternative land-based systems to determine whether the airborne system is a reasonable alternative. Obtaining data previously collected (e.g., historical photographs, records, etc.) also factors in to cost considerations (USAEC 2009). However, the high mobilization and operation cost of airborne WAA systems can be significantly reduced through proper planning. For example, several nearby sites may pool their resources and contract for an airborne WAA geophysical survey under a single aircraft mobilization cost.

There are land-based systems that are appropriate for any size MRA. For example, man-portable systems are appropriate for smaller sites or areas with challenging terrain, while vehicle-towed arrays may be more appropriate for larger sites.

There are underwater systems that are appropriate for any size MRA. For example, handheld sensors can be deployed with divers for smaller sites. Towed arrays may be deployed for larger MRAs. For underwater WAA, water depth is often the limiting factor.

4.6 Can wide-area assessment detect munitions constituents?

WAA is used to identify MRSs. WAA technologies are not capable of detecting munitions constituents (MC), but WAA may identify areas where MC sampling would be appropriate based on concentrations of geophysical anomalies and/or MRFs. Characterization of MC within an MRS is then performed using more traditional environmental media sampling.

5. REGULATOR AND STAKEHOLDER CONSIDERATIONS

5.1 Where does wide-area assessment fit into the regulatory/munitions response process?

DOD requires munitions response to follow the CERCLA process. Since WAA helps distinguish MRSs within MRAs, these technologies are best suited for site characterization performed during CERCLA site inspection and remedial investigation. The decision of whether or not to include WAA technologies should be made by the project team through a systematic planning process using appropriate planning tools (DQOs, Technical Project Planning [TPP], Uniform Federal Policy Quality Assurance Project Plan, Triad, etc.).

5.2 What decisions can wide-area assessment support?

WAA can provide evidence to support the following:

- delineating an MRA into one or more MRSs
- identifying MRSs with no evidence of concentrated munitions use
- prioritizing MRSs for MR
- validating or updating the CSM
- estimating anomaly density for alternatives analysis during the feasibility study

Following is an example of the use of WAA to validate and update the CSM. The initial CSM included MRFs identified by a ground reconnaissance team within the circle in Figure 5-1. Geophysical surveys were conducted along statistically based transects to delineate MRSs and estimate anomaly density. Geophysical data collected along the transects revealed that the MRS was larger than indicated by the CSM and provided an estimate of anomaly density.

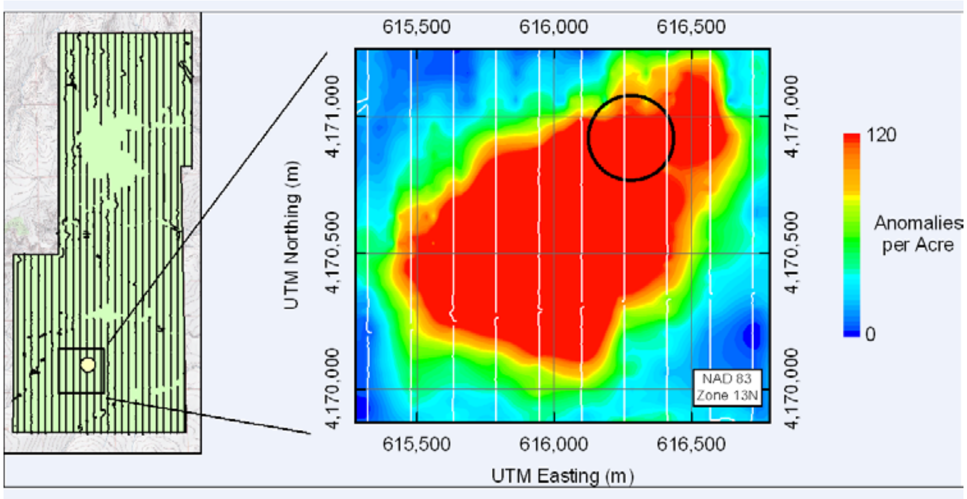

Figure 5-1. Estimated anomaly densities derived from ground-transect data. The circle in the figure bounds a target area visually identified by a ground reconnaissance team. The figure on left shows geophysical transects across the MRA. The figure on the right shows an expanded view of the transects across the target circle and the estimated anomaly density derived from those transects. The area containing high anomaly densities extends well past the target circle visually identified by the ground reconnaissance team.

When using WAA to delineate MRSs within an MRA, a high degree of confidence in the data collected is required. The consequences of concluding that a large area does not contain areas of concentrated munitions use, when in truth it does, can be severe. Process control, starting with planning and continuing through data collection, is fundamental to ensuring high confidence in the data collected. Quality requirements should be met at all times. Requirements such as equipment calibration, transect spacing, crew qualifications, photography settings, platform height, platform speed, geospatial accuracy, etc. should be determined and documented in the

Quality Assurance Project Plan (QAPP, see EPA 2005, ITRC 2008). Procedures for monitoring conformance to the requirements and corrective actions, if needed, should also be documented in the QAPP and implemented during the key activities of the entire WAA process.

5.3 How is wide-area assessment used to eliminate areas from consideration?

WAA data can be used to support making a “No Further Action” decision in situations where the data are of sufficient quantity and quality to support that decision. The requirements for data quantity and quality must be established using the DQO process. Eliminating an area from further consideration often requires a much higher degree of confidence in the quantity and quality of the data than what would be required to advance through the CERCLA process.

5.4 If wide-area assessment does not identify MRFs of concentrated anomalies, can it be concluded that UXO/DMM is not present at the site?

No. WAA is designed to detect and characterize areas of concentrated munitions use. Individual UXO/DMM may still be present at the site. The WAA reconnaissance process is not designed to detect individual munitions. Therefore, no statement about the absence of individual munitions is possible based on WAA results alone.

5.5 Is it possible that wide-area assessment could miss an area of concentrated munitions use?

Yes. The WAA process is only as good as the assumptions used to design it. If data collection is designed to identify larger MRFs, such as would be expected from a bombing range, then smaller MRFs may not be detected. If a type of munition is unknown or not recognized, data collection design may be inadequate to identify concentrated munitions use of that munition. An incorrect CSM may lead to incorrect decisions.

5.6 How do you decide when you have sufficient data to draw a conclusion?

If the CSM is adequate and the quality control program demonstrates that the DQOs have been achieved, the data should be sufficient for decision making. EPA has developed tools such as the DQO process and Triad, and the U.S. Army Corps of Engineers has developed the TPP process. If new information is discovered that changes the CSM, the project team should evaluate the adequacy of the DQOs and revise them as appropriate.

6. COSTS AND OTHER RESOURCES

6.1 How much does wide-area assessment cost?

The major factors affecting costs include the following:

- ***Site size*—**On smaller sites, mobilization costs are not efficiently amortized and dominate the cost estimates. As the site size increases, the cost per acre decreases (Table 6-1). It may not be economically feasible to employ WAA systems (particularly airborne) on small sites, but several small sites could be bundled for efficiency.

- ***Site conditions*—**Factors such as topography, weather, and vegetation can make both data collection and analysis more difficult and costly.
- ***Location*—**Remote sites far from services require additional logistics support, increasing the mobilization/demobilization costs and potentially decreasing daily productivity.

Table 6-1 shows estimated cost ranges for production deployments of common technologies discussed in this document, as compiled from USAEC 2009 and other sources. The estimated costs listed are for data collection and analysis only; site conditions can change them considerably.

Table 6-1. Estimated cost ranges for production deployments of common technologies

Technology	Cost per acre	Production (acres/day)	Site limitations	What is identified?
Orthophotography/ LiDAR (100% site coverage)[a]	$18/acre for a 10,000-acre site; $16/acre for a 50,000-acre site	1,000s	Not suitable for sites with dense/layered vegetation or areas where development, erosion, etc. have significantly changed or obscure the ground surface.	Munitions-related features (craters, firing points, target berms, aiming circles, etc.)
Land-based geophysics (towed array, 4% site coverage)[b]	$100/acre for a 1,000-acre site; $70/acre for a 5,000-acre site	10[c]	Not suitable for sites with dense vegetation or steep terrain.	Geophysical anomalies
Land-based geophysics (man-portable, 4% site coverage)[b]	$200/acre for a 1,000-acre site; $175/acre for a 5,000-acre site	1[c]	Suitable for most sites. Limited to where a person can walk.	Geophysical anomalies
Underwater geophysics[d]	Varies significantly based on site conditions	Varies by site	Factors such as tide, current, seafloor topography and cultural items present all influence the ability to perform underwater geophysics.	Geophysical anomalies
Helicopter-deployed geophysics (100% coverage)	$150/acre for a 1,000-acre site; $75/acre for a 5,000-acre site	400	Not suitable for sites with steep terrain or impediments to flying 2–3 m above the ground surface.	Geophysical anomalies

[a] Costs presented are for conducting both technologies concurrently. Costs for deployment of each technology individually would likely be very similar to concurrent deployment since data for both technologies are collected during a single deployment from the same platform. Therefore, data analysis would be the primary difference in cost if the data for both technologies were not collected concurrently.

[b] All land-based geophysics include the cost of planning transects and performing data analysis with VSP. Costs for vegetation clearance (if required) have not been included.

[c] Statistically sampling 4% of the MRA at a rate of 10 acres per day equates to sampling 250 acres of the MRA per day.

[d] Cost ranges for comparable off-the shelf, production technologies for underwater WAA are not available. Costs estimates should be determined on a site-by-site basis.

6.2 How long does it take to collect data?

LiDAR/orthophotography can survey thousands of acres a day. A 10,000-acre site can be completed in less than two weeks, including time for any weather delays. The helicopter-deployed geophysical systems can survey about 400 acres per day and, with multiple flight crews, up to 800 acres a day. At this rate of production, the survey of a 10,000-acre site would require approximately four weeks.

At a typical site, land-based and underwater systems can survey up 10 acres per day for vehicle-towed systems and 1 acre per day for man-portable systems. Site conditions like fences, terrain, and obstacles can substantially decrease this production rate. See Table 6-1 for estimates of platform-specific production rates.

6.3 Where can I find more information on wide-area assessment?

Section 7 provides bibliographical entries for references used in this document. ESTCP 2008 provides more information and details concerning the ESTCP WAA Pilot Project. USAEC 2009 contains more information on cost-effectiveness of WAA.

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Appendix B

Acronyms

ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
CSM	conceptual site model
DMM	discarded military munitions
DOD	U.S. Department of Defense
DQO	data quality objective
EMI	electromagnetic induction
ESTCP	Environmental Security Testing and Certification Program
FAQ	frequently asked question
GIS	geographic information system
GPS	Global Positioning System
HRR	Historical Records Review
ITRC	Interstate Technology & Regulatory Council
LiDAR	light detection and ranging
MC	munitions constituent
MD	munitions debris
MEC	munitions and explosives of concern
MR	munitions response
MRA	munitions response area
MRF	munitions-related feature
MRS	munitions response site
NOAA	National Oceanic and Atmospheric Administration
PBR	precision bombing range
QAPP	Quality Assurance Project Plan
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
ROV	remotely operated vehicle
SAR	synthetic aperture radar
SERDP	Strategic Environmental Research and Development Program
TPP	Technical Project Planning
TNT	2,4,6-trinitrotoluene
UXO	unexploded ordnance
VSP	Visual Sample Plan
WAA	wide-area assessment