FINAL REPORT

ESTCP Pilot Project Wide Area Assessment for Munitions Response

July 2008

Dr. Herb Nelson,
ESTCP

Ms. Katherine Kaye,
ESTCP Support Office, HydroGeoLogic, Inc.

Dr. Anne Andrews,
ESTCP

Environmental Security Technology
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EXECUTIVE SUMMARY

1.0 BACKGROUND

Munitions response is a high-priority problem for the Department of Defense. Approximately 3,000 sites, comprising tens of millions of acres, are suspected of contamination with military munitions, including unexploded ordnance and discarded military munitions. The bulk of these are formerly used defense sites, which are no longer under Department of Defense control. They are used for a variety of purposes, including residential development, recreation, grazing, and parkland, often without restriction. A typical site is thousands of acres; a number exceed 10,000 acres. Detailed investigation of the entire inventory using current practices is cost prohibitive within current and anticipated funding levels. With current planning, estimated completion dates for munitions response on many sites are decades out.

However, few, if any, historic installations are uniformly contaminated from fence line to fence line. In most cases, munitions contamination is centered on target areas, firing points, disposal sites, and the like, as seen in the example in Figure ES-1 from Pueblo Precision Bombing Range #2, CO. Historical records about the locations of these areas are helpful in planning, but are often inaccurate and incomplete. According to some estimates, no more than 20% of the tens of millions of suspected acres are actually contaminated with munitions. Thus, applying a technology or combination of technologies to holistically examine a potential site and accurately delineate the contaminated areas would allow limited cleanup resources to be used more effectively and inform decisions regarding the remainder of the land.

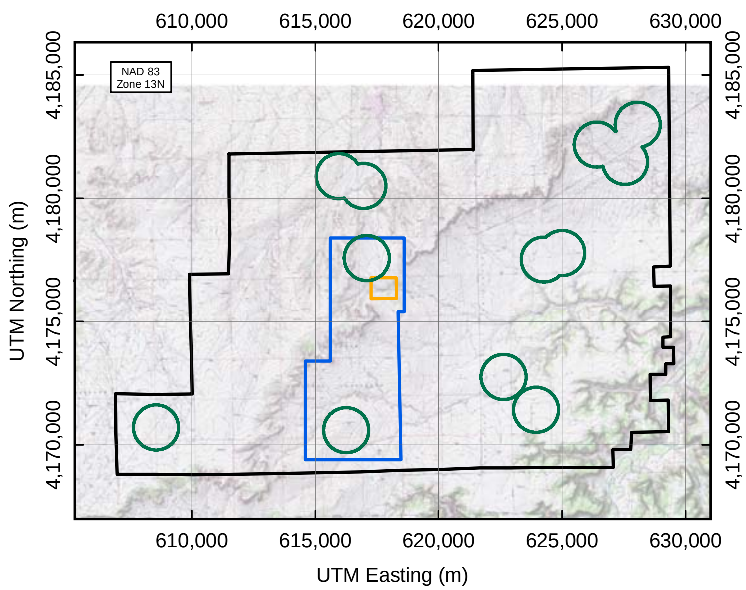


Figure ES-1. Map showing Pueblo PBR #2. The historical installation boundary, shown in black, encompasses about 68,000 acres. The known and suspected targets target areas from the munitions response inventory are outlined in green, and a suspected 75-mm range is in orange. The WAA demonstration area boundary is shown in blue.

The objective of wide area assessment (WAA) is to quickly and cost effectively assess 100% of a potentially contaminated site. Beginning with historical records, a conceptual site model (CSM) is used to record the best understanding of the site. WAA is a means to gather a preponderance of evidence that improves the understanding of the site and builds confidence in the conclusions. A suite of commercially available technologies provides data to

- Identify areas of concentrated munitions use.
- Collect information that will support decisions on areas with no indication of munitions presence.
- Collect data to support planning, prioritization, and contracting when a site must ultimately be cleaned up.

WAA can provide information needed to support decisions at various stages of the munitions response process. Throughout the process, there is a need to identify munitions response sites (MRSs), characterize the nature and extent of the munitions contamination, and collect sufficient information to let a cleanup contract. On areas that do not contain concentrations of munitions, sufficient information is needed to support decisions about whether any additional action is needed and ultimately to manage areas that will likely never be subject to intensive cleanup.

2.0 THE ESTCP WAA PILOT PROGRAM

The Defense Science Board Task Force on Unexploded Ordnance issued a series of recommendations about this problem in its December 2003 report (Ref 1). Recommendation 1 was to "Institute a national area assessment of the identified 10 million acres [of land involved]." They elaborate on this recommendation: "The Task Force envisions an intensive five-year campaign to assess all 10 million acres with the goal of delineating where the UXO [unexploded ordnance] are and where they are not. This campaign would use the full range of techniques and instruments including the helicopter-borne sensor where applicable."

The Environmental Security Technology Certification Program (ESTCP) is charged with promoting innovative, cost-effective environmental technologies by demonstrating and validating those technologies. In response to the Defense Science Board Task Force report and congressional interest, ESTCP designed a WAA pilot program to validate the application of a number of recently developed and validated technologies as a comprehensive approach to WAA.

The WAA pilot program had three primary objectives:

- Demonstrate and evaluate the effectiveness of the individual technologies and a WAA process to identify areas of concentrated munitions use.
- Demonstrate that WAA data can support decisions on areas that show no evidence of concentrated munitions use.
- Understand the site-specific factors such as terrain, vegetation, and munitions type that affect applicability and limitations of the technologies.

Secondary objectives included demonstrating that WAA data can be used to better characterize the nature and extent of munitions contamination to support cost estimation, prioritization, and planning.

3.0 METHODS

The WAA pilot project began with the selection of sites for the demonstrations, the selection of technologies to demonstrate, and the development of a demonstration process to determine how the WAA data products would contribute to supporting regulatory decisions. The approach was to demonstrate multiple mature technologies on sites where technical success was likely. A key aspect of this approach was validation, both of the data products and the conclusions.

The WAA pilot program was conducted in two phases. Phase I (2005–2006) intentionally explored the capabilities of WAA technologies with minimal limitations imposed by the environment. Phase II (2006–2007) evaluated performance under more challenging site conditions to further establish the capabilities and limitations of the technologies and was conducted in a manner more consistent with production operations.

3.1 Site Selection

Four sites were chosen for the WAA pilot program. Since all these sites were far too large to conduct an assessment of their entirety, a representative subsection of each site was chosen for the demonstration.

- **Pueblo PBR #2, CO—**A 7,500-acre demonstration area was selected to include two known bombing targets, one of which was reportedly used for only practice bombs and the other of which was used for both practice and high-explosive bombs, and a suspected 75-mm target. No other targets were indicated in the historical record.
- **Kirtland PBRs, NM—**A 5,000-acre demonstration area was selected to include three known bombing targets, one of which was reportedly used for high-explosive bombs and the other two suspected of containing only practice bombs; a simulated oil refinery target whose location was not known; and an area slated for development that was not suspected to have been used for munitions.
- **Victorville PBR, CA—**A 5,600-acre demonstration area was selected to include Demolition Bombing Target "Y," which was reportedly used for high-explosive demolition bombs, and PBR Target 15, used for low-altitude delivery of practice bombs.
- **Former Camp Beale, CA—**An 18,000-acre demonstration area was carved out of the larger 64,000-acre formerly used defense site. The Camp Beale study area contains portions that are flat and open, gradual slopes, and valleys between steep hills. Vegetation varies from sparse shrubs and trees to dense, continuous groves. The site includes areas of benign and challenging magnetic geology. Munitions reported to have been used included a wide range of bombs, artillery, mortars, and grenades.

3.2 Technology Selection

One of the main criteria used in the selection process was that technologies be mature and their expected performance well understood and well documented. The goal was to demonstrate a process using technologies that could be readily contracted, ideally through multiple vendors. The requirement for the selection was independently validated prior successful performance by the vendors using the proposed technology. Figure ES-2 illustrates the WAA technologies selected for the pilot program.

3.2.1 LiDAR and Orthophotography

High-altitude LiDAR and orthophotography were deployed from fixed-wing and rotary-wing platforms. LiDAR measures variation in surface elevation and orthophotography provides high-resolution, accurately located color photographs. These sensors are designed to detect "munitions-related features," such as target circles and craters associated with munitions use at the site and thus the potential for munitions contamination. These technologies produce a rapid and efficient survey of 100% of the site to provide a quick look to identify features associated with munitions use.

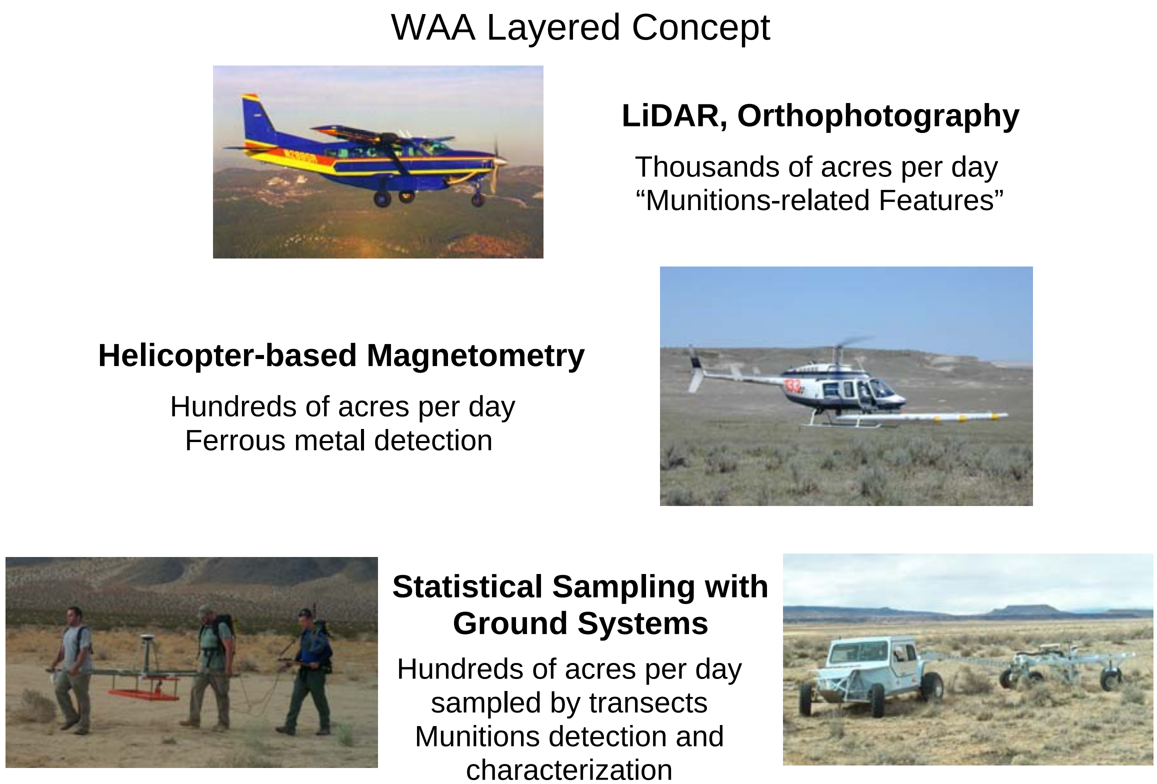


Figure ES-2. Layered technology approach to WAA used in the ESTCP pilot program.

3.2.2 Helicopter-Based Magnetometer

The low-altitude helicopter magnetometer array is designed to detect surface and subsurface ferrous metal. The helicopter magnetometer data are analyzed to extract distributions of magnetic anomalies, which can be used to locate and bound targets. This technology may be deployed to survey nearly 100% of a site if it is amenable to low-altitude flight. It could also be deployed to survey only areas of interest at full coverage or to survey widely spaced transects.

3.2.3 Statistical Sampling with Ground Systems

Ground-based geophysics transects were used to detect and circumscribe areas of concentrated metallic anomalies. Transects were planned and analyzed using the unexploded ordnance module of the Visual Sample Plan (VSP) software. The transect data were collected using towed-array systems and supplemented by a litter-carried sensor where necessary. Ground-based technologies would not be deployed to cover 100% of a site, but transects can be collected at a cost and schedule that support WAA objectives.

3.2 WAA Product

The primary product is a map indicating preliminary boundaries of concentrated munitions use. The confidence of the conclusions, based on multiple lines of evidence provided by data interpretation and the validation, is transparent and documented in the final CSM. The areas identified as having concentrated munitions present will presumably be designated MRSs and move to the next phase of the munitions response process, where the characterization data may be used for prioritization and planning.

Areas outside identified targets show no indication of concentrated munitions use, either through the historical record or the WAA. Characterization information on these areas can be used to support site-management decisions. Any areas of remaining uncertainty will need to be addressed through more detailed investigations in the next phase of the munitions-response process.

The WAA product is not intended to draw a boundary around a target area beyond which no munitions are expected, nor to detect individual isolated munitions outside of concentrated areas. In addition, the WAA technologies demonstrated here do not detect munitions constituents.

4.0 SAMPLE RESULTS

4.1 Characterizing Known Targets

The ability to verify and characterize known bombing targets using WAA has been well demonstrated. All target areas from the historical records at all sites were seen in at least one of the orthophotography and LiDAR images, and all were seen in one or both of the geophysics data sets. Observing craters in the LiDAR data can help verify the use of HE munitions, as seen in Figure ES-3.

The ability to verify and characterize artillery and mortar targets was demonstrated at Camp Beale. In general, fewer persistent ground scars can be observed in the orthophotography and LiDAR images, but structures (bunkers), firing points, and craters were readily observed. Geophysics data associating concentrations of metallic anomalies with high-airborne features were required to draw conclusions, particularly where the features were ambiguous.

The geophysics data led to a quantitative estimate of the number of anomalies and the area they covered. In several cases, including the PBR example in Figure ES-3, target areas were larger and more complex than indicated in the record. Here, the WAA data provide valuable information to allow for more credible cost estimates.

4.2 Eliminating Suspected Targets

WAA was used to eliminate a suspected 75-mm range at Pueblo. In this case, there was a well defined hypothesis to be tested. The absence of features in any of the WAA data indicates with multiple lines of evidence that 75-mm targets were not present in the suspected area. It is much more challenging to use WAA to eliminate all possible types of target areas.

At Camp Beale, WAA was used to reduce the footprint of concentrated munitions use within overlapping range fans. For several areas within safety fans or immediately adjacent to historical ranges, no evidence of munitions use is seen in the orthophotography and LiDAR images or in the geophysics data. While this provides multiple lines of evidence that no areas of concentrated munitions are present, the complex historical use and the generally higher background anomaly density at Camp Beale leave somewhat greater uncertainty.

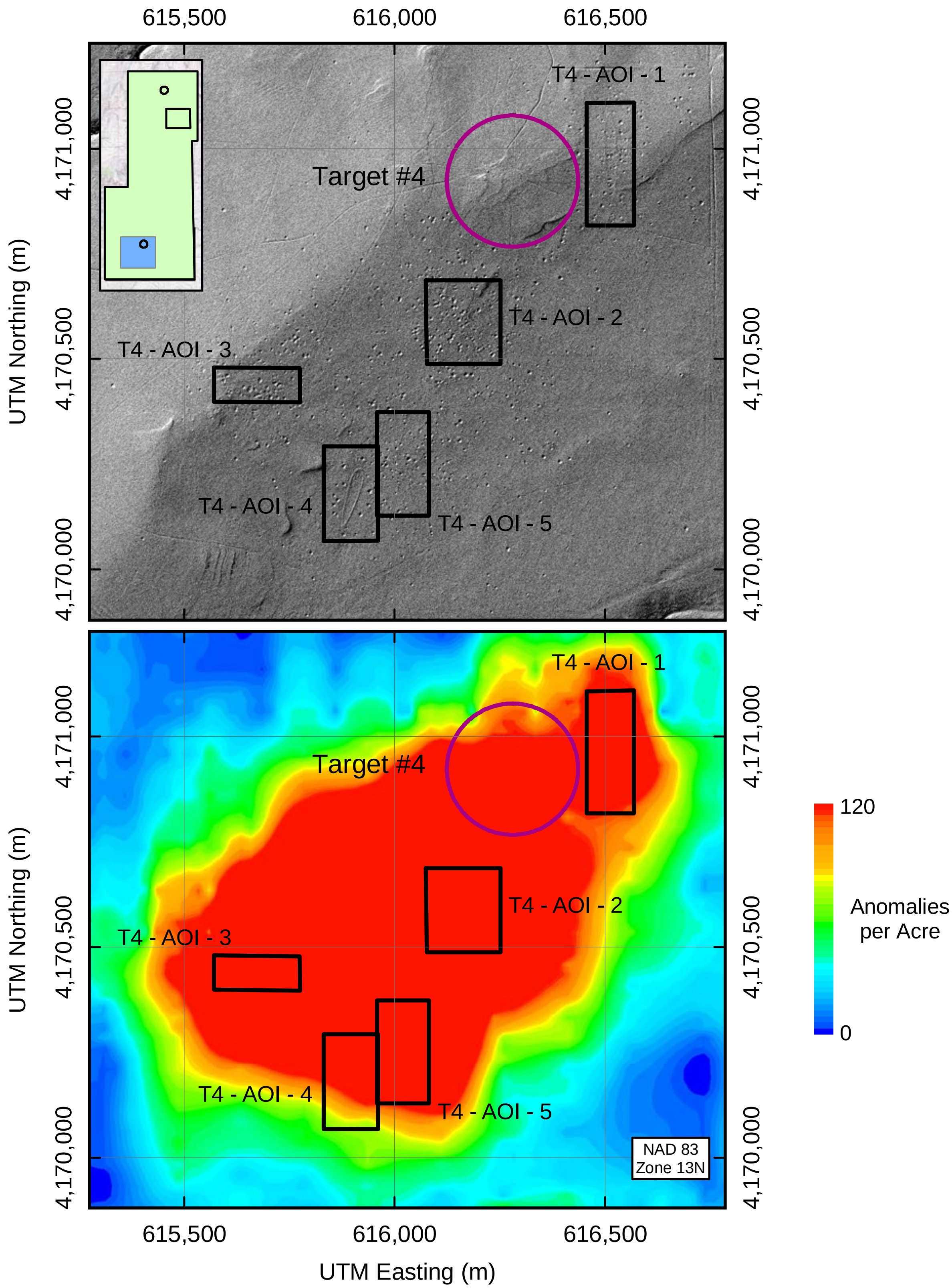


Figure ES-3. LiDAR data from Pueblo PBR #2 showing ship-shaped targets surrounding a target ring and a number of bomb craters. The anomaly density map is derived from ground transect data.

4.3 Locating Suspected Targets

A simulated oil refinery target was mentioned in the historical record for Kirtland, but its location only generally described. During the course of the pilot project, the location and extent of this target were well established in multiple data sets. Figure ES-4 shows the LiDAR image and the anomaly density derived from the helicopter magnetometer data.

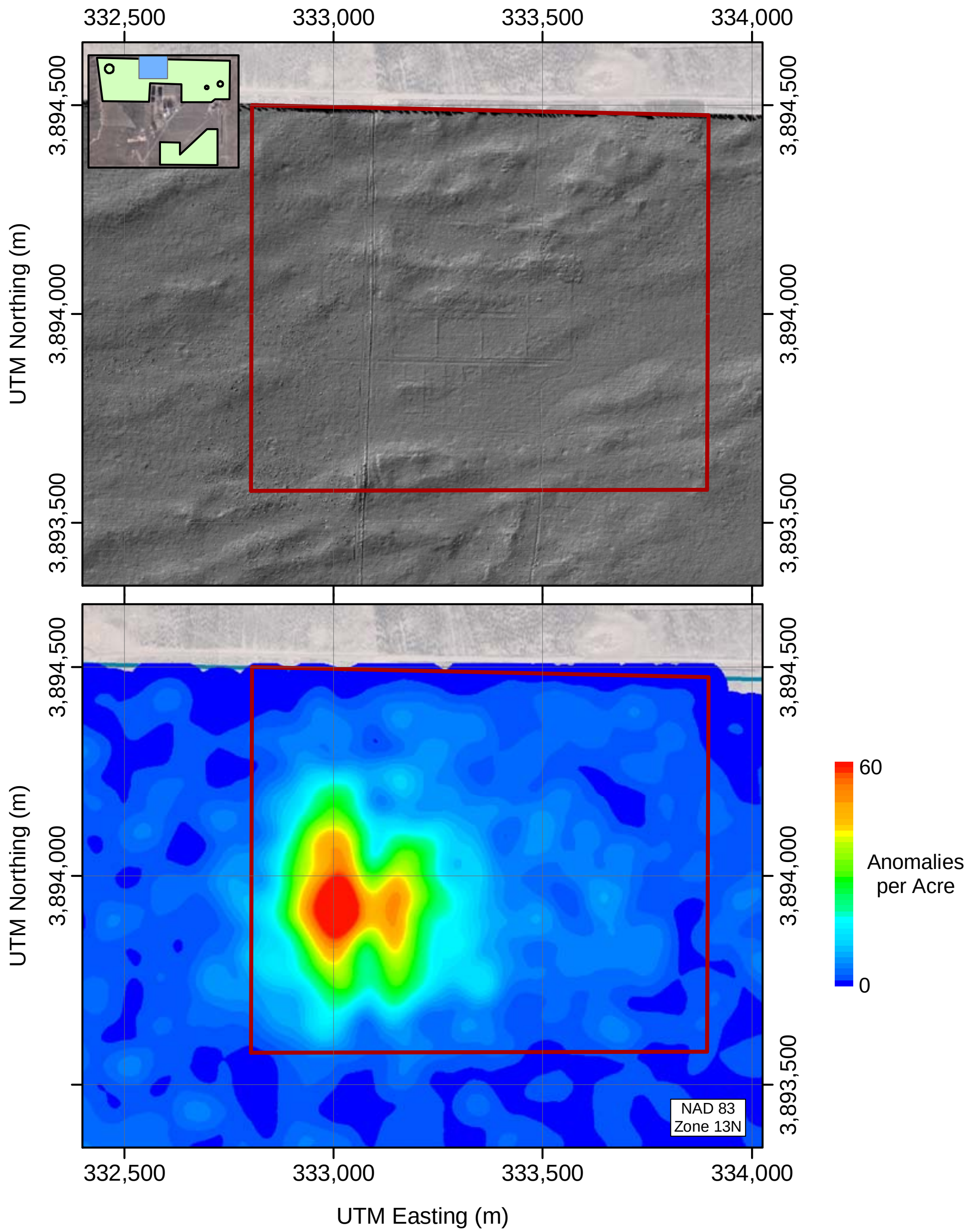


Figure ES-4. LiDAR (top) and anomaly densities from the helicopter magnetometer (bottom) data for the refinery target. The red boundary encompasses the features identified in the high-airborne data, as well as anomaly concentrations that extend to the west of the cell structure.

4.4 Identifying Lands with No Concentrated Munitions Use

For the WAA pilot project sites, WWII practice bombing targets were evident in most of or all the data sets. The lack of indication of additional target areas in any data set, therefore, provides strong evidence that no additional target areas are present. Of course, this does not exclude the possible presence of isolated munitions away from target areas, such as might result from pilot error. In addition, many features that could not be unambiguously identified in the data required validation by ground reconnaissance.

For more complex sites, the conclusions about lands with no indications of concentrated munitions use are less certain. The historical usage of the former Camp Beale was much more varied, in terms of both military and nonmilitary activities. In addition, data collection and analysis were complicated by challenging terrain, vegetation, and geology on parts of the site. Together, these factors resulted in greater uncertainty regarding conclusions about the remainder of the site, where there were no indications of concentrated munitions use. Nevertheless, there are areas with no known historical munitions use, no military features identified in the high-airborne images, and no concentrations of anomalies detected in the geophysics where there is high confidence that no target area exists.

5. MAJOR CONCLUSIONS

5.1 LiDAR and Orthophotography

LiDAR was very successful in detecting craters, aiming circles, and other large features constructed from earthen berms as was common in the WWII era. It is relatively inexpensive and can be used to screen an entire site quickly. Figure ES-5 illustrates the LiDAR image of a ship-shaped target that was formed from an earthen berm at Kirtland. The remaining feature is about 2 m wide and raised about 10 cm above the surrounding area. As shown in the photograph, it cannot be discerned at ground level, and it was difficult to locate even during validation when the ground team knew what to look for and where.

Orthophotography detected craters, aiming circles, and other large munitions-related features. It is relatively inexpensive, can be collected in conjunction with the LiDAR, and can be used to screen an entire site quickly. Overall, the orthophotographs showed fewer of the large features identified in the program than did LiDAR. However, a few features unique to the orthophoto were not seen in LiDAR at all, including the aiming circle indicating target N-2 at the Kirtland site, as seen in Figure ES-6. There is value in both data sets, which are acquired simultaneously on a single flight.

LiDAR and orthophotography rely on the detection of telltale features left from past activities. Munitions-related features may be obscured over time or by the presence of tall grasses, ground leaf cover, or other interference between the aircraft platform and the ground surface. In fact, a few target areas identified by concentrations of anomalies in geophysics data did not have corresponding visible ground scars. Some features that were seen in the data could not be positively identified from the data and required validation.

By themselves, LiDAR and orthophotography may not be sufficient to declare an area free of concentrated munitions, but they provide a valuable layer of evidence that can both support and add to initial knowledge about a site.

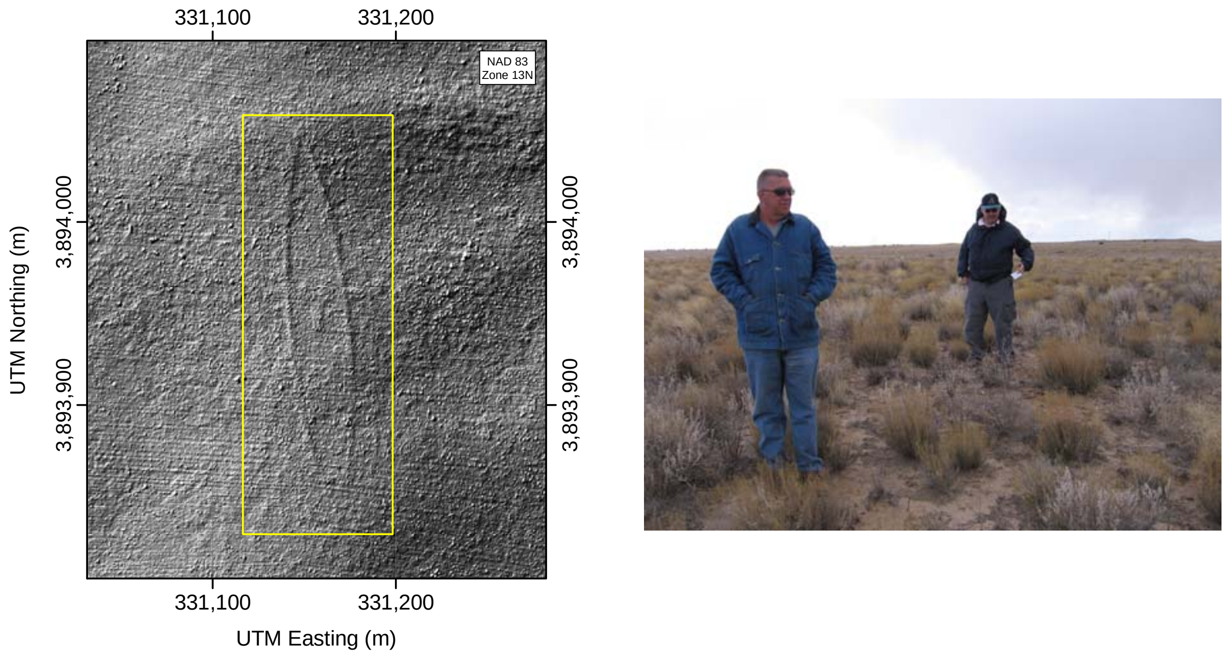


Figure ES-5. LiDAR image showing ship target at Kirtland and reconnaissance photo of the area. The field crew is standing on the location of the berm forming the ship.

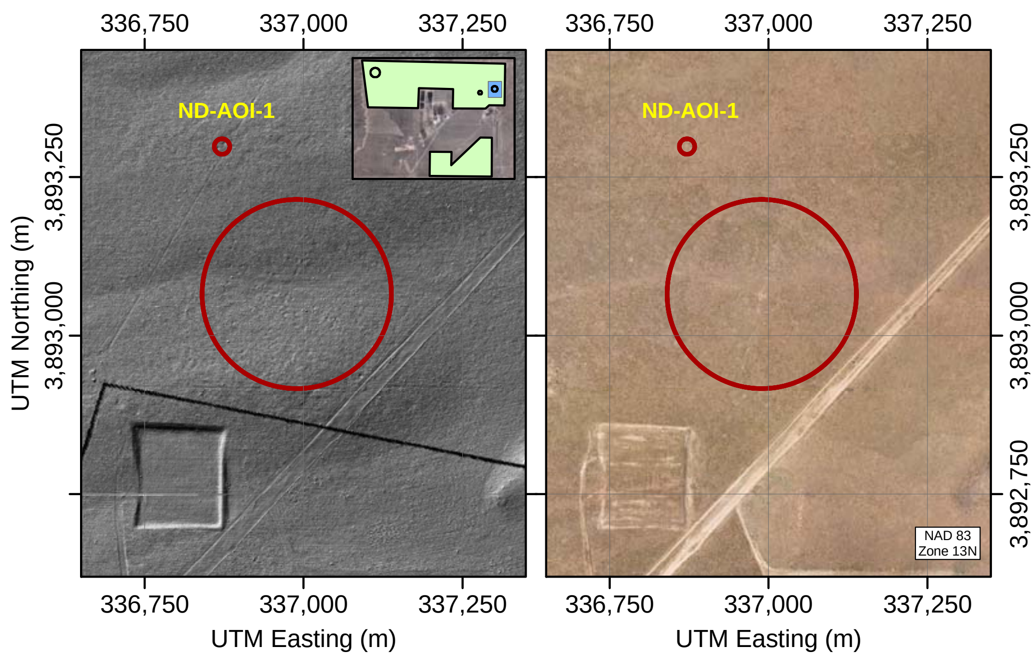


Figure ES-6. LiDAR and orthophotography images of "New" Demolitions Impact Area at KPBR. The target is seen more clearly in the orthophotograph.

5.2 Helicopter Magnetometer

The helicopter magnetometer is effective for detecting concentrations of munitions and estimating the size of the target area requiring remediation. It can be used to screen accessible areas of entire sites relatively quickly. The helicopter magnetometer could also be used to survey only a fraction of a site using transects, although that was not done in this program.

Helicopter magnetometry relies on the detection of ferrous munitions or related debris from low-altitude flight. The detection capability will be lower for smaller munitions types and small fragments, and the sensor will be challenged by interference from either natural geologic clutter or abundant man-made ferrous clutter. Low-altitude flight may not be possible at sites with challenging terrain or vegetation.

5.3 Ground Geophysics Transects

Ground transects were effective for detecting concentrations of munitions and fragments or scrap of any size. Transect data were successfully used to estimate the size and density of the target area requiring remediation. The sensors deployed on ground-based platforms were capable of detecting all target types to common depths of interest. Anomaly-density estimates from ground-based sensors should be most accurate for typical cleanup requirements.

VSP was useful for planning transects and for interpreting the data in a quantitative manner. The results can provide quantifiable determination and confidence that a postulated target area is or is not present. Analysis of the data can provide estimates of the number of anomalies that will ultimately require investigation and the size of area to be remediated. The tool provides a transparent and real-time means of testing the effect of assumptions on the transect planning. Assumptions about size, density, and usage can be varied, and the effects on the needed transects and costs evaluated until the project team arrives at a design that achieves the objectives and can be implemented with the available resources. Successful application of VSP requires a good hypothesis describing the target area and the background.

Transects may not provide a practical approach for detecting relatively small munitions-contaminated areas. Single burial pits on land or underwater disposal sites that result from a load dumped from a single barge will have very limited footprints. Planning transects to find such sites, particularly within vast areas to be searched, is likely to require coverage rates and resources well beyond what could be termed WAA.

5.4 Costs

The costs for WAA vary widely based on several factors. Table ES-1 shows estimated cost ranges for production deployments of the various technologies demonstrated in the pilot program. On most sites, not all of these technologies will be used. On some sites, individual technologies may be appropriate for only subsections of the site.

Table ES-1. Cost ranges for WAA technologies.

Technology	Cost Range per Acre Investigated ($)
Orthophotography/LiDAR (100% coverage)	5–20
Helicopter magnetometer (100% coverage)	100–125
Statistical ground transects (2% coverage)	15–80

The major factors affecting costs include

- *Site size*—On smaller sites, mobilization costs are not efficiently amortized and dominate the cost estimates. It may not be economically feasible to employ WAA systems (particularly the high airborne) on a very small single sites, but these 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 will require additional logistics support and decrease daily productivity.

Cost ranges for comparable off-the shelf production technologies for underwater WAA are not available. A limited demonstration of transect surveys using an underwater magnetometer array system was conducted, and costs are summarized in Chapter 9.

5.5 Factors Affecting Capabilities and Limitations of WAA Technologies

Factor	LiDAR	Orthophotography	Helicopter Magnetometry	Ground Transects
Geology	Not affected.	Not affected.	Effectiveness will decrease in magnetic geology. Heavy geology will render useless.	Magnetometer-based systems will be affected most by geology. For moderate geology, combined magnetometer/electromagnetic induction systems may have an advantage. For severe geology, electromagnetic induction systems will be less affected than magnetometer-based systems.
Persistence of Munitions-Related Features	Weathering, intentional clearance, or subsequent land use can obscure features of interest.	Weathering, intentional clearance, or subsequent land use can obscure features of interest.	Not affected.	Not affected.
Terrain	Minimal effects. Could mask or be mistaken for features.	Minimal effects.	Only applicable for relatively flat sites (slope less than 12–15 degrees).	In principle transect data can be collected anywhere. Terrain will dictate the platform and the data-collection efficiency.

(continued)

Factors Affecting Capabilities and Limitations of WAA Technologies (continued).

Factor	LiDAR	Orthophotography	Helicopter Magnetometry	Ground Transects
Vegetation	Heavy vegetation will reduce the density of LiDAR points sampling the ground surface. Presence of heavy grasses, leaf cover on the forest floor, etc will obscure features.	Heavy vegetation will block the view of the ground surface.	Isolated trees can be avoided and will have little effect. Tall brush will force higher flight altitudes and reduce detection capability. Forested areas cannot be surveyed.	In principle, transect data can be collected anywhere. Vegetation will dictate the platform and navigation.
Human Use Not Related to Munitions	Increased detection of non-munitions features requiring investigation. Alterations of the surface may obscure features.	Increased detection of non-munitions features requiring investigation. Alterations of the surface may obscure features.	Physical access to the site can be problematic (right of entry, fences, power lines, recreational activity). High density of magnetic clutter can make it impossible to locate target areas. Areas of concentrated non-munitions (fences, homesteads) can be confused with munitions.	Physical access to the site can be problematic (right of entry, fences, power lines, recreational activity). High density of magnetic clutter can make it impossible to locate target areas. Areas of concentrated non-munitions (fences, homesteads) can be confused with munitions.
Munitions Type	Detects visible craters or berms (cross hairs, ships, pebbles, etc.). Detects structural remnants of firing points, small arms ranges, etc.	Detects visible craters or aiming points. Detects structural remnants of firing points, small arms ranges, etc.	Detects individual items 81 mm or larger. Smaller munitions and fragments detected with reduced probability.	Sensors can detect all items of interest. A reasonable estimate of target size and density is needed for meaningful transect design.

1.0 INTRODUCTION

1.1 Background—The Munitions Response Problem

Munitions response is a high-priority problem for the Department of Defense (DoD). Approximately 3,000 sites, comprising tens of millions of acres, are suspected of being contaminated with military munitions, including unexploded ordnance and discarded military munitions. The bulk of these are formerly used defense sites, which are no longer under DoD control. They are used for a variety of purposes, including residential development, recreation, grazing, and parkland, often without restriction.

A typical site is thousands of acres; sizes range from hundreds of acres to hundreds of thousands of acres. Detailed investigation of the entire inventory using current practices is cost prohibitive within current and anticipated annual funding levels. With current planning, estimated completion dates for munitions response on many sites are decades out.

However, few, if any, historic installations are uniformly contaminated from fence line to fence line. In most cases, munitions contamination is centered on target areas, firing points, disposal sites, and the like. Historical records about the locations of these areas are helpful in planning, but are often inaccurate and incomplete. According to some estimates, no more than 20% of the tens of millions of suspected acres are actually contaminated with munitions. Thus, applying a technology or combination of technologies to holistically examine a potential site and accurately delineate the contaminated areas would allow limited cleanup resources to be used more effectively and inform decisions regarding the remainder of the land.

The Defense Science Board Task Force on Unexploded Ordnance issued a series of recommendations about this problem in its December 2003 report (Ref. 1). Recommendation 1 was to "Institute a national area assessment of the identified 10 million acres [of land involved]." They elaborate on this recommendation: "The Task Force envisions an intensive five-year campaign to assess all 10 million acres with the goal of delineating where the UXO [unexploded ordnance] are and where they are not. This campaign would use the full range of techniques and instruments including the helicopter-borne sensor where applicable."

1.2 The Wide Area Assessment Concept

The objective of wide area assessment (WAA) is to quickly and cost effectively assess 100% of a potentially contaminated site. Beginning with historical records, a conceptual site model (CSM) is used to record the best understanding of the site. The WAA is a means to gather evidence that improves the understanding of the site and builds confidence in the conclusions. A suite of commercially available technologies provides data to

- Identify areas of concentrated munitions use.
- Collect information that will support decisions on areas with no indication of munitions presence.
- Collect data to support planning, prioritization, and contracting when a site must ultimately be cleaned up.

The WAA can provide information needed to support decisions at various stages of the munitions response process, but this information is generally more effective when used early in the site investigation process. Throughout the process, there is a need to identify munitions response sites (MRSs), characterize the nature and extent of the munitions contamination, and collect sufficient information to let a cleanup contract. On areas that do not contain concentrations of munitions, sufficient information is needed to support decisions about whether any additional action is needed and ultimately to manage areas that may or may not be subject to intensive munitions cleanup actions.

1.3 The WAA Pilot Program

The Environmental Security Technology Certification Program (ESTCP) is charged with promoting innovative, cost-effective environmental technologies by demonstrating and validating those technologies. In response to the Defense Science Board Task Force report and congressional interest, ESTCP designed a WAA pilot program to validate the application of a number of recently developed and validated technologies as a comprehensive approach to WAA.

ESTCP was committed to making the information generated by the WAA pilot program useful to a broad stakeholder community. An Advisory Group composed of representatives of the Services and State and National regulators was established at the beginning of the program. This Advisory Group was involved in site selection, program design, data review, and development of conclusions for each site and the methods as a whole. The Advisory Group has been heavily involved in drafting this report.

The WAA pilot program consisted of a number of demonstrations at formerly used defense sites designed to evaluate the use of commercially available technologies. The pilot program sought to demonstrate that these technologies could meet WAA objectives and to understand the site-specific factors, such as terrain, vegetation, and munitions type, that affect applicability and limitations of the technologies.

In the course of the pilot program, the technologies were demonstrated at

- Former Pueblo Precision Bombing Range (PBR) #2, La Junta, Colorado.
- Former Kirtland PBRs N-2, N-3, and New Demolitions Impact Area, Albuquerque, New Mexico.
- Borrego Military Wash, Borrego Springs, California.
- Victorville PBRs Y and 15, Landers, California.
- Former Camp Beale, Marysville, California.
- Former Erie Army Depot, Camp Perry and Toussaint River, Port Clinton, Ohio.
- The Delacarlia Impact Area at the Spring Valley formerly used defense site, Washington, D.C.

The first four sites were selected to demonstrate a process under conditions where the technologies were expected to perform well. The motivation was to explore an overall WAA process with the Advisory Group and consider the types of decisions that various data products could support. The last three sites exhibit different, more challenging conditions and were chosen to test the capabilities and limitations of various technologies in different environments.

1.4 About This Report

This report provides an overview of the entire WAA pilot program for project managers, regulators, and stakeholders. It provides a summary of the demonstrations on each site, with emphasis on the process that was used and the products that can be expected from WAA, and illustrates how these products can be used to build confidence in conclusions about a site. Information is provided to document the methods used to obtain those products and ensure data quality meets project objectives. To allow project teams to determine where the demonstrated technologies application would be appropriate, this report summarizes what has been learned about their capabilities and limitations. The report is not necessarily intended to be read sequentially from cover to cover, nor is it intended to provide comprehensive technical results, which are found in individual vendor reports.

A group of frequently asked questions about WAA is followed by an overview of the program approach, objectives, and criteria used for site selection. This report then describes the technologies demonstrated in the pilot program and discusses the methods used to validate the data collected and the conclusions drawn at each site.

The four major demonstration sites (Pueblo PBR #2; Kirtland N-2, N-3, and New Demolition; Victorville PBRs Y and 15; and former Camp Beale) are each the subject of a chapter. These chapters summarize the historical information about the sites gathered during this program, the data collected, analyses of those data, and conclusions drawn about the sites. For the other three sites, this information is included in the appendixes.

Following the individual site summaries is a discussion of the capabilities and limitations demonstrated by each of the technologies and an estimate of the costs for deploying the technologies singly and in combination.

2.0 FREQUENTLY ASKED QUESTIONS ABOUT WIDE AREA ASSESSMENT

What is Wide Area Assessment?

WAA is a process for locating and characterizing MRSs within a munitions response area. By some estimates, up to 80% of the tens of millions of acres that are suspected to contain munitions are free of concentrated munitions. Thus, an approach that can accurately delineate the contaminated MRSs could significantly reduce the area that requires remediation, allowing limited cleanup resources to be used more effectively.

The WAA process can consist of a combination of technologies. High-airborne light detection and ranging (LiDAR) and orthophotography are able to survey thousands of acres per day. For the most part, however, they detect munitions-related features rather than munitions themselves. Geophysical sensors mounted on low-flying helicopters or on underwater platforms can detect medium and large munitions directly but are limited by terrain, tree cover, or underwater obstructions. Geophysical sensors mounted on ground platforms can detect all munitions types of interest in sufficient quantities to support wide areas assessment objectives, but can only economically be deployed to survey statistically planned transects covering a small percentage of the site's total area.

Where could this fit into the regulatory/munitions response process?

Information on location, extent, and characteristics of munitions contamination, as well as evidence indicating areas without concentrated munitions contamination, is useful in the munitions response process. The WAA data can be used during the site assessment and investigation phases to (1) support decisions on clean-up priorities and necessary actions on areas that show no evidence of munitions and (2) support cost estimates and contracting. In general, the earlier in the process WAA is employed, the more valuable it will be.

What decisions can WAA support?

WAA can provide evidence for defining areas of concentrated munitions use. In addition, the data collected during a WAA can be used in planning and assigning priority to a munitions response action by defining the approximate area of the contaminated site and the anomaly density within that area. WAA can also delineate the areas outside the concentrated use boundary, which will support a different response action.

To what degree can you eliminate areas?

Taken together with historical information, results from the suite of WAA sensors can add significantly to the weight of evidence to support eliminating an area from further consideration. Conclusions can be drawn with much more certainty if there is a specific hypothesis to test as articulated in the initial CSM. At the Pueblo PBR #2 demonstration, for example, it was concluded a suspected 75-mm range was not present in the study area. It is much more difficult to eliminate all possible contamination sources. If the WAA is designed to detect a munitions-affected area with specified characteristics, it can be said with quantifiable confidence that areas of that type do or do not exist. It cannot similarly be stated that all other types of muntions-affected areas do not exist.

If you do not find any evidence of munitions, is my site clean?

The WAA process is designed to detect and characterize areas of concentrated munitions use. The ability to make definitive statements depends on the hypothesis that is used to set up the WAA data objectives. If you design the assessment to detect bombing targets, you are likely not to find a 20-mm range even if it exists. When no evidence of concentrated munitions use is observed in any of the WAA sensor data, this adds to the weight of evidence that no such areas exist. The WAA process is not designed to detect individual items so no statement about the presence or absence of individual munitions is possible based on WAA results alone.

What does concentrated munitions use mean?

A primary objective of the WAA approach is to identify areas of “concentration munitions use.” In this pilot program, the phrase means an increased density of anomalous features identified through the use of WAA technologies that locate areas intentionally used for military activities such as impact areas, target areas, or other “concentrations” such as open burn/open detonation areas. Anomalous features include ground surface features (i.e. target rings or craters) detected by LiDAR/orthophotography, or geophysical anomaly concentrations detected by geophysical systems. The concentration of anomalous features that can be detected will depend on site conditions, types of munitions, frequency of historical target usage, and the site background anomaly density. Therefore, a standard quantitative number cannot be used to define an anomaly density that constitutes ‘concentrated,’ as the contrast between the site background anomaly density and the concentrated area will vary for each site. Boundaries assigned to areas of concentrated munitions use do not include individual errant rounds as low densities of munitions could be located beyond the boundary edge.

What about individual munitions items?

The WAA process is not designed to search for individual munitions items. Orthophotography and LiDAR do not detect munitions directly, but rather munitions-related features. The helicopter-based geophysical sensors can detect individual items that are medium-sized (81–105 mm) and larger, but the analysis techniques employed for WAA are oriented toward detecting areas of concentrated munitions use rather than individual items. The vehicular systems can detect all munitions types of interest in sufficient quantities to meet the objectives of WAA, but are only deployed over a small percentage of the site on widely spaced transects. Individual items between transects will not be detected.

How does Wide Area Assessment differ from a survey for site clearance?

The goal of WAA is to delineate areas of concentrated munitions use, such as bombing targets, aim points, and firing lines and provide evidence other parts of the site have not been subjected to concentrated munitions use. WAA is not concerned with stray munitions or with necessarily detecting every item in an area of concentrated use. That is why techniques such as helicopter magnetometer and transect surveys, which do not have probabilities of detection of 100%, can be used in WAA. When a clearance action is warranted, a more detailed survey of the contaminated areas will be required for the purposes of detecting and removing munitions to meet project objectives.

How do I perform a Wide Area Assessment on my site?

Each of the technologies used in the WAA pilot program is commercially available today, often from a number of vendors. A number of firms are equipped to take on the role of services provider for a WAA. These services could be readily contracted in response to a Request for Proposals.

Are all three technology layers required for every site?

No. On some sites, an individual technology may be sufficient to meet project objectives. On others, the technologies can be employed sequentially, where the information from one is used to guide decisions about deployment of the others. On other sites, an iterative approach may be needed to address uncertainties.

Is geophysics required for WAA?

It depends on the WAA objective and the site characteristics. On some sites in this program, the high airborne technologies detected all of the targets of interest and, in retrospect, may have been sufficient alone. On the Former Camp Beale site in California, where few munitions-related features remain or exist, geophysics was essential to support conclusions.

For the geophysical sensors, are transects or 100% coverage recommended?

The helicopter system was deployed at 100% coverage for the purposes of the pilot program, but the system could be deployed to survey transects in operational WAAs. The report *Analysis of Full-Coverage Magnetometer Data in Relation to Statistically-Based Site Characterization Tools*, written by Sandia National Laboratories and Pacific Northwest National Laboratory, evaluates the performance of helicopter transects for the WAA mission. (Ref. 2). The coverage selected for the helicopter system is driven by the operational WAA objective, acreage of the site, and the project budget. The ground-based system should be deployed in transects because 100% coverage is not cost-effective for the purposes of WAA.

Must digital geophysics be used for transect surveys?

Digital geophysics for transect surveys was validated prior to this pilot program and was utilized in this program. It is desirable for numerous reasons including that it captures a record of the data and that a consistent anomaly selection threshold may be applied that is not impacted by operator judgment.

Should orthophotography/LiDAR always be the first step?

In most cases, the high-airborne techniques are the best first step. Affording a wide overview of the site efficiently and at relatively low cost, they allow the site manager to deploy the other techniques efficiently. For a few classes of sites (sites underwater, sites with periodic flowing water, sites with blowing sand, etc.) these high-airborne techniques may not offer enough information to make their use worthwhile. Sites with heavy vegetation may also be problematic for these techniques. Finally, the mobilization costs of high-airborne techniques may be prohibitive for smaller sites unless several small sites can be covered in one deployment.

Can satellite imagery be used for WAA?

This pilot program has shown pixel sizes of 10 cm or 20 cm are required to resolve many of the munitions-related features at the sites that were investigated. Commercially available satellite imagery is not able to provide this resolution. Most easily available satellite images have 1 m pixels, with the best as small as 30 cm. For this reason, this program did not evaluate the use of satellite imagery for WAA.

Figure 2-1 illustrates the problem. The left panel shows a portion of the former Camp Beale site in the 10-cm pixel orthophoto collected in this program. The target circles are clearly visible in this photograph. The right panel shows the standard 1 ft (30 cm) pixel photo of the same area in which the surface features are much less obvious and may not be noticed by an analyst.

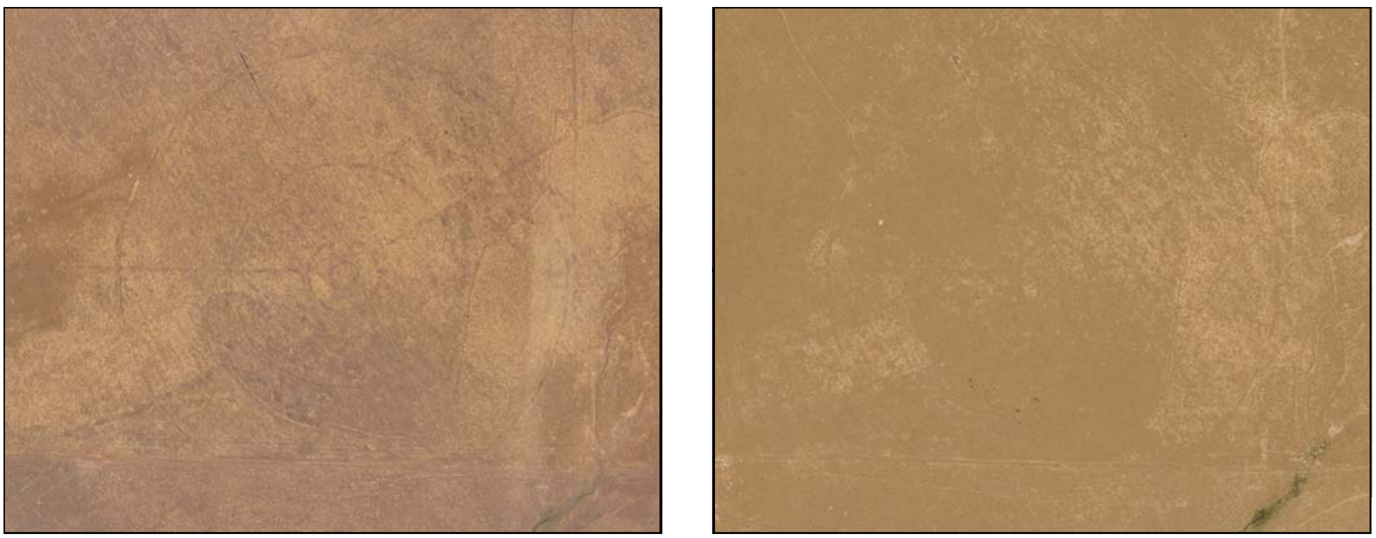


Figure 2-1. Comparison of 10-cm pixel orthophotograph (left) of a portion of the former Camp Beale with a conventional 1 ft (30 cm) pixel aerial photo (right).

What will orthophotography/LiDAR show that historical photos do not?

This should not be thought of as an either/or choice. Historical photos, where available, should be included in WAA with other historical information. In this program, historical photographs were used as input for the initial CSM used to plan deployment of the WAA layers. The use of both in the WAA process can add to the weight of accumulated evidence regarding the site. It has been shown that photographic pixel sizes of 10 cm to 20 cm are required to resolve many of the munitions-related features at the sites that were investigated. In addition, the LiDAR data often revealed features (e.g., craters and low berms) that were not visible in the orthophotographs. On the other hand, many munitions-related features are visible in historical photographs, particularly those taken during operation of the site or shortly after it was closed.

What does WAA add to historical information?

WAA does not replace historical research. WAA should be used to confirm historical information and address data gaps. The results of historical research are used to develop the initial CSM, guide the planning of WAA, define program objectives, and establish data requirements.

Is there any point in applying WAA in wooded areas?

Wooded areas can limit the accessibility and degrade the data quality of each of the available sensor platforms. In other programs, modern LiDAR systems have shown impressive performance through even dense tree cover, but the density of points reaching the ground, and thus the ability to detect small features, drops as the canopy density increases. On some sites, this can be mitigated by timing data collection when leaf cover has minimal impact. Of course, in this situation, orthophotographs quickly lose their value. Significant tree cover affects the ability of the helicopter system to fly at the 2 m to 3 m altitude necessary to obtain reasonable detection performance. In wooded areas, statistical assessments using ground systems may still be performed. The conditions will dictate the appropriate sensor and platform. The vehicular systems can be used through light trees, but only man-portable versions are useful as the trees become very dense.

To what depth are items detected?

WAA does not depend on detecting the deepest items. The majority of munitions-related items are near the surface and easily detected at rates that will support finding areas of concentrated use. In most cases, a well-deployed vehicular system can detect military munitions at depths of interest for fired munitions. This, of course, will be site specific and requires careful application of the technology. For sites with particularly unfavorable geologic interference, the depth of detection can be decreased. Since the amplitude of the anomaly associated with an item falls off rapidly with the distance of the sensor from that item (the third power of the distance for the magnetometers and even faster for the electromagnetic induction [EM] systems), the helicopter system, which typically flies 2 or 3 meters above the ground, has a shallower detection depth. This is mitigated somewhat by the fact that the noise on the helicopter-based sensors is often lower than the vehicular sensors. Even so, detection probabilities fall off dramatically for items more than a meter below the surface.

Can all WAA technology layers be used on both land and underwater sites?

The high-airborne sensors were demonstrated only on terrestrial sites for this program. To date, an analog of the high-airborne technologies has not been validated for underwater sites. The application of high-resolution optical or sonar imaging techniques is the subject of research.

The helicopter system was demonstrated in this program only on land and very shallow water areas. In a marine environment, the distance between the array and the targets will increase by the water depth, so only large munitions are expected to be detected at any reasonable efficiency. Other deployment concepts are possible. For example, the helicopter system could be used to survey islands that were used for targets and the surrounding shallow water in conjunction with the marine towed array.

Transect-based technologies were used in this pilot program on the land and water. The ground-based systems used on land were either towed by a vehicle or man-portable. An underwater equivalent array was used for the marine sites. The land and marine systems provide comparable results to support site characterization.

What about marine sites? Are there water-depth limitations?

The marine system used in the pilot program is towed at a height of 1 to 2 meters off the bottom. It has a tow cable that allows it to survey 6 or 7 meters below the surface. So the practical limit with this system is around 9 meters. Other contractors have performed marine surveys at comparable or shallower depths. The sensors themselves are not limited to this depth. A system that could survey at 50 to 100 meters is technically feasible, but none is currently available. Very shallow waters and marshes can be surveyed with the understanding that the depth of detection is decreased by the depth of the water.

What are the detection limitations of each sensor?

The LiDAR and orthophotography sensors are able to detect craters or other surface features on the order of 1-m diameter. The ground-based sensors can detect items as small as 20 mm, but the efficiency of detection is lower for targets this small. The current helicopter-based sensors can detect items the size of 2.75-inch rocket warheads with reasonable efficiency and 81-mm mortars with reduced probability of detection. Less than 100% detection efficiency is not a problem for WAA, since it is focused on detecting areas of concentrated munitions, not single items.

What targets of interest is WAA useful for?

At the first year's sites (Former Pueblo PBR #2, Former Kirtland PBRs N-2, N-3, and New Demolitions Impact Area, Victorville PBRs Y and 15), WAA has been shown to be ideally suited for WW II practice bombing targets, and all the munitions-related features were detected by multiple technologies. At former Camp Beale, which included artillery and mortar targets, persistent indicators exploited by orthophotography and LiDAR were not always present, and multiple lines of evidence were needed to draw conclusions. The Toussaint River site was used for proof firing of artillery and was successfully delineated using WAA methods. The remaining targets of interest to consider are firing points, burial pits, and open burn/open detonation areas. The applicability of WAA to these targets will depend on the size of munitions and the size of the target area relative to the size of the area to be searched. The helicopter system flying 100% coverage would find a burial trench, but transects designed to find a trench may need to be so closely spaced that transect surveys are not efficient.

How much does it cost?

As with all surveys, the cost of a WAA will depend on the size of the site and its condition. Economies of scale will make large sites less expensive to survey per acre and small sites more expensive. It is possible to develop rough estimates for a nominal site of moderate size and average terrain. The WAA pilot program demonstrators estimate orthophotography/LiDAR can be used for a 10,000 acre site for about $220,000. The helicopter-borne magnetometer array can survey the same site for about $1 million. The vehicular array can survey transects that cover about 2% of the 10,000 acres for about $250,000. Of course, these figures are for data collection and analysis only, and site conditions can change them considerably. The cost of developing an initial CSM and updating it at the conclusion of data analysis must be added to these numbers.

How long does it take to collect the data?

The high-airborne sensors can survey thousands of acres a day. A 10,000-acre site can be completed in less than 1 week, including time for weather delays if encountered. The data collection rate for the helicopter system is highly variable, but on average this technology can survey about 400 acres per day and, with multiple flight crews, up to 1,000 acres a day. That translates to about 4 weeks for a 10,000-acre site. The vehicular systems can survey up to 40 lane-km per day at an intermediate difficulty site, although ground conditions like fences, terrain, and obstacles can decrease this production rate substantially. That corresponds to 20 acres/day. Since the ground systems are typically deployed on only a small percentage of the site (e.g. 2%), they can survey transects covering the 10,000-acre site in 2-3 weeks.

These estimated data collection times, of course, do not account for the time required for pre-survey historical research and field work planning, data analysis, reporting, and validation. Depending on local requirements and the current situation at the site, these non-survey tasks can account for the vast majority of the time required for a WAA.

What are the smallest areas for which a WAA is appropriate?

WAA is a process that is applicable to almost any site. It will generally not be efficient to deploy the airborne sensors to fewer than several thousand acres. Often, nearby smaller sites can be grouped so a number of them can be covered in one deployment of the aircraft.

What factors guide the choice between helicopter and ground-based geophysical surveys?

The obvious factor to consider first is whether a helicopter can be flown over the site at altitudes low enough (2 or 3 meters) to achieve an acceptable probability of detection for the munitions of interest. At present, validated helicopter platforms are limited to magnetometer sensors. If the geology at the site is not amenable to the use of magnetometers, use of a helicopter platform may be precluded. The choice of platform also depends on the targets of interest. The helicopter-based sensors can detect items the size of 2.75-inch rocket warheads with reasonable efficiency and 81-mm mortars with reduced probability of detection. For smaller munitions items, a ground system is probably the best choice.

Another factor that will drive the selection will be the cost effectiveness. This will depend on the extent of the site that needs to be covered for the objectives. Both systems are affected by terrain and vegetation. The ground systems can drive through and around low-density treed areas that might force the helicopter system to fly too high for reasonable detection efficiency. Shallow washes and streams that may make the use of ground systems inefficient are not limitations for the helicopter systems.

Can you detect munitions constituents?

No. The high airborne sensors detect munitions-related features and the geophysical sensors detect metal. None of the sensors deployed in the WAA pilot program is capable of detecting explosive fillers, bulk explosives or munitions residues in soils. However, WAA can provide important information about where it would be valuable to sample for them.

How are the data of WAA validated?

The technologies demonstrated in the WAA program have been well validated for this purpose. It is necessary to ensure the data collected meets specifications. In this program, appropriate calibration targets were used for each of the sensors.

How are the conclusions of WAA validated?

There will always be ambiguous features that require field validation. This can be accomplished with a site visit to disambiguate the features. In this program, a UXO technician and geophysicist visited the ambiguous features.

What emerging WAA capabilities should I watch?

A number of technologies are being demonstrated in the ESTCP that may be applicable to WAA. They include gradient magnetometer and EM sensors for the helicopter platform, the use of ultralight aircraft for the geophysical surveys, and enhancements to the target sizing model in the Visual Sample Plan (VSP). In the underwater environment, advanced sonar or optical techniques are being tested for WAA. These underwater technologies are well developed for other applications, but their ability to detect concentrated areas of munitions remains a subject of research.

3.0 PILOT PROJECT APPROACH

3.1 General Approach of the WAA Pilot Program

The WAA pilot project began with the selection of sites for the demonstrations, the selection of technologies to demonstrate, and the development of a demonstration process. The approach was to demonstrate multiple mature technologies on sites where technical success was likely to determine how the WAA data products would support the technical planning process and regulatory decisions, as well as guide additional site characterization. A key aspect of this approach was validation, both of the data products and the conclusions. Figure 3-1 shows the general process schematically and the corresponding section numbers of this report are labeled.

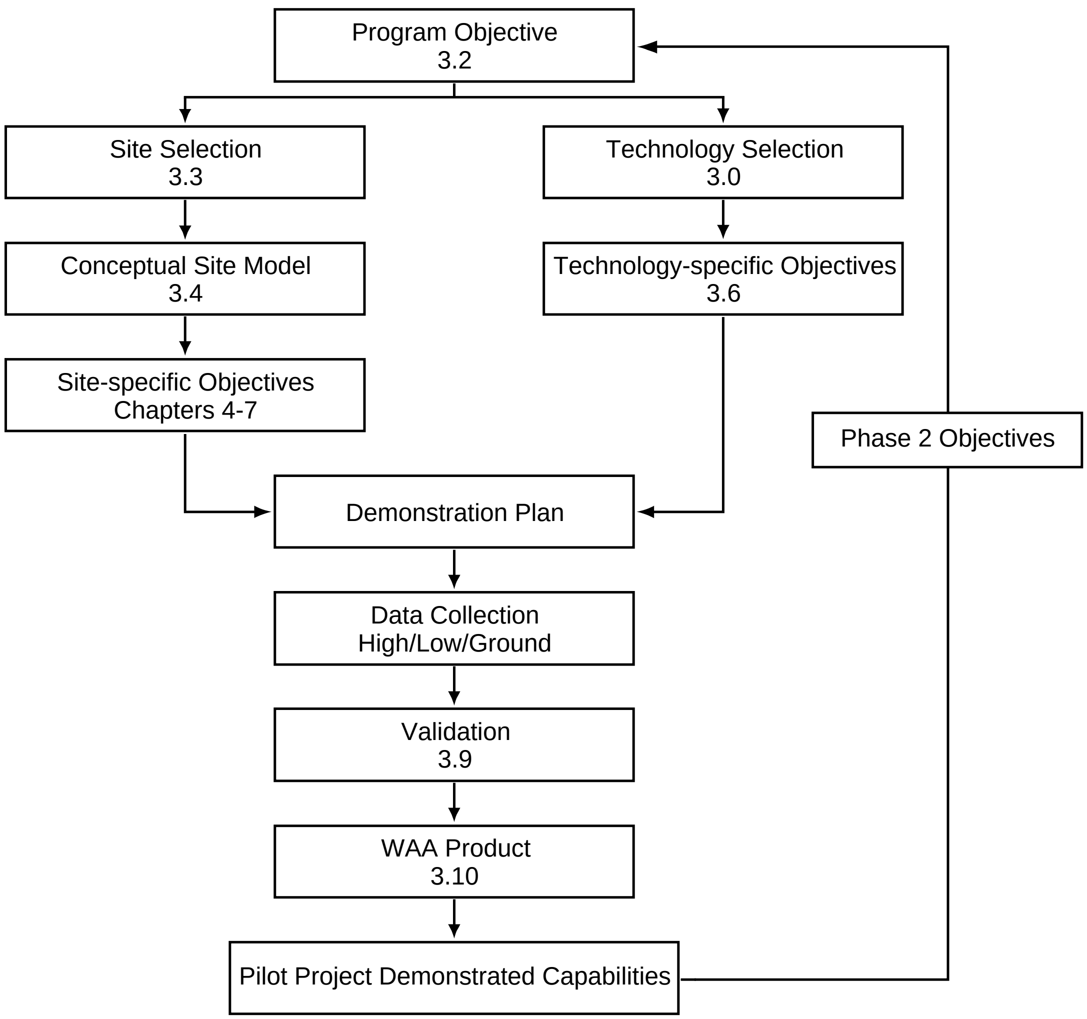


Figure 3-1. WAA pilot program process.

The WAA pilot program was conducted in two phases. Phase I (2005–2006) intentionally explored the capabilities of WAA technologies with minimal limitations imposed by the environment. All the WAA technologies were deployed on 100% of the accessible areas on each demonstration site to allow direct comparison of the information contributed by each layer. Phase II (2006–2007) evaluated performance under more challenging site conditions to further establish the capabilities and limitations of the technologies. In Phase II, technologies were applied sequentially, as might be the case in an operational situation, to explore the ability to use the information produced by a quick assessment of the entire site using one asset to guide decisions about additional data that might be needed to address uncertainties on parts of the site. These data would then be collected in a more limited deployment of more expensive and time-consuming platforms.

3.2 Pilot Program Objectives

The WAA pilot program had three primary objectives:

- Demonstrate and evaluate the effectiveness of the individual technologies and a WAA process to identify areas of concentrated munitions use.
- Demonstrate WAA data can support decisions on areas that show no evidence of concentrated munitions use.
- Understand the site-specific factors such as terrain, vegetation, and munitions type that affect applicability and limitations of the technologies.

Secondary objectives included demonstrating WAA data can be used to better characterize the nature and extent of munitions contamination to support cost estimation, prioritization, and planning.

Technology-specific objectives and metrics are in the detailed demonstration reports prepared by each technology vendor. (Refs 3–23)

3.3 Selecting Test Sites

In preparation for the pilot program, ESTCP issued a call for nominations of demonstration sites. Inputs were received from each of the Services and participants in the WAA Advisory Group. In addition, ESTCP nominated a number of sites at which earlier efforts could be leveraged. Six finalists were selected from the list of nominees.

Desired site characteristics for Phase I included:

- Existence of known and suspected areas of concentrated munitions use.
- Large areas believed to be free of concentrated munitions use.
- Favorable geology, terrain, vegetation, and weather conditions.
- Existing rights of entry.
- Interest of local service managers and regulators.

Each of the final candidates was visited by ESTCP staff accompanied by a local official knowledgeable about the site. These visits were conducted to gather information such as site conditions, accessibility, and logistics requirements. Finally, the relevant Archives Search Reports were consulted to evaluate the quality of initial information available to construct a CSM for each of the six sites.

As a result of the selection process, three sites were originally chosen for Phase I of the WAA pilot program. Since all these sites were far too large to conduct an assessment of their entirety, a representative subsection of each site was chosen for the demonstration. For the most part, the areas were selected to include known target areas, suspected target areas, and tracts with no record of munitions use.

Pueblo PBR #2, CO—A 7,500-acre demonstration area was selected out of the 68,000 acre range complex to include two known bombing targets, one of which was reportedly used only for practice bombs and the other of which was used for both practice and high-explosive bombs, and a suspected 75-mm target. No other targets were indicated in the historical record. The site ownership is divided between multiple private individuals, the state of Colorado, and the Comanche National Grasslands, maintained by the U.S. Forest Service. The current land use on the site is primarily cattle ranching.

Kirtland PBRs, NM—A 5,000-acre demonstration area was selected to include three known bombing targets, which are part of a much larger set of bombing ranges encompassing 15,246 acres. One of the bombing targets was reportedly used for high-explosive bombs and the other two are suspected of containing only practice bombs. A simulated oil refinery target whose location was not known, and an area slated for development that was not suspected to have been used for munitions make up the remainder of the site. The site is owned by the City of Albuquerque. The current use of the site includes a municipal airport, a shooting range, and a waste treatment facility.

Borrego Maneuver Area, CA—A 7,500-acre WAA demonstration area was selected to encompass the Military Wash Impact Area, which is representative of a large number of munitions sites associated with the nearby California-Arizona Maneuver Area that totals 256,000 acres. The site contains a variety of targets and munitions-related features, including bombing, strafing, and rocket targets with rake (observation) stations that were firing points for 40-mm and 90-mm antiaircraft weapons systems. There also may have been an air-to-ground railway strafing target, as well as a bermed area for ground-to-ground firing as part of an Army anti-mechanized target. The demonstration site lies within the Anza-Borrego Desert State Park and the Ocotillo Wells State Vehicular Recreation Area, and the primary use is recreation.

Permit constraints prevented the completion of the study at the Borrego Maneuver Area. Some data were collected, and a summary is provided in Appendix B of this report. The Borrego site was ultimately replaced with:

Victorville PBR, CA—A 5,600-acre demonstration area was selected to include Demolition Bombing Target "Y," which was reportedly used for high-explosive demolition bombs, and PBR Target 15, used for low-altitude delivery of practice bombs. These targets are part of a larger complex of ranges. The site is maintained by the Bureau of Land Management, and the current use is primarily for recreational off-road vehicles and camping.

In Phase II, the program objectives were expanded to more fully explore the capabilities and limitations of the technologies in more challenging conditions. A number of sites with varying munitions types and environmental challenges were considered, and the former Camp Beale in California was selected.

Former Camp Beale, CA—An 18,000-acre demonstration area was carved out of the larger 64,000-acre formerly used defense site. The Camp Beale study area contains portions that are flat and open, gradual slopes, and valleys between steep hills. Vegetation varies from sparse shrubs and trees to dense, continuous groves. The site includes areas of benign and challenging magnetic geology. Munitions reported to have been used included a wide range of bombs, artillery, mortars, and grenades. The site currently has multiple private land owners, and a portion is contained in the Spenceville Wildlife Preserve. Currently, sparse residential development exists, and recreational uses include hunting, fishing, and hiking. Areas of the site have been proposed for dense residential development.

Further background information regarding each of sites is included in the Test Site History and Characteristics section of their corresponding chapters.

3.4 Conceptual Site Models

A CSM is a planning, analysis, and interpretation tool used to record the best understanding of a site. A CSM is a dynamic document that is updated as new information is obtained. CSMs were created for each demonstration site. The initial version of the CSM described the study area, assessed what was known and unknown about it, and highlighted uncertainties. It served as a working hypothesis about the study areas that needed to be tested. An associated geographic information system (GIS) database was also created to provide the foundation for designing a data-collection plan and to assist all demonstrators in analyzing their data.

The initial version of the CSM was based largely on the previously generated information, such as Archives Search Reports. Local site team meetings were conducted with property owners and other stakeholders to incorporate additional anecdotal information. Based on the initial CSM, each technology vendor prepared a plan detailing the data-collection protocols and analysis procedures that would be used to evaluate the technology. As the various demonstrations occurred, each technology vendor provided an analysis of its data to ESTCP. Analysts identified features of interest, including munitions-related features seen in the high-airborne data (such as craters and aiming circles) and areas with elevated density of ferrous anomalies. As these results were received, the CSMs were updated for each site. The final versions of the CSMs document the results and conclusions at each of the study areas. The first and final versions of the CSMs for each site are available as stand-alone documents. (Refs 24–30)

3.5 Technology Selection

The technologies used in the WAA pilot were selected using an open solicitation. A wide variety of technologies ranging in maturity from developmental to commercial-off-the-shelf were proposed. One of the main criteria used in the selection process was that technologies be mature and their expected performance well understood and well documented. The goal was to demonstrate a process using technologies that could be readily contracted, ideally through multiple vendors. The requirement for the selection was independently validated prior successful performance by the vendors using the proposed technology.

The technologies selected are represented in Figure 3-2. Detailed descriptions follow.

3.5.1 LiDAR and Orthophotography

High-altitude LiDAR and orthophotography were deployed from fixed-wing and rotary-wing platforms by two different contractors, URS Corp and Sky Research. LiDAR measures variation in surface elevation and orthophotography provides high-resolution, accurately located color photographs. These sensors are designed to detect “munitions-related features,” such as target circles and craters associated with munitions use at the site and thus the potential for munitions contamination. These technologies produce a rapid and efficient survey of 100% of the site to provide a quick look to identify features associated with munitions use. They may also provide secondary information about the locations of structures, roads, and other features that aid in understanding site use and history and may be valuable for planning future work.

3.5.2 Helicopter-Based Magnetometer

The low-altitude helicopter magnetometer array was deployed at each site by the same contractor, Sky Research. This technology is designed to detect surface and subsurface ferrous metal. The helicopter magnetometer data are analyzed to extract either distributions of magnetic anomalies, which can be used to locate and bound targets, or individual anomaly parameters (i.e. location, depth, rough size), which are used to provide information for remediation planning. This technology may be deployed to survey nearly 100% of a site if it is amenable to low-altitude flight. The efficiency will be lower and the cost higher than the high-altitude systems. Depending on the objectives, it could also be deployed to survey only areas of interest (AOIs) at full coverage or to survey widely spaced transects, sampling only a fraction of the site.

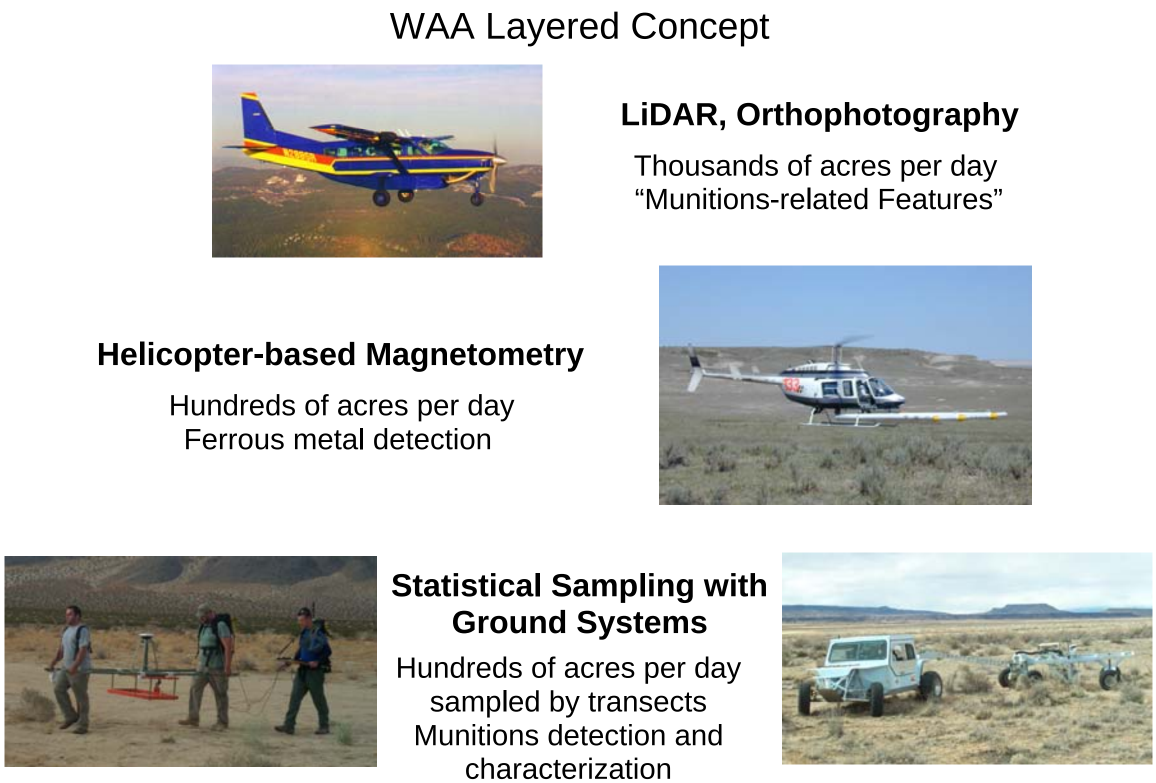


Figure 3-2. Layered technology approach to WAA used in the ESTCP pilot program

3.5.3 Ground Systems

Ground-based geophysics transects were used to detect and circumscribe areas of concentrated metallic anomalies. Transects were planned and analyzed using the UXO module of the VSP software developed by Pacific Northwest National Laboratory and Sandia National Laboratories. The transect data were collected using two different towed-array systems deployed by SAIC and NOVA Research and supplemented by a NOVA Research litter-carried sensor where necessary. Ground-based technologies would not be deployed to cover 100% of a site, but for sites unsuitable for low-level flight or containing challenging geology that prevents the collection of useful magnetometer data, ground transects could be collected at a cost and schedule that can support WAA objectives.

3.6 Technology-Specific Objectives

The approach used for the WAA pilot program consisted of applying these technologies in a layered fashion from high altitude to ground level. The overall objective of the multilayered approach was to produce high-quality data from multiple sources. These data would be used to explore how various combinations could support site decisions—for example, by providing a preponderance of evidence that identifies areas of concentrated munitions use or areas that appear not to be related to munitions activities.

The objectives of demonstrating the high-altitude LiDAR and orthophotography were:

- To demonstrate "munitions-related features" could be detected and used to identify areas of concentrated munitions.
- To examine whether and in what conditions the absence of such features is a reliable indicator that concentrated munitions are not present.
- To demonstrate information obtained by the high airborne layer can be used to guide deployment of the other layers.

The objectives of demonstrating the low-altitude helicopter magnetometer array were:

- To demonstrate surface and subsurface ferrous metal could be detected with sufficient reliability to locate and bound targets.
- To collect information to optimize detailed ground-based surveys that would ultimately be needed to support munitions removal, primarily estimates of the target area size and number of anomalies.

The objectives of demonstrating ground-based geophysics transects were:

- To demonstrate the ability to locate and bound targets based on statistical survey of transects covering a small percentage of the site.
- To collect information to optimize detailed ground-based surveys that would ultimately be needed to support munitions removal, primarily estimates of the target area size and number of anomalies.

To compare the contributions of the various layers in different site conditions, during Phase I of the WAA program all three data layers were collected on 100% of the demonstration sites where terrain and vegetation allowed. In Phase II, the three layers were deployed in a manner more consistent with a real-world approach—one that considers time and budget constraints faced by site managers. In this model, the high-airborne sensors were deployed to the site first, and the results from these sensors (location of munitions-related features and AOIs or terrain and vegetation obstacles) were used to guide the deployment of the other two layers. In addition, the helicopter- and ground-based systems were deployed in areas in which the site conditions permitted the collection of useful data, rather than in overlapping areas for comparison or validation purposes.

3.7 Technology Descriptions

Each technology is described briefly below; detailed descriptions can be found in the individual vendor reports. (Refs 3–23). Chapters 4–7 contain discussions of the data collected by each technology and the resulting analysis.

3.7.1 High-Airborne Sensors

High-airborne sensor data were used at all the terrestrial sites in the WAA program to identify munitions-related features such as craters, target circles, and associated ground and vegetation disturbances. The sensor data are subjected to both automatic target recognition routines (craters, target rings, linear features, etc.) and human analysis (ship-shaped targets and other nonstandard features). Each anomalous feature identified in the LiDAR data or orthophotography is labeled as either a munitions-related feature or an AOI and flagged for further investigation. In addition, vegetation (both sensors) and slope (LiDAR) maps can be produced from these data to guide the deployment of the low-airborne and ground-based survey platforms.

3.7.1.1 LiDAR

LiDAR is deployed from relatively high-flying fixed- or rotary-wing aircraft. A pulsed laser is directed downward from the aircraft. The time of return determines surface elevation, as illustrated in Figure 3-3. The position and orientation of the laser are precisely measured using an advanced Global Positioning System (GPS) and inertial navigation system. This allows for the accurate calculation of the point of reflection of the laser signal from the ground, man-made structures, or vegetation. Multiple returns from a single laser pulse can be detected, increasing the chance of sampling the ground surface through gaps in vegetation. As the aircraft advances, the laser spot is swept across the ground as illustrated in the figure. With reasonable altitude, flight speeds, and laser repetition rates, point densities up to 4 to 6 per square meter can be achieved. This allows reliable detection of features on the order of 1 meter. Under conditions that achieve this data quality, a LiDAR system can survey thousands of acres per day. Figure 3-4 shows a portion of the LiDAR data set from the Target 4 complex at Pueblo PBR #2. One of the ship-shaped targets and a number of bomb craters are easily seen.

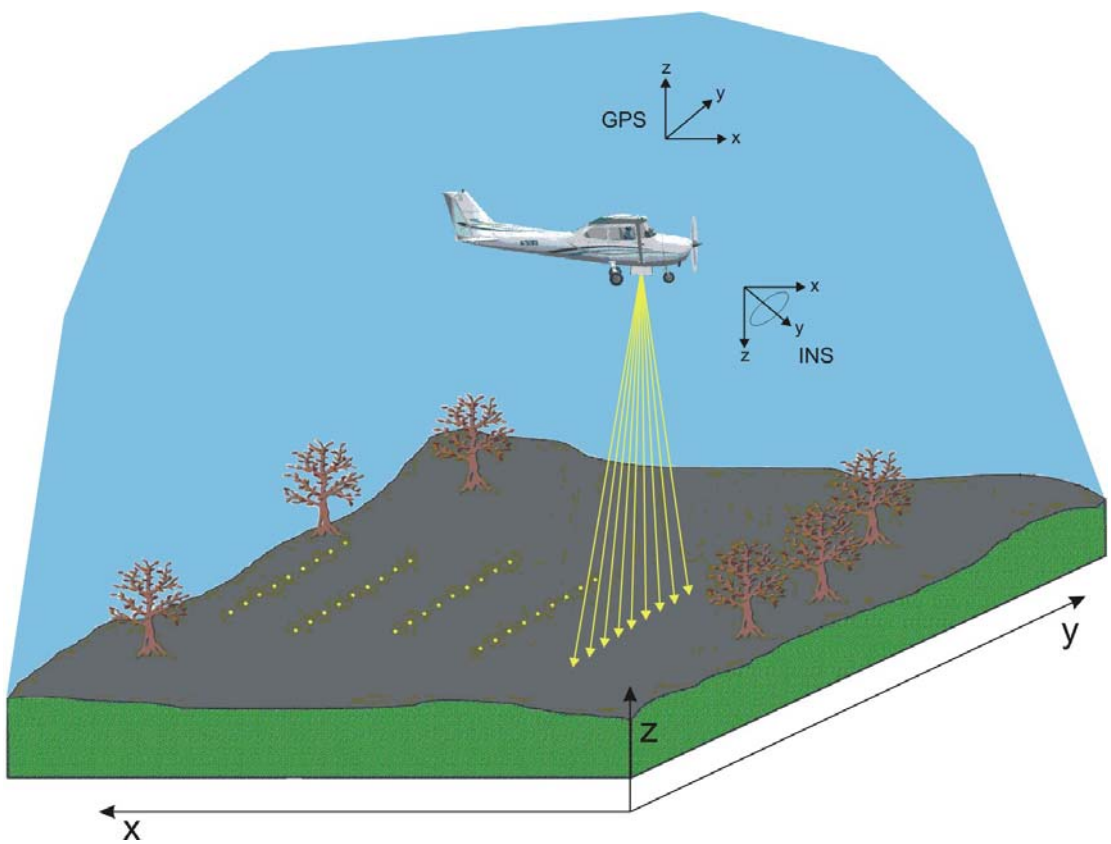


Figure 3-3. LiDAR data collection.

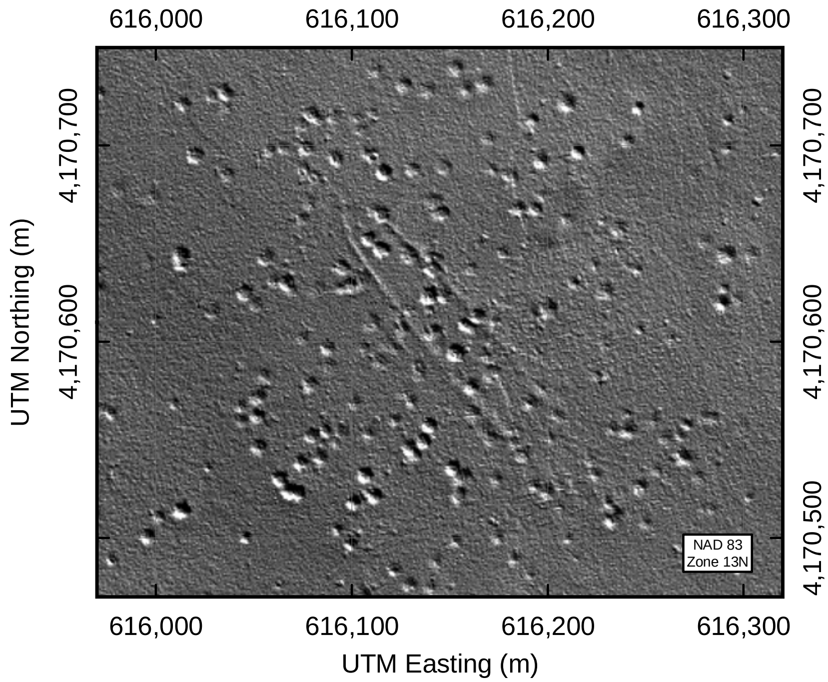


Figure 3-4. LiDAR data from Pueblo PBR #2 showing a ship-shaped target and a number of bomb craters.

3.7.1.2 Orthophotography

Airborne digital cameras are co-mounted with the LiDAR sensors, and the orthophotographs are collected simultaneously with the LiDAR data. Cameras with an image density of roughly 4,000 × 4,000 pixels are generally favored, because the width of the images collected is similar to the 300-m or 400-m LiDAR swath. Once collected, the individual digital images are assembled into a mosaic and color balanced. The resulting composite images are orthorectified using the LiDAR data to accurately locate each photo pixel and to eliminate distortion caused by camera angle and topography. The final pixel size depends on the flight altitude and the number of pixels collected by the specific camera. Pixel sizes in the range of 10 cm to 20 cm can be achieved with reasonable combinations of flight speeds and elevations. As with the LiDAR sensor, this technology can survey thousands of acres per day. Figure 3-5 is an example of the orthophotography collected at the Former Kirtland New Demolitions area.

3.7.2 Helicopter-borne Magnetometer Array

In the implementation of the airborne magnetometer used in the pilot program, an array of seven cesium-vapor full-field magnetometers is mounted in a boom carried on the front of a helicopter (Figure 3-6). The location of the sensors and the orientation of the boom are determined using two Real Time Kinematic GPS systems. Because the magnetic signal falls off quickly with distance, the helicopter typically is flown 1 to 3 meters above the ground surface. Depending on the munitions items of interest, an appropriate maximum altitude is selected to ensure the data meets project objectives. This technology can survey about 400 acres per day.

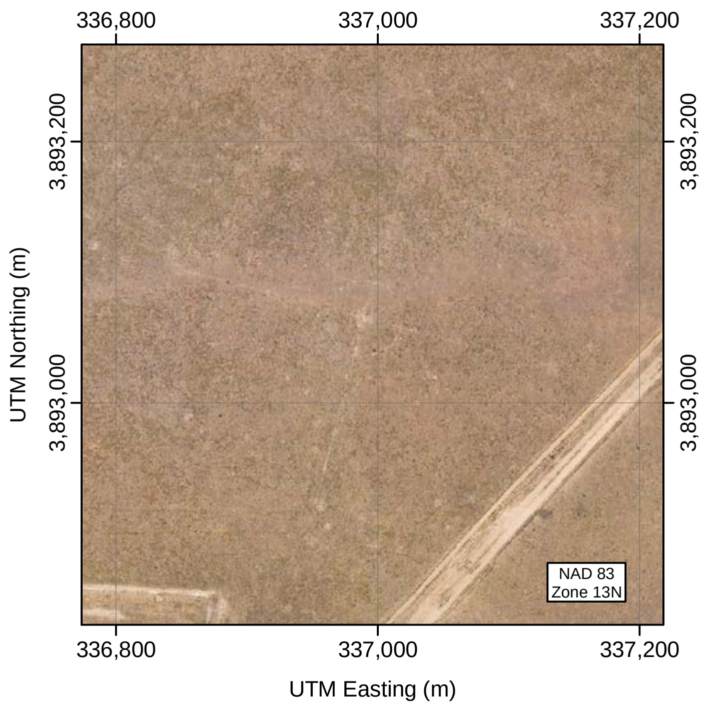


Figure 3-5. Orthophotograph of the New Demolitions Impact Area of the Former Kirtland Bombing Range. The cross hairs and circle used to designate the target are seen easily.

Figure 3-6. Photograph of the helicopter-borne magnetometer array during a survey.

Following a survey, helicopter magnetometer sensor and position data files are converted to magnetic anomaly maps. These data can then be used to create anomaly density contours. Figure 3-7 shows an example magnetic anomaly map and the corresponding anomaly density contour map covering the Target 4 complex at the Pueblo site. At this target, magnetic anomalies are concentrated not only in and around the target circle but extend to the southwest as well, indicating this target likely had more than one aim point.

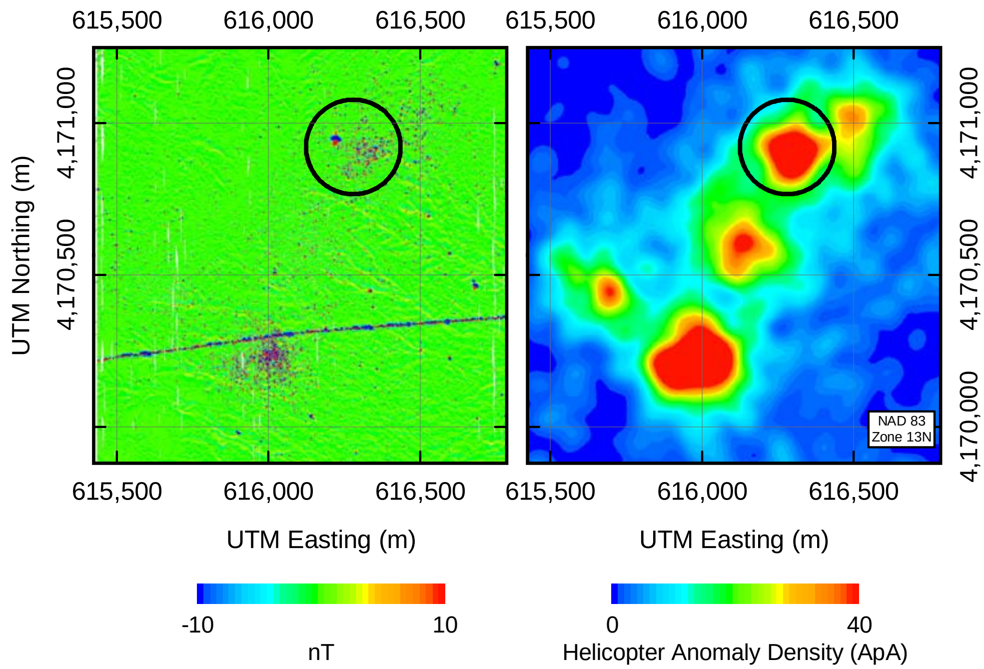


Figure 3-7. Magnetic anomaly image constructed using data collected by the helicopter-borne magnetometer array at the Pueblo PBR #2 (left) and the corresponding anomaly density contours (right). There is a concentration of anomalies near the target circle and extending to the southwest. The linear feature in the left image running east-west is a fence.

The magnetic anomaly data are analyzed in several ways. The first priority is to extract distributions of magnetic anomalies to locate and bound areas of concentrated munitions use. At a site such as Pueblo, where the geologic background is moderate, automatic anomaly-selection algorithms can be employed for this task. At sites with substantial geologic interference such as the Victorville site, current automatic anomaly-detection routines are not able to differentiate anomalies resulting from ferrous metal items from the background effectively, so an analyst performs the task manually. In addition, individual anomalies can be selected and analyzed using physics-based models to estimate parameters such as target size, position, and depth. These parameters can then be used as inputs during planning for site remediation.

The threshold for anomaly selection is determined after the data have been collected at each site. A histogram of the number of detections as a function of threshold is constructed and the threshold is chosen to exclude background noise. This threshold can be compared to the known signal from the item(s) of interest at the site to ensure an acceptable probability of detection is achievable. Sites with high geologic background may require a threshold that results in a probability of detection below 1. This methodology would not be appropriate for a clearance operation, but it is consistent with the WAA objective of identifying areas of concentrated munitions contamination, which does not require detection of every item.

3.7.3 Ground-based Surveys

Ground-based surveys were conducted along statistically planned transects that typically covered 1% to 3% of each site. For sites of this size, it would be prohibitively expensive—and beyond the goal of the WAA—to survey the entire site with the ground systems. Transect surveys have proven to be a reliable and relatively efficient method to identify and bound areas of concentrated munitions contamination. In this section, the planning tool used in the pilot program will first be discussed and then the geophysical sensors used for the surveys will be discussed.

3.7.3.1 Visual Sample Plan Statistical Planning Tool

VSP is a statistical sampling software package that provides site investigators with a simple to use, statistically defensible method of gathering and analyzing data for site characterization. VSP contains a module to aid in transect sampling to identify areas where the likelihood of concentrated unexploded ordnance presence is elevated. The VSP user specifies parameters that describe the operating characteristics of the sensors to be used, such as the transect width, anomaly detection efficiency, and false alarm rate. The user also specifies the size of the target area expected and the required probability of traversing and detecting that target area. VSP computes the transect spacing required to achieve these probabilities, calculates statistics that allow the user to evaluate the effectiveness of the design, 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 and their Data Quality Objectives. These methods and tools allow a project team to balance against costs and other constraints.

This is shown schematically in Figure 3-8. VSP has been used to define transect spacing on the site shown outlined in blue. The suspected targets, along with an estimate of their size, were inputs to VSP, which calculated the transects shown to meet the user-specified probabilities of traversing the various targets and recognizing target areas were traversed.

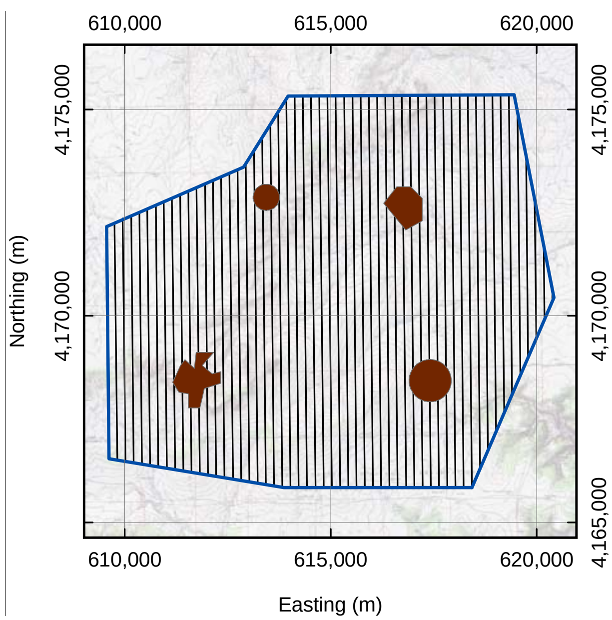


Figure 3-8. Example of planned transects resulting from the use of VSP.

After survey data have been collected, VSP's target-identification algorithm uses a circular window that systematically moves along each transect surveyed and marks points where the window has a greater anomaly density than expected from background. Because there is often no prior estimate of background anomaly density, VSP makes it possible to examine the distribution of densities found during the survey. The user can then determine an optimum density above the background for target detection; this is termed the critical density in VSP. The effect of window size on target area detectability can be determined iteratively. With the optimum window size and appropriate background density determined, cells along the transects belonging to potential target areas are identified, as shown by the pink squares in the lower left image of Figure 3-9 from Pueblo PBR #2 Target 4.

A second module within VSP uses geostatistical estimation to interpolate information away from the transect locations to unsurveyed locations of a site. Both the probability that any location on the site lies within a target area and the anomaly density can be estimated. The image on the right side of Figure 3-9 shows the anomaly density estimated for the Pueblo site and Target 4 is outlined in black. Density maps such as this are used in the pilot program to derive target boundaries.

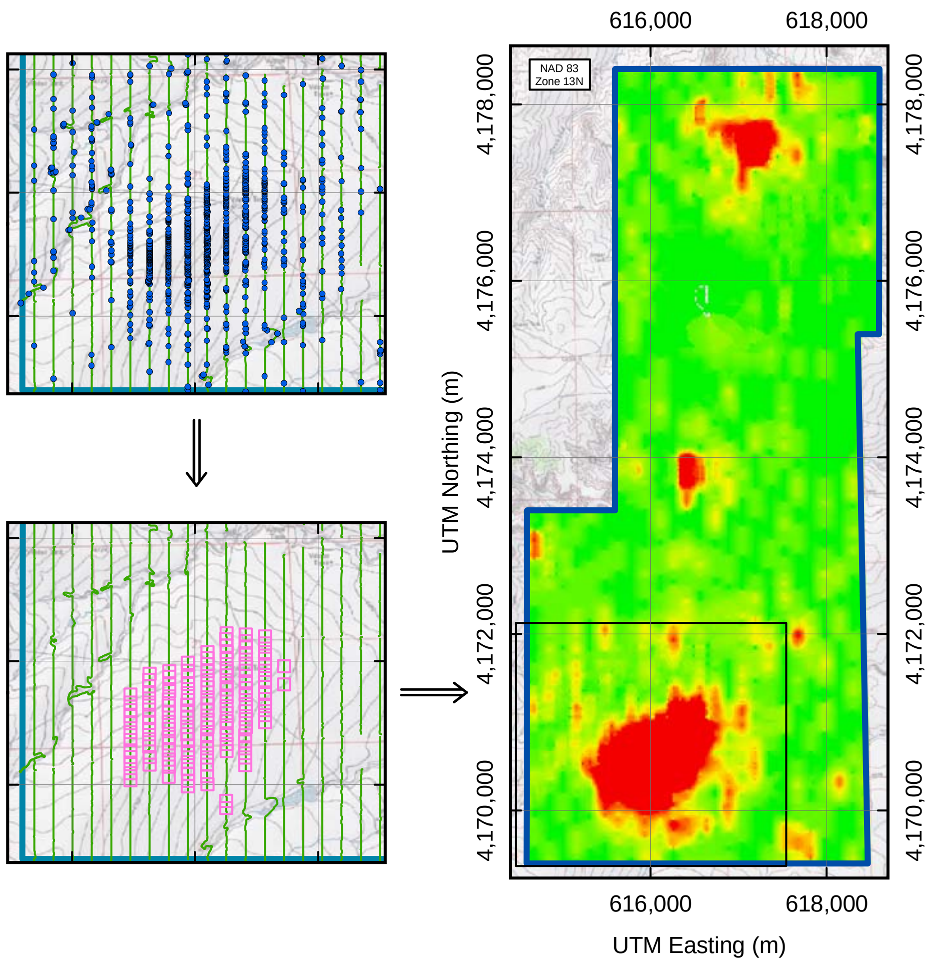


Figure 3-9. Example of VSP ground-transect data analysis process for Pueblo PBR #2 Target 4.

3.7.3.2 Vehicle-towed Magnetometer or Electromagnetic Induction Array

Figure 3-10 shows a custom-built, low-magnetic-signature vehicle used to tow a linear array of cesium-vapor total-field magnetometers. Sensor positions are measured in real-time with position accuracies of roughly 5 cm using high-performance Real Time Kinematic GPS receivers. An on-board guidance display allows the VSP-planned transects to be imported and guides the operator to follow those transects. Depending on site terrain and the presence of obstacles such as extensive fences or ravines, survey productivity of 15 to 40 lane-km per day can be achieved. For transects sampling a small percentage of the site, this translates to investigating 500–1,000 acres per day. This system was used for surveys at the Pueblo and Victorville sites.

Figure 3-10. Vehicular-towed magnetometer array.

An additional sensor trailer containing an array of EM61-MK2 EM sensors was used in the former Camp Beale demonstration, where geologic conditions resulted in an unacceptable background using the magnetometers.

Transect survey data are converted to magnetic or electromagnetic anomaly maps in a method similar to that employed for the helicopter-borne array. An automatic anomaly-selection routine then extracts anomaly locations and amplitudes, which are transmitted to the VSP team for analysis. The transect course over ground and anomaly locations shown in the upper left image of Figure 3-9 were used to produce the density map on the right side of that figure.

The threshold for selecting anomalies in the transect data was chosen in an analogous manner to that for the helicopter system. A histogram of number of declarations versus threshold was constructed and a threshold chosen just above the site noise. This threshold was applied to data from the calibration strip to ensure items of interest at the site were detectable to sufficient depth.

3.7.3.3 Vehicle-Towed Simultaneous EM and Magnetometer System

A low-ferrous vehicle and a nonmetallic towed platform design includes both magnetometer and EM61 sensors in a low-noise environment (see Figure 3-11). By interleaving the magnetometer and EM61 data-acquisition cycles, the sensor hardware avoids saturation of the magnetometers by the EM pulse. This interleaving is accomplished by monitoring the pulse from the EM61, waiting a preset amount of time for the pulse and the secondary fields generated by the pulse to ring down, and then sampling the magnetometer for a short window. The combined magnetometer/EM system surveyed approximately 20 lane-km per day. For transects sampling a small percentage of the site, this translates to investigating several hundred acres per day.

The sensor data are positioned using a Real Time Kinematic GPS, heading, and platform geometry; gridded on a 10-cm grid; and visualized. The magnetometer data are filtered using a demedian filter. The gridded magnetometer and EM61 data are then viewed together in a custom software package for manual target picking by an experienced analyst. This system was used at the Kirtland site.

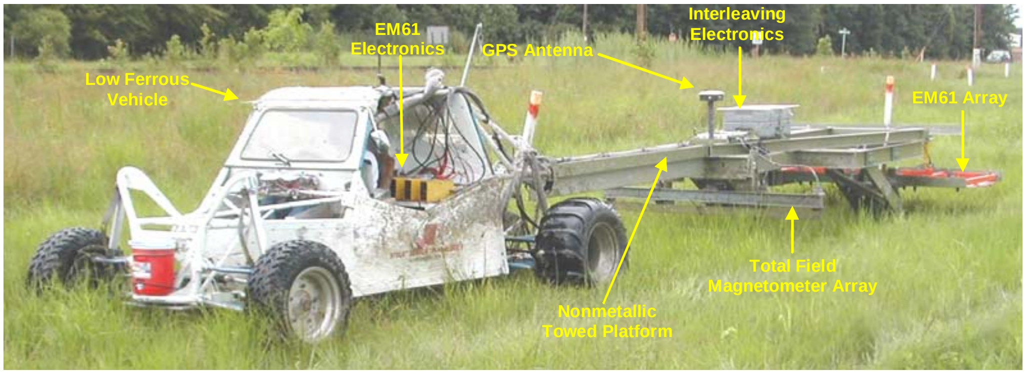


Figure 3-11. Vehicular-towed simultaneous magnetometer/EM system (VSEMS).

3.7.3.4 Man-portable System

Areas on several of the sites were not amenable to vehicular surveys; in these areas a man-portable sensor was required. A litter-carried EM system (Figure 3-12) was designed to collect data equivalent to that collected by the vehicular system. The sensor is carried to avoid the motion-induced noise that would result from a short-wheelbase cart bouncing over rough terrain and to increase its utility in vegetation.

Figure 3-12. Litter-carried EM system in use at the Victorville site.

Because this is a single-sensor system, not only is survey speed lowered, but the transect swath width is reduced by a factor of 2. This system surveyed approximately 15 acres of transects at Victorville and 50 acres at Former Camp Beale.

3.7.4 Geographic Information Systems

The ability to organize and compare geospatial WAA data sets is critical. GISs integrate spatial information from multiple diverse sources with accuracy and consistency, and are used to manage data within munitions response project teams and to communicate information to stakeholders. This information can be shared on websites created for project teams or the public. All data products in this report were created within a GIS.

3.8 Sensor Performance Confirmation

To establish each sensor was operating correctly and data quality was sufficient for the project objectives, the pilot program employed performance confirmation methods (i.e., function checks) specifically designed for each of the technologies. Although these specifications may not translate directly to requirements for all sites, they give an indication of the data quality that was used to achieve the performance in this program, and gross deviations from these ranges should be carefully scrutinized. Even though an operational WAA may not require this level of performance confirmation work, some means of verifying proper system performance should always be established. Sensor performance confirmation results are presented in Chapter 8, and the details of each are contained in the vendor's final reports. (Refs 3–6, 8–10, 12–14, 16–18, 20–21, and 23)

3.8.1 High Airborne Data

The effectiveness of LiDAR and orthophotography will depend on image quality. Factors that affect LiDAR image quality include the point density on the ground, which will determine the size of feature that can be observed; the vertical resolution, which will determined the height of the feature that can be observed; and the horizontal location accuracy, which will affect image quality and the ability to accurately locate features. Factors that will affect orthophotography include pixel size on the ground, which will determine the size of the smallest feature that can be detected; the horizontal location accuracy, which will affect image quality and the ability to accurately locate features; and the focus and contrast qualities of the photograph.

For calibration of the high airborne data, fiducials were emplaced throughout each site. The fiducials consisted of wooden tables of known height for LiDAR calibration; painted white crosses on the tables were used for orthophotography calibration. Many such fiducials were used throughout each site to calibrate and register each pass. In addition to the emplaced fiducials, man-made craters of varying sizes were dug to calibrate the LiDAR and orthophotography sensor performance as suggested by the Advisory Group. The objective of surveying the man-made craters was to determine the minimum sized crater that could be detected with high-airborne sensors. Figure 3-13 gives an example of both types of fiducials.

Figure 3-13. Examples of craters and calibration fiducials used for the High Airborne data.

3.8.2 Helicopter Magnetometer

The effectiveness of the helicopter magnetometer array will depend on several factors:

- Proper absolute and relative sensitivity of the magnetometer or EM sensing elements—absolute, in the sense that measurements are consistent with the governing physics, and relative, in day-to-day consistency, which will determine the size and depth of objects that can be detected.
- Accurate location of the individual sensor measurements, which will affect the overall data quality and determine the ability to estimate parameters for individual targets.
- Appropriate coverage with no gaps. (The actual requirement will depend on objectives.)
- Height above ground not exceeding a few meters, which will determine the size and depth of objects that can be detected. (The actual requirement will depend on objectives.)
- Meaningful interpretation of the data. Target-picking thresholds and analysis using physics-based models should produce physically meaningful parameters.

Data specifications for the pilot project exceeded what was needed to support the primary WAA objectives of finding MRSs and determining areas are free of concentrated munitions use. For these demonstrations, data specifications also considered secondary objectives of characterizing target areas which could be supported with modest additional effort. In practice, for the primary objective of WAA, gaps in coverage, lower sensitivity (higher altitude), and reduced location accuracy may be acceptable.

The helicopter system was calibrated by surveying a test strip at each site that contained emplaced items. Table 3-1 lists the calibration targets used. The calibration targets were placed on the ground, and the positions of the targets were surveyed to confirm positioning accuracy. Each day, the system was flown over the targets at two altitudes, and the resulting signatures were compared to calculated responses to confirm the system was operating at its expected sensitivity. No targets were buried, and no attempt was made to measure a probability of detection for the helicopter system. Measured signal strengths were compared to archived data with large sets of emplaced munitions to verify the system was operating properly.

Table 3-1. Example of helicopter magnetometer array calibration targets placed on the ground surface.

Item	Depth	Orientation
8-inch steel cube	ground level	N/A
100-lb bomb simulant	ground level	1 N-S 1 E-W
155-mm projectile	ground level	1 N-S 1 E-W
2.7-inch warhead	ground level	1 N-S 1 E-W

3.8.3 Ground-Based Magnetometer and EM

The effectiveness of ground sensors will depend on several factors, similar to those for the helicopter magnetometer:

- Proper absolute and relative sensitivity of the magnetometer or EM sensing elements—absolute, in the sense the measurements are consistent with the governing physics, and relative, in day-to-day consistency, which will determine the size and depth of objects that can be detected.

- Accurate location of the individual sensor measurements, which will affect the overall data quality and determine the ability to estimate parameters for individual targets.
- Appropriate coverage with no gaps. (The actual requirement will depend on objectives.)
- Meaningful interpretation of the data. Target-picking thresholds and analysis using physics-based models should produce physically meaningful parameters.

The performance of the ground systems was verified using a line of confirmation targets. To verify sensitivity and location accuracy, arrays of items ranging in size from 37-mm to 155-mm projectiles were buried at surveyed locations in a line that was driven over each morning and evening. The recorded signal strengths were compared to archived data from the Standardized Unexploded Ordnance Technology Demonstration Sites for common items to confirm the system was operating properly.

3.9 Validation

Validation served two purposes:

- Confirming the sensor data are accurate measures of physical features (e.g., the location and size of detected craters).
- Confirming conclusions about the site derived from sensor data by field observation and documentation (e.g., verifying a feature designated as an old homestead is not, in fact, a munitions-related feature).

The main objectives of the validation were to carefully document the correctness of the conclusions drawn from the data on all areas of the site and to eliminate remaining sources of uncertainty relating to either the data or the conclusions.

None of the WAA technologies uniquely detects munitions. The high airborne systems detect munitions-related features, and the geophysical systems detect ferrous or other metallic objects. As such, the product of WAA will be the identification, through one or more of the data layers, of features that serve as indicators of target areas, but may or may not be target areas. The Program Office, in consultation with the Advisory Group, developed a validation plan for each site after the analyses of survey data were complete.

In the end, data layer comparisons and reconnaissance were most useful for validating conclusions. For example, geophysics may be used to validate features in the high airborne data. Regardless, field reconnaissance will likely be needed to validate WAA conclusions on almost any site. Total coverage surveys of small areas and intrusive investigations were primarily useful for validating the data and their ability to support conclusions for the pilot program, but neither will likely be needed to implement WAA.

3.9.1 WAA Data Layer Comparison and Cross Validation

An intrinsic aspect of the layered approach to the WAA pilot process is the ability to utilize each data set to cross-validate detected features and evaluate the contribution of each sensor to the overall conclusions. In Phase I, the data sets generally covered each entire study area, and the result was an abundance of overlain data sets to compare.

If a munitions-related feature was detected in the orthophotography data, the same area in the LiDAR data was examined to determine if the feature was visible. The location of that same feature would then be reviewed in the magnetometer data sets to determine if an elevated concentration of anomalies was present. The boundaries of the areas of concentrated anomalies were compared. Numerous examples of observing AOIs in multiple data sets built a preponderance of evidence of munitions use in these areas. Comparisons in some cases eliminated ambiguity in interpretation. For example, if an area exhibited an ambiguous but evidently man-made feature in the LiDAR, but no corresponding concentration of anomalies was observed in the geophysics layers, the area could be dismissed as unlikely to contain a concentration of munitions. In another example of data layer comparison, combined magnetometer and EM ground-based data could be used to select appropriate anomalies to pass on to the analysis stream. Finally, the absence of features of interest in any data set was a strong indicator that no concentrated munitions were present in an area.

3.9.2 Ground Reconnaissance

Ground reconnaissance was conducted to verify features of interest, primarily from the high-airborne data sets. A team consisting of a UXO technician and a geophysicist deployed to each site to visit, photograph, and if necessary, interrogate with a hand-held geophysical instrument the identified features. The ground teams documented the features by taking field notes that included the exact GPS location, size measurements, and a full description of the feature. Features such as ship target outlines, target circles, and suspected craters were investigated. Ambiguous AOIs such as berms and structures were visited and documented as well. In an operational WAA, the ground-based data collection crew could be directed to document features of interest they encounter to reduce or eliminate the need for an additional site visit.

3.9.3 Total Coverage Surveys

The validation surveys consisted of total coverage with the ground-based systems of selected small areas. The total coverage areas were chosen to address a number of objectives, including defining site background, exploring target boundary definition, and confirming helicopter and transect-based target selections. For all total coverage areas, the geophysics data corresponding to individual anomalies were analyzed to obtain estimates of size and depth of the detected compact metal objects. In some cases, all items in the background areas were excavated. The intrusive investigation results on the total coverage areas provided further insight into the extent of the target and helped support conclusions about whether military activity occurred in those areas. Together, these served to validate both the data and the conclusions.

3.9.3.1 Validating the Data

Data from the 100% coverage areas were analyzed to select all possible geophysical anomalies. Of the anomalies with sufficient signal to allow analysis with a dipole model, the fitted target parameters were compared to the parameters derived from either the helicopter data or the ground-transect data. The 100% coverage areas were also the basis of intrusive investigations discussed below.

3.9.3.2 Validating the Conclusions

Areas outside the high-anomaly-density target centers were chosen to provide information on the anomaly density drop-off of a target area as a function of distance from the target center or to provide estimates of the intrinsic parameters associated with individual anomalies to better characterize the distribution of types of munitions and clutter present.

Total coverage surveys were also conducted in areas expected to represent the naturally occurring site background. The number of anomalies found in these patches was tabulated to support calculations of the background level in anomalies per acre for each site. These results were a reference point to identify the higher density target areas, supported conclusions about whether an area was used for military activity, and supported the creation of target boundaries that relied on site background calculations.

3.9.4 Excavation

The final step used to validate the data on the Kirtland and Pueblo sites consisted of the intrusive recovery of selected items. As above, the anomalies were selected to address multiple objectives, including confirming the locations of target boundaries, exploring the objects that were present in areas deemed to be background, and evaluating the data for determining nature and extent in the characterization of target areas.

3.9.4.1 Validating the Data

The items excavated were chosen based on analysis of the anomaly signatures measured by the helicopter and ground-based magnetometer arrays. Anomalies in these data sets had been fitted to a dipole response model, and target parameters such as location, depth, and rough size were extracted. Items of varying sizes and at different depths were dug in these areas to provide a representative picture of their distribution. For both the helicopter and ground systems, the actual items recovered were compared to the predicted size and depth parameters.

3.9.4.2 Validating the Conclusions

Anomalies in particularly quiet areas where munitions were not expected to be present were dug to provide information on the site background. In higher density areas, anomalies were dug to gain information on the types of munitions used and other debris. Once items were recovered in the intrusive investigation, they were labeled as intact munitions, munitions-related scrap, non-munitions-related scrap, or geology and populated into maps as seen in the site-specific results chapters.

The intrusive recovery of items benefited the WAA pilot program by supporting the technology validation objective, but it is not seen as a necessary step in the implementation of WAA at future sites. In consultation with the Advisory Group, the program discontinued validation by intrusive investigation after the first two sites.

3.10 WAA Product

The objective of the pilot project was to demonstrate that WAA provides information that can be used to support management and regulatory decisions in munitions response. The primary product that can be used to support such decisions is a map that reflects the findings of each data layer individually and in combination for each site, indicating areas of concentrated munitions use. The confidence of the conclusions, based on the preponderance of evidence provided by data interpretation and the validation, is transparent and documented in the final CSM.

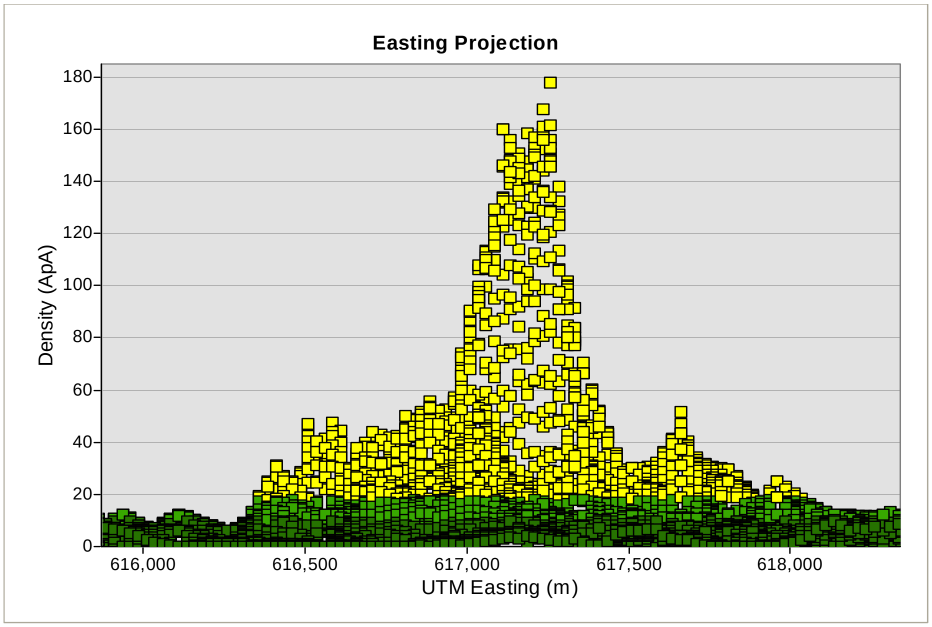
The areas identified as having concentrated munitions present will presumably be designated MRSs and move to the next phase of the munitions response process, where the characterization data may be used for prioritization and planning. Areas outside identified targets show no indication of concentrated munitions use, either through the historical record or the WAA.

Characterization information on these areas can be used to support site-management decisions. Any areas of remaining uncertainty will need to be addressed through more detailed investigations in the next phase of the munitions-response process.

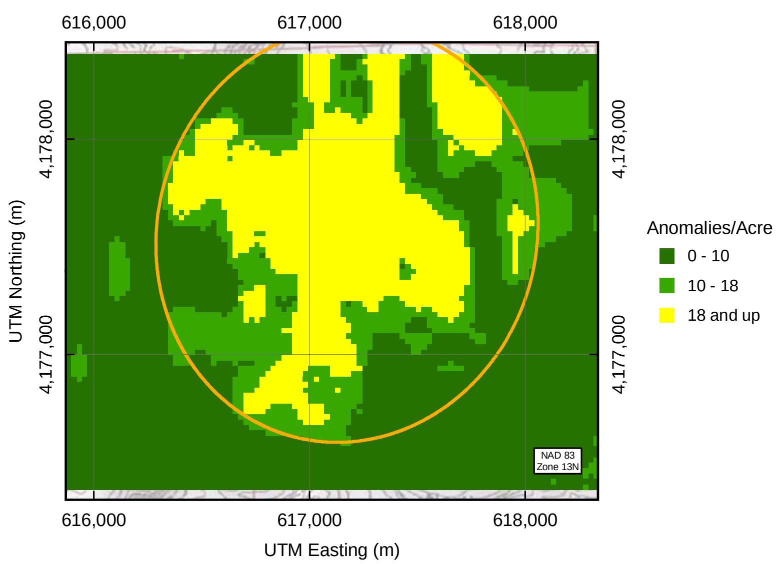
The primary difficulty with drawing lines on a map is that there is no straightforward and unambiguous method to draw a boundary around a target area beyond which no munitions are expected using the data from WAA. Nevertheless, the data can be used to estimate approximate extent and anomaly densities, information that is not currently available, to guide planning and cost estimation. These estimates will be affected by many factors, including the target selection criteria, which must be set at a level appropriate for detecting the objects of interest. In this program, conservative anomaly selection criteria were used for the ground systems, and appropriate scaling factors accounting for the reduced sensitivity of the helicopter platform were established.

The pilot project considered multiple methods to produce a best estimate of the size and number of anomalies in the area that would ultimately need to be investigated in a cleanup. These included placing the boundary at apparent background, encompassing 95% of detected anomalies within the boundary, and using geostatistics to estimate the likelihood a region is within a target area. All these methods gave qualitatively similar results.

The method depicted in Figure 3-14 was ultimately used. On any site, there is always a background level of geophysical anomalies that arise from naturally occurring sources and nonmilitary man-made metal. The target areas are superimposed on this background; the contrast between the target area density and the background will govern the confidence with which these areas can be delineated. Anomaly density maps from magnetic or EM data are analyzed to extract the regions with excess alarm density caused by the targets from the remainder of the site background. An example of this final product is shown in Figure 3-14. Densities peak in the target center and fall to a gently fluctuating background as the distance from the target center increases. It is explicitly recognized that munitions-related anomalies exist outside the line, and final target boundaries to support cleanup must be established by detailed survey and validation that is beyond the scope of WAA.



(a)



(b)

Figure 3-14. Target boundary delineation. In (a), the yellow symbols represent pixels where the anomaly density (anomalies per acre) exceeds background on a one-dimensional slice across a bomb target. The green symbols are the pixels determined to be background. Panel (b) shows the map of the bomb target. The orange ellipse circumscribes the target area.

4.0 PUEBLO PRECISION BOMBING RANGE #2 DEMONSTRATION

Pueblo PBR #2 was selected for this study because the site characteristics aligned with the pilot program objective to deploy the technologies on sites where capabilities and limitations could be demonstrated with limited interference from site-specific factors. Pueblo PBR #2 has generally flat terrain, primarily grassy vegetation, and minimal interfering geology. Historical records note the number of munitions types used was limited and larger munitions items were expected. The site contained known target areas, suspected target areas, and areas that were expected to be free of concentrated munitions use. In addition, a prior demonstration in 2004 for the ESTCP project, Airborne, Multi-Sensor, Wide-Area Assessment of Ordnance Contaminated Sites (MM-0416), had occurred at the site, so previously collected high-airborne data was available for a portion of the demonstration area.

Currently, Pueblo PBR #2 is scheduled for a site inspection in 2008 in the DoD munitions response process. The information from WAA on this site could be incorporated into the site inspection and used by site managers and regulators to support future planning, prioritization, and cost estimation. The WAA data were analyzed to bound each target area and identify areas free of concentrated munitions use. For target areas, the total acreage and estimated number of anomalies associated with the bounded target areas are end products of this study that can be used to define the scope of the future remediation work. Information such as the type of munitions used on each target and terrain and vegetation challenges can also serve as useful inputs to future planning. The characterization of the remaining land as free of concentrated munitions use will also serve the planning process and may guide regulatory decisions about the need for future actions.

4.1 Test Site History and Characteristics

The former Pueblo PBR #2 consists of 67,769 acres located approximately 20 miles south of La Junta, Colorado, in Otero County (Figure 4-1). The site was used by local populations for cattle grazing until the War Department assumed control of the lands to construct the Pueblo PBR #2 (1942 to 1946). During active operations, the ranges were under the Western Flying Training Command, supporting the Pueblo Army Air Field as part of the Second Air Force.

The training ranges consisted of a bombing camp with two runways and nine precision bombing targets, along with an air-to-ground pattern gunnery range. In March 1943, E-1 sonic bomb scoring targets were installed at five of the Pueblo PBR #2 targets. In December 1944, crews also constructed a skip and a submarine target for the 471st Combat Crew Training School. The training documents indicate the ranges were heavily used. During flight training, aviators used M-38A2 100-lb practice bombs. From 28 August to 1 October 1945, the intended training also included rocket firing, ground gunnery, aerial gunnery, and dive bombing. In January 1944, crews completed 672 high-altitude bombing releases during training. In March 1944, the 491st Bomb Group completed 1,449 high-altitude bombing releases. In 1944, Chinese B-25 Mitchell Bomber students practiced firing 75-mm cannons using the M72 shot, an armor-piercing projectile. Pueblo PBR #2 was excessed by the war department in 1946.

In August 1946, Tibbits Contractors Inc. conducted a surface clearance on the range and issued a Certificate of Clearance. It is not known how much of the range was cleared under this contract, nor is the location of the clearance indicated. However, it is reasonable to assume the clearance was conducted on some or all of the established bombing targets. The Certificate of

Clearance stated the land was surface cleared and free from explosives and was suitable for cattle grazing, consistent with the standard to which ranges of this era were cleared. Also in 1946, the Department of the Interior cleared a 1,400-acre portion of the range, which again was not identified, except that the Archives Search Report noted the clearance results indicated it was not part of the bombing targets. A Certificate of Clearance was not issued for the Department of the Interior effort.

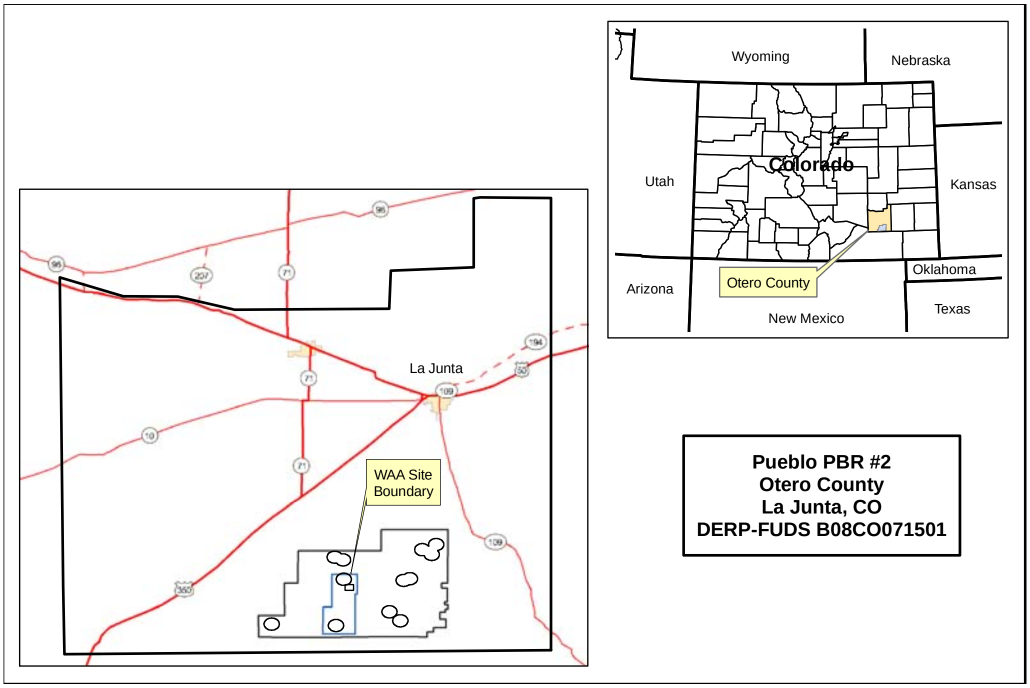


Figure 4-1. Map showing the location of Pueblo PBR #2 within the state of Colorado (right) and the location of the WAA program study area within Pueblo PBR #2 (left).

The following munitions have been found on Pueblo PBR #2 before this investigation:

- Bomb, General Purpose, 100-lb, AN-M30 and AN-M30-A1
- Bomb, Practice, 100-lb, M38A2
- Bomb, Practice, 100-lb, Mk 15 Mod 3
- Bomb, Incendiary, 4-lb, AN-M50A1
- Shot, Armor-Piercing, M72 (75-mm)
- Small Arms Ammunition, Caliber 50

A 7,500-acre WAA study area was selected. Figure 4-2 shows its location within the Pueblo PBR #2 boundaries. Currently, the lands within the study area are primarily Federal lands that are managed by the U.S. Forest Service as the Comanche National Grasslands, with portions owned by or leased to private owners or owned by the State of Colorado. All privately owned lands within the study area are used for cattle grazing. (Refs 26, 31)

4.2 Pueblo PBR #2 Study Area Objectives and Program Design

The Pueblo PBR #2 objectives included confirming the presence of two known targets (Target #3 and Target #4), determining if there is evidence of a suspected 75-mm air-to-ground target, and assessing the remaining land in the study area to determine if there is evidence of any unknown targets. In addition, this study investigated the types of munitions associated with each target to determine if the results aligned with the historical records documented in the original CSM.

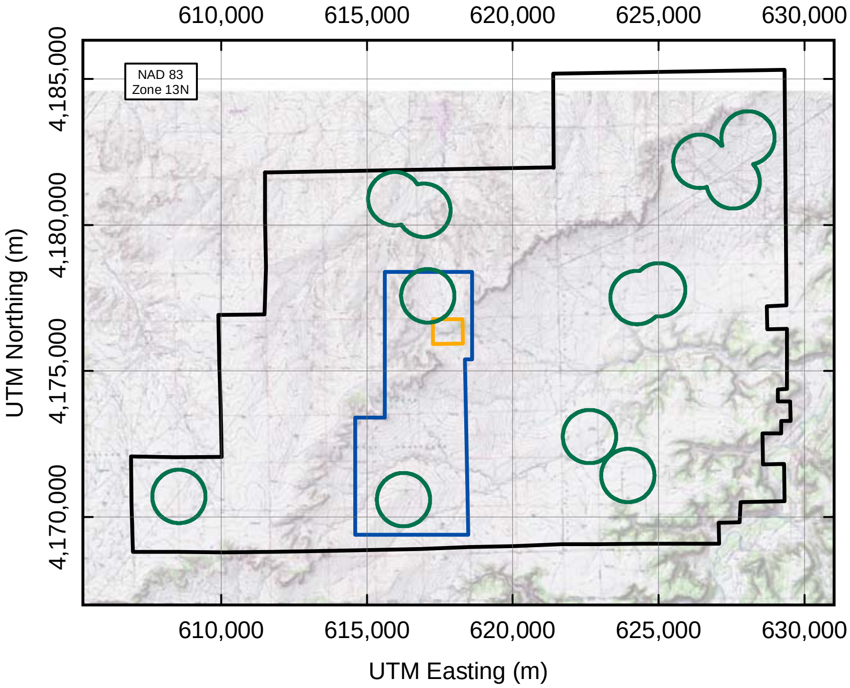


Figure 4-2. Map showing Pueblo PBR #2. The WAA demonstration area boundary is shown in blue, the known and suspected targets target areas from the munitions response inventory are outlined in green, and the suspected 75-mm range is in orange.

The technologies demonstrated at Pueblo PBR #2 include LiDAR, orthophotography, a helicopter-borne magnetometer array, and a ground-based magnetometer array.[1] The high-altitude technology layers surveyed 100% of the 7,500-acre study area, as shown in Figures 4-3 and 4-4. As shown in Figure 4-5, the helicopter magnetometer array surveyed nearly 5,000 acres of the study area where terrain and vegetation would allow. The ground-based magnetometer array surveyed in transects, sampling about 2% of the total acreage for a total of 143 acres of transects. The ground-based transects were designed using VSP as discussed in the section below. The ground system surveyed an additional 379 acres at 100% coverage for validation as shown in Figure 4-6. The anomaly density contours created from the helicopter magnetometer data and the estimated anomaly densities from the ground-based transect data are presented in the data analysis sections of this chapter unless otherwise noted. Detailed results can be found in the technical reports prepared by each of the technology vendors. (Refs 3–8)

[1] As part of ESTCP Project 200416, synthetic aperture radar and hyperspectral image data were also collected on a part of the study area. The results of this work are summarized in Appendix A.

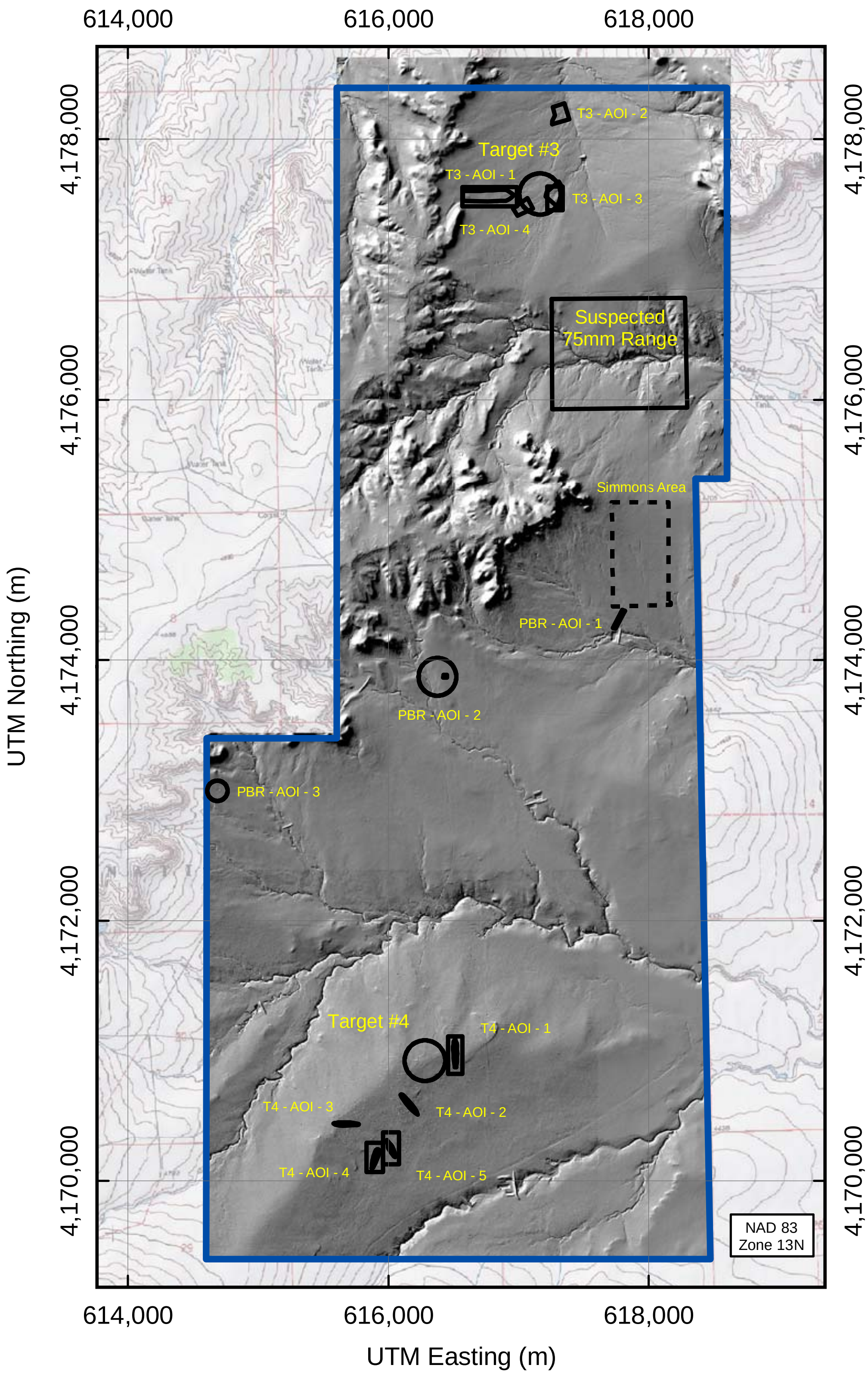


Figure 4-3. The Pueblo PBR #2 WAA targets and AOIs are labeled and overlain on the LiDAR data. 100% of the site was covered with this technology.

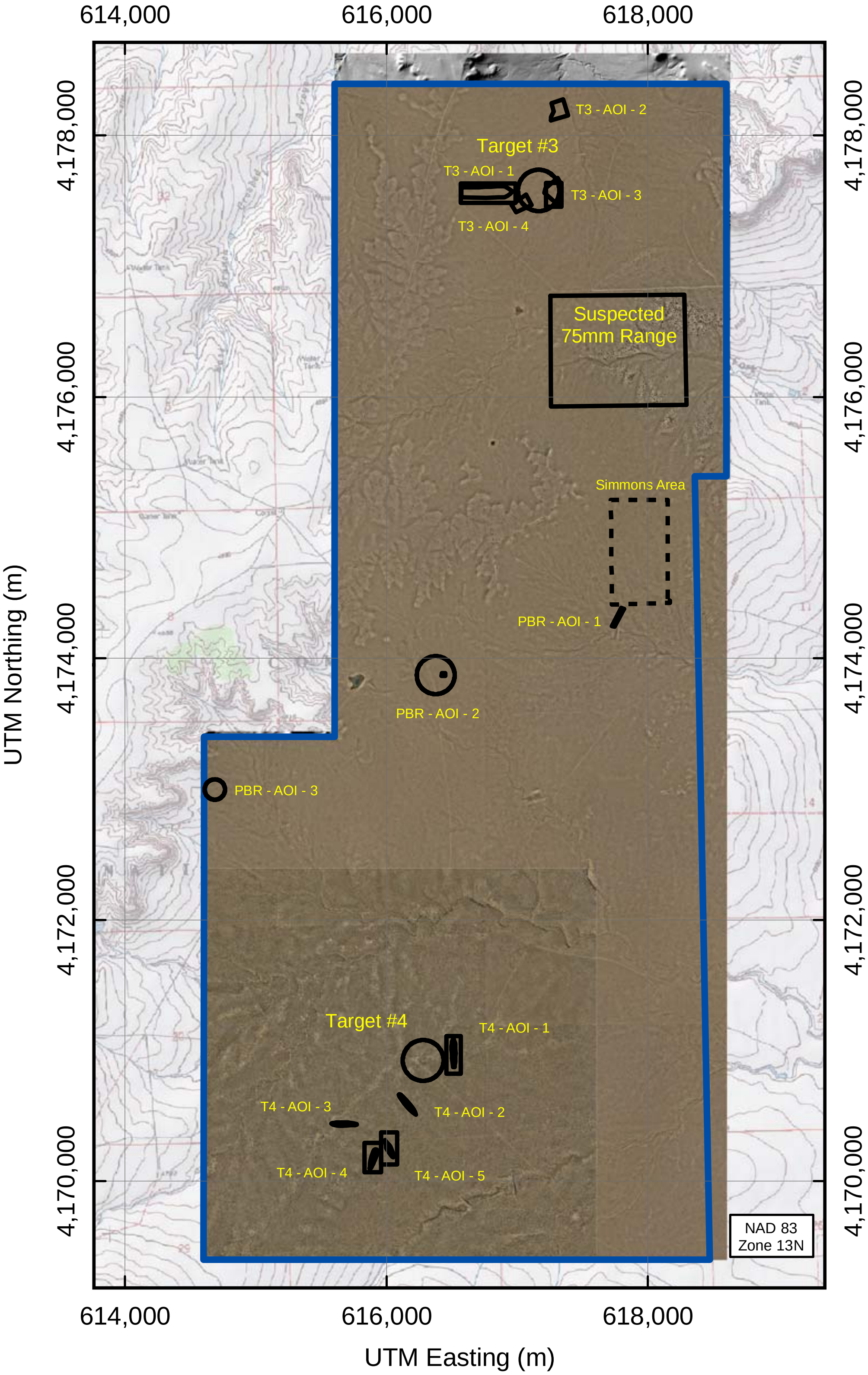


Figure 4-4. Pueblo PBR #2 orthophotography data. Targets and AOIs are labeled. 100% of the site was covered with this technology.

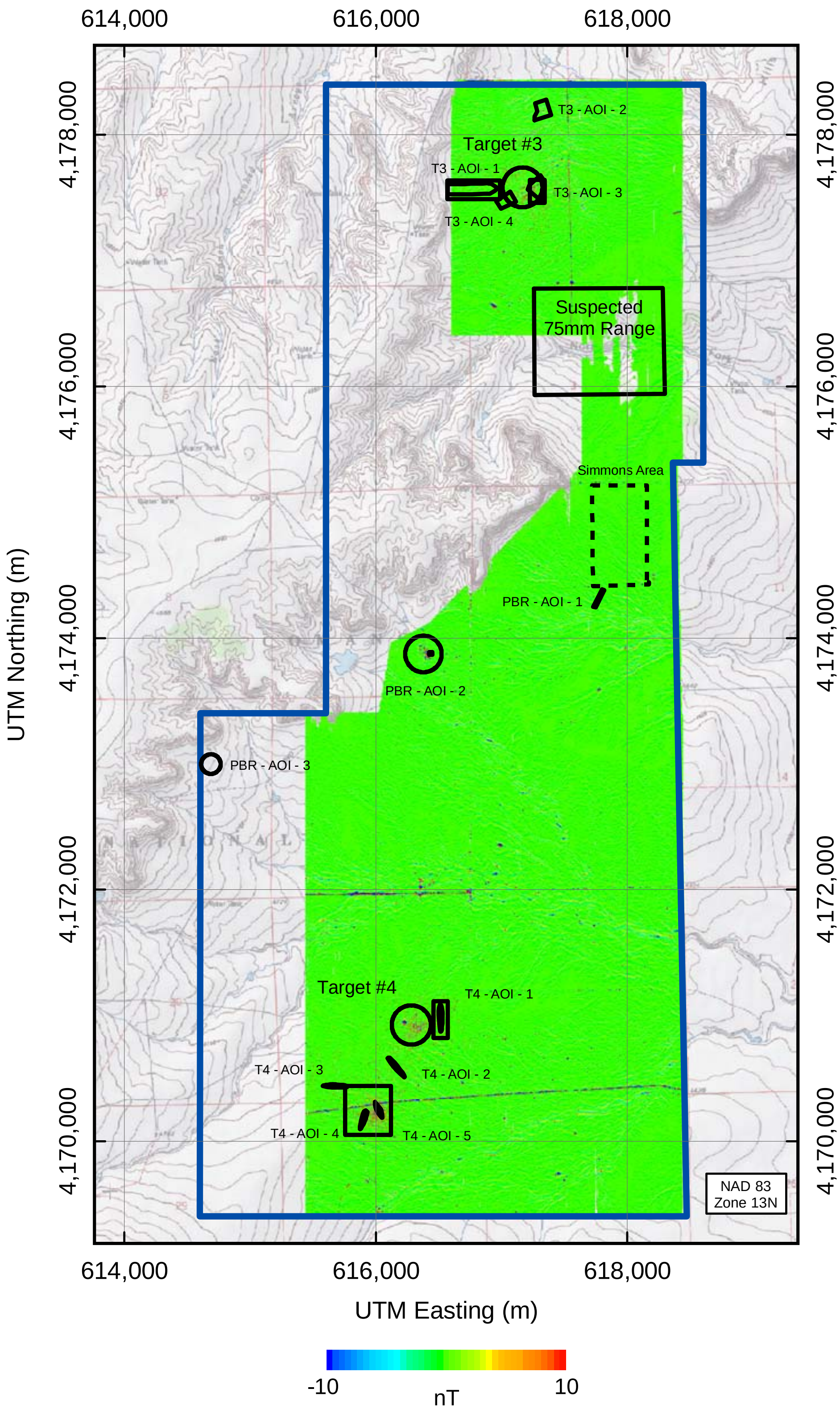


Figure 4-5. Pueblo PBR #2 helicopter magnetometer data. Targets and AOIs are labeled. Approximately 5,000 acres of the 7,500-acre site were surveyed at 100% coverage. Gaps in the suspected 75-mm range were due to terrain and tree cover.

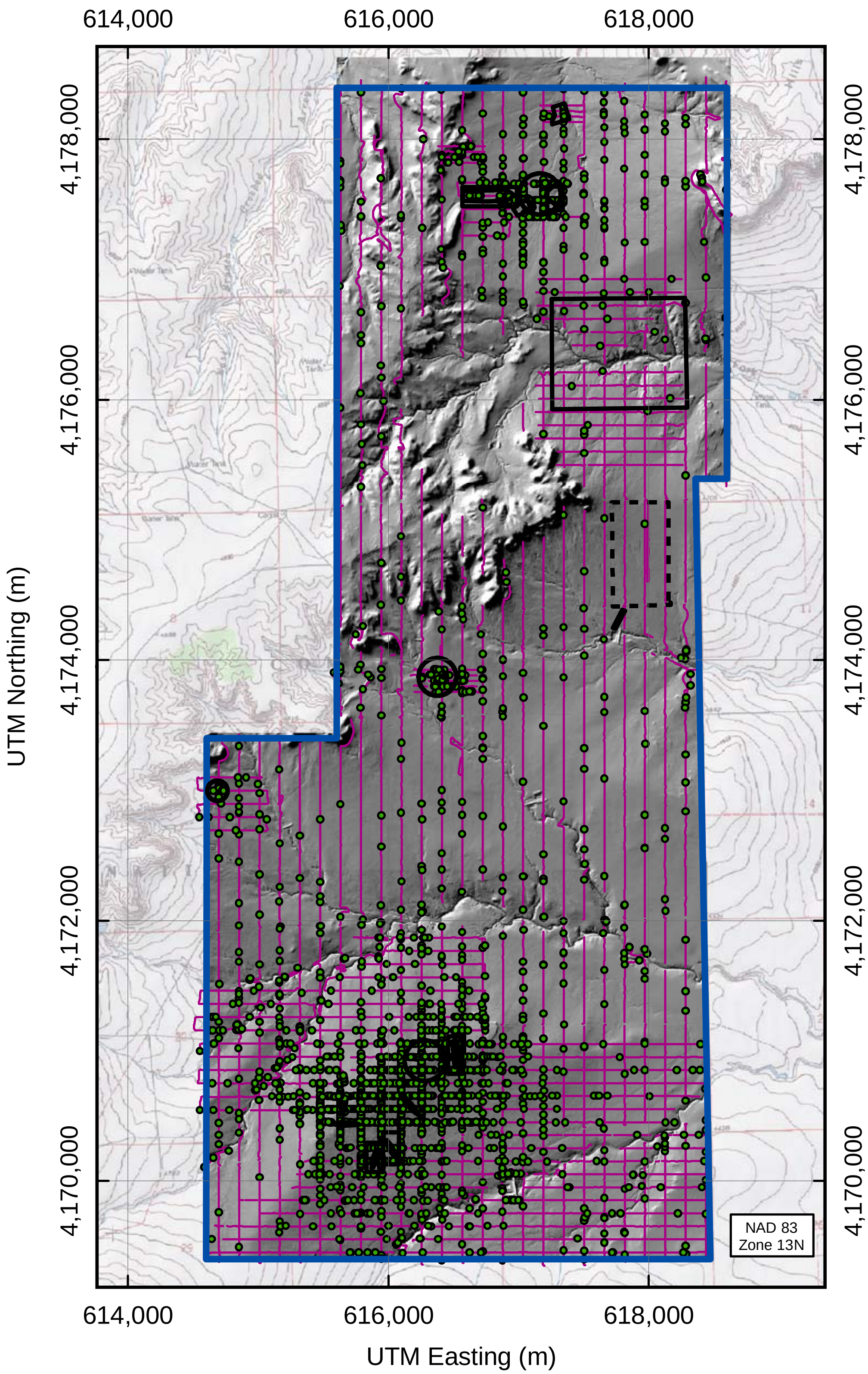


Figure 4-6. Pueblo PBR #2 ground-transect magnetometer anomaly locations overlain on the LiDAR image. Targets and AOIs are labeled in Figure 4-3. The transects as driven are shown in pink and the anomalies detected are noted as green dots. The system was able to traverse the majority of the site, although in a few areas terrain obstructed the array.

4.2.1 Ground-based Transect Design

The ground-based magnetometer system transects were planned prior to the survey. Transects designed to detect bomb targets were planned for the entire site. The suspected 75-mm area was also covered by transects designed to detect a smaller target area that would be associated with 75-mm rounds. The VSP transect design process was divided into two general approaches for comparison. The first approach relied only on the first version of the CSM. The second approach utilized the CSM along with the high-airborne results to compare the two methods and make a future recommendation on the most successful process.

4.2.2 Initial CSM Transect Design Approach

The first transect design approach relied only on the original version of the CSM, developed from the Archives Search Report and ESTCP site visits. The transect design approach was separated into *sparse* and *dense* transect designs. The methods were compared to determine the value added from the more conservative dense design.

The *sparse* transect design approach was developed from historical knowledge of the size of the two known target rings. The direction of flight was not known, so a circular target based on the 305-m diameter target rings identified in the CSM formed the basis of the sparse transect designs. A transect pattern was designed to ensure a 99% probability of traversal of a circular 305-m diameter 100-lb bomb target by a 2-m wide array. The factors used to determine the probability of recognizing a target area was traversed were not used in the planning for this site. It was assumed that if a target were traversed, it would be recognized.

The magnetic footprint of a target area relative to the size of the aiming circle was unknown, and the question arose whether it could have been smaller if the bombers were quite accurate. Therefore, a *dense* transect design was developed to ensure a high probability of traversing a 152.5-m diameter target area. The dense design was built upon the existing sparse design transects. The ground-based system collected data on the dense transects during the survey, and the sparse transect design was later separated from the dense transects for analysis and comparison. Table 4-1 shows the VSP inputs used to develop the transect designs for bombing targets.

The CSM indicates the 75-mm training involved firing projectiles from a nose-mounted cannon in a bomber. This usage is expected to result in a long, elliptical target shape with a narrow dimension across the flight path and a long dimension in the direction of flight. For the 75-mm area, the target AOI used for the VSP planning was hypothesized to be an ellipse 400 m by 100 m, although the longer dimension could in fact be much longer. The orientation of the ellipse was unknown, so transects were planned in both the N–S and E–W directions. The resulting parameters are shown in Table 4-2.

4.2.3 Transect Design Based on High-Airborne Results

The second transect design was developed using the high-airborne results to further guide the design. It was determined the sparse first design was adequate.

Table 4-1. Summary of first transect design approach for bomb targets.

	Dense	Sparse
Primary objective of design	Detect the presence of potential 100-lb bomb circular 500 ft (152.5 m) diameter target areas	Detect the presence of potential 100-lb bomb circular 1,000 ft (305 m) diameter target areas
Type of sampling design	Transect	Transect
Shape of target area	Circular	Circular
Diameter of target area	153 m	305 m
Transect pattern	Parallel	Parallel
Transect width	2 m	2 m
Computed transect spacing	155 m	310 m
Required probability of traversing the target area	99%	99%
Number of transects	27	14
Transect coverage	387,374.63 m^2 (1.296%)	195,361.17 m^2 (0.654%)

Table 4-2. Summary of transect design approach for a 75-mm target.

Primary objective of design	Detect the presence of potential 75-mm target of dimension 400 m × 100 m
Type of sampling design	Transect
Shape of target area	Elliptical
Dimensions of target area	400 m × 100 m
Transect pattern	Square grid
Transect width	2 m
Computed transect spacing	294 m
Required probability of traversing the target area	100%
Number of transects	10
Transect coverage	25,000 m^2 (1.52%)

4.3 Performance Assessment

The results from each WAA data layer were analyzed separately and in combination. The high-airborne data were collected first and used as the starting point to identify munitions-related features and AOIs. As the helicopter and ground-system data were received, they were examined to identify areas of concentrated anomalies. Any areas identified in these two data sets that did not correspond to features identified in the high-airborne data were added as additional AOIs.

All layers of WAA data and the validation results confirm the locations of Target #3 and Target #4 and support a conclusion that a 75-mm target is not located in the study area. In addition, Target #4 was found to be larger and more complex than indicated in the historical records due to the presence of several neighboring ship-shaped targets. Consistent with the CSM, the WAA data and the supporting validation results show no other evidence of concentrated munitions. Figures 4-3 to 4-6 show the study area, indicating the targets and AOIs described below. The areas investigated are discussed from north to south.

4.3.1 Target #3 (Northern Section of Study Area)

Bombing Target #3 is in the northern part of the WAA study area in the original CSM. The location of this target in relation to the entire study area is noted in the inset in Figure 4-7.

4.3.1.1 Data Analysis, Interpretation, and Evaluation

The location of Target #3 is confirmed in all layers of the WAA data. The 1,000-ft diameter target ring along with inner concentric rings are clearly evident in the orthophotograph and LiDAR data (Figure 4-7). A number of depressions in and surrounding the target circle identified in the LiDAR data were selected for further investigation as possible munitions-related craters. The original CSM indicated only practice bombs were used on this target, and the depressions were found to have no evidence of high explosives (HE) use, as discussed in the validation section below.

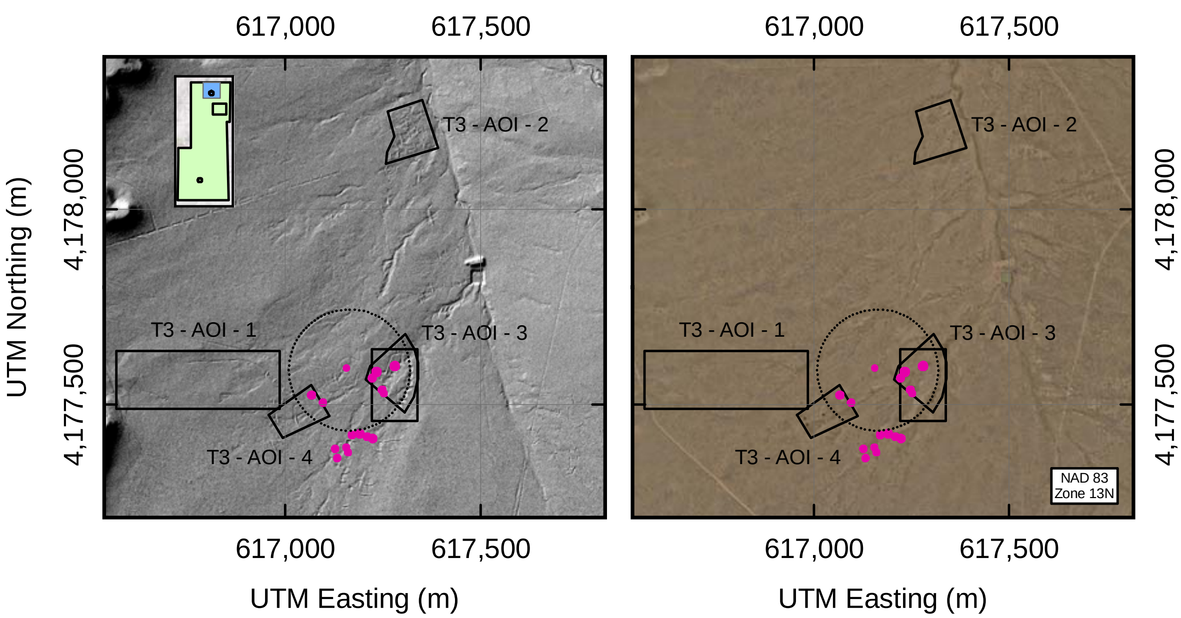


Figure 4-7. LiDAR (left) and orthophotography (right) data from the area near Target #3. The target and AOIs are identified. Depressions are circled in pink. The depressions were determined not to be munitions-related craters.

The helicopter magnetometer data show a concentration of anomalies within the target circle, as seen in the anomaly density contours presented on the left of Figure 4-8. The estimated anomaly densities from the ground-based transect data, located on the right of Figure 4-8, show anomalies densities that exceed the threshold used to flag a potential target area (VSP critical density) in and surrounding the target circle.

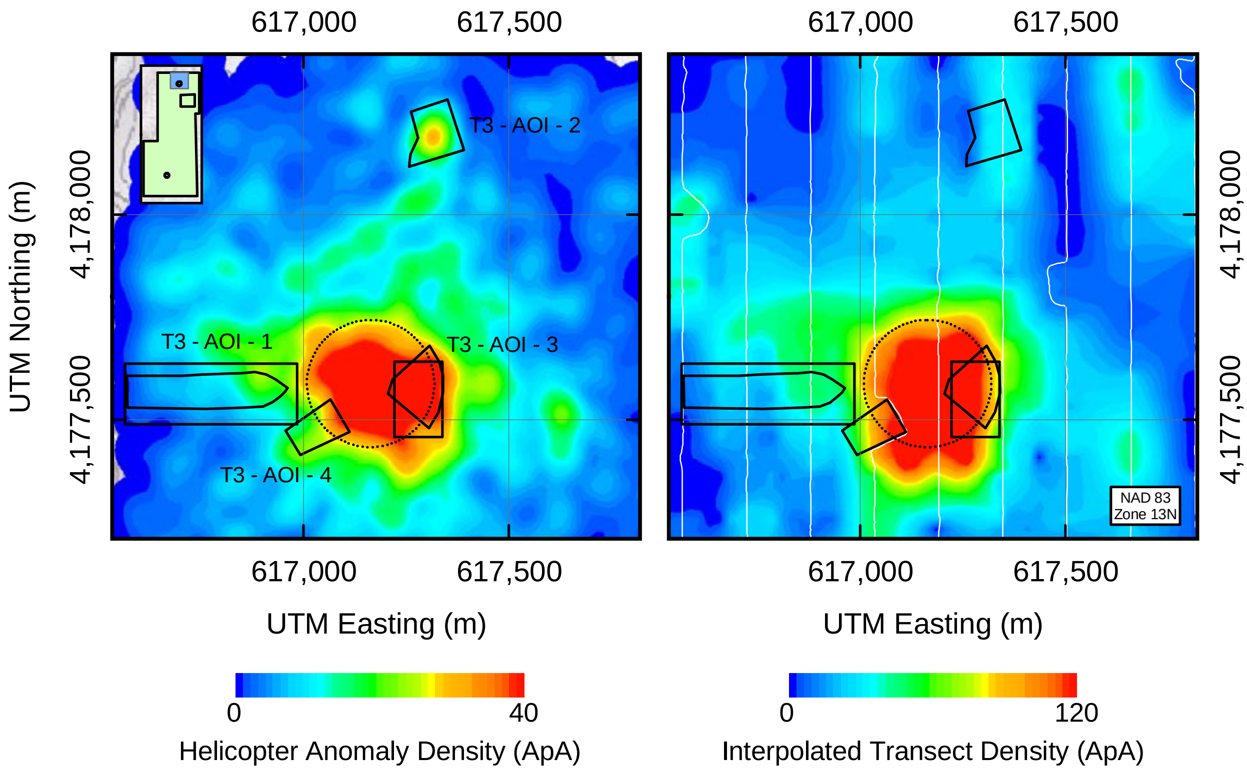


Figure 4-8. Helicopter magnetometer anomaly density contours from Target #3 are shown on the left. Estimated anomaly densities from ground-transect data are shown in the right from the area near Target #3. The actual transect course over ground is shown as white lines. Elevated anomaly densities are seen at the target circle in both data sets.

In addition to the target circles, four AOIs (T3-AOI-1 to T3-AOI-4) were identified from the high-airborne data in the vicinity of Target #3. As shown in Figure 4-7, an outline of a partial ship-shaped figure to the west of Target #3 (T3-AOI-1) was identified in the high-airborne data. Multiple lines of evidence support the conclusion that the identified shape is not munitions related. This AOI differs from the ship-shaped AOIs in the Target #4 area that are clearly munitions related. The outline is indented rather than raised, as was more typical of targets. In addition, the AOI's approximate 300 m × 100 m size is much larger than the other ship targets found on this site (i.e., ship target T4-AOI-1, which is approximately 200 m × 30 m). The elevated anomaly density seen inside this AOI was determined to be spillover from the adjacent main bombing target.

A raised area north of Target #3 (T3-AOI-2) was identified in the high-airborne data, as shown in Figure 4-7. Collectively, the WAA data could not definitively identify this AOI. The validation results (below) were used as the primary source to judge it is not munitions related.

An indented area with cell-like structures (T3-AOI-3) was identified within the target circle in the high-airborne data, as shown in Figure 4-7. In Figure 4-8, the anomaly density contours for the helicopter magnetometer and the estimated anomaly densities from ground-based transect data show elevated anomaly concentrations that are attributed to its location inside the target circle. This feature is in an area where munitions-related activity occurred, but the specific use of the feature is unclear.

A fenced area that bisects the outer target circle (T3-AOI-4) was identified in the high-airborne data, as shown in Figure 4-7. Multiple lines of evidence support the conclusion that this feature is not munitions related. Helicopter magnetometry identified the fence. Ground-based transects could not survey this AOI because the fence completely enclosed the area but the density was estimated from the surrounding transects as shown in Figure 4-8.

4.3.1.2 Validation

The validation results for Target #3 support the location of the target circle and confirm practice bombs were used on this target. Practice bomb scrap was found in and surrounding the target circle during the intrusive investigation and ground reconnaissance, which is consistent with the original CSM. Figure 4-9 shows the intrusive investigation results.

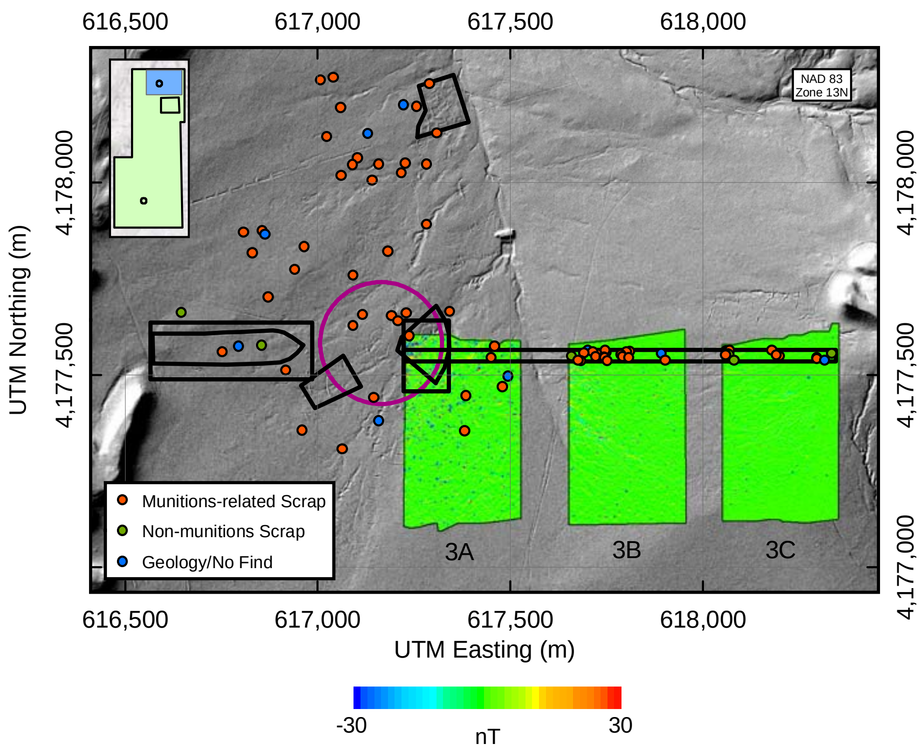


Figure 4-9. The intrusive investigation results associated with Target #3, along with three 100% coverage ground-based magnetometer surveys (3A, 3B, 3C). A reduction in the concentration of anomalies is observed in the 100% coverage areas from area 3A eastward. Munitions-related items were found in the intrusive investigation, including in 3C which is farthest from the target.

The LiDAR data revealed a number of depressions in and near the target circle, as seen in Figure 4-7. The ground reconnaissance team visited, measured, and searched the depressions with a hand-held metal detector. The team located the circular depressions and found no HE fragments. In addition, the diameter and depth of the depressions were not consistent. The team noted erosion and man-made soil movement, such as holes dug to construct nearby erosion-control berms, are potential sources of the depressions. All evidence found in this assessment indicated that only practice bombs were present at this target. It cannot be ruled out, however, that a small number of HE munitions may be present.

The validation results also support the WAA data conclusions for each of the AOIs. The ground reconnaissance crew noted the features identified near the ship-shaped T3-AOI-1 were likely related to agricultural activity. The ground reconnaissance and intrusive investigation both revealed practice bomb scrap at T3-AOI-1. The presence of these items confirms the WAA data conclusion that the elevated concentration of ground-based magnetic anomalies is likely spillover from Target #3, due to its proximity to that target.

Munitions-related scrap associated with practice bombs was found during the intrusive investigation of the raised area to the north of Target #3 (T3-AOI-2), but no munitions-related scrap was observed during the ground reconnaissance. The ground reconnaissance team located trenches and berms, but was unable to determine their use.

Practice bomb scrap was found during the ground reconnaissance and the intrusive investigation of the cell-like structures (T3-AOI-3) located within the target circle. The ground reconnaissance team located the cell-like features but was unable to confirm their specific usage. The validation results support the WAA data conclusion that munitions-related activity occurred on the cell-like structures because it is located within the target circle, although the specific use of the feature itself is unclear.

An intrusive investigation of the fenced area (T3-AOI-4) was not conducted, but practice bomb scrap was found on the surface during ground reconnaissance. During a WAA program site visit, the landowner said the fenced area was constructed to keep cattle away from newly planted trees. The validation results support the WAA data conclusion that this feature is not munitions related.

To define the extent of the target area, three areas of 100% coverage ground-based magnetometer data were collected near the target center radiating eastward (3A, 3B, 3C), as shown in Figure 4-9. An analysis of anomaly density in a series of 30 m × 30 m cells across these areas found that anomaly density as a function of distance dropped off significantly at about 400 m from the target center (anomalies are the black symbols in Figure 4-10). The helicopter magnetometer data were plotted in the same fashion, resulting in a similar density drop-off (helicopter anomalies are the green symbols in Figure 4-10). These distributions led to an expectation that the edge of this target could be defined by the significant drop in the anomaly density to what appeared to be a level site background density. Using this model, the anomalies in 3B and 3C were expected to be background anomalies. Intrusive sampling found practice bomb scrap, along with cultural clutter and geology, in all three areas.

4.3.1.3 Target Boundary Decision

Munitions-related items are found beyond the obvious density drop-off, and the anomalies associated with Target #3 extend farther than a simple reading of Figure 4-10 might indicate. Figure 4-11 presents the helicopter magnetic anomalies and the estimated anomaly densities from the ground-transect data. The blue boundary on the helicopter magnetometer figure encompasses 95% of anomalies detected above site background. The boundary does not represent an attempt to include every anomaly; by definition 5% of the population of anomalies are outside this area, and the area ultimately requiring action must be refined by more detailed characterization. The orange line on the ground-transect-derived estimated anomaly density plot bounds the area where the anomaly density is above the threshold of 18 anomalies per acre derived by fitting the cumulative anomaly density histogram to two distributions (representing background and target). The contours on the map correspond to anomaly density at or below the average site background, above average background but below the target threshold, and above the threshold. These boundaries do not imply isolated munitions are not present on the remaining land. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

The ground-transect-derived boundary was selected as final boundary for Target 3 because it encompasses the larger area and is more conservative. The bounded area is approximately 660 acres and contains an estimated 14,500 anomalies detectable by a ground-based sensor, which will serve as inputs to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

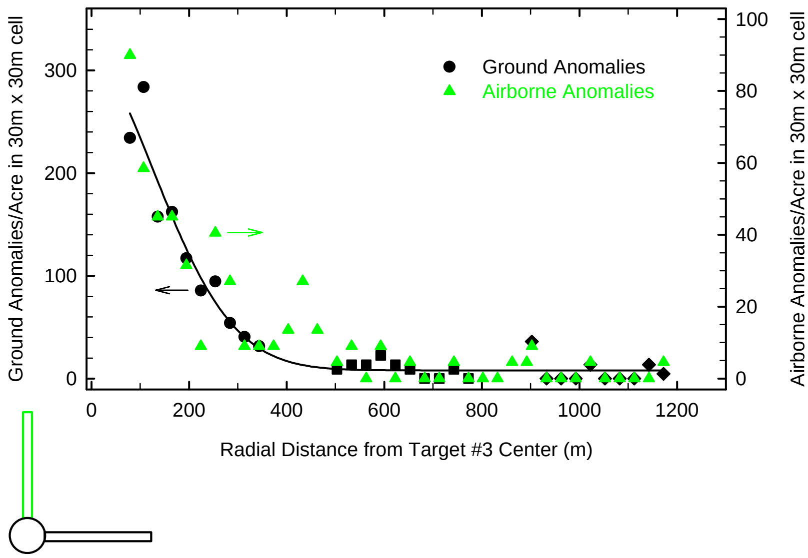


Figure 4-10. Magnetic anomaly densities as a function of distance from the center of Target #3. The ground-based anomaly densities were determined from a swath across the top of the total coverage areas. The black symbols are the densities in each 30 m × 30 m cell, and the line is a fitted function. The helicopter anomaly densities are the plotted green symbols. Both plots show a similar density drop-off as distance increases from the target.

4.3.2 Suspected 75-mm Target (Central Study Area)

The suspected 75-mm target area was included in the Archives Search Report based on an interview with a landowner who reported that a 75-mm round was found in this central section of the WAA study area. The location of this suspected target in relation to the entire study area is noted in the inset in Figure 4-12. The location of this target area is slightly shifted in the inventory reported in 2006 Defense Environmental Program report, although no additional work was done to support this. (Ref. 32). The Archives Search Report boundaries were used for this study.

4.3.2.1 Data Analysis, Interpretation, and Evaluation

The WAA data layers provide no evidence that a 75-mm target is located in the study area. As shown in the figure, the high-airborne data do not show any munitions-related features. Both data sets show the deep wash that cuts across the site. The roughness of the terrain surrounding the wash is clearly observed in the LiDAR image. Numerous trees are apparent in the orthophotograph.

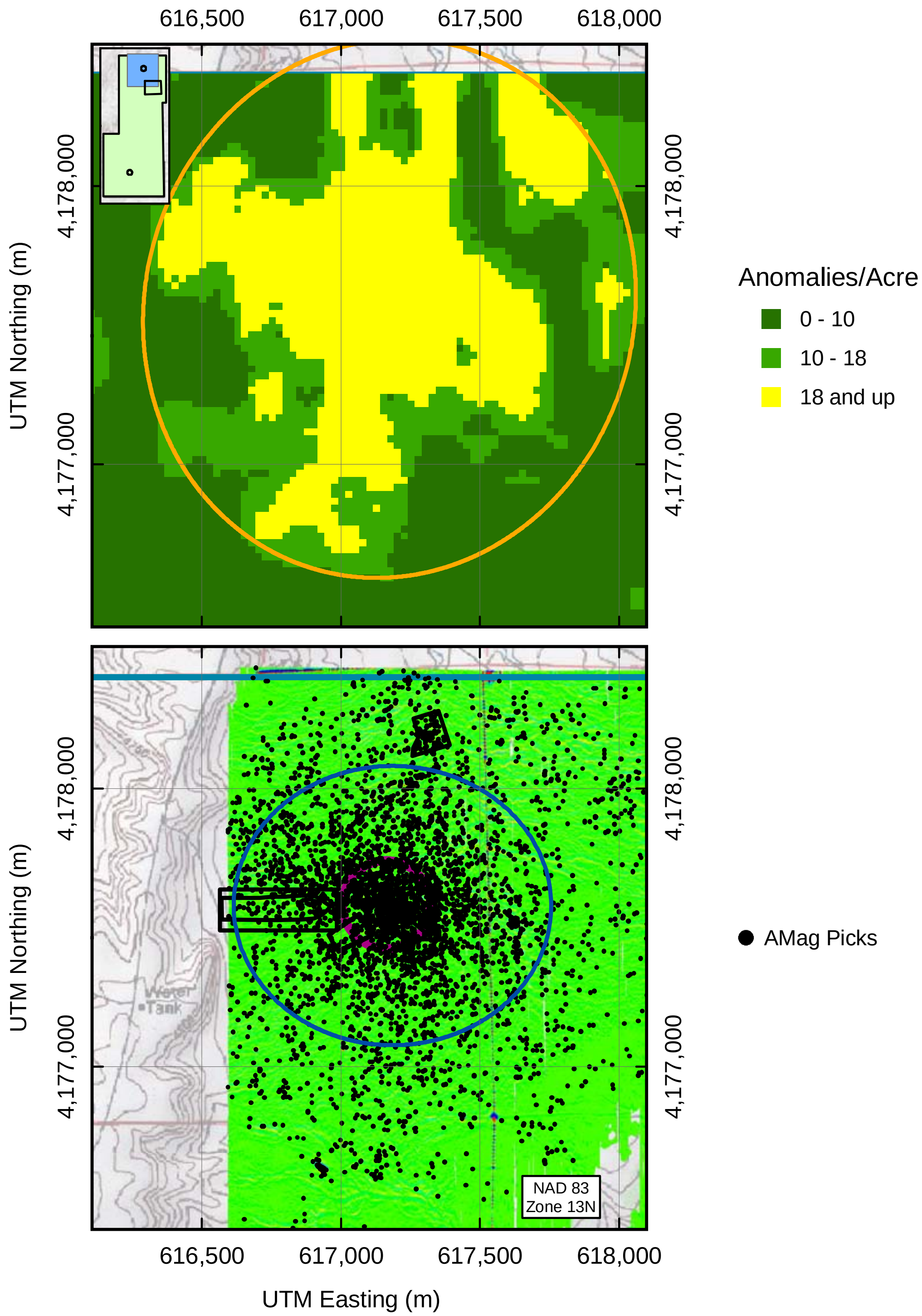


Figure 4-11. The ground-system magnetic anomaly density contours (top), with the breaks in density corresponding to site background density and the density cutoff for target delineation, and the helicopter magnetic anomalies (bottom). The boundaries represent 95% of the anomalies above site background for the helicopter magnetometer data set and the extent of estimated anomalies above background for the ground-transect data. The ground-transect boundary is larger and is used as the final conservative boundary for this target (as seen in Figure 4-30).

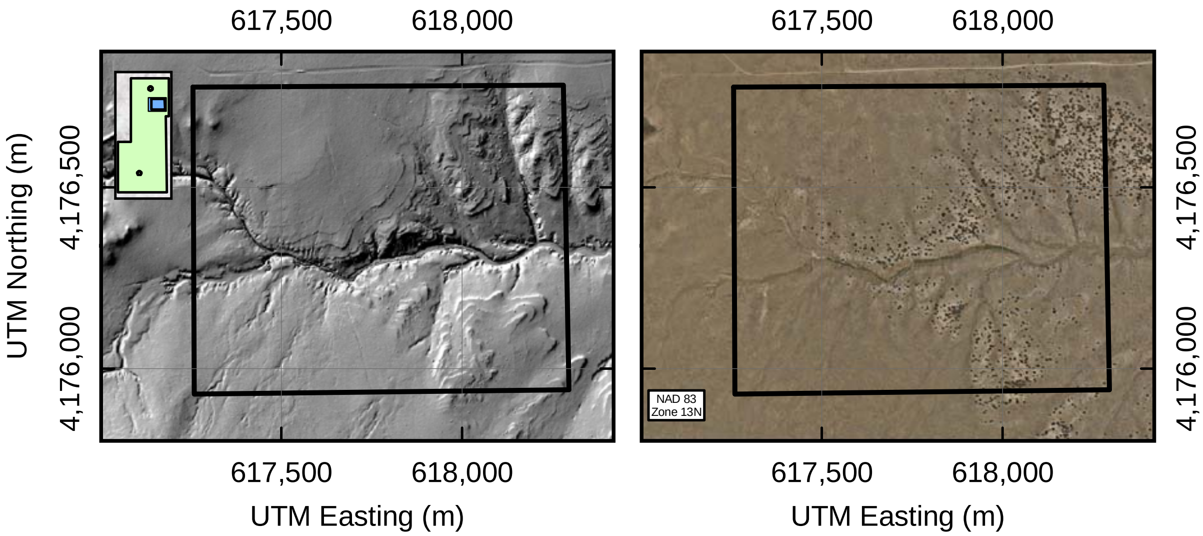


Figure 4-12. LiDAR (left) and orthophotography (right) data from the suspected 75-mm range. No munitions-related features are seen in either data set. The extent of the deep wash is clearly visible in the LiDAR data, and numerous trees are visible in the orthophotograph.

The combination of rough terrain and a substantial number of trees limited the coverage of the helicopter magnetometer array and, to a lesser extent, the ground-based system, as shown in Figure 4-13. Only data collected when the helicopter was below 3 m in altitude are plotted in Figure 4-13. Any data collected at a higher altitude exceed the offset distance where a reasonable probability of detection can be expected for 75-mm rounds. No concentration of anomalies that would indicate a target area is observed in either data set. Small data gaps were investigated on foot with a hand-held magnetometer.

4.3.2.2 Validation

The validation results support the WAA conclusion a 75-mm target is not located in this area. All areas that were inaccessible to the helicopter and ground systems were investigated on foot. A visual inspection of the wash, supplemented with a hand-held magnetometer, found no evidence of a 75-mm target (Figure 4-14). A ground team also investigated 50 randomly selected trees to determine if munitions-related items were located in these inaccessible areas. Metal was detected under three trees, as seen in Figure 4-15. None of the items were related to 75-mm munitions.

Two areas of 100% coverage ground-based magnetometer data, shown in Figure 4-15, were obtained in and near the suspected 75-mm range to confirm the conclusion that no concentrations of anomalies are located in this part of the site. Area A is on the northern edge of the 75-mm area. Area B, to the south of the 75-mm area, was intended to serve as a background baseline. All anomalies in coverage areas A and B were intrusively investigated. Scrap related to practice bombs was found in area A at higher concentrations than in area B. In addition, ground reconnaissance identified a few scrap items from practice bombs. The munitions-related scrap in both areas is thought to be due to a low density of isolated individual items, likely from nearby Target #3.

Subsequent interviews with landowners during the data collection revealed that the original 75-mm round that led to the creation of the potential target area in the Archives Search Report was, in fact, found well outside of the WAA study area.

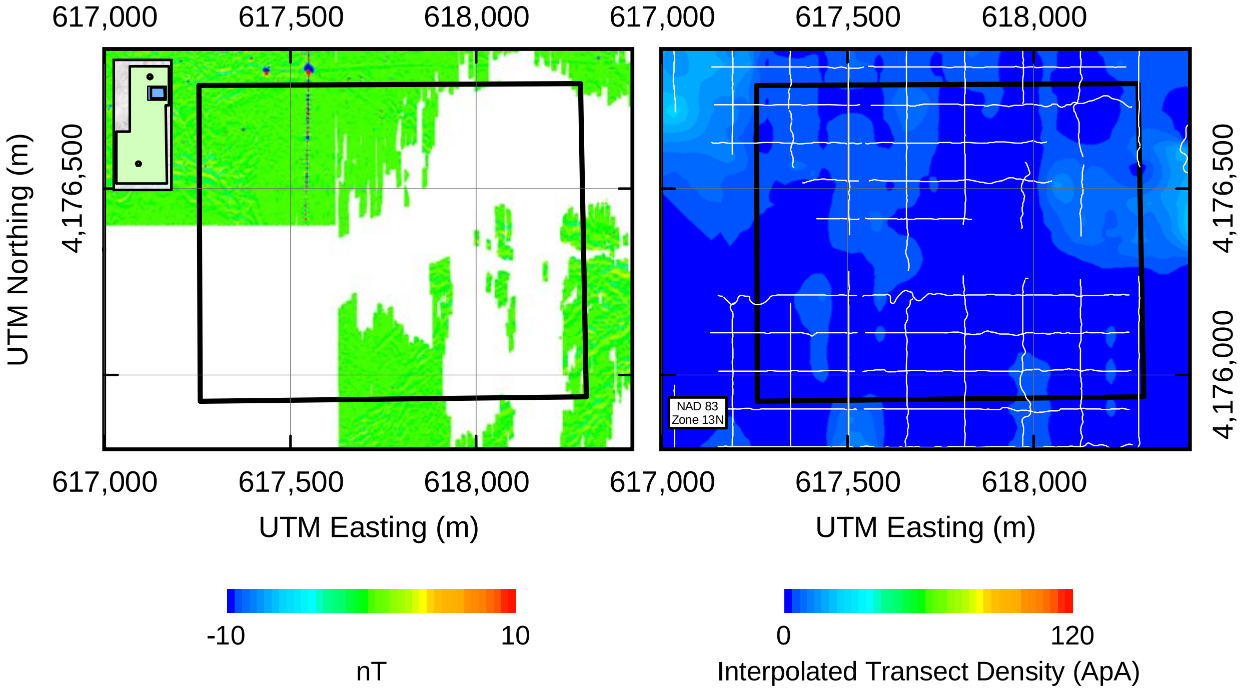


Figure 4-13. Helicopter magnetometer data from the suspected 75-mm target are shown on the left. Estimated anomaly densities from ground-transect data are shown on the right with the transects as driven in white. Each image indicates the areas that could not be surveyed due to the terrain and/or vegetation. There are no concentrated areas of anomalies in either data set.

Figure 4-14. Areas in the suspected 75-mm range that were inaccessible due to the vegetation or terrain were investigated on foot. A visual inspection was conducted, supplemented with a hand-held magnetometer, and no evidence of a 75-mm target was found.

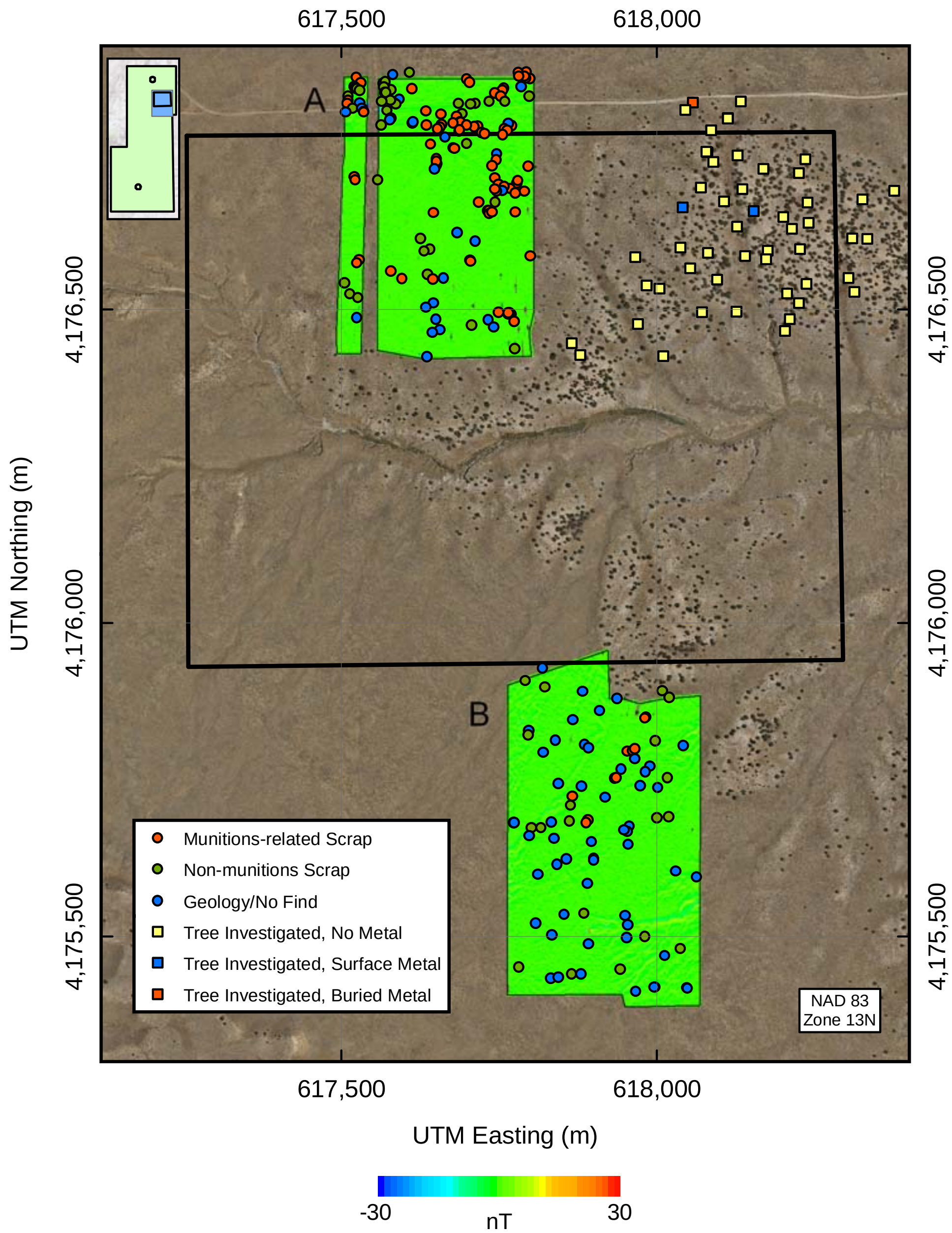


Figure 4-15. Areas of 100% coverage ground-based magnetometer data (A, B) and the intrusive investigation results in the suspected 75-mm target area. Munitions-related scrap related to 100-lb practice bombs was found in both 100% coverage areas. No munitions-related scrap was found beneath the trees that were investigated.

4.3.3 Target #4 (Southern Section of Study Area)

Bombing Target #4 is located in the southern part of the WAA site. The location of this target in relation to the entire study area is noted in the inset in Figure 4-16.

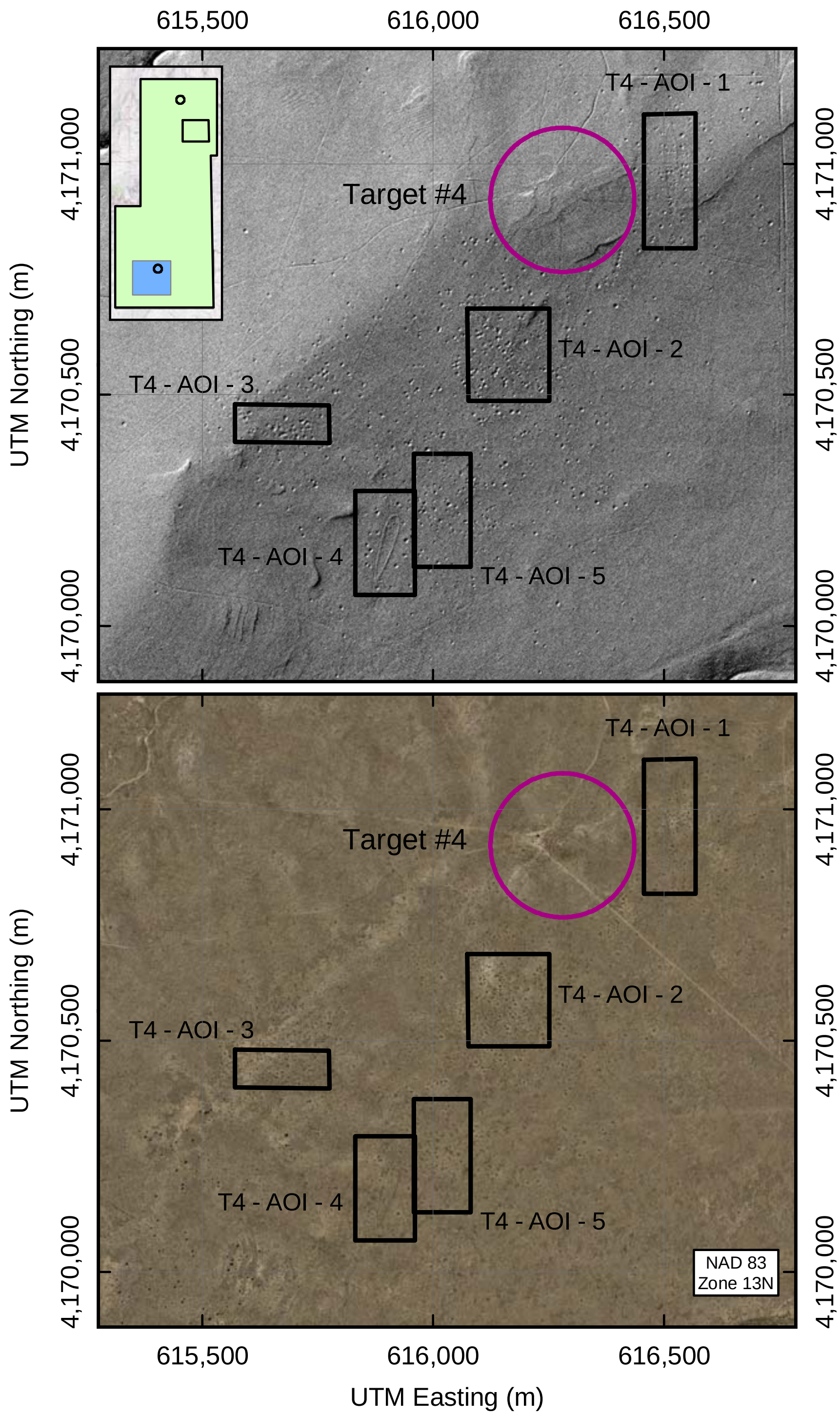


Figure 4-16. LiDAR (top) and orthophotography (bottom) images of the area around Target #4. The target circle and the AOIs are labeled. The craters are clearly visible in the LiDAR data.

4.3.3.1 Data Analysis, Interpretation, and Evaluation

All the WAA data layers confirm the location of Target #4 and show it is more complex than was indicated in the historical records and extends further to the southwest than expected. The 1,000-ft diameter target circle and numerous craters are clearly evident in the high-airborne data and five additional AOIs that contain ship-shaped targets surround the central target circle in the figure.

Initially, four ship-shaped AOIs (T4-A0I-1 to T4-A0I-4) were identified in the analysis of the high-airborne data (see Figure 4-16). Analysis of the crater pattern revealed an additional area of high crater density, which was further investigated in the LiDAR data to reveal an additional ship target (T4-AOI-5). Its presence was confirmed in a historical photograph. The magnified high-airborne data in Figure 4-17 show an example of a ship-shaped target.

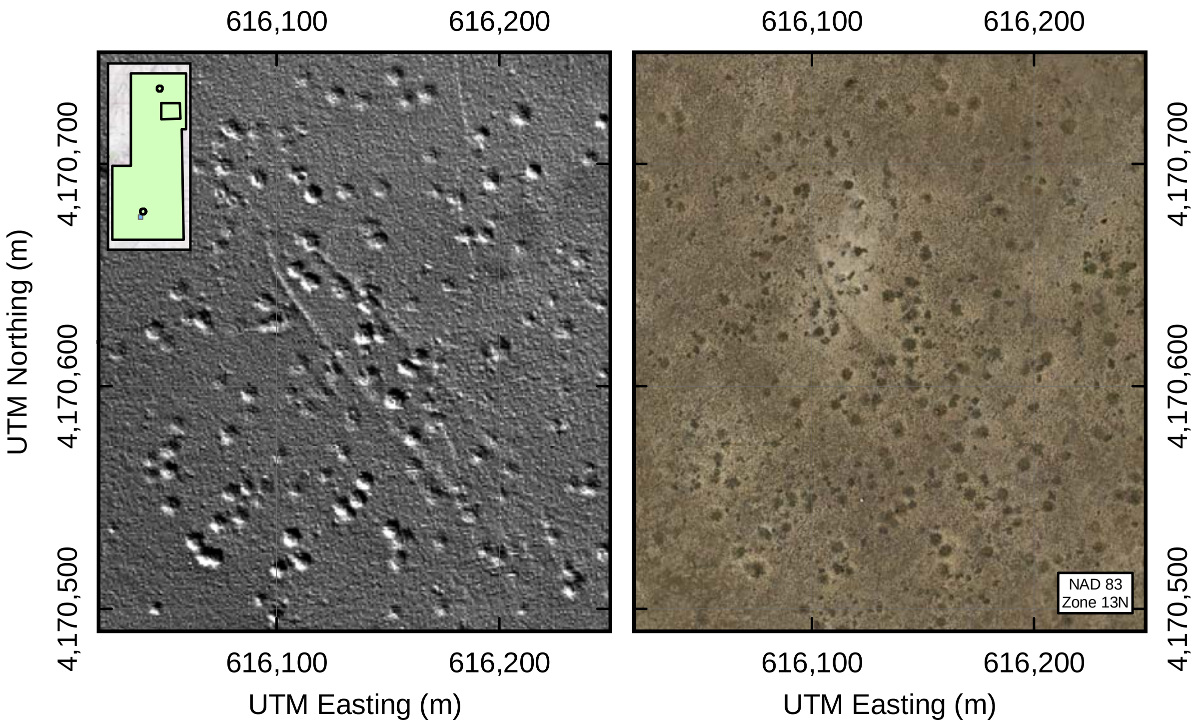


Figure 4-17. T4-AOI-2 LiDAR data (left) and orthophotography data (right) from Target #4. The ship-shaped target and the craters are visible in both data sets.

The LiDAR data show extensive craters in the area of Target #4, consistent with the use of HE bombs on this target as noted in the CSM. No craters are evident inside the target circle or the most prominent ship target, but both are surrounded by craters that extend to their edges. This suggests the area inside the circle and this ship target were cleared and perhaps bulldozed as part of a surface clearance.

The anomaly density contours for the helicopter magnetometer and estimated anomaly densities from ground-transect data (Figure 4-18) both show concentrated areas of anomalies that can be associated with either the main target circle or the auxiliary ship-shaped targets seen in the orthophotography and LiDAR images. These data show concentrated anomalies both inside and immediately outside the target circle and the ship target where no craters are seen, which supports the theory that both were heavily used and subsequently cleared.

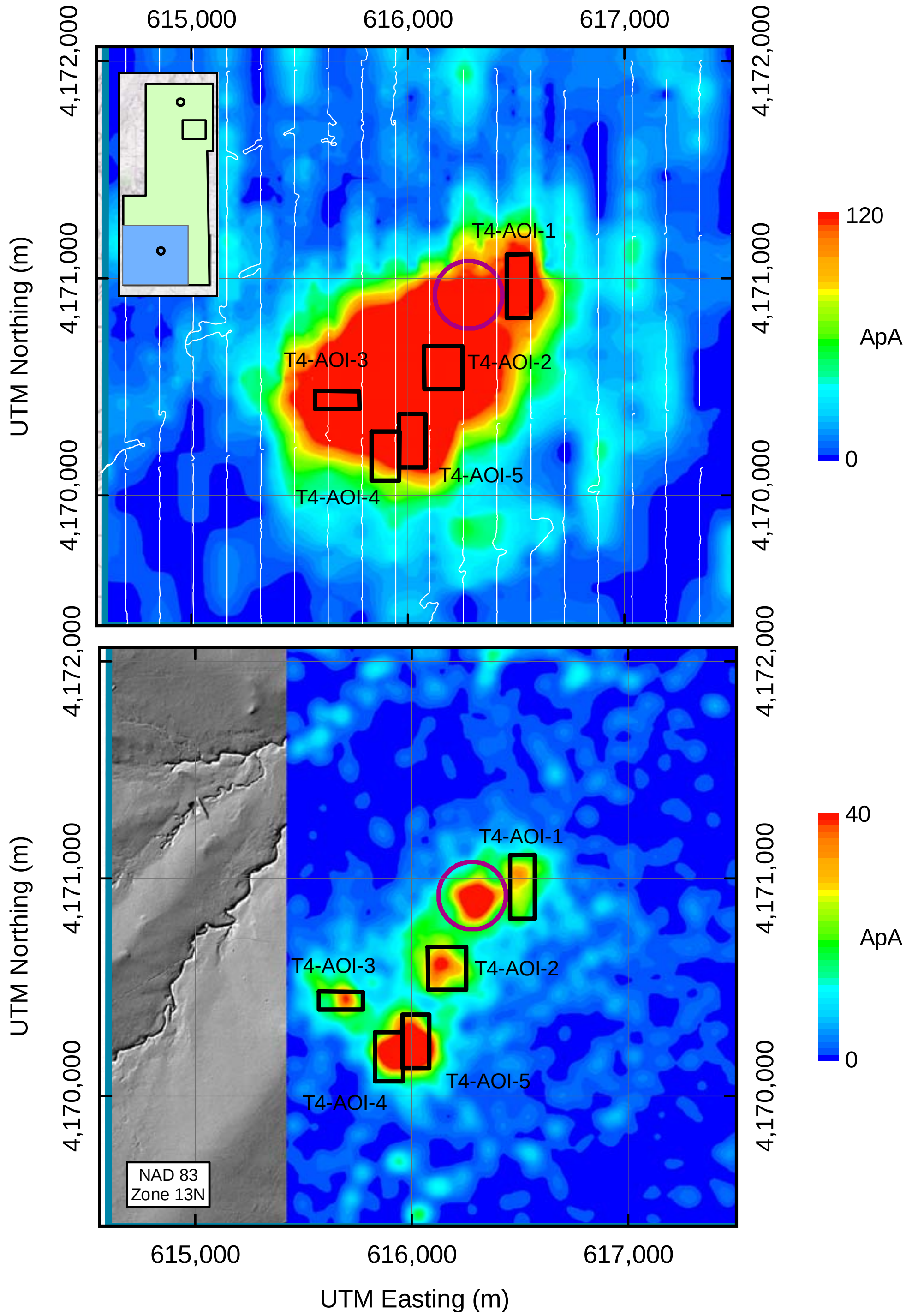


Figure 4-18. Estimated anomaly densities from the ground-transect data with the transects shown as white lines (top) and the helicopter magnetometer data (bottom) for the area around Target #4. High concentrations of anomalies in the ground-based transect data extend from the area surrounding the target circle to the southwest, which corresponds with the helicopter results.

4.3.3.2 Validation

The validation results for Target #4 support the location of the target circle and the ship-shaped targets and confirm the target area is more complex and extensive than historical records indicated. Figure 4-19 shows the intrusive investigation results. Anomalies were selected for validation from the helicopter magnetometer data including numerous samples inside the target ring and several ship-shaped targets. During the intrusive investigation and ground reconnaissance, HE and practice bomb scrap were found in and surrounding the target circle and AOIs. Figure 4-20 is an example of practice bomb scrap that was recovered.

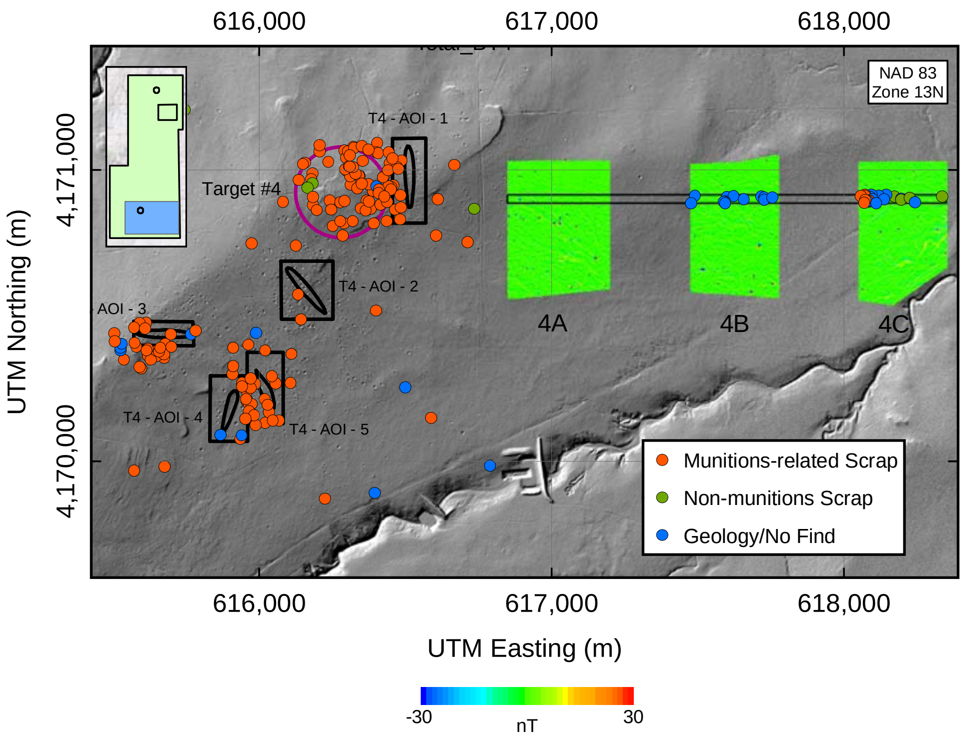


Figure 4-19. Areas of total coverage ground-based magnetometer data (4A, 4B, and 4C), along with the intrusive investigation results for Target #4. Munitions-related scrap was found in and surrounding the target circle and the ship-shaped targets and also in the farthest coverage area, 4C. Area 4A was not intrusively investigated.

Figure 4-20. Practice bomb scrap recovered from the Target #4 intrusive investigation.

The ground reconnaissance team verified subtle berms that compose sections of the ship outlines for all AOIs except T4-AOI-3. The remnants of this feature were so subtle it could not be seen by visible inspection. The LiDAR images revealed features that would not be found by a ground team site visit.

Selected depressions identified during the LiDAR analysis were visited, measured, and searched with a hand-held metal detector by the ground reconnaissance team. The depressions were determined to be munitions related: the crater depths and diameters were roughly the same size, and munitions-related scrap, including HE fragments, was found in many of the craters that were investigated.

Three areas of total coverage ground-based magnetometer data (4A, 4B, 4C) were collected beyond the eastern edge of the target to explore the extent of the target (see Figure 4-19). A plot of density versus radial distance was made from each total coverage area, as was done for Target #3. The analysis of anomaly density from these areas shows a significant drop-off in density at about 800 m from the target center to a level that appears to represent site background. Using this model, it was expected the items beyond this point would be non-munitions items.

Intrusive sampling was not performed on area 4A. Because the area was so near the target center, munitions-related items were expected, and little information would be gained in confirming their presence. Intrusive sampling was conducted on 4B and 4C. In the subset of items sampled in 4B, primarily geologic items were found. Munitions-related scrap was found in 4C, the area farthest from the target. It is expected munitions-related scrap is also present in 4B, but none was encountered in the small number of items dug.

4.3.3.3 Target Boundary Decision

As before, the presence of munitions-related items in 4C shows the edge of the target is more difficult to assess than a simple reading of a density fall-off plot would indicate. Figure 4-21 presents the helicopter magnetic anomalies, the crater density distribution, and the anomaly density contours created from the ground-based magnetometer data. The shapes of the boundaries drawn on the figures reflect multiple overlapping target centers encompassed in the target complex.

The blue boundary on the helicopter magnetometer data map encompasses 95% of anomalies detected above site background. The orange boundary around the crater density contour was created to encompass all areas with crater density greater than 2 per acre. The boundaries do not represent an attempt to include every anomaly; by definition, 5% of the population of magnetic anomalies and isolated craters are outside the bounded areas, and the ultimate area requiring action must be refined by more detailed characterization. The orange line on the ground-transect-derived density-contour plot bounds the area where the anomaly density is above the threshold derived by fitting the cumulative anomaly density histogram to two distributions (representing background and target). The contours on the map correspond to anomaly density at or below the average site background of 10 anomalies per acre, above average background but below the target threshold, and above the threshold of 18 anomalies per acre. These boundaries do not imply that no isolated munitions are present on the remaining land. It is beyond the scope of WAA to identify isolated single munitions or munitions-related items.

The boundary derived from the ground-based transect data encompasses the largest area of the three data sets and was selected as final conservative boundary for Target 4. Since this is an HE target, this is not unexpected. The ground system is more sensitive and will see fragments the helicopter system will not. These fragments will be more dispersed from the aim point than larger ordnance scrap, so a larger area is expected from the ground-based data. The bounded area is approximately 800 acres and contains an estimated 55,000 anomalies detectable by a ground-based sensor. This information will serve as input to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

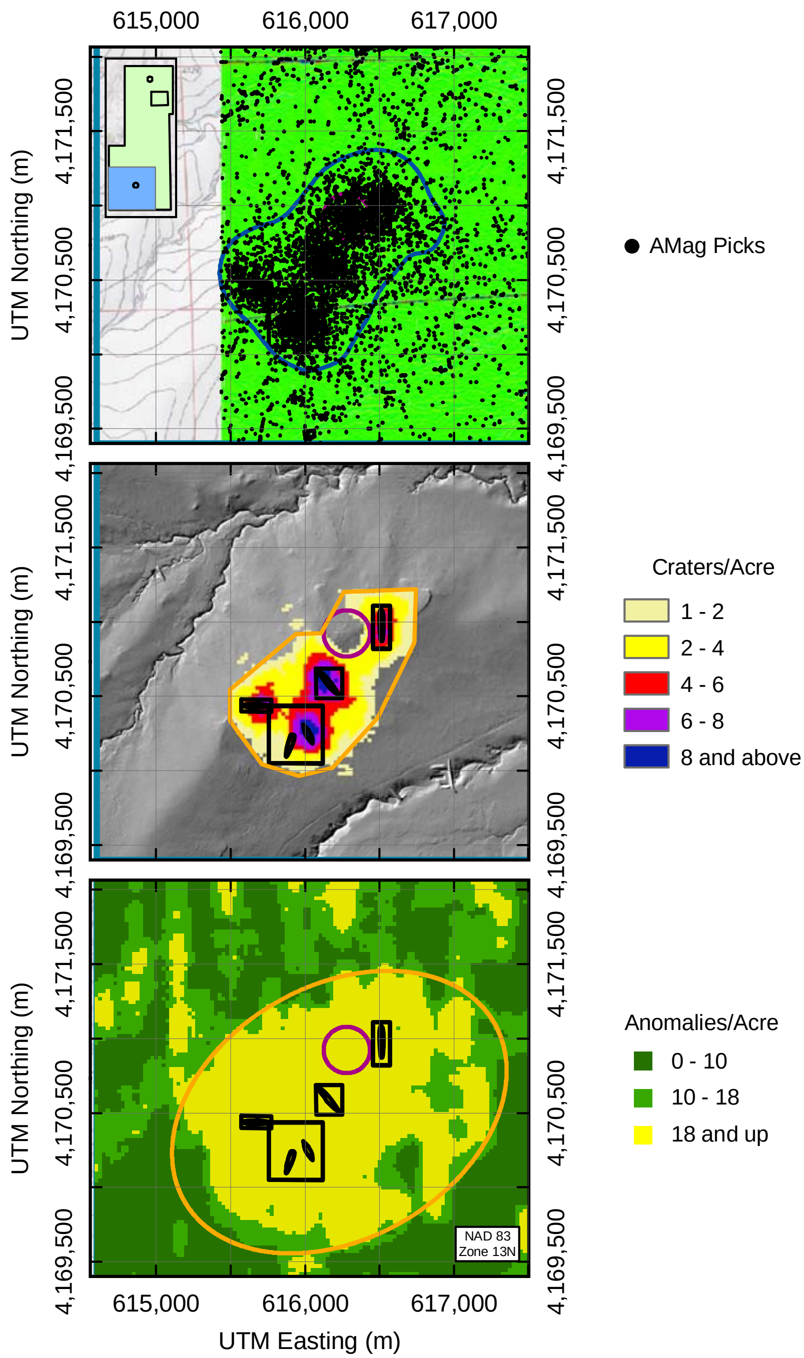


Figure 4-21. The helicopter magnetometer anomalies (top), the crater density contours (middle), and the estimated anomaly densities from the ground-transect data (bottom). The ground-based transect boundary is the largest and is the final conservative boundary for this target.

4.3.4 Simmons Area

A large area in the eastern central side of the site was chosen to investigate and quantify the naturally occurring background. The Simmons Area was so named because the Simmons family leases this land for its cattle. The location of the Simmons Area in relation to the entire study area is noted in the inset in Figure 4-22.

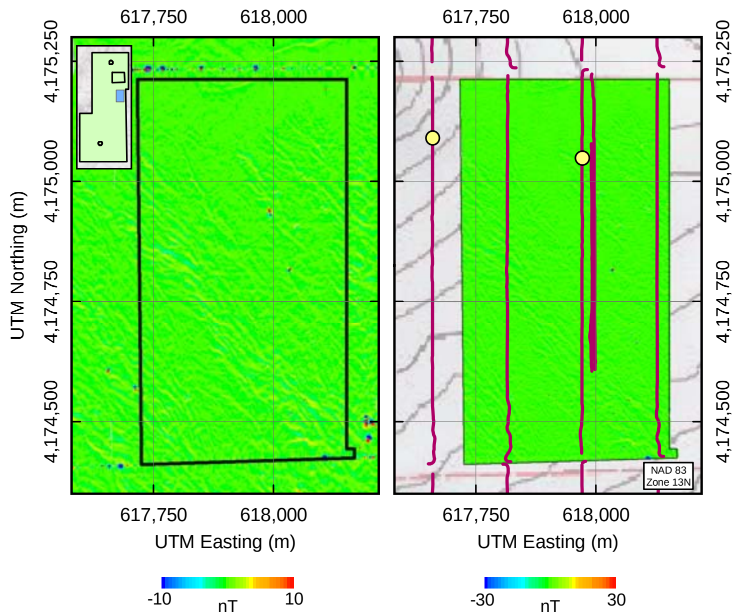


Figure 4-22. Helicopter magnetometer data (left) and 100% coverage ground-based magnetometer data with the transect results (right) from the Simmons Area (note the scale difference in the two plots). No concentrations of anomalies are present.

4.3.4.1 Data Analysis, Interpretation, and Evaluation

The Simmons area shows no features of interest in the high-airborne data sets and no concentrations of anomalies in any of the magnetometer data. The ground-based transects overlain on the 100% coverage ground magnetometer data are shown in the figure, along with the helicopter magnetometer data.

4.3.4.2 Validation

All anomalies identified within this area were intrusively investigated (see Figure 4-23). The threshold for selecting targets was set at the noise level, so the large number of no-finds is not surprising. Many of the items selected would never have been picked as likely targets. While the majority of the items found were geology, non-munitions-related scrap, or empty holes, five pieces of munitions-related scrap were found. None of the data suggest this area was the site of concentrated munitions use. Nevertheless, the presence of five munitions-related items at this great distance from the nearest target area illustrates the difficulty in drawing bright-line boundaries, outside of which no munitions are present.

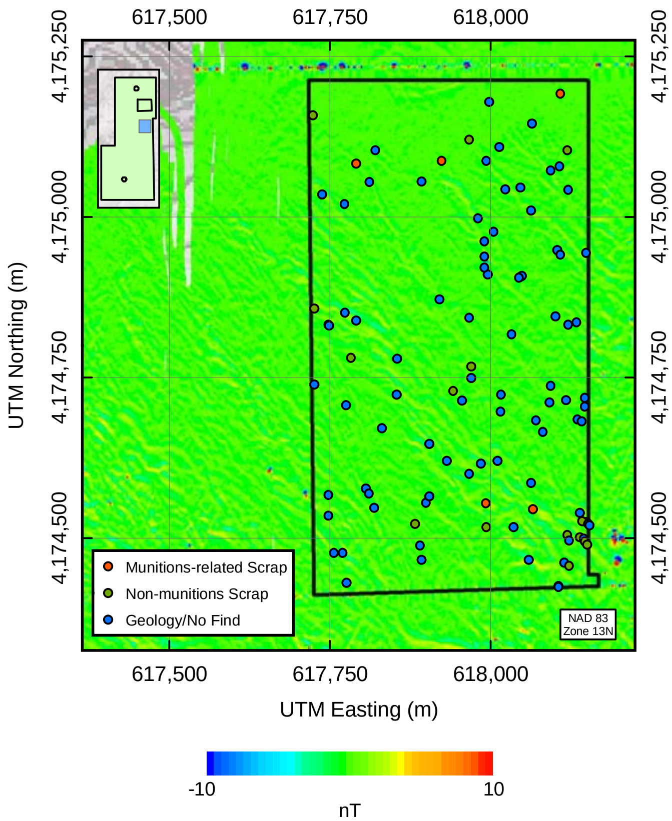


Figure 4-23. Intrusive investigation results from the Simmons Area overlain on the helicopter magnetometer data. The five pieces of munitions-related scrap found illustrate the difficulty in drawing boundaries that mark a true edge of target areas, outside of which no munitions are expected.

4.3.5 Remainder of the Study Area

A primary objective of the pilot program was to collect data to support decisions on areas that show no evidence of concentrated munitions use. The remaining land within the Pueblo PBR #2 WAA study boundary is not associated with specific target areas in the initial CSM. Three additional AOIs were identified within the study area, and multiple lines of evidence support the conclusion that these three AOIs are not munitions related. All other remaining land showed no indications of munitions use. The locations of the AOIs in relation to the entire study area are noted in the data figure insets associated with each AOI.

Out of the 7,500 acres surveyed, roughly 5,500 acres were found to be free of concentrated munitions use. At this site, this information can be used to support future munitions response actions for non-target areas, such as appropriate controls or consideration of no-further action decisions.

4.3.5.1 PBR-AOI-1—Berm

In Figure 4-24, PBR-AOI-1 appears to be a berm used to direct water runoff to the nearby basin and multiple lines of evidence support the conclusion that this AOI is not munitions related. A large berm-like feature is visible in the LiDAR image for PBR-AOI-1. There is no concentration of magnetic anomalies associated with this feature as can be seen from the helicopter anomaly density contours.

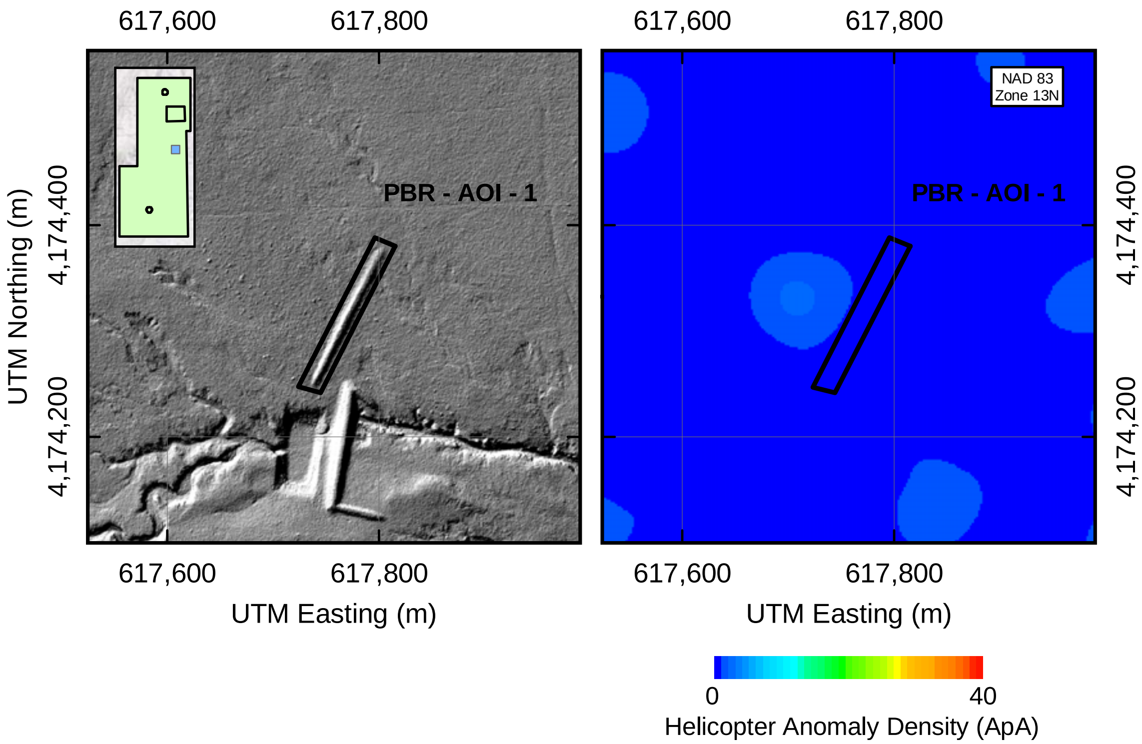


Figure 4-24. LiDAR (left) and helicopter magnetometer anomaly density contours (right) data showing the berm (PBR-AOI-1). There is no concentration of metal associated with this feature as seen in the magnetometer data. This feature is used to direct water into the basin to the south of the berm seen in the LiDAR data.

The ground reconnaissance team observed a berm that appears to direct water southward to a basin (see Figure 4-25). The ground reconnaissance team did not observe munitions-related scrap but did encounter a few pieces of metal that were not munitions related. Based on the findings from the ground reconnaissance, an intrusive investigation was deemed unnecessary in this area.

Figure 4-25. The raised berm (PBR-AOI-1), visible behind the ground reconnaissance team member, extends to the right.

4.3.5.2 PBR-AOI-2—Wooden Structure

Figure 4-26 shows a small structure within what appears to be concentric circles (PBR-AOI-2) identified in the LiDAR data. The helicopter magnetometer anomaly density contours seen in Figure 4-26 and the ground-transect data (not pictured) from this area show a significant concentration of magnetic anomalies associated with this structure. The WAA data are ambiguous for this AOI.

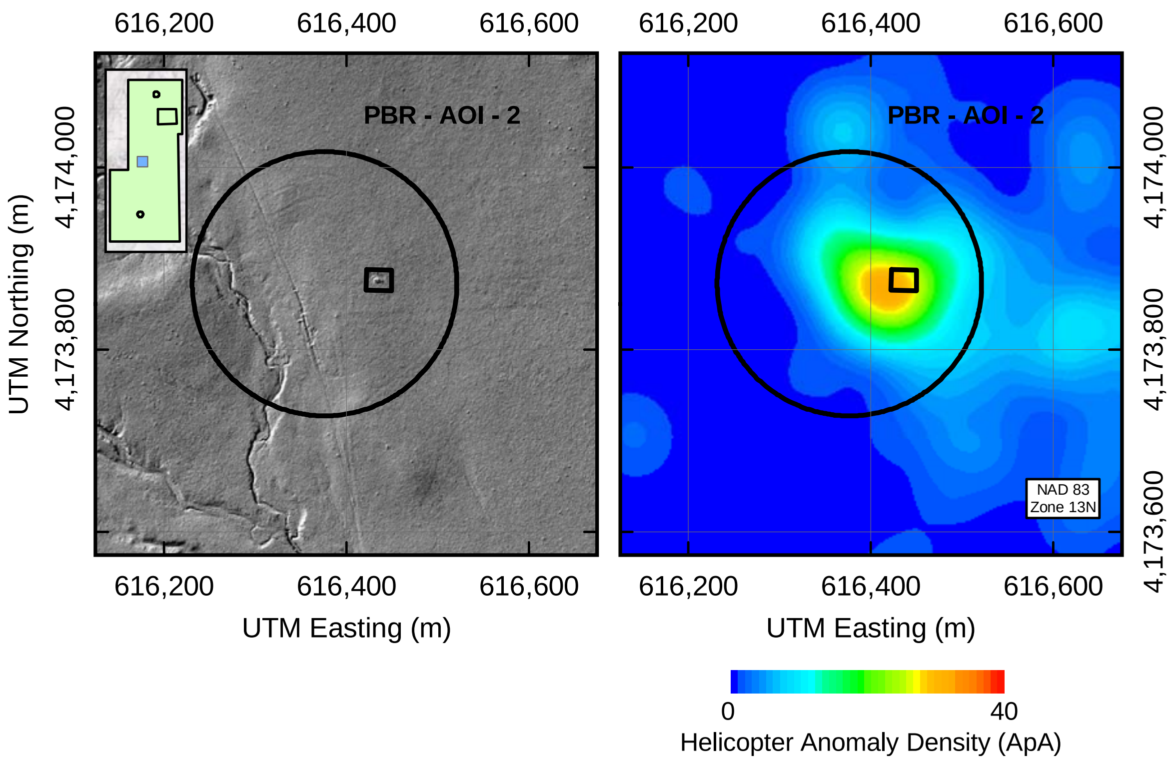


Figure 4-26. LiDAR data (left) and helicopter magnetometer anomaly density contours (right) showing the area denoted PBR-AOI-2. The magnetometer density map shows a high concentration of magnetic anomalies. This area is thought to be an old cabin, and the magnetic anomalies are attributed to remnants of ranch activities.

The ground reconnaissance crew located a dilapidated wooden structure, which is possibly a small cabin, as shown in Figure 4-27. No munitions-related scrap was observed, but abundant amounts of metal were found, including items such as a watering or feeding trough, pipes, and nails. The reconnaissance team assessed that this area is related to ranch activities, rather than munitions. The team did not observe circular features that correspond with the concentric circles that are visible in the LiDAR. A possible source of rings would be an irrigation pivot. The land owner did not permit an intrusive investigation in this area. The validation results are the primary source for the conclusion that this AOI is unlikely to be munitions related, but some small uncertainty remains.

Figure 4-27. Ground reconnaissance photo of the structure identified as PBR-AOI-2.

4.3.5.3 PBR-AOI-3—Large Depression

In Figure 4-28, the LiDAR data from PBR-AOI-3 show a significant depression on the western edge of the WAA site. In the same area, a concentration of anomalies is seen in the estimated anomaly densities from the ground-based transect data. The WAA data for this AOI are ambiguous.

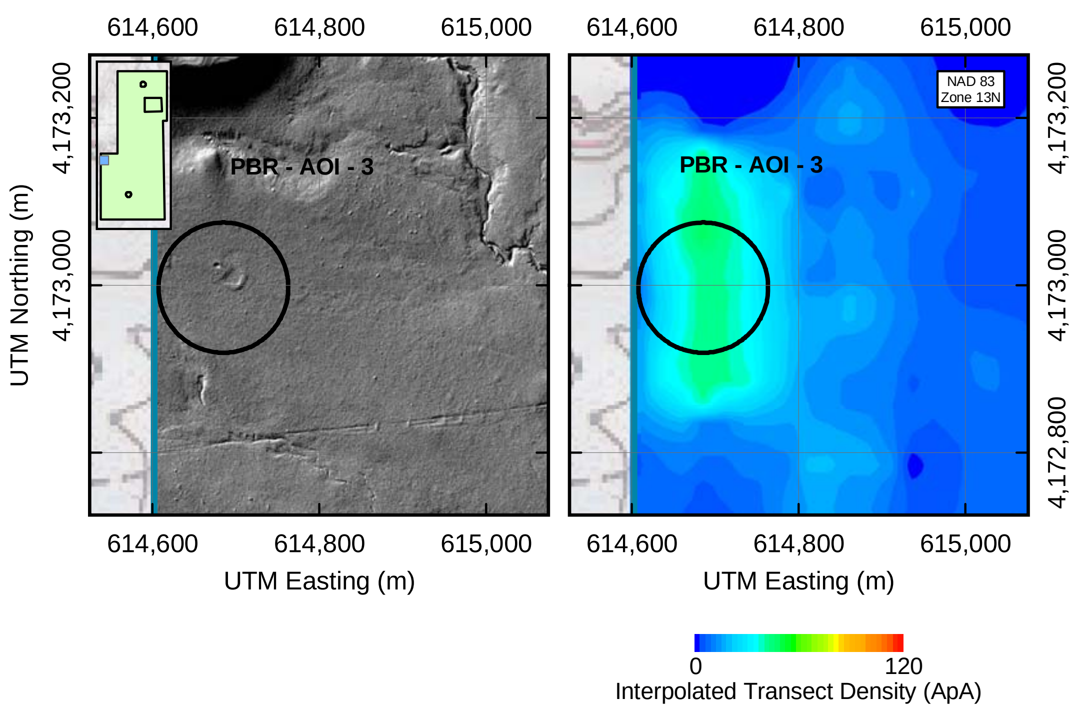


Figure 4-28. LiDAR data (left) and estimated anomaly densities from the ground-transect data (right) from the area denoted PBR-AOI-3. A broad depression is seen in the LiDAR data, and concentrated anomalies are seen in the ground-transect data. This area was determined to be an old water well and trough.

Figure 4-29 shows the remnants of an old water well and a concrete water trough observed by the ground reconnaissance team. The team also observed foundation stones and a piece of steel with handle and louvers. An intrusive investigation was not deemed necessary in this area based on the findings from the ground reconnaissance. The ground reconnaissance results are the primary source for the conclusion that this AOI is not munitions related.

Figure 4-29. Ground reconnaissance photograph showing the old water well and trough (PBR-AOI-3)

4.4 Conclusions from the Pueblo Demonstration

4.4.1 Site Conclusions

The Pueblo PBR #2 WAA study area was known to contain two precision bombing targets (Target #3 and Target #4) and suspected to contain a 75-mm air-to-ground target. The location of the last was initially identified as having a high level of uncertainty because it had been identified based on the report of a landowner finding a 75-mm round in the vicinity. Contradictory historical evidence suggested the 75-mm range was located outside of the study area. The results of the WAA data analysis, confirmed by the validation, provide a preponderance of evidence to support the following conclusions about the study areas.

Target #3

- The results are consistent with the initial CSM. All WAA data confirmed the location of Target #3. Munitions-related scrap located in the area confirmed the target area.
- The area of the target is estimated to be 660 acres with some 14,500 anomalies detectable by a ground-based sensor. Because the contrast between the target area and background densities is high, there is high confidence in these estimates.
- No evidence of HE bombs was found at this target, consistent with the historical information. No munitions-related craters were seen in the high-airborne data, and only practice bomb scrap was located during the ground reconnaissance.

Suspected 75-mm Target

- WAA resolved the uncertainty in the initial CSM. WAA determined a 75-mm target is not located in the study area. Small gaps in the magnetometer data where the systems were unable to survey due to the terrain or vegetation were verified by a ground team inspection with a handheld magnetometer.

Target #4

- The results modified the initial CSM. All WAA data confirmed the location of Target #4, but also indicated a much more extensive and complex target area than suggested from historical records. Munitions and munitions-related scrap located in the area confirmed the target area.
- The boundaries of this target were substantially expanded to encompass five adjacent ship-shaped bombing targets. The entire complex target area encompasses 800 acres and contains some 55,000 magnetic anomalies detectable by a ground-based sensor. Because the contrast between the target area and background densities is high, there is high confidence in these estimates.
- WAA confirmed a mixture of HE and practice bombs were used on Target #4. The craters in the LiDAR confirm HE use, and practice bombs parts were found during reconnaissance.

Remainder of Study Area

- WAA confirmed that all the other areas within the Pueblo PBR #2 WAA study area not associated with specific target areas in the initial CSM show no evidence of concentrated munitions use.
- Out of the 7,500 acres surveyed, roughly 6,000 acres were found to be free of concentrated munitions use.

4.4.2 Technology Conclusions

The data analysis results from this site provide further insight into the capabilities and limitations of the demonstrated technologies.

4.4.2.1 High-Airborne Technology Conclusions

The high-airborne data were effective in identifying munitions-related features and other features:

- In general, the LiDAR data provide more informative images than the orthophotography data for this site. The munitions-related features, AOIs, and the general characteristics of the site are more clearly observed in the LiDAR data. The LiDAR was particularly useful in identifying target circles, ship-shaped targets, and craters. The presence or absence of craters is useful in determining whether the target was used for practice or HE bombs. Crater density contours support conclusions on the usage and extent of Target #4. Many features observed in the LiDAR data were too subtle to be seen on the ground.
- The most beneficial uses of orthophotography data on this site were in confirming the features identified in the LiDAR data and mapping vegetation that challenged the other technologies. No features were seen exclusively in the orthophotographs.

4.4.4.2 Low-Airborne Technology Conclusions

- The helicopter magnetometer data were successfully used to identify elevated concentrations of magnetic anomalies from surface and subsurface objects. Anomaly density analyses provided supporting evidence on the usage and extent of target areas.
- As a part of the validation process, selected anomalies in the helicopter data were successfully analyzed and excavated to provide information on the extent of the target and the types of munitions used on the site.
- Terrain and vegetation limitations of the low-airborne system were seen at this site. The system was not able to access the steep wash area in the suspected 75-mm target. In addition, a portion of the data collected on the suspected 75-mm target area was not usable because the trees required the helicopter to fly at an altitude where the system is not expected to detect 75-mm rounds.

4.4.4.3 Ground-based Technology Conclusions

- The ground-based transect data were successfully used to identify concentrations of anomalies. The combination of the ground-transect data and the VSP analysis were used to develop anomaly-density contours. These contours were used to develop the target boundaries for both Target #3 and Target #4.
- Approaches using dense and sparse transects, corresponding to conservative and less conservative assumptions about the target areas, were investigated. For this study, the sparse transects, which were planned based on information from the historical target ring size, were more than sufficient to locate the bomb target areas. The additional information from the dense transects in the suspected 75-mm range did not change the conclusion that no such range was present.
- As a part of the validation process, the ground systems surveyed 100% coverage patches. From these, selected anomalies were successfully analyzed and excavated to provide information on the extent of the target and the types of munitions used on the site. These areas were also used to produce an estimate of the anomaly density drop-off from each target.
- The ground-based towed system was also limited by the terrain and vegetation at this site, although to a lesser extent than the helicopter system. While the wash was inaccessible to the array, trees were well separated and could easily be avoided by the 2-m wide platform.

4.4.3 Combined Technology Conclusions

The contributions of the various data layers at this site are primarily observed by comparing the two types of targets.

4.4.3.1 HE Target Conclusions

The most useful data layers for detecting and characterizing the HE target were LiDAR, helicopter magnetometer, and the ground-based transect data.

- The high airborne data identified the aiming circle and the ship-shaped targets associated with Target #4, which provide evidence to the extent of the target boundary. Analysis of the crater pattern revealed an area of high crater density that did not correspond to an aiming circle or ship target. This area was further investigated in the LiDAR data to reveal an additional ship target. The HE craters were less prominent in the orthophotography data, and it is questionable if the additional ship-shaped target would have been located if only orthophotography were used.

- The ground-based transect data and helicopter magnetometer each detected the HE target. The helicopter magnetometer system was not able to survey small portions of the entire study area due to terrain and vegetation limitations. The contours from the helicopter data show more detail about local density variations within the larger target complex.

4.4.3.2 Practice Bomb Target Conclusions

All of the data sets successfully detected the practice bomb target (Target #3).

- Both high airborne data sets identified the concentric target circles. Depressions were identified in the LiDAR data. While these depressions were determined not to be munitions related, the fact they were identified in the LiDAR data and not the orthophotography data favors the use of LiDAR on this site.
- The helicopter magnetometer system and the ground-based transects were able to detect and characterize the practice bomb targets. These data sets are redundant and only one is needed to provide information on the extent of the target, even though they differ by roughly a factor of 3 in sensitivity.

4.4.4 Target Boundary Decisions

Figure 4-30 shows the boundaries created for Targets #3 and #4 based on data from the WAA pilot program. The Target #3 and Target #4 boundaries were created from the estimated anomaly densities from the ground-based transect data. These boundaries represent the areas of anomaly density above approximately twice the site background density of 10 anomalies per acre. The boundaries do not represent an attempt to include every anomaly associated with the target, and the area ultimately requiring action must be refined by more detailed characterization. These boundaries do not imply that no isolated munitions are present on the remaining land. It is beyond the scope of WAA to identify single munitions or munitions-related items.

The WAA pilot program data have been provided to support the ongoing site inspection on PBR #2. For areas that are selected to move to the investigative phase, the WAA data provide a wealth of information that is not currently available for characterizing the target areas. The calculated acreage and estimated number of anomalies in each target boundary will support munitions response planning, prioritization, and cost estimation. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity. Data characterizing this land can be used to support decisions on whether additional actions or controls are needed.

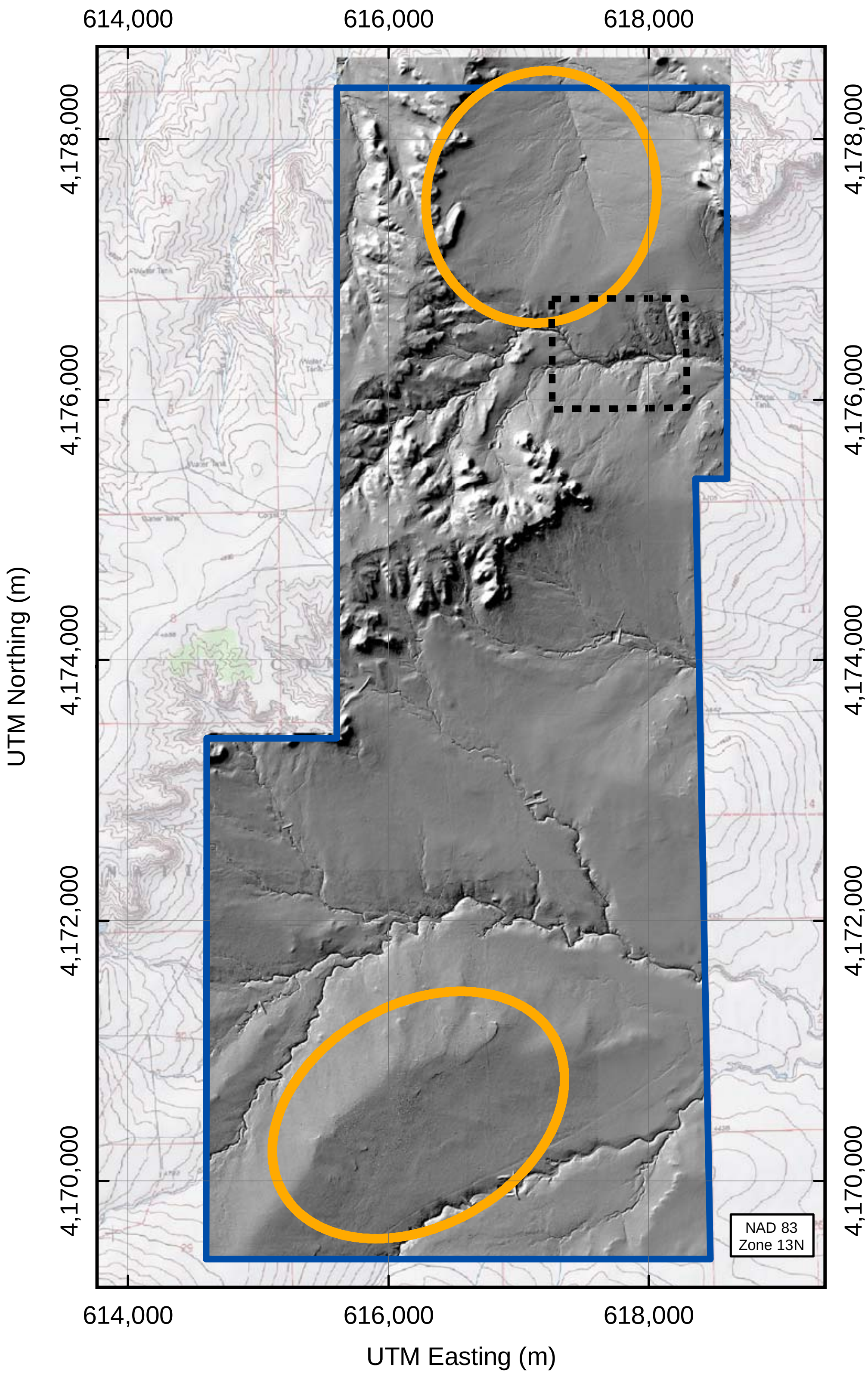


Figure 4-30. The orange boundaries encompass the best estimate of the target extent as established from the WAA data. The dotted black square indicates the suspected 75-mm target, which was determined not to exist in the study area.

5.0 FORMER KIRTLAND PRECISION BOMBING RANGE DEMONSTRATION

The former Kirtland PBRs were selected for this study because the site characteristics aligned with the pilot program objective to deploy the technologies on sites where capabilities and limitations could be demonstrated with limited interference from site-specific factors. The former Kirtland PBRs have generally flat terrain; limited vegetation, including shrubs and grasses*;* and moderate interfering geology. Historical records show the munitions types used were limited and larger munitions items were expected. The site contained known target areas, suspected target areas, and areas that were expected to be free of concentrated munitions use. The southern portion of the study area was chosen because it did not include any known target areas.

Currently, the former Kirtland PBRs are scheduled for a Remedial Investigation/Feasibility Study (RI/FS) in the DoD munitions response process. The information from WAA on these sites could be incorporated into the RI/FS and used by site managers and regulators to support future planning, prioritization, and cost estimation. The WAA data were analyzed to bound each target area and identify areas free of concentrated munitions use. For target areas, the total acreage and estimated number of anomalies associated with the bounded target areas are end products of this study that can be used to define the scope of the future remediation work. Secondary information such as the type of munitions used on each target and terrain and vegetation challenges can also serve as useful inputs to future planning. Characterizing the remaining land as free of concentrated munitions use will help the planning process and may guide regulatory decisions about the need for future actions.

5.1 Test Site History and Characteristics

The former Kirtland PBRs, which are part of a much larger set of bombing ranges used for training during World War II, are located 10 miles west of Albuquerque, New Mexico (see Figure 5-1). Shown in Figure 5-2 are two parcels totaling 5,000 acres that were selected for the WAA demonstration. The northern parcel contains several known and suspected targets, and the southern parcel does not contain any known targets. The following targets are in or near the WAA study area:

- The N-3 Impact Area, located in the northwest corner of the site, is a 1,000-ft diameter target circle used for 100-lb practice bombs and for scrap storage. A Certificate of Clearance, a standard document of that era, was issued for the target and scrap.
- The Simulated Oil Refinery Target is reported to exist in historical records, but the location is not specified. It is believed to lie northwest of the airport, which is visible in Figure 5-2, and was used for 100-lb practice bombs. Historical records document the target was visible in the aerial photo as a rectangular area 2,000 ft long in the east-west direction and about 500 ft wide in the north-south direction. The records state the rectangle is broken into cells, ranging in size from about 20 ft by 250 ft to 50 ft by 250 ft.
- The N-2 Impact Area is a target circle that was used for 100-lb practice bombs. It is near the airport, and a small part of it may become part of a future airport runway.
- The "New" Demolitions Impact Area is a target circle located adjacent to the N-2 Impact Area and near a road. It was used for HE bombs and probably was used more lightly than the other targets. The target circle is about 1,000 ft in diameter. While no intact HE bombs

have been found on the ground surface to date, a subsurface HE bomb was uncovered during gas line installation.

- The N-1 Impact Area was not investigated in this study, but it may affect some of the southern portion of the site.

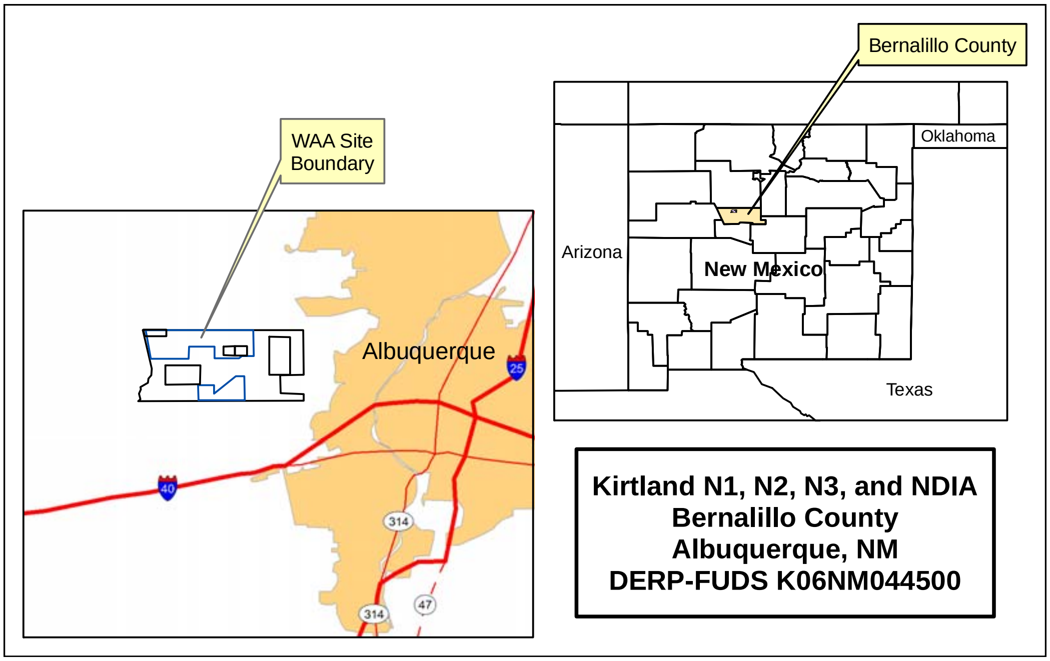


Figure 5-1. Area map showing the location of the Kirtland PBRs within the state of New Mexico and the location of the WAA program study area outlined in blue.

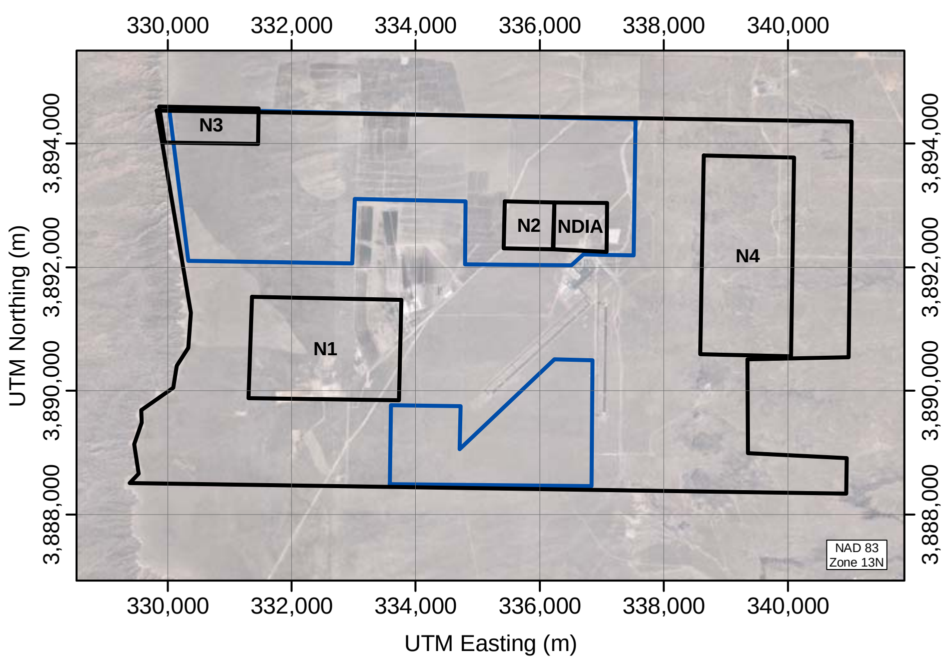


Figure 5-2. Map showing the Kirtland PBR complex. The WAA demonstration area boundaries are shown in blue. There is a northern section and southern section. The outer boundary is the formerly used defense site boundary.

In the near term, expected development on and near the WAA lands is primarily from industry and manufacturing. Significant infrastructure and development, including a municipal airport, a shooting range, a soil amendment facility, and nearby housing, already exist on and near the WAA lands. (Refs. 24, 33)

5.2 Former Kirtland PBR Study Area Objectives and Program Design

The former Kirtland PBR primary objectives included confirming the presence of three known targets, determining the existence and location of the suspected oil refinery target, and assessing the remaining land in the study area to determine if there is evidence of any unknown targets. In addition, the secondary objectives were to characterize the nature and extent of munitions concentrations in this study area and investigate the types of munitions associated with each target to determine if the results align with the historical records documented in the initial CSM.

The technologies demonstrated at the former Kirtland PBRs include LiDAR, orthophotography, a helicopter-borne magnetometer array, and a ground-based magnetometer/EM dual-mode array. The high-altitude technology layers surveyed 100% of the 5,000-acre study area, as shown in Figures 5-3 and 5-4. Figure 5-5 shows the helicopter magnetometer surveyed nearly 5,000 acres of the study area. The ground-based transects were designed using VSP. The ground-based magnetometer/EM array surveyed the majority of the transect plan, sampling approximately 3.3% of acreage for a total of 192 acres of transects. An additional 158 acres were surveyed by the ground system at total coverage for validation. Anomaly density contours created from the helicopter magnetometer data and the estimated anomaly densities from the ground-based transect data are presented in the data analysis sections of this chapter unless otherwise noted. Detailed results can be found in the technical reports prepared by each of the technology vendors. (Refs. 9–12)

5.2.1 Ground-based Transect Design

The ground-based magnetometer/EM system transects were planned before the survey. The transect design approach relied on the initial CSM, developed from the Archives Search Report and ESTCP site visits. The transect design approach was separated into *sparse* and *dense* transect designs. The methods were compared to determine the value added from the more conservative dense design.

The *sparse* transect design approach was developed from historical knowledge of the size of the known target circles. A circular target, based on the 305-m (1,000-ft) diameter target rings identified in the initial CSM, formed the basis of the sparse transect designs. A transect pattern was designed to ensure a 99% probability of traversing a target. The probability of detecting a target area feature was not used. These target searches were planned over the entire study area.

A *dense* transect design was also developed to ensure a high probability of traversing a 500-ft diameter circular target. Because practice bombs do not produce fragmentation, it was theorized that the resulting practice target footprints may be smaller than the outer aiming circle.

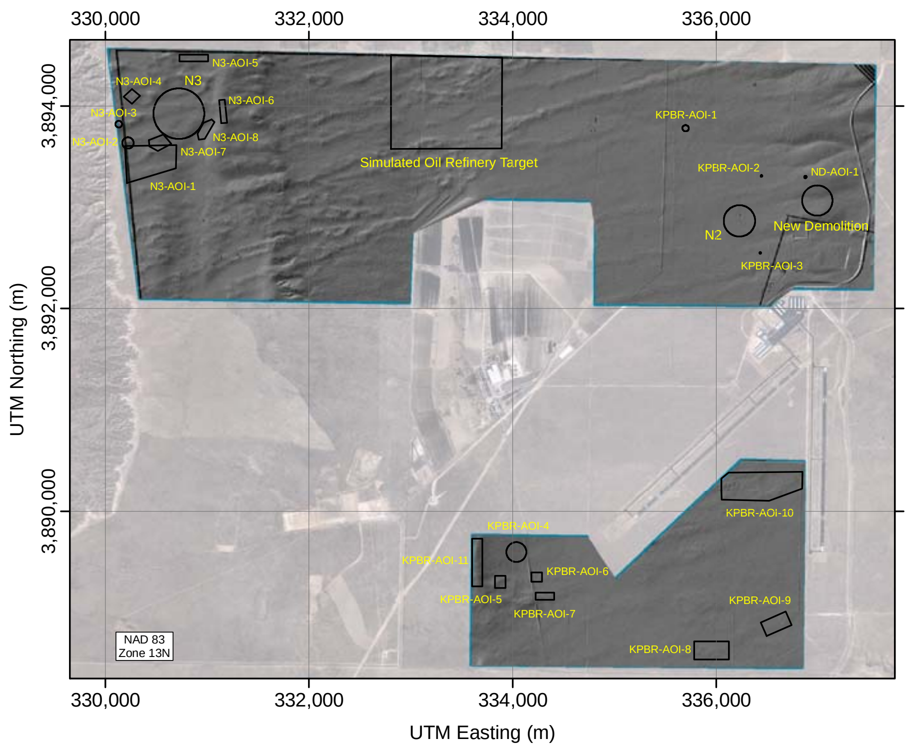


Figure 5-3. The Kirtland WAA site targets and AOIs that were investigated are labeled and overlain on the LiDAR data. This technology covered 100% of the study area.

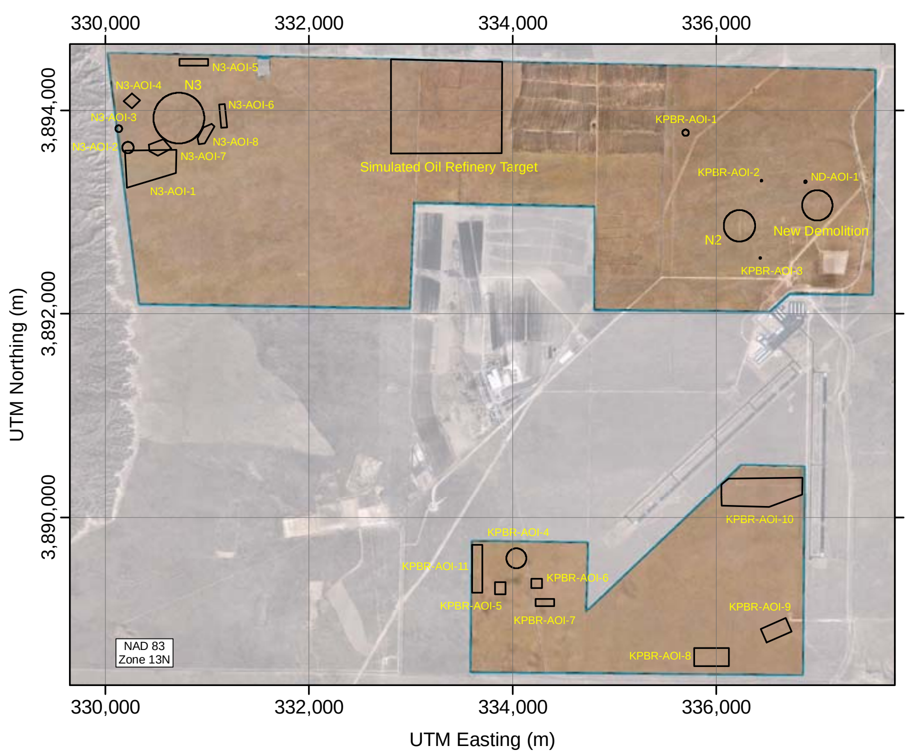


Figure 5-4. Kirtland PBRs orthophotography data. This technology covered 100% of the study area.

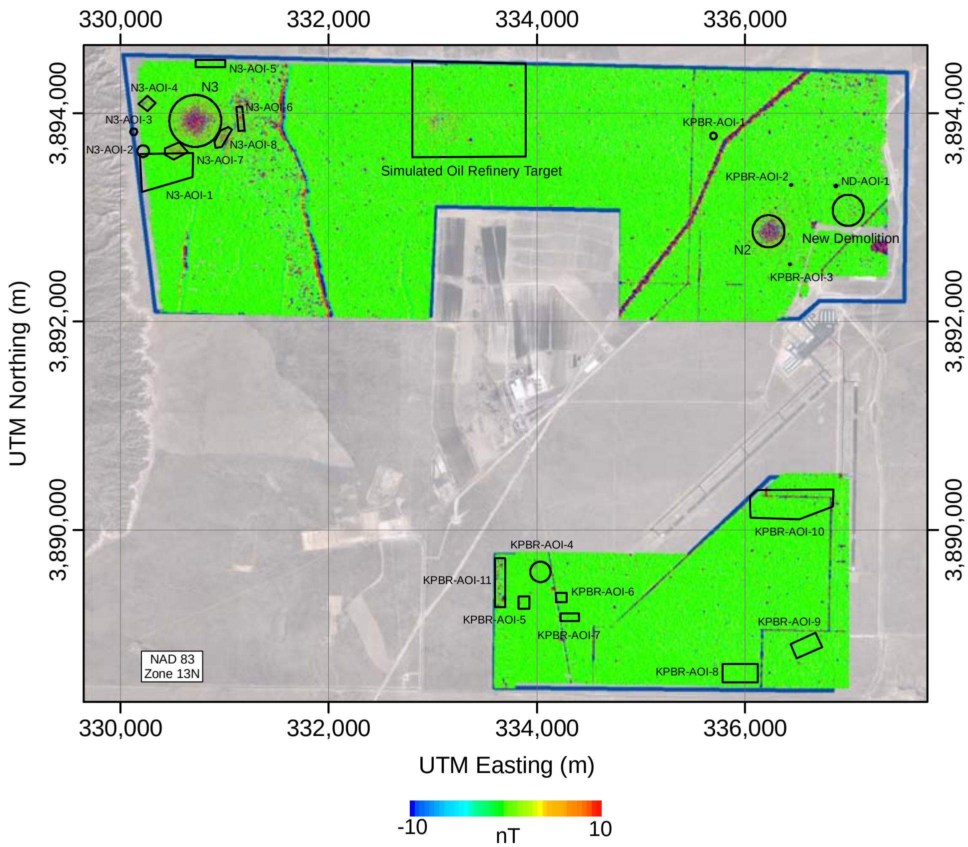


Figure 5-5. Kirtland PBRs helicopter magnetometer data. Approximately 5,000 acres of the site were surveyed at 100% coverage. The small data gap seen in the northeast of the study area boundary occurs because the low-flying helicopter could not cross a busy road.

A separate transect design was also developed to search for refinery targets using the size of an individual cell indicated in the initial CSM, assuming each cell may have served as a target for the bombers. A 50 ft × 250 ft cell was used, with the 250 ft dimension oriented in the east-west direction. The dense design was built upon the existing sparse design transects. The ground-based system collected data on the dense transects during the survey, and the sparse transect design was later separated from the dense transects for analysis and comparison. Tables 5-1 and 5-2 show the VSP inputs used to develop these transect designs.

5.3 Performance Assessment

The WAA data layers were analyzed separately and in combination. The high-airborne data were collected first and used as the starting point to identify AOIs. As the helicopter and ground-based system data sets were received, these were examined to identify areas of concentrated anomalies. The areas identified in these two data sets were compared to the potential munitions-related features and AOIs identified in the high-airborne data, and the concentrated anomaly areas that did not have high-airborne features associated with them were added as additional AOIs.

All layers of WAA data and the validation results confirm the locations of the three known targets and identify the location of the refinery target. Figures 5-3 to 5-6 show the overall site investigation area, indicating the investigated targets and AOIs. Specific discussions about the known and suspected targets, including a discussion of the data analysis, interpretation, and evaluation for each area and the associated validation efforts, follow. The areas investigated are addressed from the north (discussed west to east) and then to the south.

Table 5-1. Summary of the Transect Design Approach for Bomb Targets.

	Dense	Sparse
Primary objective of design	Detect the presence of potential 100-lb bomb circular 500-ft (152.5-m) diameter target areas	Detect the presence of potential 100-lb bomb circular 1,000-ft (305-m) diameter target areas
Type of sampling design	Transect	Transect
Shape of target area	Circular	Circular
Diameter of target area	152.5 m	305 m
Transect pattern	Parallel	Parallel
Transect width	2.5 m	2.5 m
Computed transect spacing	155 m	310 m
Required probability of traversing the target area	99% chance	99% chance
Number of transects	30	15
Transect coverage	337,000 m^2 (2.1%)	169,000 m^2 (1.1%)

Table 5-2. Summary of the Transect Design Approach for Simulated Oil Refinery Targets.

	Dense
Primary objective of design	Detect the presence of potential 50 ft (15.24 m) × 250 ft (76.2 m) cell refinery target areas
Type of sampling design	Transect
Shape of target area	Elliptical
Dimensions of target area	15 m × 75 m
Transect pattern	Parallel
Transect width	2.5 m
Computed transect spacing	79.5 m
Required probability of traversing the target area	99% chance
Number of transects	84*
Transect coverage	341,000 m^2 (3.1%)

* Note that the planned transects extended to the western edge of the site, which falls in the safety zone of a municipal firing range. Once the SORT had been located, the transect data collection was discontinued. A total of 36 transects were collected of this design.

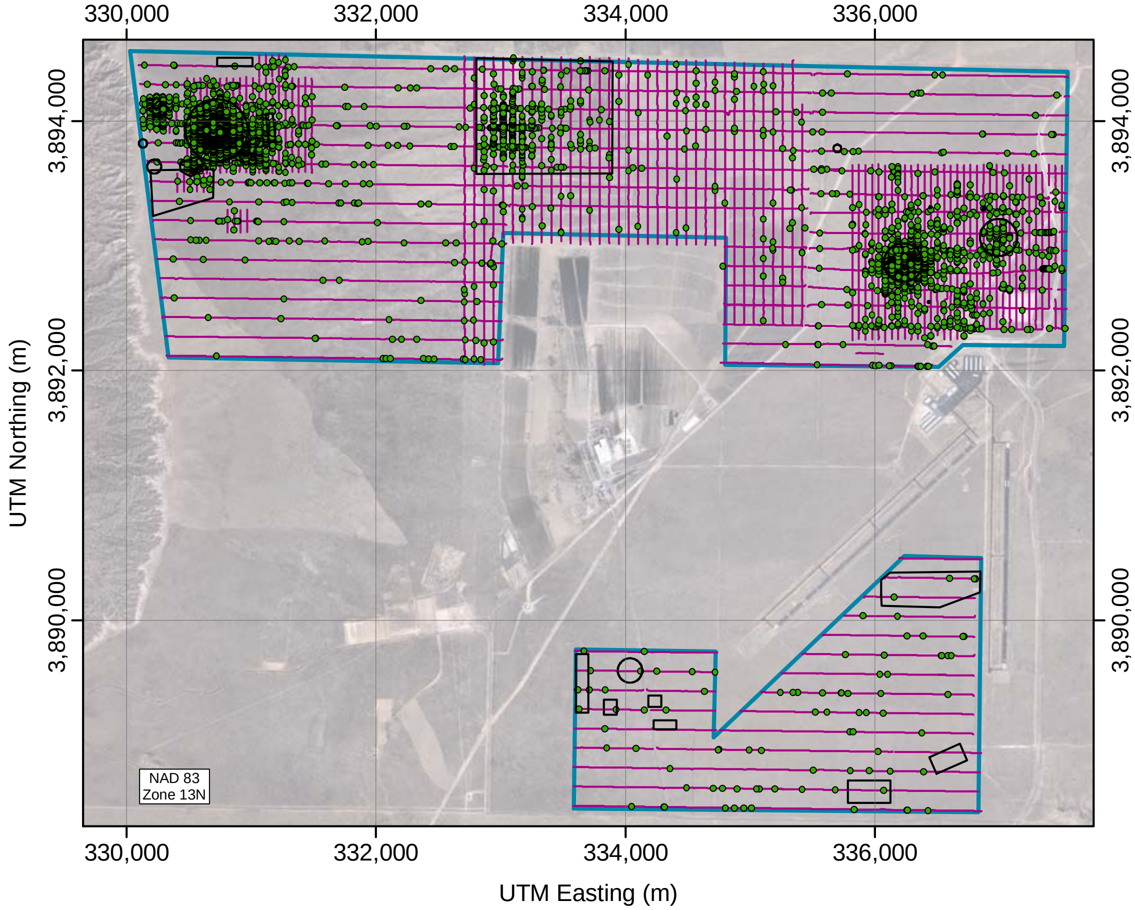


Figure 5-6. Kirtland PBRs ground-transect magnetometer anomaly locations overlain on the aerial photograph. The transects as driven are shown in pink and the anomalies are noted as green dots.

5.3.1 N-3 Impact Area (Northwest Section of Study Area)

The N-3 Impact Area is identified in the initial CSM in the northwest section of the study area. The location of this target in relation to the entire study area is noted in the inset in Figure 5-7.

5.3.1.1 Data Analysis, Interpretation, and Evaluation

All WAA data layers show the N-3 Impact Area is more complex than indicated in the initial CSM and extends to the southeast, southwest, and northwest of the target circle. In Figure 5-7, a 1,600-ft diameter target circle and four additional inner concentric target rings are clearly evident in the high-airborne data. The 1,600-ft outer ring diameter exceeds the 1,000-ft diameter noted in the initial CSM. An earlier aerial photo of the site only shows a total of four rings, and the outer ring is 1,000 ft in diameter. There is no indication of craters within the target circles, and all the munitions-related scrap retrieved from the intrusive investigation was from 100-lb practice bombs, which is consistent with the initial CSM. All evidence found in this assessment indicates only practice bombs are present at this target. However, it cannot be ruled out that a small number of HE munitions may be present.

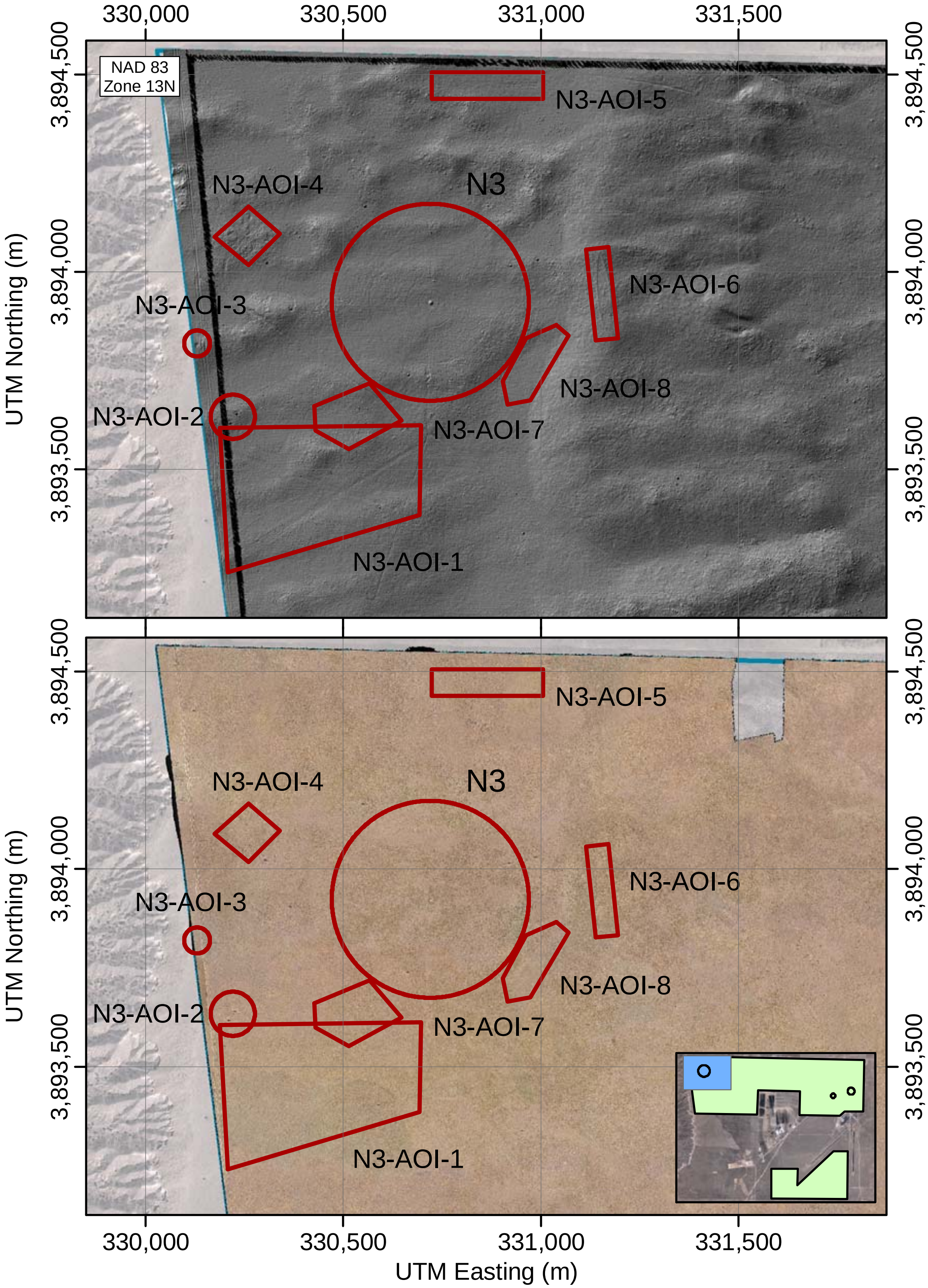


Figure 5-7. LiDAR data (top) and orthophotography data (bottom) from the N-3 Impact Area. The target and AOIs are identified.

In Figure 5-8, the anomaly density contours from the helicopter magnetometer and the estimated anomaly densities from the ground-based transect data show concentrated anomalies in and around the center of the target. A concentration of anomalies starting from the center of the target circle extending beyond the outer ring is seen in the anomaly density contours for both geophysical systems. The ground-based transect anomaly density in and surrounding this target circle also exceeded the threshold used to flag an area in VSP.

In addition to the target circle, several AOIs associated with N3 are identified in the high-airborne data. Concentrated anomalies are also seen in and surrounding a number of the eight identified AOIs. The initial CSM did not indicate any additional munitions-related activity beyond the target circle. While several of the AOIs discussed below could have been used as targets, there was not enough evidence to determine their specific use. All the AOIs are included in a single complex target.

- **Runway-Shaped Feature (N3-AOI-1)—**A runway-shaped feature was identified to the southwest of the outer target circle in the high-airborne data, as shown in Figure 5-7. In Figure 5-8, both anomaly density contour maps show a light concentration of anomalies in the eastern half of the AOI and clearly show a higher concentration of anomalies in the area that overlaps with the high-anomaly-density feature identified as N3-AOI-7, which is discussed below. The initial prediction from the presence of this feature in the high-airborne results was that it was used as a mock runway target. However, based on the low magnetometer anomaly concentrations and the results discussed in the validation section, it appears that it was not used as a target. The higher concentration areas in the north are likely spillover from a neighboring target.
- **Areas Containing Depressions (N3-AOI-2 and N3-AOI-3)—**Two areas containing depressions were flagged as potential HE craters in the high-airborne data seen in Figure 5-7. There is confidence that these features are located in an area where munitions-related activity occurred, but their specific use is unclear. For the depressions identified as N3-AOI-2, the anomaly density contours for both magnetometer systems did not indicate a concentration of anomalies (Figure 5-8). Neither geophysics system surveyed the depressions identified as N3-AOI-3 because this feature is located beyond the site fence line.
- **Raised Diamond-Shaped Feature (N3-AOI-4)—**A raised diamond-shaped area was identified in the high-airborne data, as shown in Figure 5-7. Figure 5-8 shows a high concentration of anomalies within and surrounding the AOI in the estimated anomaly densities from the ground-based transect data and the helicopter data anomaly density contours. The ground-based transect anomaly density in and surrounding this AOI also exceeded the threshold to flag an area in VSP. The specific use of this area is unclear but there is confidence munitions-related activity occurred in this area.
- **Rectangular Runway Shaped Feature (N3-AOI-5)—**A long rectangular ground disturbance shaped like a single runway was identified in the high-airborne data, as shown in Figure 5-7. Only scattered anomalies were identified in both of the geophysics data sets (see Figure 5-8). It is unlikely this feature was used as a target based on the available data; however, it lies within an area where munitions activity occurred.

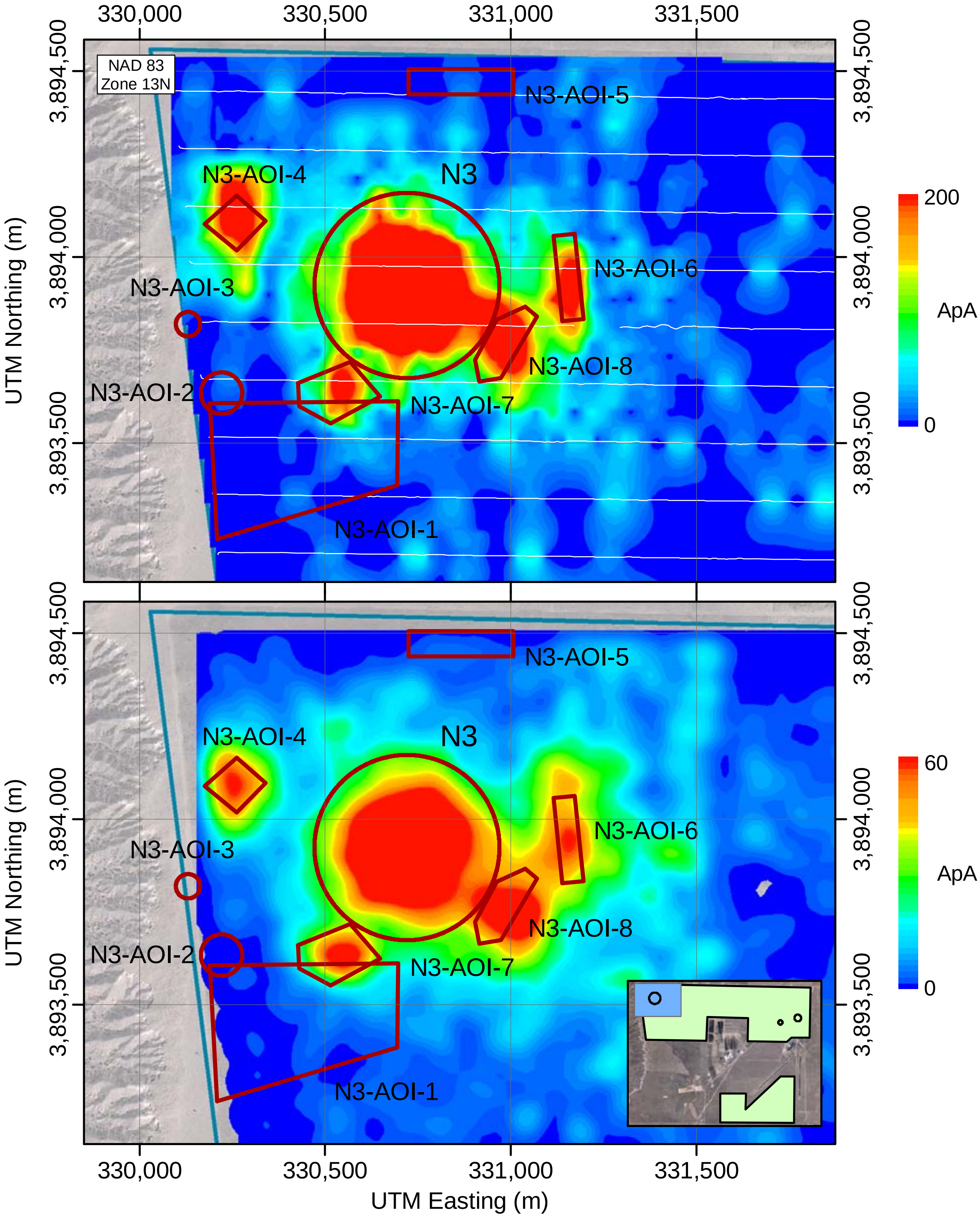


Figure 5-8. Estimated anomaly densities from the ground-transect data with the transects shown as white lines (top) and helicopter magnetometer data anomaly density contours (bottom) from the N-3 Impact Area. Elevated anomaly concentrations are associated with the target circle in both data sets.

- **Ship-Shaped Target (N3-AOI-6)—**Figure 5-7 shows a ship-shaped target identified in the high-airborne data. Multiple lines of evidence support the conclusion that this feature was used as a target. In Figure 5-8, a high concentration of anomalies is in and surrounds the target in both geophysics data sets. The helicopter anomaly density contours show a high concentration of anomalies. The ground-based transect anomaly density in and surrounding this AOI also exceeds the threshold used to flag an area in VSP.
- **Geophysical Data High Concentration Areas (N3-AOI-7 and N3-AOI-8)—**Two AOIs were identified from high concentrations of anomalies in the magnetometer data. The first AOI is a concentration of anomalies to the southwest of the target circle (N3-AOI-7) that was identified in the anomaly density contours from the helicopter magnetometer and the estimated anomaly densities from the ground-based transect data shown in Figure 5-8. No features were observed in the high airborne data shown in Figure 5-7. The ground-based transect anomaly density in and surrounding this AOI exceeded the threshold to flag an area in VSP. It is possible this area is associated with an auxiliary target associated with the N-3 Impact Area target circle, but based on the information available, the specific usage is unclear. There is confidence munitions-related activity occurred in this area.

  A concentration of anomalies southeast of the target circle (N3-AOI-8) was also identified in the magnetometer anomaly density contours in Figure 5-8. The ground-based transect anomaly density in and surrounding this AOI exceeded the threshold used to flag an area in VSP. No features were observed in the high-airborne data in Figure 5-7. This high concentration of anomalies is located at the base of the rise identified near N3-AOI-6. There is confidence this feature is located in an area where munitions-related activity occurred, but the specific use of the area is unclear.

5.3.1.2 Validation

The validation results for the N-3 Impact Area support the location of the target circle and confirm the Impact Area is more complex than indicated in the initial CSM. During the ground reconnaissance, the mound in the center of the target circle was clearly visible, and munitions-related scrap was also found. Anomalies from the helicopter data with properties most closely matching 100-lb practice bombs were preferentially selected to direct the intrusive investigation. Abundant amounts of munitions-related scrap from practice bombs were found in and surrounding the target circle during the intrusive investigation, as shown in Figure 5-9.

Munitions-related scrap and several intact practice bombs were located in the vicinity of AOIs that were intrusively investigated as shown in Figure 5-9. The ship-shaped feature (N3-AOI-6) was confirmed during ground reconnaissance. The team found the outline of the ship was marked with pebbles. The team also observed munitions-related scrap and an intact practice bomb on the surface. These results confirm this feature was used as a target.

Two areas were identified in the WAA data as potential runway targets, and the ground reconnaissance team investigated both. The team did not observe any man-made features resembling an airfield and found scattered munitions-related scrap at both locations. The validation results support the finding that these features were not targets, but are located in an area where munitions-related activity occurred.

The raised diamond feature (N3-AOI-4) observed in the WAA data was investigated during ground reconnaissance. The team did not observe any trenches or berms in the area. The team observed surface geology identified as black volcanic glass and uneven terrain that appeared to be natural. Abundant munitions-related scrap was observed. The validation results support the finding that this feature was not used as a target but is located in an area where munitions-related activity occurred.

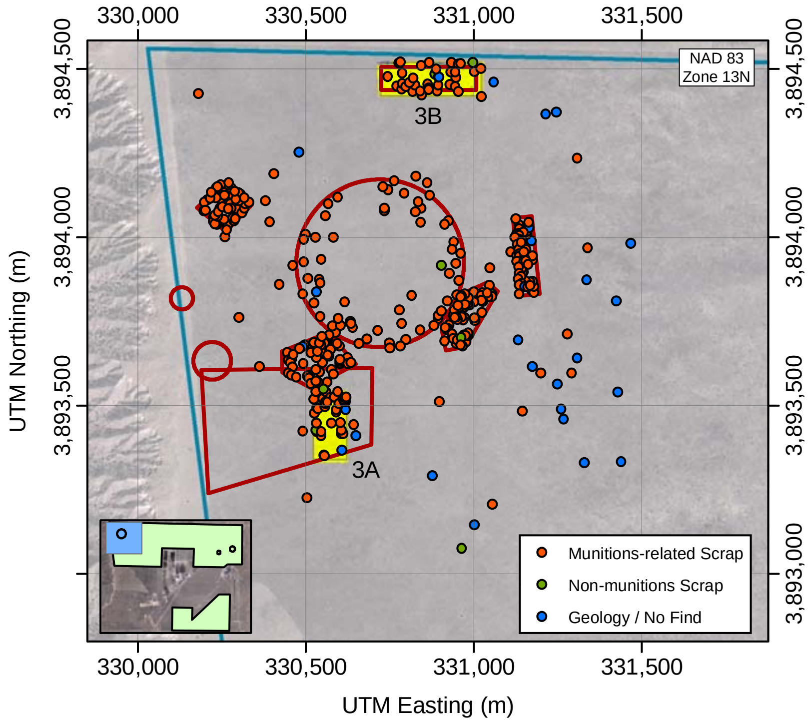


Figure 5-9. The two ground 100% coverage areas (yellow patches) and the intrusive investigation results associated with the N-3 Impact Area. A large number of munitions-related items were found in the intrusive investigation.

The two AOIs that were identified by a concentration of geophysical anomalies (N3-AOI-7 and N3-AOI-8) had similar ground reconnaissance results. The team did not observe any ground features and found small amounts of munitions-related scrap. At N3-AOI-8, the team found lumber and nails that it postulated could be from the WWII era based on their weathered appearance. The validation results support the conclusion that munitions-related activity occurred in these areas based on the presence of munitions-related scrap. The specific use of these areas is unclear from the available information.

The two areas containing suspected craters (N3-AOI-2 and N3-AOI-3) were visited, measured, and searched with a hand-held metal detector by the ground reconnaissance team. The team found no evidence of metal and the depressions appeared to be natural. These two AOIs were not intrusively investigated based on the findings from the ground reconnaissance. There is confidence these features are located in an area where munitions-related activity occurred, but their specific use is unclear.

Total coverage geophysical surveys were performed in two areas near the N-3 Impact Area (3A and 3B) to further investigate the extent of the target and the type of munitions used on this target (see Figure 5-9). Intrusive sampling performed on selected anomalies in these areas found munitions-related scrap from practice bombs. The proximity of 3B to the study boundary showed the N-3 Impact Area likely extends beyond the study boundary, as well as the formerly used defense site boundary to the north.

5.3.1.3 Target Boundary Decision

Figure 5-10 presents the anomaly density contours created from the ground-based magnetometer data. The orange boundary delineates the area where the anomaly density is above the threshold of 60 anomalies per acre derived by fitting the cumulative anomaly density histogram to two distributions, representing background and target. The boundary does not represent an attempt to include every anomaly. And the ultimate area requiring action must be refined by more detailed characterization. This boundary does not imply isolated munitions are not present on the remaining land. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

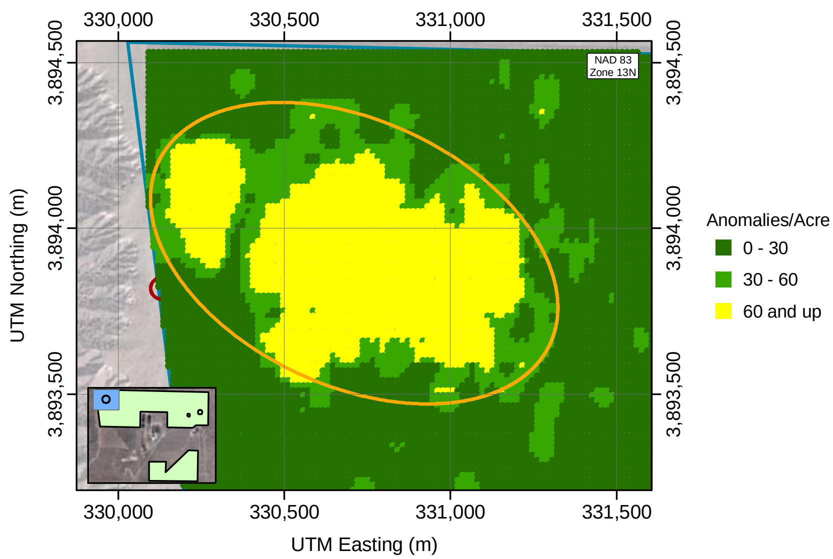


Figure 5-10. Magnetic anomaly density contours from ground-system data for the N-3 Impact Area. The orange boundary represents the best estimate of the target extent.

The bounded area is 200 acres and contains an estimated 24,000 anomalies detectable by a ground-based sensor, which will serve as inputs to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

5.3.2 Simulated Oil Refinery Target (North Central Section of Study Area)

The location of the simulated oil refinery target location was unknown from the historical documents. WAA establishes the location in the north central section of the study area. The location of this target in relation to the entire study area is noted in the inset in Figure 5-11.

5.3.2.1 Data Analysis, Interpretation, and Evaluation

The initial CSM indicates the presence of a refinery target, but does not specify its location. The Archives Search Report described the target as having rectangular cells ranging in size from 20 ft × 250 ft to 50 ft × 250 ft. Multiple WAA data sets confirm the refinery target is located in the central part of the northern section of the study area. In Figure 5-11, the LiDAR data clearly show a grid pattern containing cells scarring the surface. The larger cells measure approximately 300 ft x 300 ft and the smaller are 150 ft x 150 ft. The corresponding orthophotography data faintly show the outline of portions of the cell-shaped features. Depressions were observed in the LiDAR data and flagged for further investigation as potential craters. These depressions are located south of the cells and were determined not to be munitions related. No depressions were identified within the cells.

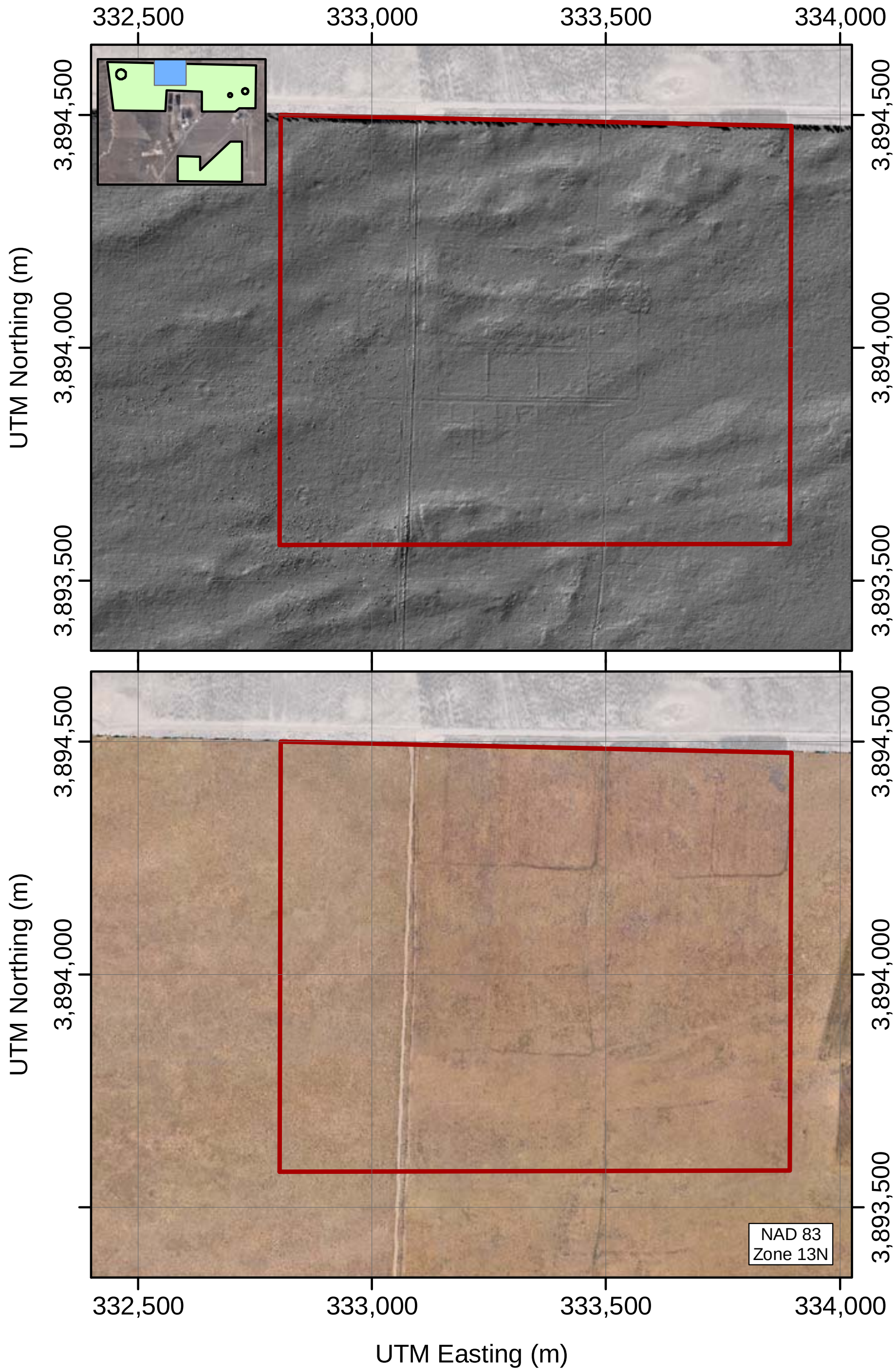


Figure 5-11. LiDAR (top) and orthophotography (bottom) data for the refinery target. The red boundary encompasses the features identified in the high-airborne data, as well as anomaly concentrations that extend to the west of the cell structure.

In Figure 5-12, the helicopter magnetometer and ground-based transect data show an elevated density of anomalies, with the highest density concentrations at the western edge of the cell pattern. The ground-based transect anomaly density in this western area also exceeded the threshold used to flag an area in VSP.

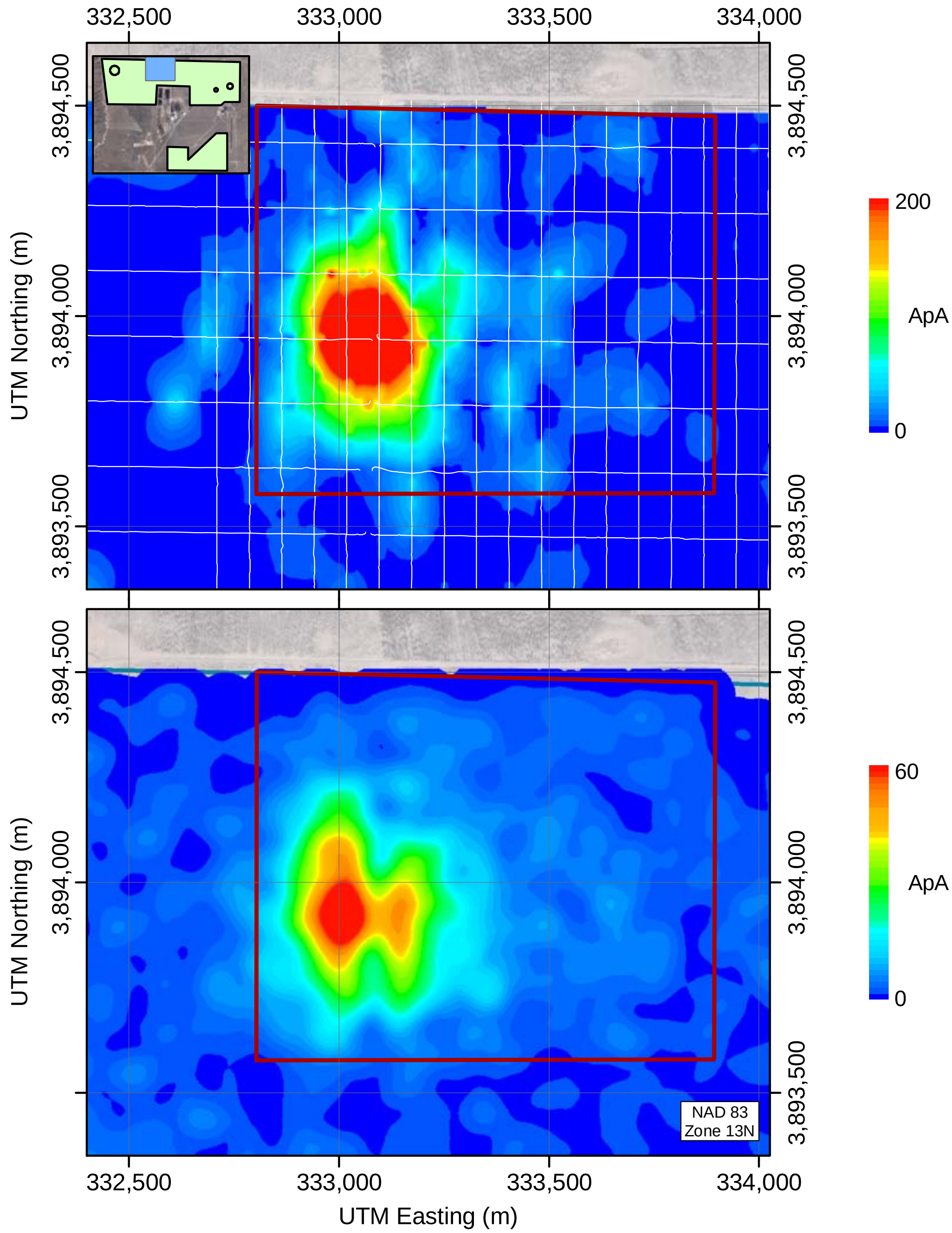


Figure 5-12. Estimated anomaly densities from the ground-based transect data with the transects shown as white lines (top) and helicopter magnetometer anomaly density contours (bottom) from the refinery target. Elevated anomaly concentrations are seen at the western side of the cell structures.

5.3.2.2 Validation

The validation efforts for the refinery target confirm the location of the target. During the intrusive investigation, munitions-related scrap was found in and surrounding the cell structures as seen in Figure 5-13. Munitions-related scrap from practice bombs was also found well to the east of the cell structures. The purpose of the intrusive investigation was to further define the extent of the target and confirm the type of munitions present. Only a select number of anomalies were dug to support this sampling. The ground reconnaissance team visited the location of the cell features and was able to observe berms and pebbles confirming WAA data. All evidence found in this assessment suggests that only practice bombs are present at this target; however, it cannot be ruled out that a small number of HE munitions may be present.

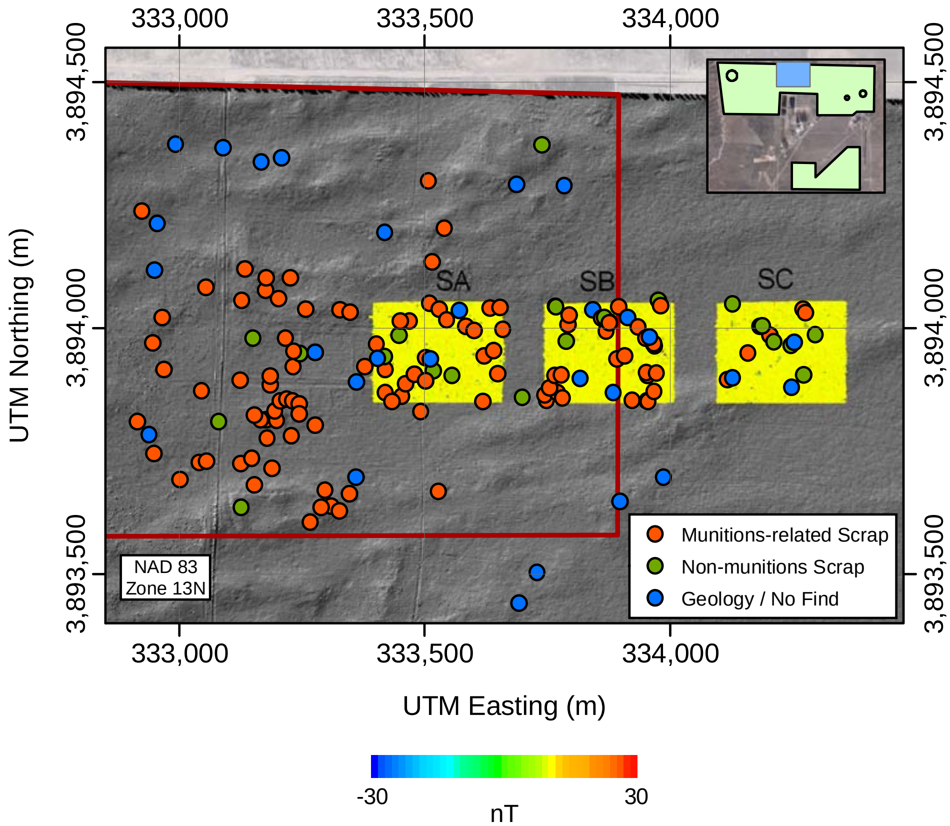


Figure 5-13. The three ground total coverage areas (yellow patches) and the intrusive investigation results associated with the refinery target.

As discussed above, analysis of the LiDAR data identified several depressions to the south of the cell structures that were further investigated during ground reconnaissance. The depressions were visited, measured, and searched with a hand-held metal detector. The team determined these are not munitions-related features. Instead, they appeared to be associated with a man-made soil amendment area or related to prairie dog burrows. The team observed only one munitions-related item in a depression.

To define the extent of the target area as shown in Figure 5-13, three total coverage areas were surveyed radiating eastward from the target (SA, SB, and SC). An analysis of anomaly density per acre shows a density drop to 5 anomalies per acre as distance increases from the target. During the intrusive investigation, munitions-related scrap was found in each of these three total coverage areas.

In Figure 5-14, the EM data from the total coverage surveys show rings that were found to align with the centers of cell features. After their existence was known, they were faintly observable in the ground-based magnetometer data but they were not observed in the helicopter magnetometer data. The origin of these features is unknown, but their presence and alignment provide additional evidence to confirm the location of the refinery target. The ground reconnaissance team visited these ring features. Several pieces of metal scrap were observed, but it was unclear for all but one piece if they were munitions related. At the location of three of the rings, no topographic, geologic, or cultural features were observed that would account for the ring shape. At one ring location, a faint non-continuous semicircle was visible as a wide bare soil patch. The origin of these rings is unknown.

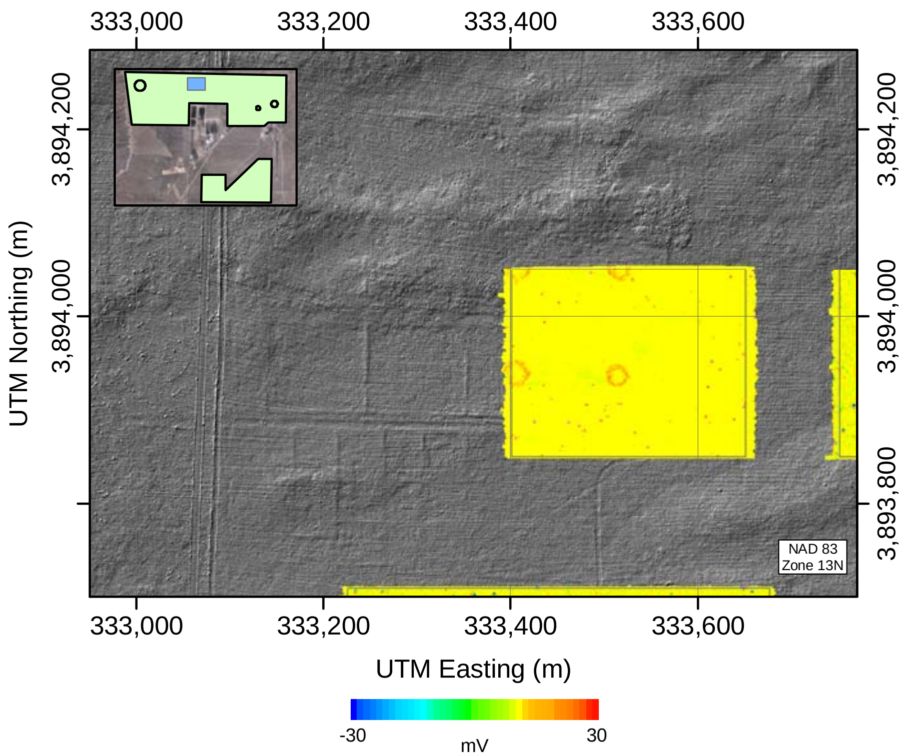


Figure 5-14. The rings observed in the EM ground-based total coverage data (red rings) align with the centers of cell features seen in the LiDAR data.

5.3.2.3 Target Boundary Decision

Figure 5-15 presents the anomaly density contours created from the ground-based magnetometer data. The orange boundary delineates the area where the anomaly density is above the threshold of 40 anomalies per acre derived by fitting the cumulative anomaly density histogram to two distributions, representing the background and target. The boundary does not represent an attempt to include every anomaly, and the ultimate area requiring action must be refined by more detailed characterization. This boundary does not imply isolated munitions are not present on the remaining land. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

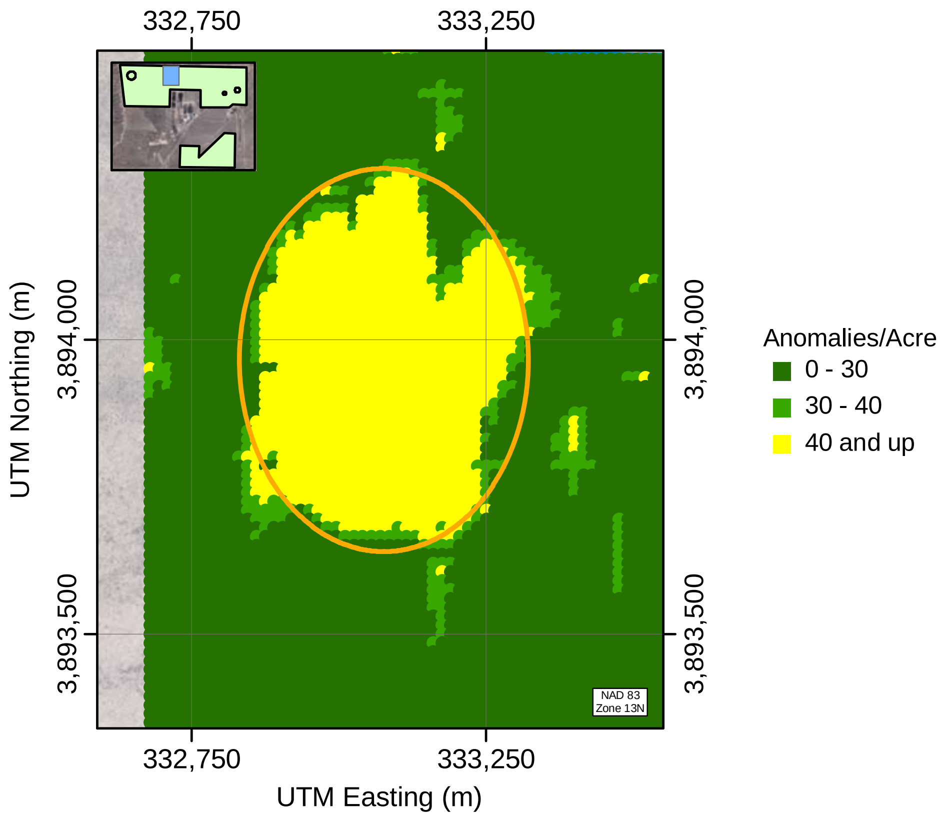


Figure 5-15. Magnetic anomaly density contours from ground-system data for the refinery target. The orange boundary represents the best estimate of the extent of the elevated anomaly density.

The bounded area is 60 acres and contains an estimated 7,000 anomalies detectable by a ground-based sensor, which will serve as inputs to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

5.3.3 N-2 Impact Area (Northeast Section of Study Area)

The N-2 Impact Area is identified in the initial CSM in the northeast section of the study area. This target is approximately a quarter mile west of the HE demolition impact area discussed in the next section. The location of this target in relation to the entire study area is noted in the inset in Figure 5-16.

5.3.3.1 Data Analysis, Interpretation, and Evaluation

The location of the N-2 Impact Area is confirmed by all WAA data layers. The 1,000 ft diameter outer target circle and the three inner concentric circles are evident in the high-airborne data shown in the figure. The target circles are more clearly seen in the LiDAR data. No craters are evident in and surrounding the target. A structure observed in the high-airborne data just to the north of the second inner target ring was further investigated. In Figure 5-17, the helicopter magnetometer density contours and estimated anomaly densities from the ground-based transect data show a concentration of anomalies in and surrounding the target circle. The ground-based transect anomaly density in and surrounding this target circle also exceeded the threshold to flag an area in VSP.

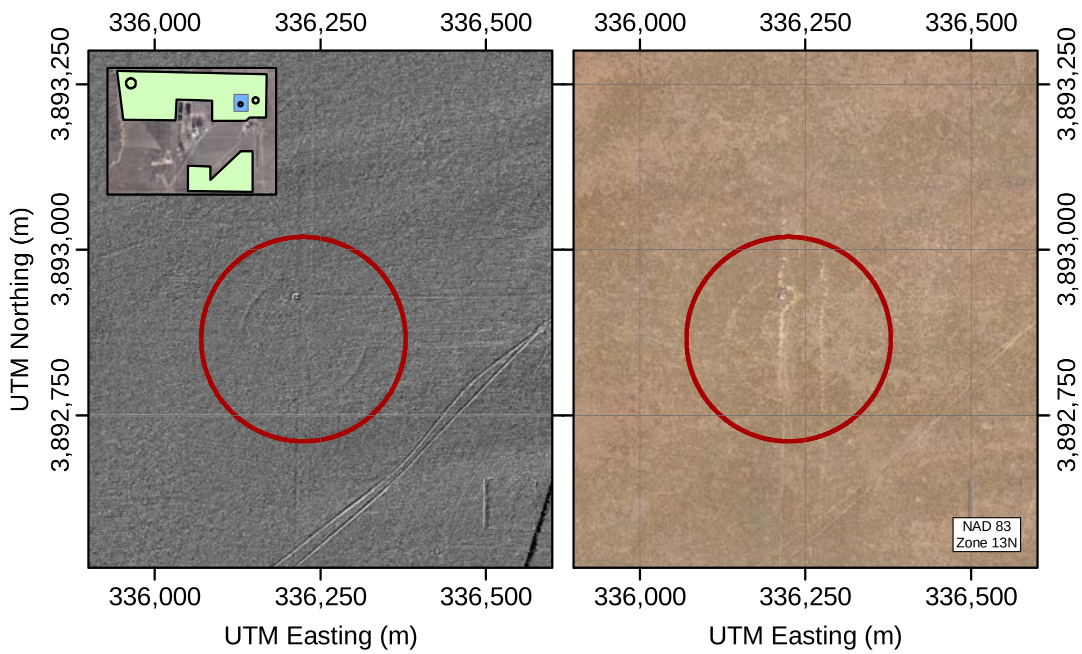


Figure 5-16. LiDAR (left) and orthophotography (right) data for the N-2 Impact Area. Portions of the target circle are visible in both data sets. No craters are evident in the high-airborne data. The structure seen in the northern section of the target circle was investigated during ground reconnaissance and is suspected to be a former observation tower.

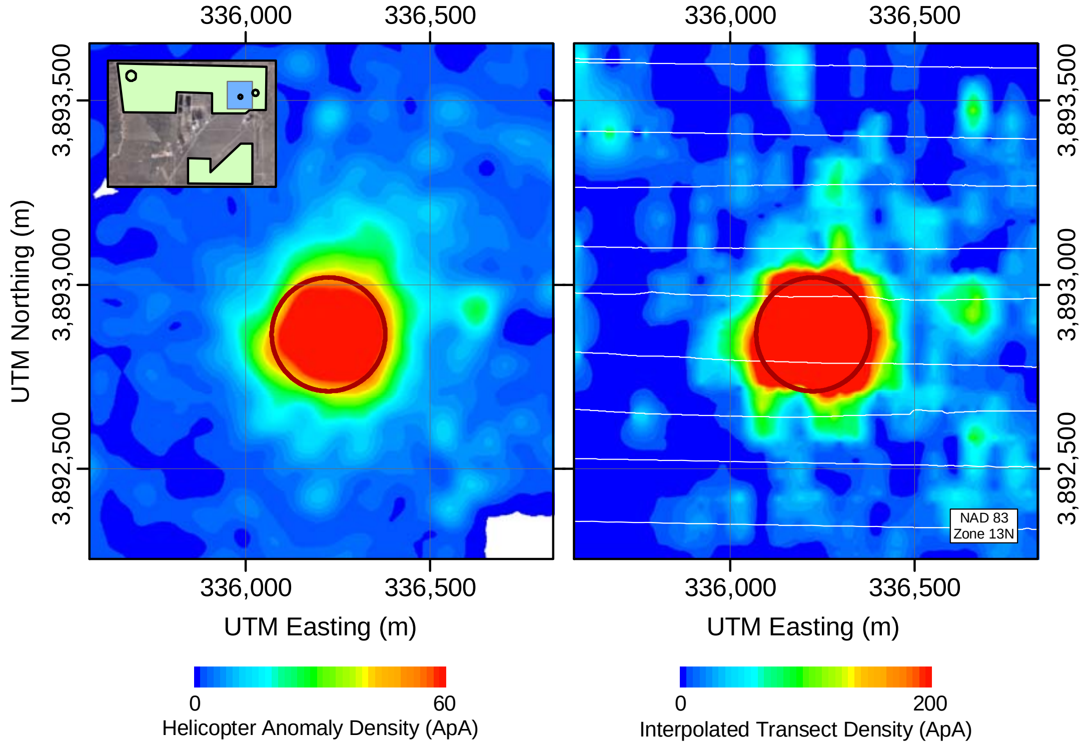


Figure 5-17. Anomaly density contours from the helicopter magnetometer (left) and estimated anomaly densities from the ground-transect data with the transects shown as white lines (right) from the N-2 Impact Area. Elevated anomaly concentrations are associated with the target circle in both data sets.

5.3.3.2 Validation

The validation results for the N-2 Impact Area support the location of the target shown in Figure 5-18. During ground reconnaissance, the team did not observe any ground features that would indicate the target circles but they did encounter abundant munitions-related scrap. All evidence found in this assessment suggests only practice bombs are present at this target. However, it cannot be ruled out that a small number of HE munitions may be present.

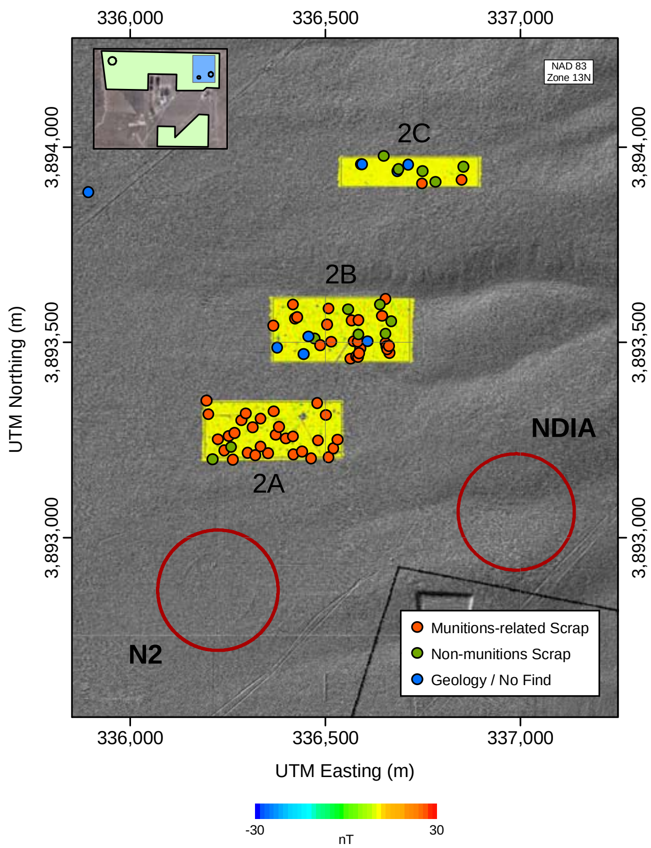


Figure 5-18. The three ground 100% coverage areas (yellow patches) and the intrusive investigation results associated with the N-2 Impact Area.

The structure identified to the north of the second inner target circle was investigated by the ground reconnaissance team. The team located a raised cinderblock building and metal roofing material nearby. The team speculated this structure could have been an observation tower. The specific use of this feature is unknown but is located in an area where military activity occurred.

Anomalies observed in the total coverage ground surveys were intrusively investigated to further define the extent of the target and confirm the type of munitions present. Three areas (2A, 2B, 2C) radiated to the northeast direction of the target circle as shown in Figure 5-18. Munitions-related scrap was found in each area.

5.3.3.3 Target Boundary Decision

Figure 5-19 presents the anomaly density contours created from the ground-based magnetometer data. The orange boundary delineates the area where the anomaly density is above the threshold of 80 anomalies per acre derived by fitting the cumulative anomaly density histogram to two distributions, representing the background and target. The boundary does not represent an attempt to include every anomaly, and the ultimate area requiring action must be refined by more detailed characterization. This boundary does not imply isolated munitions are not present on the remaining land. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

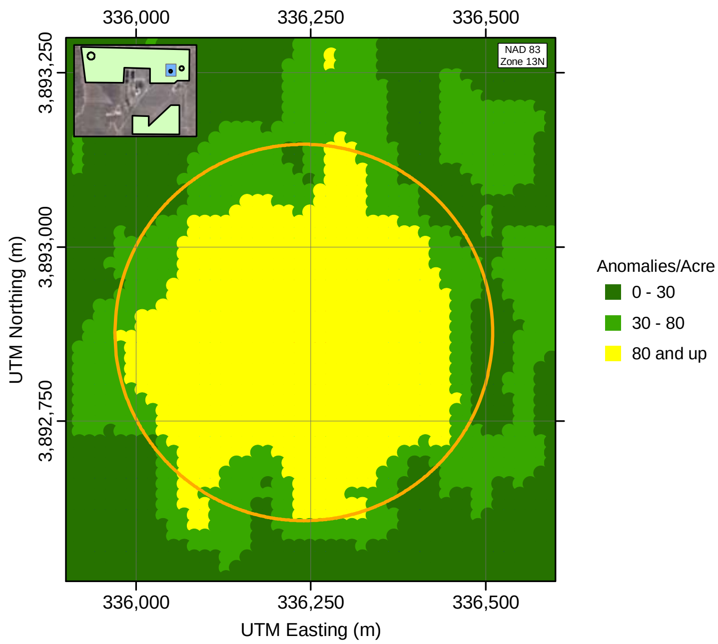


Figure 5-19. Magnetic anomaly density contours from ground-system data for the N-2 Impact Area. The orange boundary represents the best estimate of the target extent.

The bounded area is 55 acres and contains an estimated 12,500 anomalies detectable by a ground-based sensor. This information will serve as input to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

5.3.4 "New" Demolitions Impact Area (Northeast Section of Study Area)

The "New" Demolitions Impact Area identified in the initial CSM is located in the northeast section of the study area. The location of this suspected target in relation to the entire study area is noted in the inset in Figure 5-20. The initial CSM reported this was a lightly used target where HE bombs were dropped as part of graduation from training.

5.3.4.1 Data Analysis, Interpretation, and Evaluation

The location of the HE demolition impact area is confirmed by the WAA data. Two concentric target circles are evident in the high-airborne data shown in the figure. The diameter of the outer circle is 1,000 ft, and the inner circle diameter is 180 ft. The orthophotography data clearly show a cross hair centered in the target rings. Craters were evident in the LiDAR data. In Figure 5-21, the anomaly density contours for the helicopter magnetometer and the estimated anomaly densities from the ground-based transects show a low density of anomalies within the target circles. The ground-based transect anomaly density in a small area inside the target circle also exceeded the threshold to flag an area in VSP.

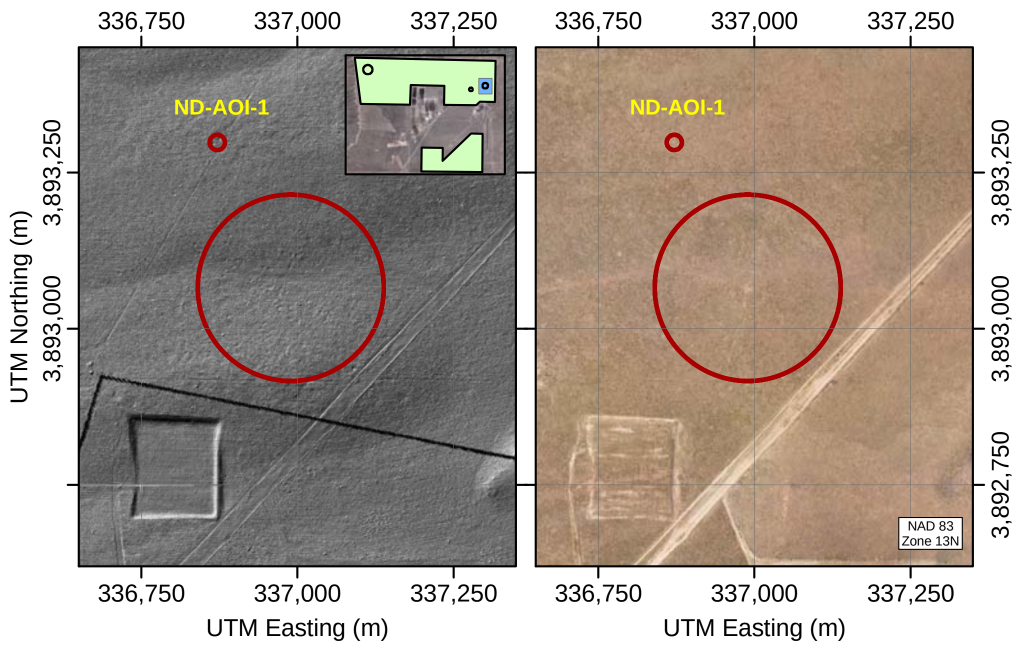


Figure 5-20. LiDAR (left) and orthophotography (right) data for the HE demolition impact area. The target rings are visible in both data sets, the cross hairs are visible in the orthophotography data, and craters are evident in the LiDAR data.

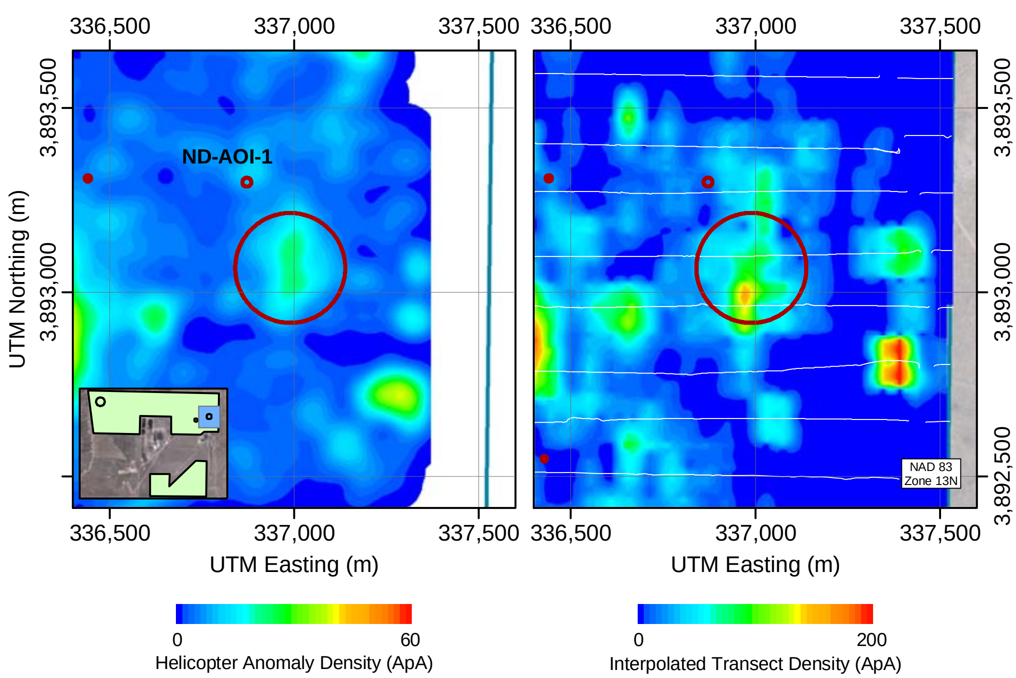


Figure 5-21. Anomaly density contours from the helicopter magnetometer from the HE demolition impact area (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right). The dense area of anomalies in the lower left of both anomaly density maps is associated with the adjacent N-2 Impact Area. Both data sets suggest this was a lightly used target.

A structure and nearby depression (ND-AOI-1) to the northwest of the target circle were identified in the LiDAR data in Figure 5-20 and flagged for further investigation. The helicopter magnetometer data show concentrated anomalies in this area. One ground-based transect surveyed this area, and an individual anomaly was detected. There is confidence this feature is located in an area where munitions-related activity occurred, but its specific use is unclear.

5.3.4.2 Validation

The validation results for the HE demolition impact area support the location of the target circle seen in Figure 5-22. Due to the proximity of the neighboring airport, an intrusive investigation of suspected HE munitions was not conducted. Ground reconnaissance of the area revealed heavy-walled fragments, confirming the use of HE bombs. Sparse amounts of lighter steel scrap were found by the reconnaissance team, and multiple lines of evidence support the conclusion that practice bombs were used as well. It is unclear if the intended target for the practice bombs was the HE demolition impact area or if they are spillover from the adjacent N-2 Impact Area.

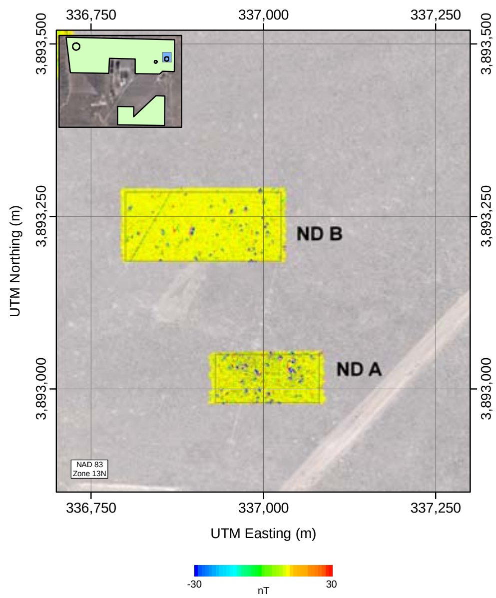


Figure 5-22. The two total coverage ground surveys (yellow patches) associated with the HE demolition impact area. A reduction in the concentration of anomalies is visible in the total coverage area ND B.

The depressions found in the high-airborne data were visited, measured, and searched with a hand-held metal detector by the ground reconnaissance team. The team observed abundant amounts of heavy-walled fragments in and surrounding the craters. The craters were similar in size, with diameters ranging from 5 m to 7 m and depths ranging from 30 cm to 60 cm. Multiple lines of evidence support the conclusion that these craters are munitions related and produced by HE bombs.

The reconnaissance team investigated the structure and depression identified as ND-AOI-1 and located a rectangular concrete foundation with protruding steel bolts that is surrounded by wood, concrete, wire, and stucco debris. The team found one piece of heavy-walled fragment.

There is confidence this feature is located in an area where munitions-related activity occurred, but the data do not provide information on the specific use of the structure.

Figure 5-22 shows two areas of total coverage (ND A and ND B) that were surveyed. ND A is located within the target circle, and ND B is located to the northwest of ND A. These areas were intended to investigate munitions type rather than to get an estimate of density drop-off, since the proximity to the airport prevented intrusive investigation. It is apparent the anomaly density decreases from within the target center to ND B.

5.3.4.3 Target Boundary Decision

Figure 5-23 presents the anomaly density contours created from the ground-based transect data. The orange boundary delineates the area where the anomaly density is above the threshold of 50 anomalies per acre derived by fitting the cumulative anomaly density histogram to two distributions, representing the background and target. The boundary does not represent an attempt to include every anomaly, and the ultimate area requiring action must be refined by more detailed characterization. This boundary does not imply isolated munitions are not present on the remaining land. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

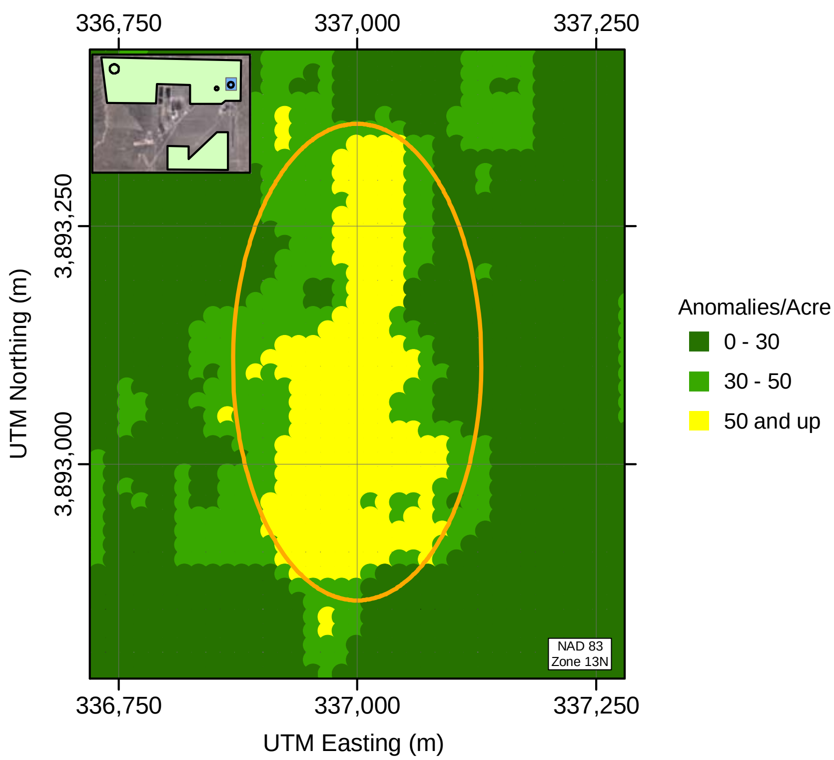


Figure 5-23.Ground-system magnetic anomaly density contours for the HE demolition impact area. The orange boundary represents the best estimate of the target extent.

The bounded area is 25 acres and contains an estimated 1,400 anomalies detectable by a ground-based sensor, which will serve as inputs to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

5.3.5 Remainder of the Study Area

This section addresses all of the other areas within the Kirtland PBR WAA study area that are not associated with specific targets identified in the initial CSM. A primary objective of the pilot program was to collect data to support decisions on areas that show no evidence of concentrated munitions use. Analysis of high-airborne results indicated 10 AOIs not associated with known or suspected targets. In addition, a concentration of anomalies in the helicopter magnetometer data was identified as an 11th AOI. Multiple lines of evidence support the conclusion that eight of these AOIs are not munitions related. It is suspected that three AOIs are the result of spillover from adjacent targets. The locations of the AOIs in relation to the entire study area are noted in the insets in each figure. All other remaining land showed no indications of munitions use.

Out of the 5,000 acres surveyed, more than 4,600 acres were found to be free of concentrated munitions use. At this site, this information can be used to support future munitions response actions for non-target areas, such as appropriate controls or consideration of no-further action decisions.

5.3.5.1 KPBR-AOI-1—Square Raised Feature

Figure 5-24 shows a square raised area north of the N-2 Impact Area identified in the high-airborne data. No concentration of magnetic anomalies is associated with this feature in either geophysics data set. The specific use is unclear.

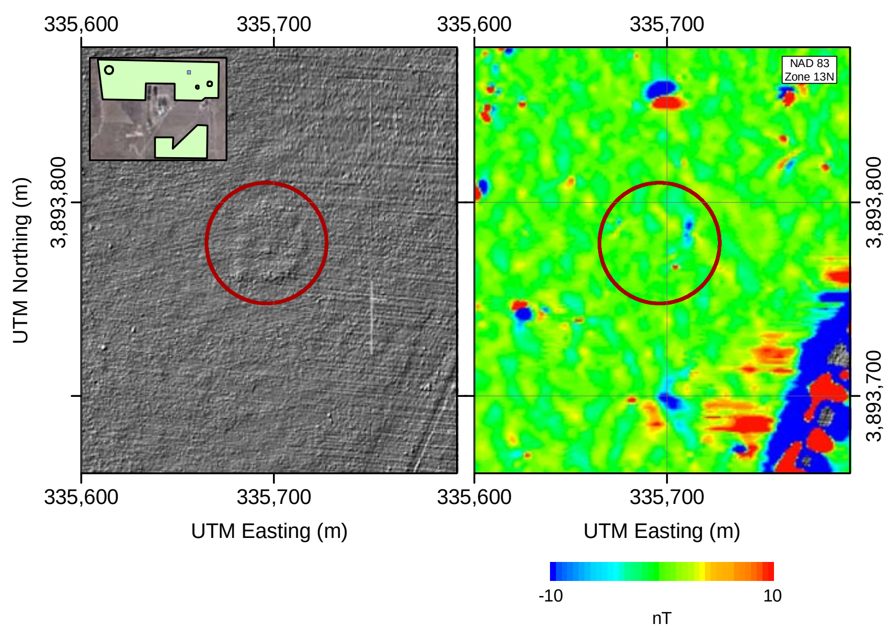


Figure 5-24. LiDAR data (left) and helicopter magnetometer data (right) from the raised area denoted KPBR-AOI-1. A raised square is visible in the LiDAR data. The magnetometer data do not show a concentration of magnetic anomalies in this area. The specific use of this feature is unknown.

The validation for this AOI included an intrusive investigation and ground reconnaissance. In Figure 5-25, the intrusive investigation results show munitions-related scrap was found in the area. Only a select number of anomalies were dug to support this sampling. The ground reconnaissance team found a slightly raised square area that contained differing vegetation than the area surrounding the feature (see Figure 5-26). Munitions-related scrap from practice bombs was found during the ground reconnaissance as well. The validation results support the conclusion that this feature may have been related to munitions activity or could be spillover from a nearby target, but it does not appear to be a target itself.

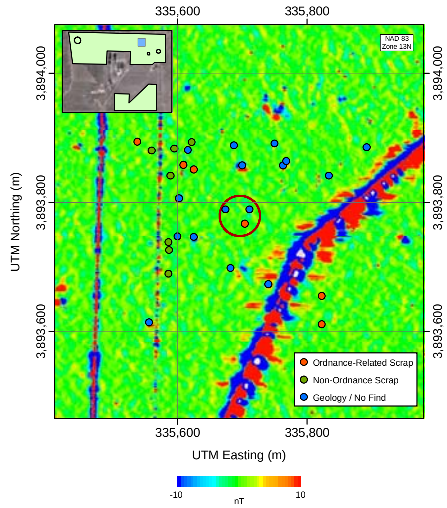


Figure 5-25. The intrusive investigation results for the raised area KPBR-AOI-1 show munitions-related scrap is present in this area.

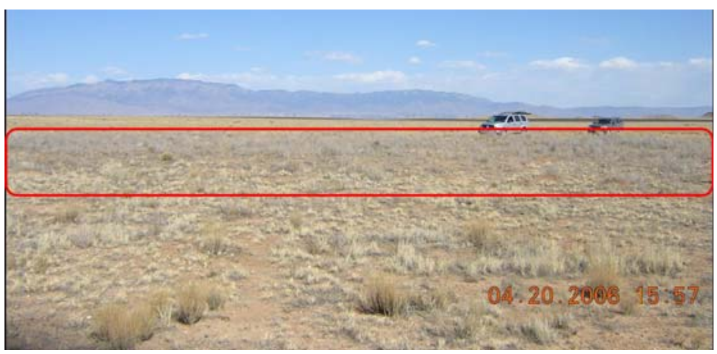


Figure 5-26. Ground reconnaissance located the slightly raised square area (outlined in red) that contained vegetation different than that of the area surrounding the feature (KPBR-AOI-1).

5.3.5.2 KPBR-AOI-2—Structure-Shaped Feature

Figure 5-27 shows a feature that appears to be a structure (KPBR-AOI-2) in the LiDAR data. A concentration of anomalies in the helicopter magnetometer data is associated with this structure. No ground-based transects traversed this area. Multiple lines of evidence support the conclusion that this structure is not munitions related.

During the ground reconnaissance, the team located a rectangular concrete foundation (see Figure 5-28). Ferrous debris was located but no munitions-related scrap was found. An intrusive investigation was deemed unnecessary in this area based on the ground reconnaissance findings. The validation results support the conclusion that this structure is not munitions related.

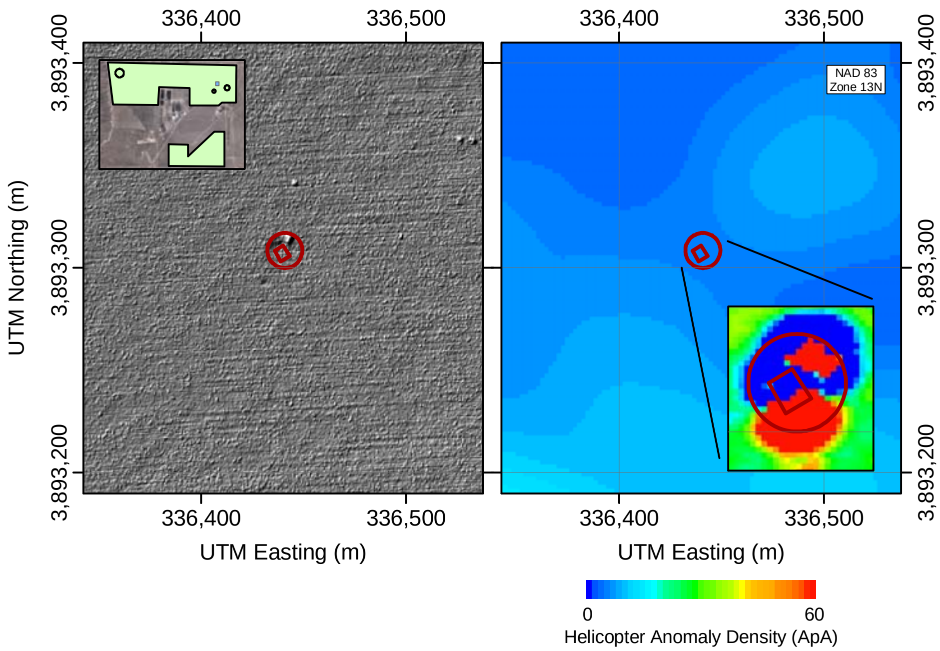


Figure 5-27. A structure (KPBR-AOI-2) is visible in the LiDAR data on the left. Anomaly density contours from the helicopter magnetometer data are shown on the right. The concentration of magnetic anomalies from the helicopter data associated with the structure is shown in the inset.

Figure 5-28. Ground reconnaissance of the structure identified as KPBR-AOI-2. This structure was found to be a rectangular-shaped concrete foundation.

5.3.5.3 KPBR-AOI-3—Depression South of N-2 Impact Area

Figure 5-29 shows a depression south of the N-2 Impact Area (KPBR-AOI-3) identified in the high-airborne data. A concentration of anomalies in the helicopter magnetometer data is associated with this structure. No ground-based transects traversed this area. Multiple lines of evidence support the conclusion that this structure is not munitions related.

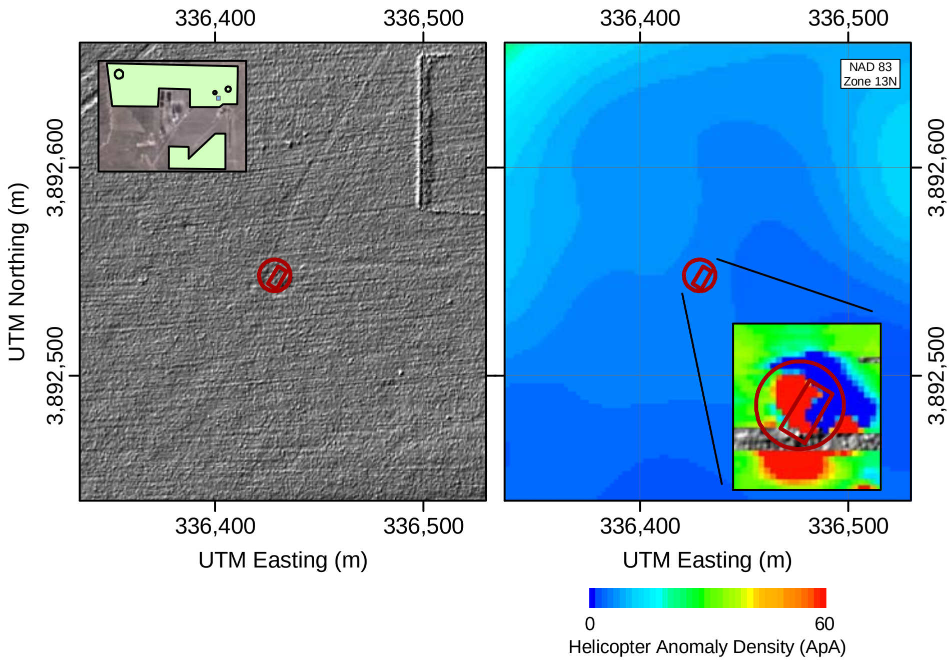


Figure 5-29. LiDAR data from the depression denoted KPBR-AOI-3 is shown on the left. Anomaly density contours from the helicopter magnetometer are shown on the right. The concentration of magnetic anomalies from the helicopter data associated with this area is shown in the inset.

The ground reconnaissance team observed a foundation and debris associated with a small building (see Figure 5-30). The area surrounding three sides of the foundation appears to have been excavated, and it forms the depression that was observed in the high-airborne data. No munitions-related scrap was observed. The validation results support the conclusion that this structure is not munitions related.

Figure 5-30. Ground reconnaissance of KPBR-AOI-3 found the remains of a building foundation and associated building debris. The area surrounding the foundation appears to have been excavated, which accounts for the depression.

5.3.5.4 KPBR-AOI-4—Circular Feature with Depressions

Figure 5-31 shows a circular feature with depressions in the center located in the southern section of the site (KPBR-AOI-4) identified in the high-airborne data. The diameter of the circle is 500 ft. Scattered anomalies are associated with this feature in the helicopter magnetometer data as seen in Figure 5-31. Scattered anomalies are also present in the ground-based transect data. There is confidence munitions-related activity occurred in this area, but it is not clear this feature is munitions related. It is possible that it was a lightly used target or spillover from the nearby N-1 Impact Area.

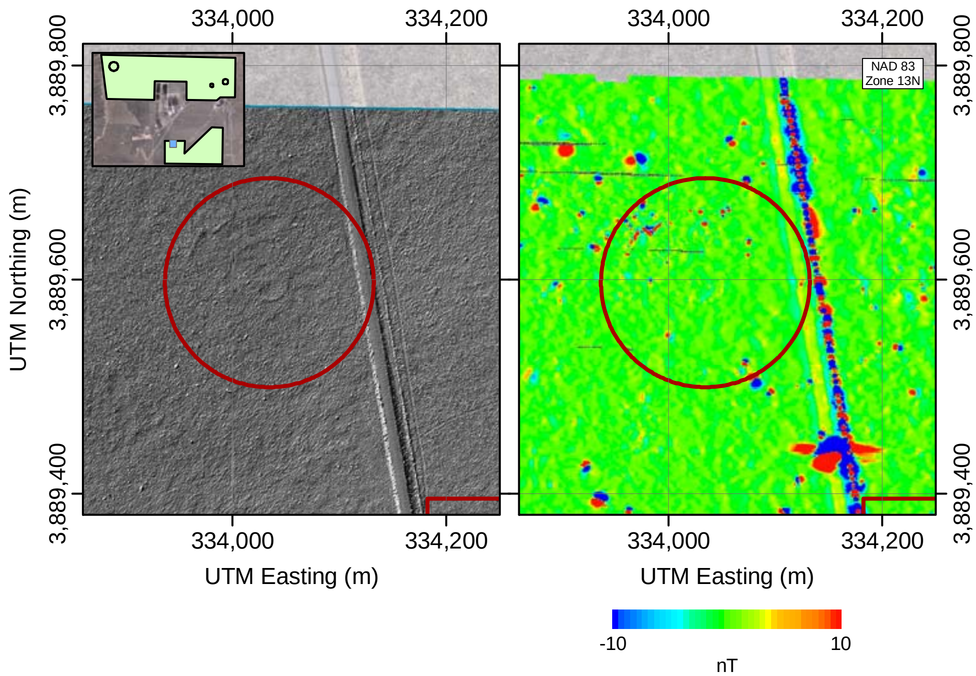


Figure 5-31. LiDAR data (left) and helicopter magnetometer data (right) from the circular feature denoted KPBR-AOI-4. A circular feature is visible in the LiDAR data. Scattered anomalies are seen in the magnetometer data.

The ground reconnaissance team located two ring-shaped features. The inner ring, with a 49-ft radius, is lined with light-colored pebbles. The team identified black volcanic glass on portions of the inner ring (see Figure 5-32). The outer ring is raised by approximately 10 cm with gradual edges and has a 171-ft radius. The ring diameters measured by the reconnaissance team are smaller than those associated with the ring identified in the LiDAR data. Munitions-related scrap from practice bombs was found in the area. An intrusive investigation was conducted on this area and scattered munitions-related scrap was found primarily in the northern section of the ring (see Figure 5-33). The purpose of the intrusive investigation at this AOI was to confirm if munitions or associated scrap are present. Only a select number of anomalies were dug to support this sampling. The validation results support the conclusion that munitions-related activity occurred in this area and that this feature may have been munitions related or may be spillover from the N-1 Impact Area.

Figure 5-32. Ground reconnaissance of KBPR-AOI-4 located two ring-shaped features. This figure shows the black volcanic glass that lines a portion of the inner ring.

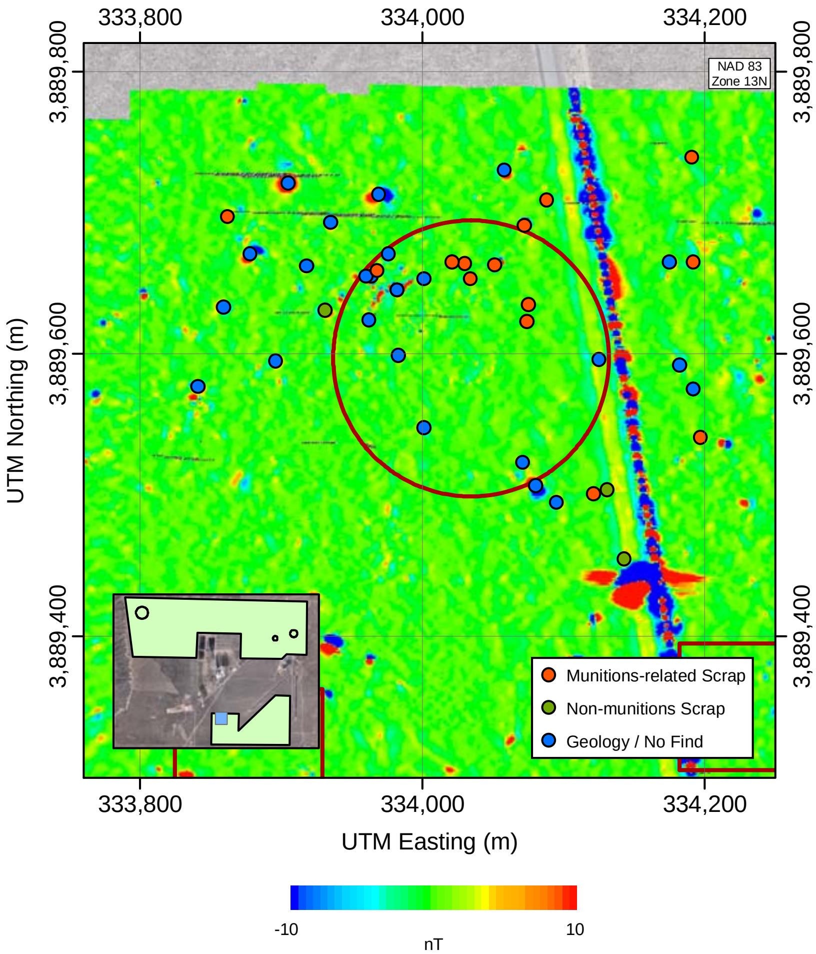


Figure 5-33. The intrusive investigation results for the circular feature KPBR-AOI-4 show munitions-related scrap is present in this area.

5.3.5.5 KPBR-AOIs 5–10—Depressions

Figure 5-34 shows multiple depressions identified in the high-airborne data (KPBR-AOI-5 through KPBR-AOI-10) that are all approximately 65 ft in diameter. A low density of anomalies identified in the helicopter data are seen throughout the south area (Figure 5-34), consistent with site background, and no concentrations are associated with the depressions seen in the figure. The ground-based transect data show scattered anomalies with each of the AOIs except KPBR-AOI-6, which was not traversed with the ground-based system.

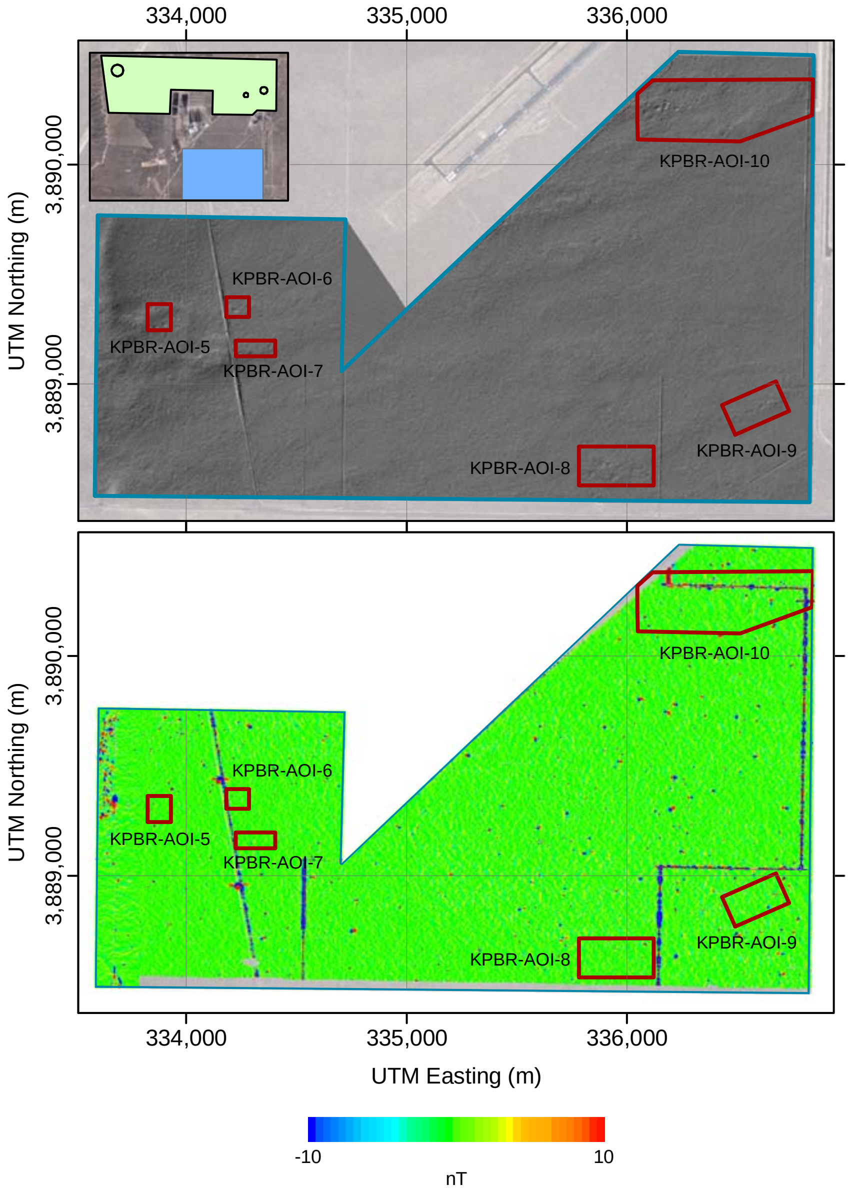


Figure 5-34. Multiple depressions, denoted as KPBR-AOI-5 through KPBR-AOI-10, are visible in the LiDAR data (top). Scattered anomalies are seen in the helicopter magnetometer data (bottom) in these AOIs.

The depressions found in the high-airborne data were visited, measured, and searched with a hand-held metal detector by the ground reconnaissance team (see Figure 5-35). The team did not find any munitions-related scrap and had no responses from the hand-held magnetometers in any of the depressions. These features are suspected to be collapsed animal burrows. Multiple lines of evidence support the conclusion that these features are not munitions related.

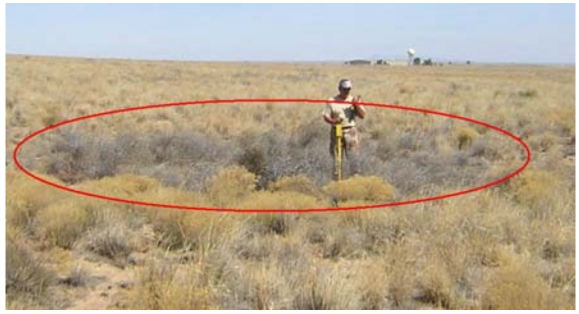


Figure 5-35. The ground reconnaissance team investigated the depressions identified as KPBR-AOI- 5 through KPBR-AOI-10. This figure shows the depression identified as KPBR-AOI-5 circled in red. No munitions-related scrap was found in these areas. The depressions are suspected to be collapsed animal burrows.

5.3.5.6 KPBR-AOI-11—Concentration of Geophysical Anomalies

Figure 5-36 shows a concentration of anomalies (KPBR-AOI-11) in the helicopter magnetometer data. The high-airborne data do not show any obvious features. The ground-based transects show scattered anomalies in the area. The ground-based transect anomaly density for the entire southern portion of the study area, including this area, did not exceed the threshold used to flag an area in VSP.

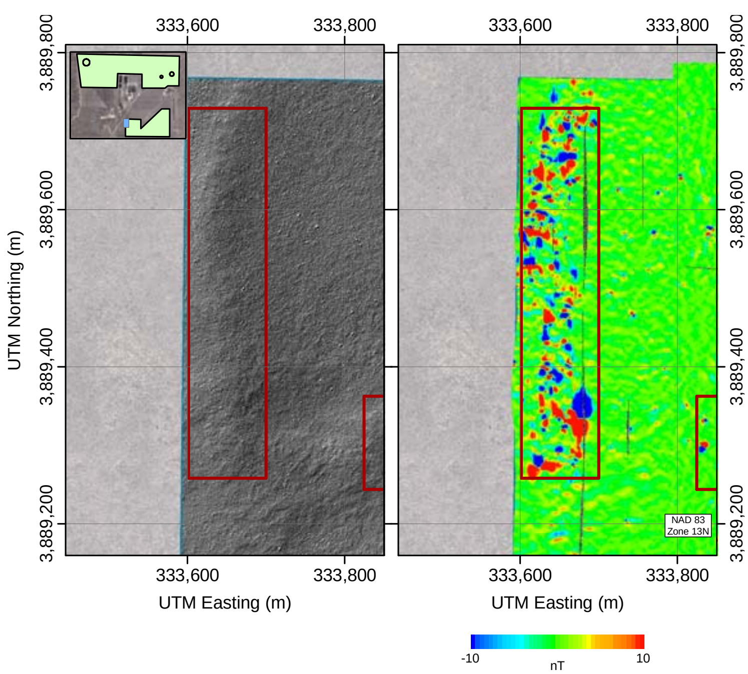


Figure 5-36. LiDAR data (left) and helicopter magnetometer data (right) from KPBR-AOI-11. A concentration of anomalies is seen in the helicopter magnetometer data. The LiDAR data do not show any obvious features.

The ground reconnaissance team found a concentration of alluvial pebbles which caused a response from the hand-held magnetometer (see Figure 5-37). The team did not observe any munitions-related scrap. During the intrusive investigation, primarily geologic items were unearthed, but scattered munitions-related scrap was found in the northern section of the AOI. There is confidence munitions-related activity occurred in this area. It is likely the anomalies result from a combination of local geology and spillover from the nearby N-1 Impact Area.

Figure 5-37. The ground reconnaissance team investigated KBPR-AOI-11. The team located a concentration of alluvial pebbles that caused responses from the hand-held magnetometer.

5.4 Overall Site Conclusions

The WAA study area was known to contain three target areas, the N-3 Impact Area, N-2 Impact Area, and the HE demolition impact area, and suspected to contain a refinery target. Historical records indicate all areas except the HE demolition impact area were used for only practice bombs. The locations of the three known target areas and this historical use of the targets were confirmed by all of the WAA data layers and validation efforts. The N-3 Impact Area was found to be larger and more complex than the initial CSM had indicated. The location of the refinery target was unknown in the initial CSM and identified through WAA. These results provide a preponderance of evidence to support the following conclusions about the site:

N-3 Impact Area

- The results show the target extent is greater and more complex than indicated in the initial CSM. All WAA data layers confirm the location of the N-3 Impact Area. One ship-shaped target, an additional outer target ring on the target circle, and two areas of concentrated anomalies were identified.
- The area of the target is estimated to be 200 acres with some 24,000 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is low, resulting in a high contrast between the background and the target density. Therefore, there is high confidence in these acreage and density results.

- The historical records indicate only practice bombs were used on this target area, and the findings of this study are consistent with the initial CSM. Ample evidence of practice bombs was observed. No craters or heavy-walled fragments, which would be evidence of HE bombs, were found at this target.

Simulated Oil Refinery Target

- WAA resolved the uncertainty in the target location in the initial CSM. Evidence of the refinery target is observed in all WAA data layers.
- The area of the target is estimated to be 60 acres with some 7,000 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is low, resulting in a high contrast between the background and the target density. Therefore, there is high confidence in these acreage and density results.
- The historical record indicates only practice bombs were used on this target area, and the findings of this study are consistent with the initial CSM. Ample evidence of practice bombs was observed. No craters or heavy-walled fragments, which would be evidence of HE bombs, were found at this target.

N-2 Impact Area

- The results are consistent with the initial CSM. All WAA data layers confirm the location of the N-2 Impact Area.
- The area of the target is estimated to be 55 acres with some 12,500 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is low, resulting in a high contrast between the background and the target density. Therefore, there is high confidence in these acreage and density results.
- The historical record indicates only practice bombs were used on this target area, and the findings of this study are consistent with the initial CSM. Ample evidence of practice bombs was observed. No craters or heavy-walled fragments, which would be evidence of HE bombs, were found at this target.

"New" Demolitions Impact Area

- The results are consistent with the initial CSM. All WAA data layers confirm the location of the HE demolition impact area.
- The area of the target is estimated to be 25 acres with some 1,400 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is low, allowing even this lightly used target to be identified and bounded with high confidence.
- The presence of HE craters and heavy-walled fragments found in the validation indicate HE bombs were used on this target. In addition, practice bombs were found on this target, suggesting mixed-munition types were used on this target or spillover from the N-2 Impact Area.

N-1 Impact Area

- The N-1 Impact Area was not included in the WAA study area, but it is suspected the circular feature and high anomaly concentration (KPBR-AOIs 4 and 11) are the result of spillover from this target. This area, included in the target boundary decision discussion below, is captured as a dashed arc in Figure 5-38.

Remainder of the Study Area

- All the other areas within the Kirtland WAA study area that are not associated with specific targets identified in the initial CSM show no evidence of concentrated munitions use.
- Out of the 5,000 acres surveyed, more than 4,600 acres were found to be free of concentrated munitions use.

5.4.1 Technology Conclusions

The WAA results from this site provide further insight into the capabilities and limitations of each technology.

5.4.1.1 High-Airborne Technology Conclusions

- The high-airborne data were effective in identifying munitions-related features and other areas to further investigate. In general, the LiDAR and orthophotography data complemented each other at this site. The munitions-related features, AOIs, and the general terrain of the site are more clearly observed in the LiDAR data.
- LiDAR was particularly useful in identifying aiming circles, ship shaped targets and other munitions-related features. Identifying or observing the absence of craters helped support conclusions about HE bomb usage at the site. Many features observed in the LiDAR data were too subtle to be seen on the ground.
- The orthophotography data were useful in identifying the cross hairs located at the center of the HE demolition impact area target circle that were not seen in the LiDAR data.

5.4.1.2 Low-Airborne Technology Conclusions

- The helicopter magnetometer data were used to identify elevated concentrations of surface and subsurface anomalies and to estimate the site background anomaly concentration.
- As a part of the validation process, select anomalies observed in the helicopter data were analyzed successfully and excavated to provide information on the extent of targets and the types of munitions used on the site.

5.4.1.3 Ground-based Technology Conclusions

- The ground-based transect data were used to identify high concentrations of anomalies and to estimate site background anomaly density.
- As a part of the validation process, the ground systems were used to survey total coverage patches. From these, selected anomalies were analyzed successfully and excavated to provide information on the extent of the target and the types of munitions used on the site. These areas were also used to produce an estimate of the anomaly density drop-off from each target.
- The EM system detected the rings found at the center of cells in the refinery target. This information helped confirm the refinery target location by providing an additional layer of evidence.

5.4.2 Combined Technology Conclusions

The contributions of the various data layers at this site are primarily observed by comparing the two types of targets.

5.4.2.1 NDIA Conclusions

The most useful data layers for detecting and characterizing the HE demolition impact area were LiDAR, orthophotography and the ground-based transect data.

- Both high airborne data sets identified the aiming circles. The orthophotography clearly showed the cross hairs of the target which was not seen in the LiDAR data. LiDAR identified craters, which provides evidence of HE munitions use and contributes to the extent of the target boundary. The HE craters were less prominent in the orthophotography data.
- The ground-based transect data are the most useful to delineate the estimated HE target boundary. These data incorporate fragments dispersed when the round explodes, which the helicopter magnetometer may not detect. In this case, the helicopter magnetometer data does show evidence of a lightly used target.

5.4.2.2 Practice Bomb Target Conclusions

All of the data sets successfully detected the practice bomb targets (N-3 Impact Area, refinery target, and the N-2 Impact Area).

- One of the high airborne data sets identified each of the target features. LiDAR data more clearly showed the cell structures that are part of the refinery target than the orthophotography.
- The helicopter magnetometer system and the ground-based transects were able to detect and characterize the practice bomb targets. These data sets are redundant and only one is needed to provide information on the extent of the target. For practice bomb targets, where small fragments are not present, both data sets provide an accurate picture, even though they differ in sensitivity.

5.4.3 Target Boundary Decisions

Figure 5-38 shows the boundaries created for the N-3 Impact Area, refinery target, N-2 Impact Area, and the HE demolition impact area from the pilot program. In addition, the estimated extent of the N-1 Impact Area is noted as a dotted arc in Figure 5-38. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

The boundaries do not represent an attempt to include every anomaly, and the ultimate area requiring action must be refined by more detailed characterization. These boundaries do not imply that no isolated munitions are present on the remaining land. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

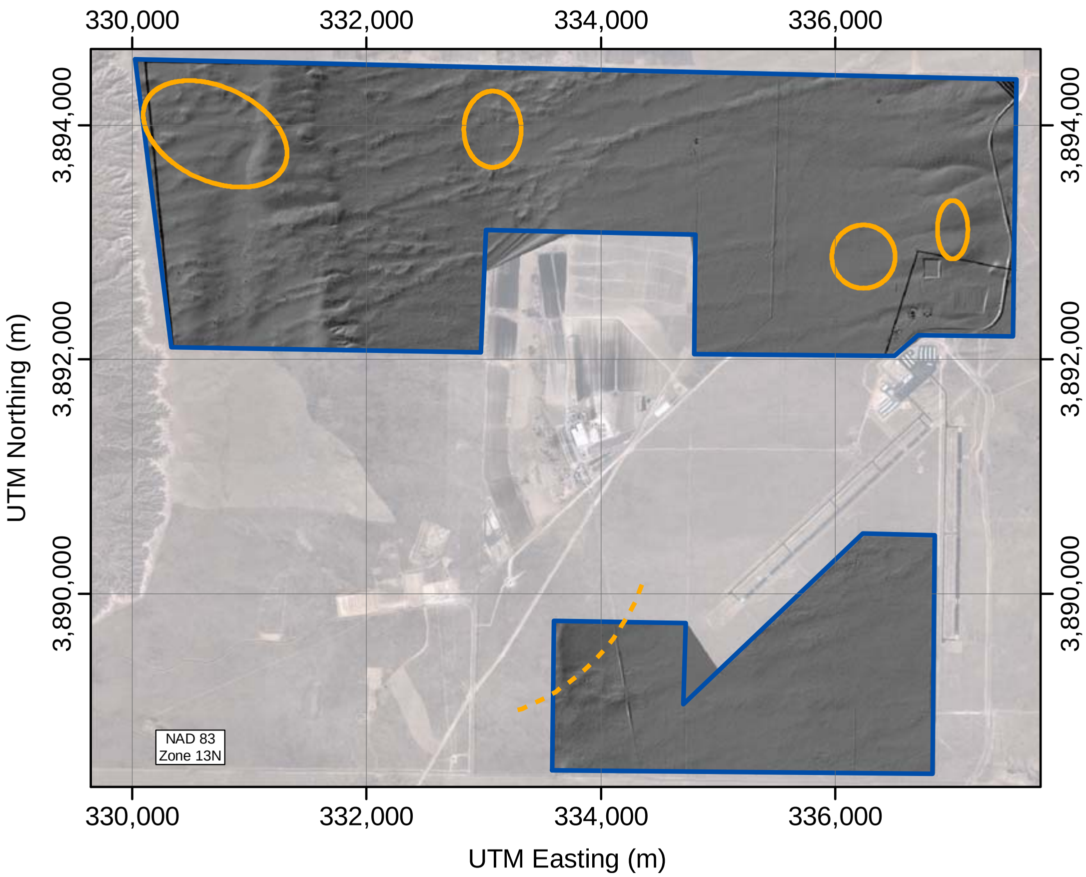


Figure 5-38. The orange boundaries encompass the best estimate of the target extent established from the WAA data. The dashed orange arc in the south is the suspected extent of the N-1 Impact Area spillover.

These data were provided to support the ongoing RI/FS at this site. For areas selected to move to the investigative phase, the WAA data provides a wealth of information that is not currently available for characterizing the target areas. The calculated acreage and estimated number of anomalies in each target boundary will support munitions response planning, prioritization and cost estimation. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity. Data characterizing this land can be used to support decisions on whether additional actions or controls are needed.

6.0 VICTORVILLE PRECISION BOMBING RANGES Y AND 15 DEMONSTRATION

Victorville PBRs Y and 15 were selected for this study because the site characteristics aligned with the pilot program objective to deploy the technologies on sites where capabilities and limitations could be demonstrated with limited interference from site-specific factors. Victorville PBRs Y and 15 have generally flat terrain, except on the outer edges of the study area, and limited vegetation. Historical records note the munitions types used were limited and larger munitions items were expected. The site contains known target areas and areas that were expected to be free of concentrated munitions use.

Victorville PBRs Y and 15 are currently in the site inspection phase of the DoD munitions response process. The information from WAA could be incorporated into the site inspection and used by site managers and regulators to support future planning, prioritization, and cost estimation. The WAA data were analyzed to bound each target area and identify areas free of concentrated munitions use. The total acreage and estimated number of anomalies associated with the bounded target areas can be used to define the scope of any future remediation work. Secondary information such as the type of munitions used on each target and terrain and vegetation challenges can also serve as useful inputs to future planning. Characterizing the remaining land as free of concentrated munitions use will also serve the planning process and may guide regulatory decisions about the need for future actions.

6.1 Test Site History and Characteristics

PBR Y and PBR 15 are part of a complex of 23 targets established for the training of both pilots and bombardiers of the Army Air Force West Coast Training Center in San Bernadino, California. The following information on the test site history was compiled in the initial CSM. The Victorville Army Flying School Bombing Ranges were part of the Advanced Twin Engine Bombardier School and the Advanced Flying School #4 located at Victorville Army Air Base. The ranges were used from 1942 to 1945. The majority of the 23 bombing targets were used for precision bombing practice using concentric aiming circles. PBRs Y and 15 are located near the Twentynine Palms Marine Base (Figure 6-1).

PBR Y was one of four target areas designated for demolition bombing training. These targets were all centered on dry lake beds due to the compactness of the soils. Demolition bombing targets differ from precision bombing targets in that demolition bombs are designed for the destruction of material targets. Demolition bombs used at the site ranged in size from 100 lb to 2,000 lb and were typically filled 50% by weight with HE. Typical fragments from demolition bombs include heavy tail plates or nose plugs, depending upon the location of the fuze. While a historical list of the exact munitions type used on this target does not exist, the fillers used on this target area were likely HE.

PBR 15 was designated as a practice target for bombardiers. Historical records state that only 100-lb, sand-filled practice bombs were delivered to this target through low-altitude drops. Although flare pot and aircraft flares were said to have been used to illuminate the target, no physical evidence has been found to substantiate their presence. Historical records note the target consists of two concentric circles marked with black road mix.

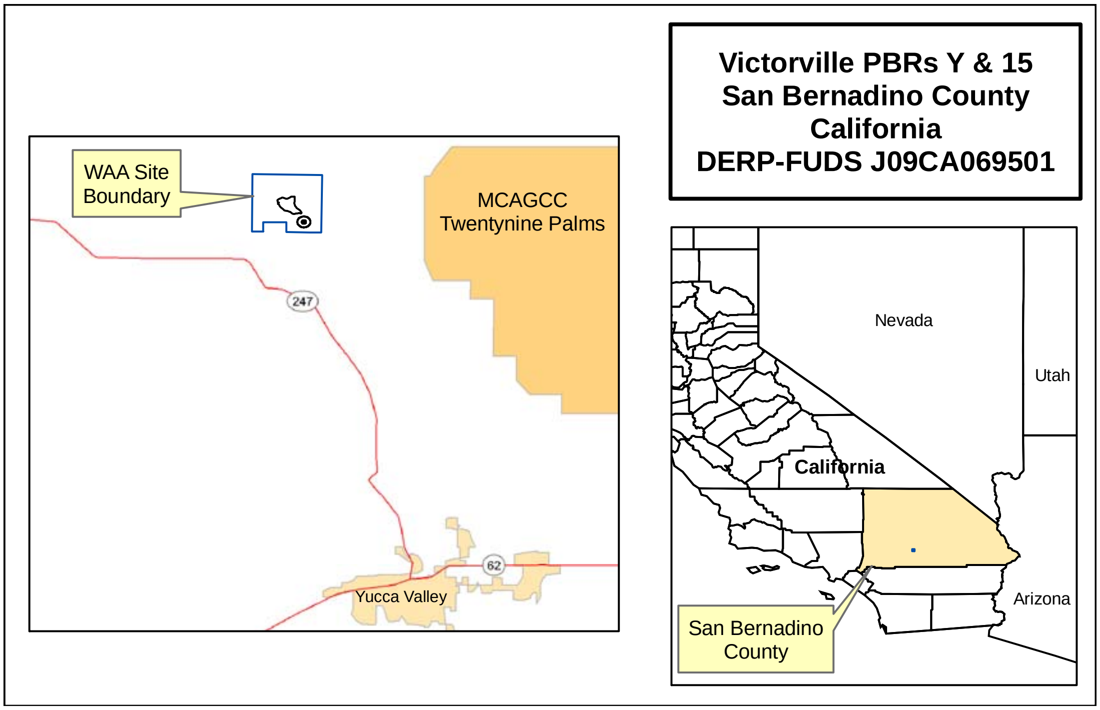


Figure 6-1. Area map showing the location of Victorville PBRs Y and 15 within the state of California and the location of the WAA program study area.

On 20 October 1947, a Certificate of Clearance, a standard document of that era, was issued. The Certificate of Clearance states the land is "suitable for grazing and/or mining only" and referred to a number of targets within the larger Victorville target complex. Some 235 tons of munitions and related debris were taken from Targets 6, 8, 9, 15, Y, 1E, and ZE. Among the items recovered were two 2,000-lb HE, twelve 100-lb HE, 629 100-lb practice bombs, and one flare, but there is no indication on which specific target any of them was found.

Figure 6-2 shows the approximately 5,600-acre WAA demonstration area. Currently, the areas in and surrounding PBR Y and PBR 15 are used for off-highway vehicle recreation and camping. The WAA demonstration area lands are managed by the Bureau of Land Management. (Refs. 25, 34, and 35)

6.2 Victorville PBR Y and 15 Study Area Objectives and Program Design

The primary objectives of the study at Victorville PBR Y and 15 were to confirm the presence of the two known targets and assess the remaining land in the study area to determine if there is evidence of any unknown targets. In addition, this study investigated the types of munitions associated with each target to determine if the results align with the historical records documented in the initial CSM.

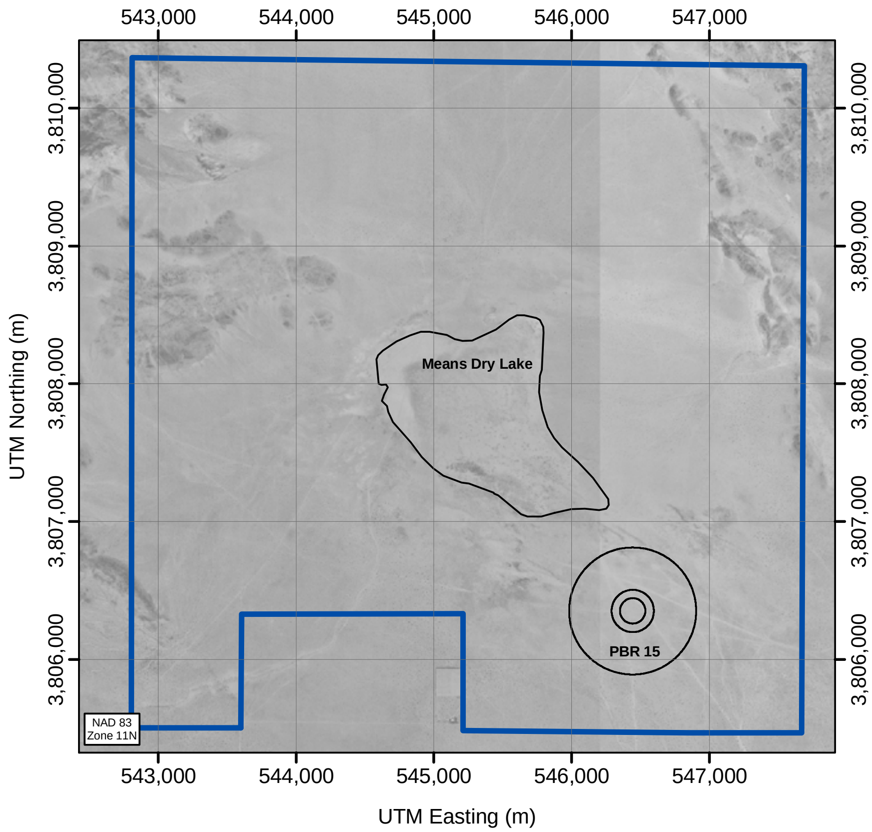


Figure 6-2. Map showing the Victorville Means Dry Lake (PBR Y) and PBR 15. The WAA demonstration area is the outer boundary shown in blue.

The technologies demonstrated at the site include LiDAR, orthophotography, a helicopter-borne magnetometer array, and a ground-based magnetometer array. In addition, a litter-carried EM system was demonstrated to fill in gaps in the ground-based towed system coverage caused by challenging terrain and to survey portions of the site with interfering geology. The high-altitude technology layers surveyed 100% of the 5,600 acre study area, as shown in Figures 6-3 and 6-4. The helicopter magnetometer system surveyed nearly 4,600 acres of the study area, as shown in Figure 6-5. Helicopter magnetometer data were not collected on the slopes that surround the study area. Ground-based magnetometer transect data covered the majority of the study area with the array. The litter-carried EM system was used to collect transects on much of the remaining area, where the towed system could not survey due to terrain and geologic interference, as shown in Figure 6-6. Combined, the transects surveyed by ground systems sampled 2% of the accessible areas, a total of 107 acres of transects. The ground-based transects were designed using VSP as discussed in the section below. For validation, an additional 125.9 acres were surveyed by the ground-based towed system at 100% coverage. The litter-carried EM system surveyed three areas, totaling about 3 acres, at 100% coverage. The anomaly density contours created from the helicopter magnetometer data and the estimated anomaly densities from the ground-based transect data are presented in the data analysis sections of this chapter. (Refs, 9, 14, 15, and 16)

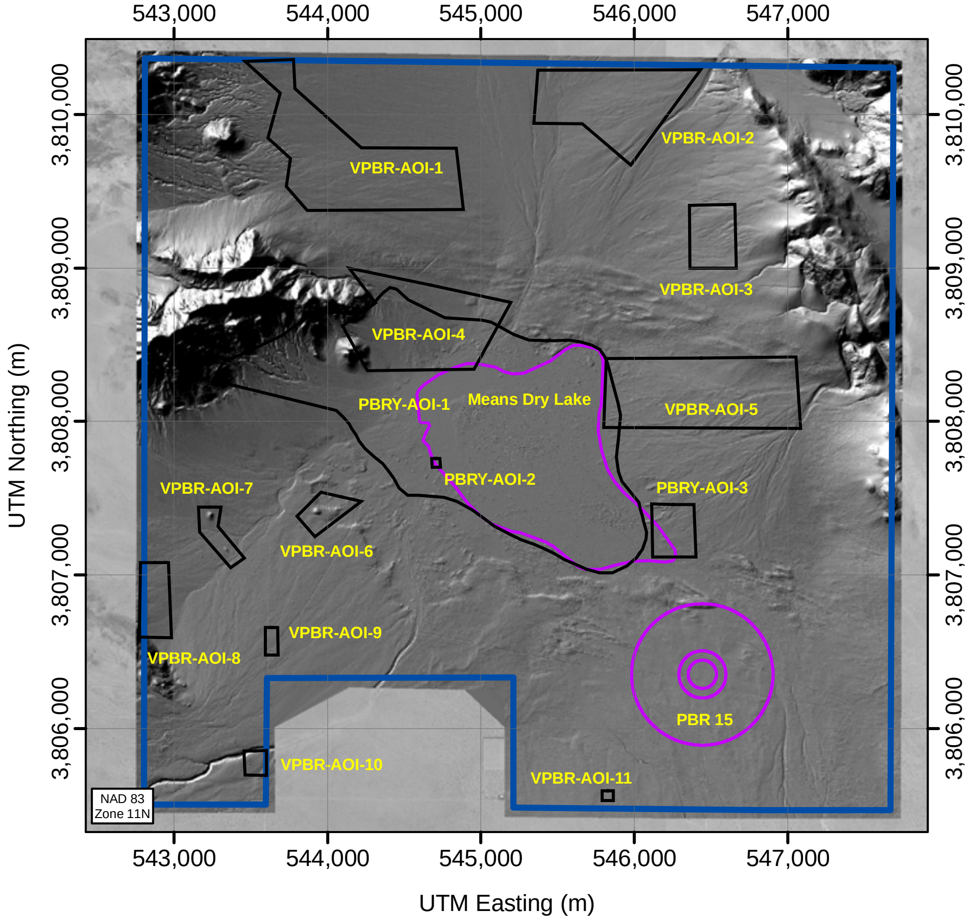


Figure 6-3. Victorville Means Dry Lake (PBR Y) and PBR 15 targets and AOIs are labeled on the LiDAR data. This technology covered 100% of the site.

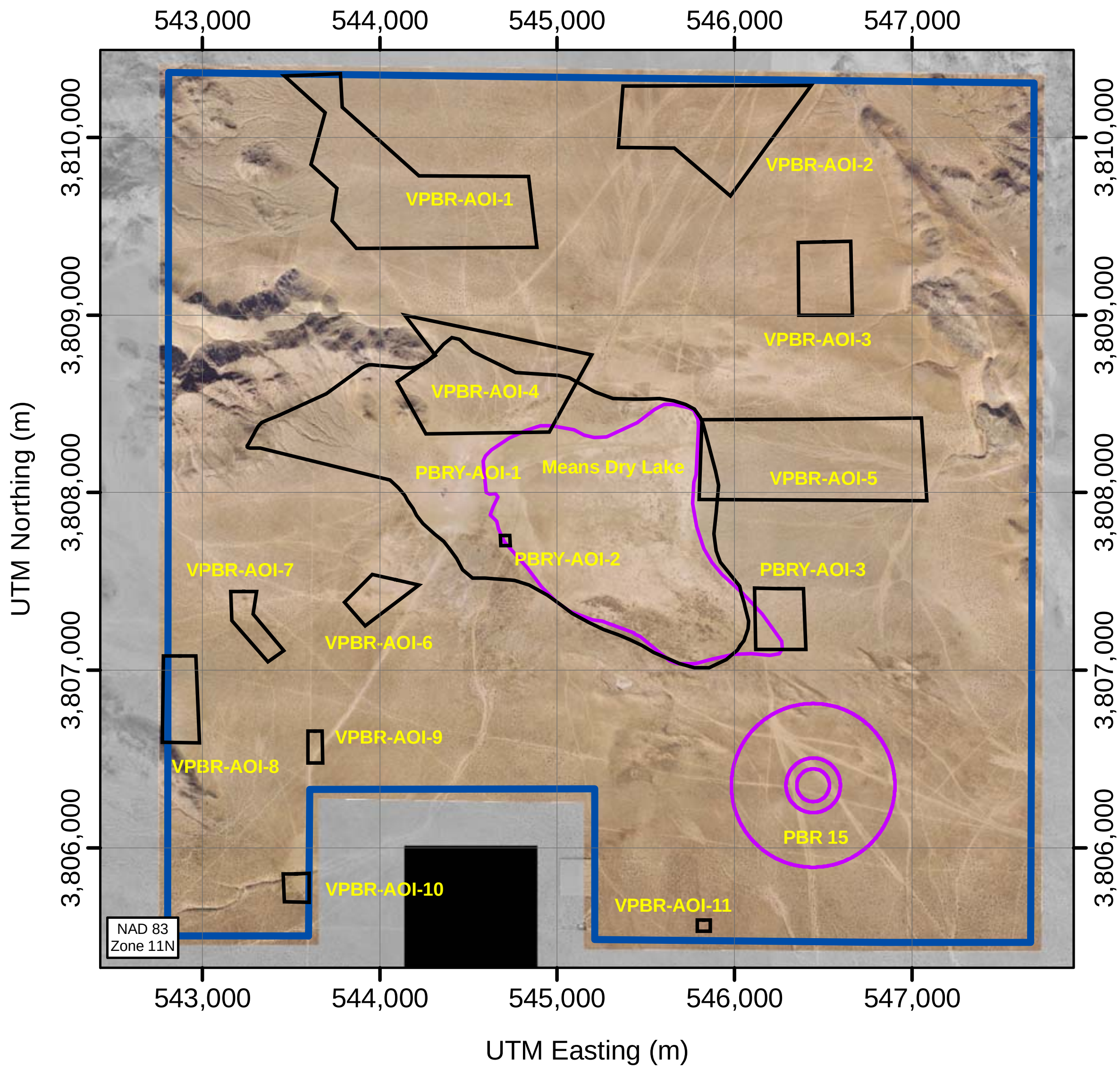


Figure 6-4. Victorville Means Dry Lake (PBR Y) and PBR 15 orthophotography data. This technology covered 100% of the site.

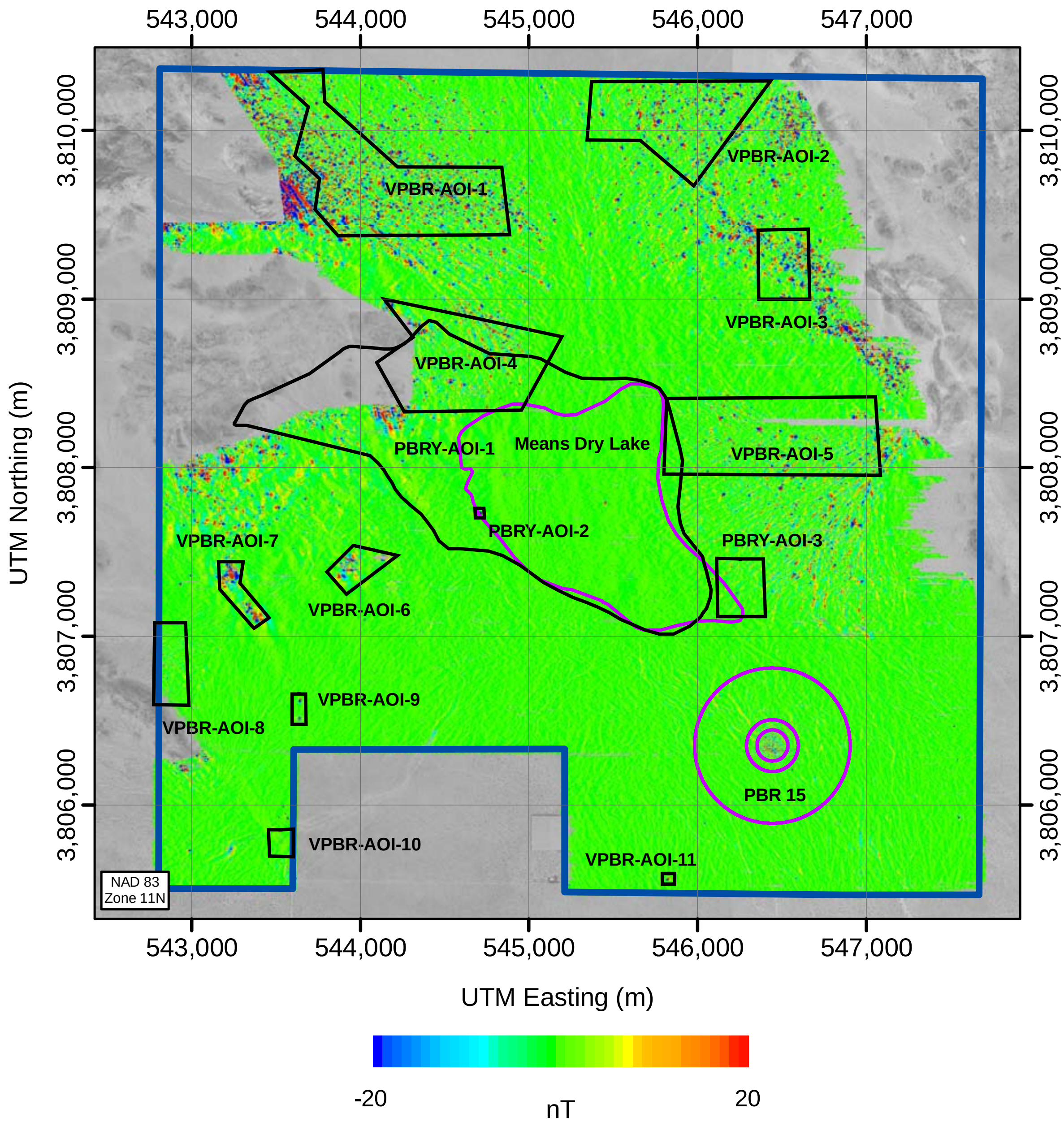


Figure 6-5. Victorville Means Dry Lake (PBR Y) and PBR 15 helicopter magnetometer data. Approximately 4,600 acres of the 5,600 acre site were surveyed. Gaps in the east and west were due to challenging terrain.

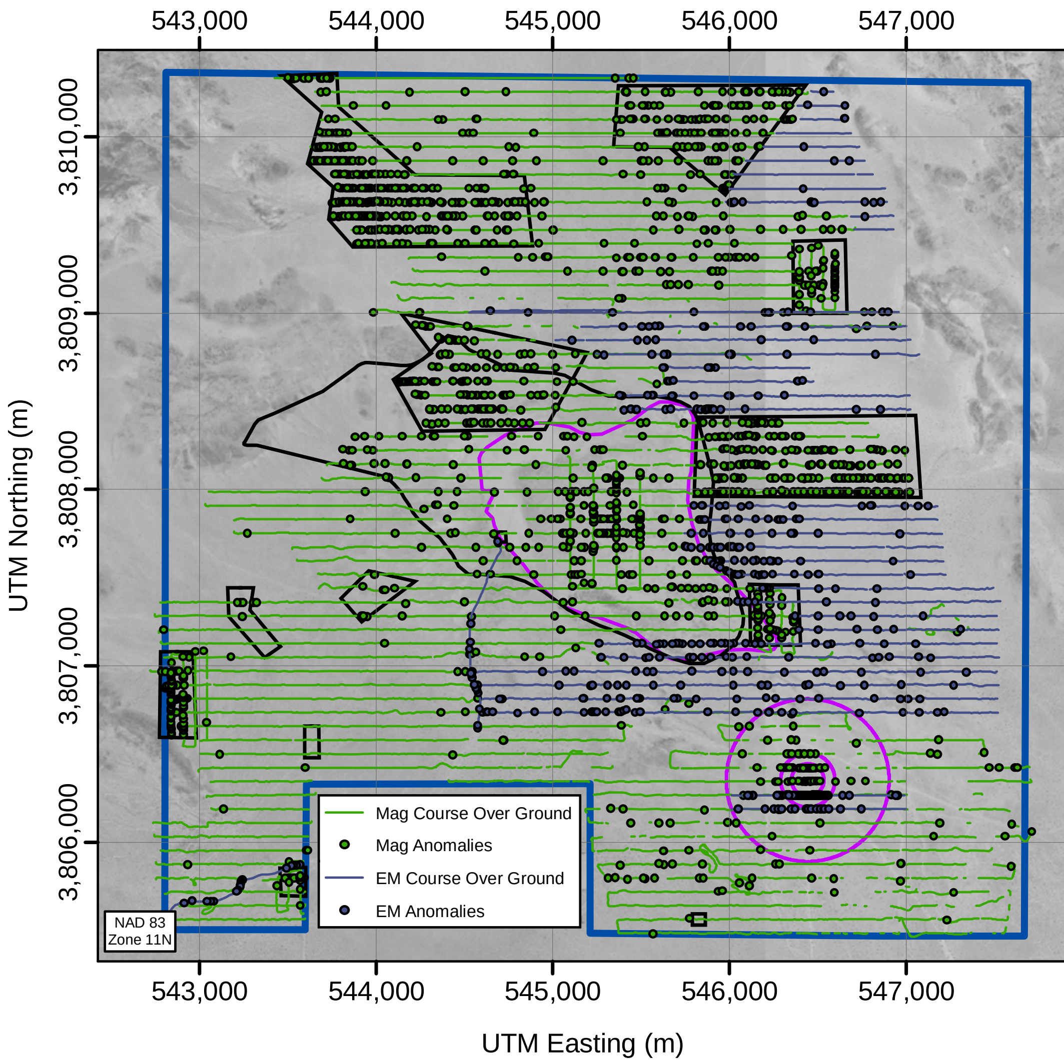


Figure 6-6. Victorville Means Dry Lake (PBR Y) and PBR 15 course over ground transects and anomaly locations. Targets and AOIs are labeled in Figure 6-3 above. The towed-array data are shown as the green transects. A litter-carried EM system (blue transects) was deployed to fill in data gaps where the towed magnetometer system was limited by terrain and geologic interference.

6.2.1 Ground-based Transect Design

Ground-based transects were planned during a joint meeting of site managers, regulators, and ESTCP Program Office representatives. The design approach was developed from historical knowledge of the two known target areas. The initial CSM for PBR Y suggested the target area could have a major axis of 250 ft and a smaller minor axis. Also, the Archives Search Report suggested the aircraft approached the targets from the south. Thus, a 100% probability of traversing a 125 ft by 250 ft elliptical target area oriented north to south was used to establish the transect spacing. This transect design resulted in 2 m wide transects spaced 78 m on center, with a 98% probability of detecting the target area. The target area assumption did not account for fragment dispersion around the impact points of HE munitions, and was considered extremely conservative. This approach is referred to as the *dense* transect design.

A *sparse* transect design was based on the low-altitude precision practice bomb target PBR 15. Based on information from the initial CSM, the visible target circles are 180 m in diameter. A transect design that has a 100% probability of traversing a 500 ft diameter circular target area was designed. This transect design covered 1.29% of the study area with 2 m wide transects spaced 154 m on center. This design had a 90% probability of detection for the target density assumed in planning.

The ground-based systems collected data using the dense design. To the extent possible, transect data were taken with the vehicle magnetometer system. Where geology and terrain prevented the magnetometer array from collecting useful data, a litter-carried EM system was used to supplement the ground-based magnetometer data. The VSP analysis was adapted to account for the narrower swath width of the 1-m wide EM system.

Because the sparse design requires only half the transects gathered from the dense design, it is a subset of the original data gathered from the conservative transects. The methods were compared to determine the value added from the more conservative dense design. Table 6-1 compares the design approaches.

Table 6-1. Summary of Transect Design Approaches for Victorville PBR Y and 15.

	Dense	Sparse
Primary objective of design	Detect the presence of 100-lb bomb elliptical target areas with a 250-ft (76-m) major axis	Detect the presence of 100-lb bomb circular 500 ft (153 m) diameter target areas
Type of sampling design	Transect	Transect
Shape of target area	Elliptical	Circular
Diameter of target area (circle)	N/A	153 m
Semi-major axis length (ellipse)	76 m	N/A
Transect pattern	Parallel	Parallel
Transect width	2 m	2 m
Computed transect spacing	78 m	154 m
Required probability of traversing the target area	100%	100%
Probability of detecting target area	98%	90%
Number of transects	74	36
Transect coverage	571,755 m^2 (2.57%)	287,326 m^2 (1.29%)

6.3 Performance Assessment

The WAA data layers were analyzed separately and in combination. The high-airborne data were collected first and used as the starting point to identify munitions-related features and AOIs. As the helicopter and ground system data were received, they were examined to identify areas of concentrated anomalies. The areas identified in these two data sets were compared to those suspected munitions-related features and AOIs identified in the high-airborne data. The concentrated anomaly areas that did not have high airborne features associated with them were added as additional AOIs.

All layers of WAA data and the validation results confirm the location of PBR 15. The high-airborne data, ground-based transect data, and the validation results confirm the location of PBR Y, which was found to be an HE target. The helicopter magnetometer system did not detect a concentration of anomalies, likely due to the small fragment size and the offset distance from the sensor to the ground surface. Based on the WAA data and the supporting validation results, the remaining land does not contain concentrated munitions. Figures 6-3 to 6-6 show the overall site investigation area, indicating the targets and AOIs. Specific discussions about the known targets are found in the subsequent sections, including a discussion of the data analysis, interpretation, and evaluation for each area and the associated validation efforts. The areas are discussed from north to south.

6.3.1 Precision Bombing Range Y

PBR Y is identified in the initial CSM as the target located on the lake bed in the central part of the WAA study area. The location of this target in relation to the entire study area is noted in the inset in Figure 6-7.

6.3.1.1 Data Analysis, Interpretation, and Evaluation

The location of PBR Y is confirmed by two of the WAA data layers. Multiple lines of evidence support the conclusion that the target is located on Means Dry Lake. A significant number of craters, which were confirmed during validation, are seen in the high-airborne data shown in Figure 6-7. The presence of the craters not only confirms the location of the target, but also confirms the use of HE bombs on it.

Historically, dry lakebed targets used structures as targets rather than surface-marked target circles. (Ref. 25) No surface features indicating a target outline were found in the high-airborne data at PBR Y. In Figure 6-8, the helicopter magnetometer anomaly density contours show only scattered anomalies throughout the lake bed, but the ground-based magnetometer system shows significant concentrations of anomalies. Demolition bombs were typically filled with a higher proportion of explosives than other types of bombs, which results in the pulverization of the bomb casing and few sizable fragments. (Ref. 25) The fragment size may be too small for the helicopter system to detect at 2 m offset, but it is detectable by the ground system, which is offset only 25 cm from the sensor to the ground surface.

In the ground-based magnetometer data, two areas with higher concentrations of magnetic anomalies were identified in the lake bed. These two areas correspond with higher crater densities, suggesting the possibility there could have been two sub-targets in this area. The anomaly density in the northern area was greater than that in the southern area, which may imply the southern area was more lightly used.

Based on the LiDAR data, the craters in the lake bed and a number of features to the north and west of it are labeled PBRY-AOI-1. Figure 6-9 shows the individual features identified as potential craters in the LiDAR analysis.

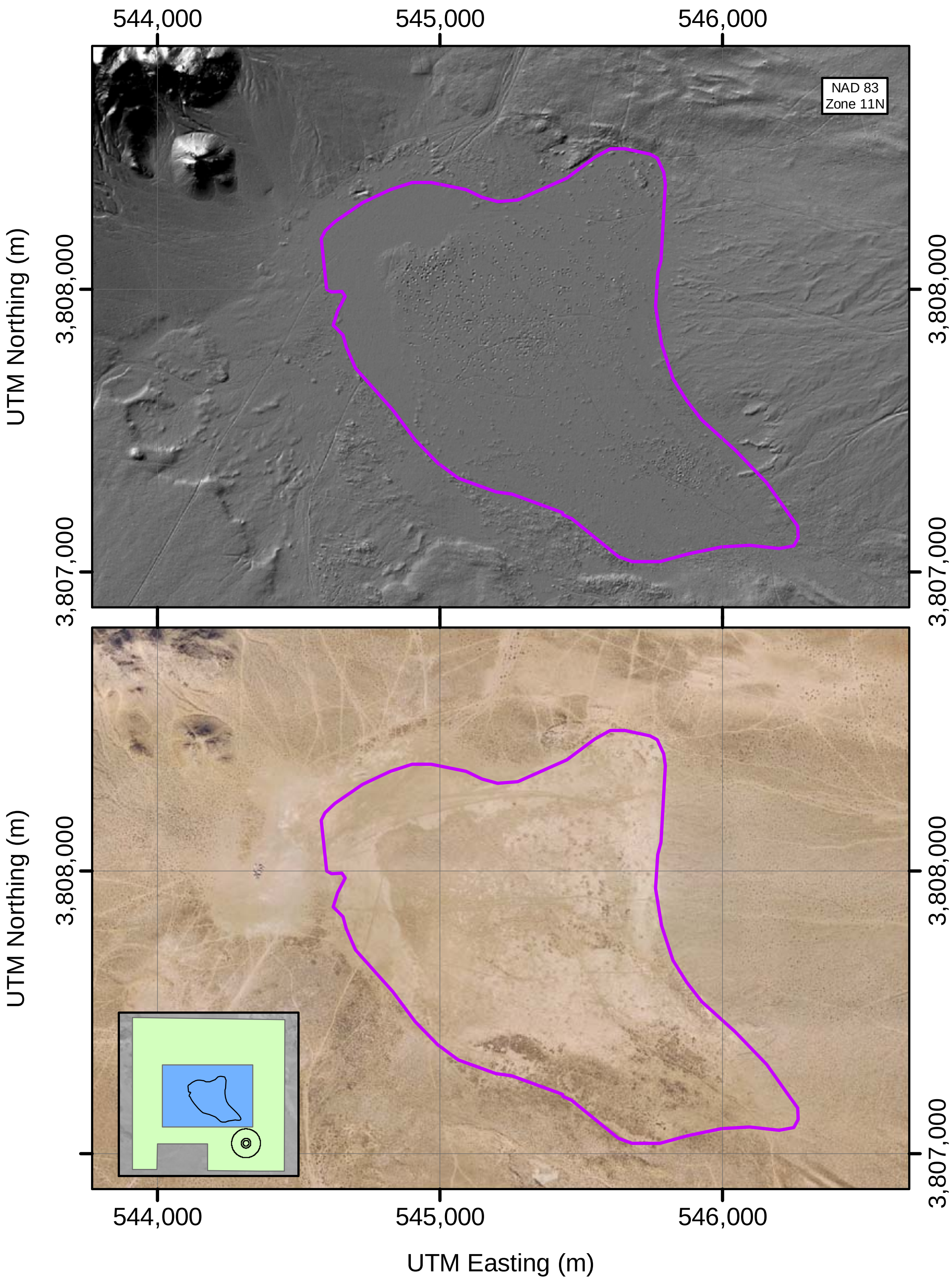


Figure 6-7. LiDAR data (top) and orthophotography data (bottom) from PBR Y in Means Dry Lake. The lake bed was used as the target, and HE craters are visible in both data sets.

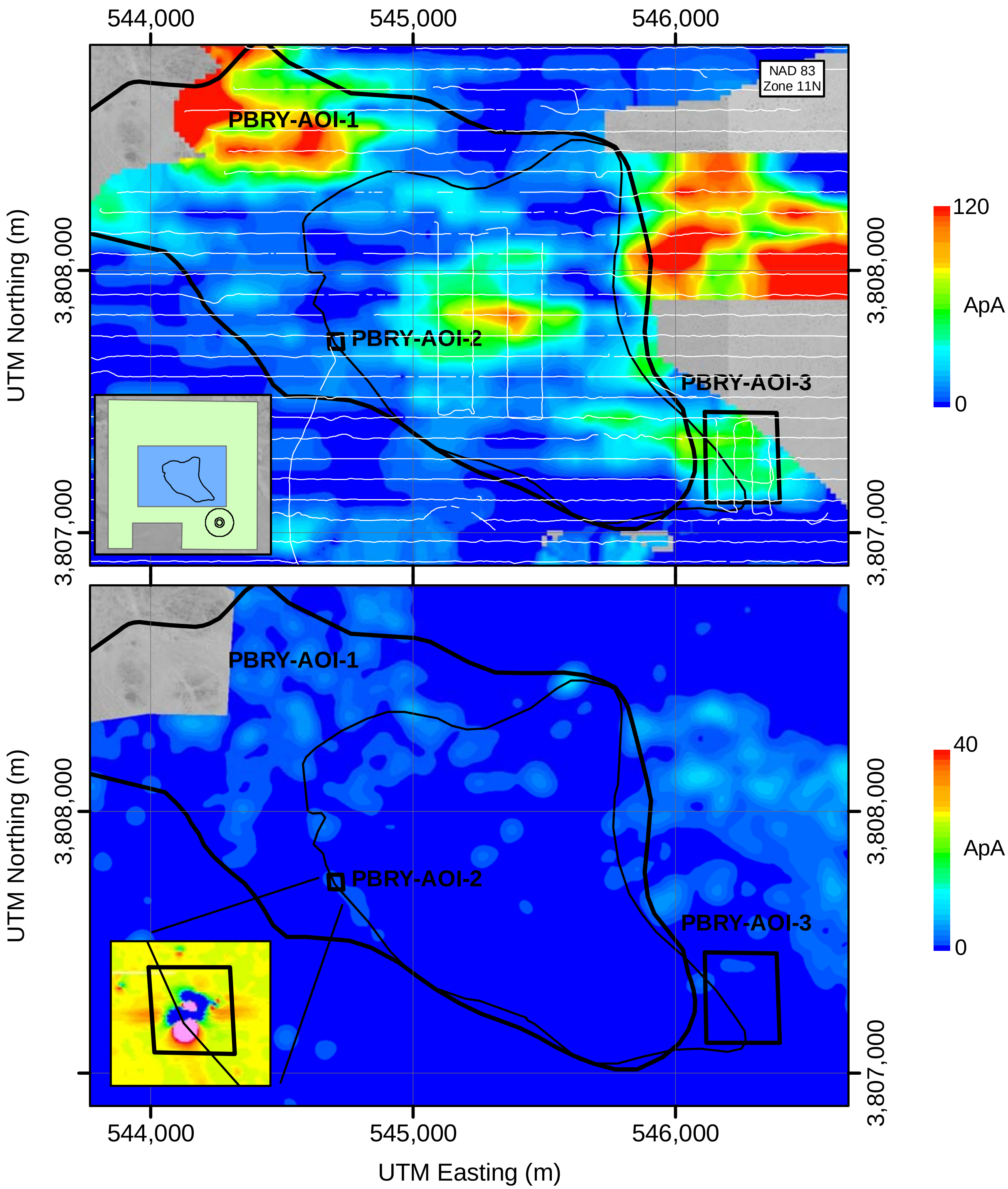


Figure 6-8. Estimated anomaly densities from the ground-based transect data with the transects shown as white lines (top) and helicopter magnetometer (bottom) for PBR Y. The ground-based transect data show elevated concentrations within the lake bed target.

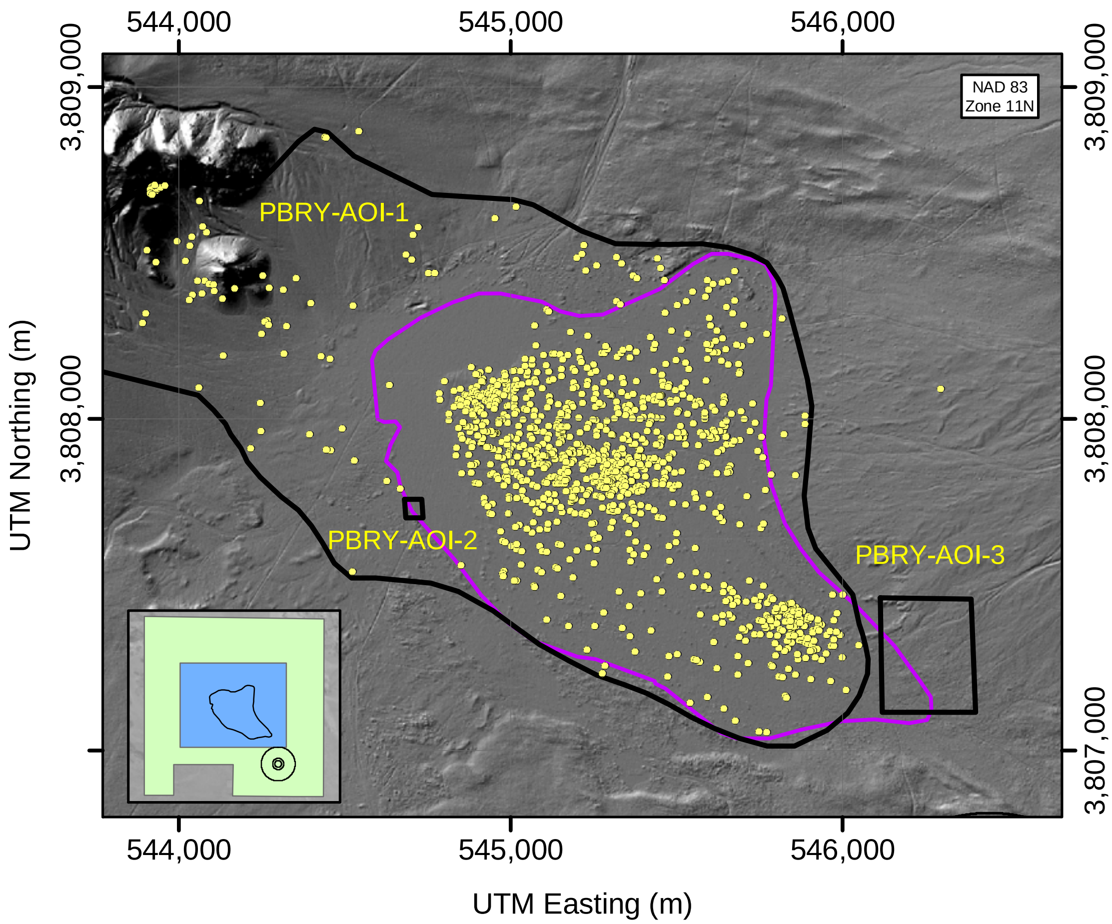


Figure 6-9. The yellow dots are depressions identified in the LiDAR data. Two distinct areas with high densities of craters seen in the lake bed are potential sub-targets of PBR Y.

The areas surrounding PBR Y to the north and east posed difficulty for the ground-based system due to soft sand and to the both the ground-based and helicopter magnetometer due to interfering geology. Surface conditions prevented parts of the ground-based transect plan from being surveyed with the towed system. Figure 6-6 shows coverage of the ground-based towed system in green and the transects that were filled in by the litter-carried system in purple. Patches of higher magnetic anomaly density (approximately 250 anomalies/acre) are seen to the east of the lake bed, where no targets are known to be present. The anomaly density threshold used to flag an area in VSP for the ground-based transect data was exceeded in each of these areas, and the helicopter magnetometer data also show high anomaly density.

It was suspected the magnetic anomalies in these areas resulted from geologic interference. To confirm this hypothesis, an additional data collection using a litter-carried EM system was conducted. An EM sensor was chosen because these sensors are less responsive to magnetically active geology. A litter-carried system was selected so the majority of the missing areas in the original transect plan could be filled. The EM transect results are shown as purple lines in Figure 6-6.

A small area of concentrated anomalies is seen in the helicopter magnetometer data on the western edge of the lake bed (PBRY-AOI-2). A ground-based system did not traverse this small area. The orthophotography data show rusted cars in the corresponding area, which were later confirmed by a field visit. Multiple lines of evidence support the conclusion that this feature is not munitions related.

An additional area of concentrated anomalies located on the southeast edge of the lakebed (PBRY-AOI-3) was detected in the ground-based transect data. The helicopter magnetometer data show only scattered anomalies. No features are present in the high-airborne data in the corresponding area. Multiple lines of evidence support the conclusion that this feature is not munitions related and it is attributed to geology based on findings in other areas of the site.

6.3.1.2 Validation

Ground reconnaissance and total coverage survey areas were the two validation methods used at this site. This site was the third of the three Phase I WAA pilot program demonstrations. The Program Office, in conjunction with the Advisory Group, determined an intrusive investigation on this site was not necessary to validate the results. The findings from the first two sites indicated the information gained from the ground reconnaissance provided enough information to confirm the site conclusions.

The validation results confirm the location of the target. Ground reconnaissance of the area in and surrounding PBR Y located heavy-walled fragments that confirmed the use of HE bombs on the target, which is consistent with the initial CSM. The reconnaissance team visited, photographed, and documented select depressions within the two concentrated areas in the lake bed (PBRY-AOI-1). Several of these depressions were confirmed as munitions-related craters by the presence of HE heavy-walled fragments. The small number of HE craters found outside of the target area does not imply a separate target; they are likely the result of munitions that did not strike the main target. The other depressions outside the lake bed were visited by the reconnaissance team. They were identified as mining prospect pits, formations from boulders, or animal burrows.

The reconnaissance team visited the area of concentrated anomalies seen in the helicopter magnetometer data on the western edge of the lake bed (PBRY-AOI-2). The four rusted vehicles identified in this area are responsible for the magnetic anomaly concentration, confirming this feature is not munitions related. Based on findings in other areas of the site, the area of concentrated anomalies located to the southeast edge of the lake bed (PBRY-AOI-3) was attributed to magnetic geology and was not visited by a reconnaissance team.

Two ground-based magnetometer total coverage areas associated with PBR Y were surveyed (see Figure 6-10). These total coverage areas (TC-02 and TC-03) were selected to provide detailed characterization of the lake bed to compare with the transect conclusions. TC-01 was surveyed to estimate site magnetic background density. In addition, four total coverage areas were selected to explore regions of high anomaly density (HOT 1-4) that was suspected to arise from geology. These are discussed below.

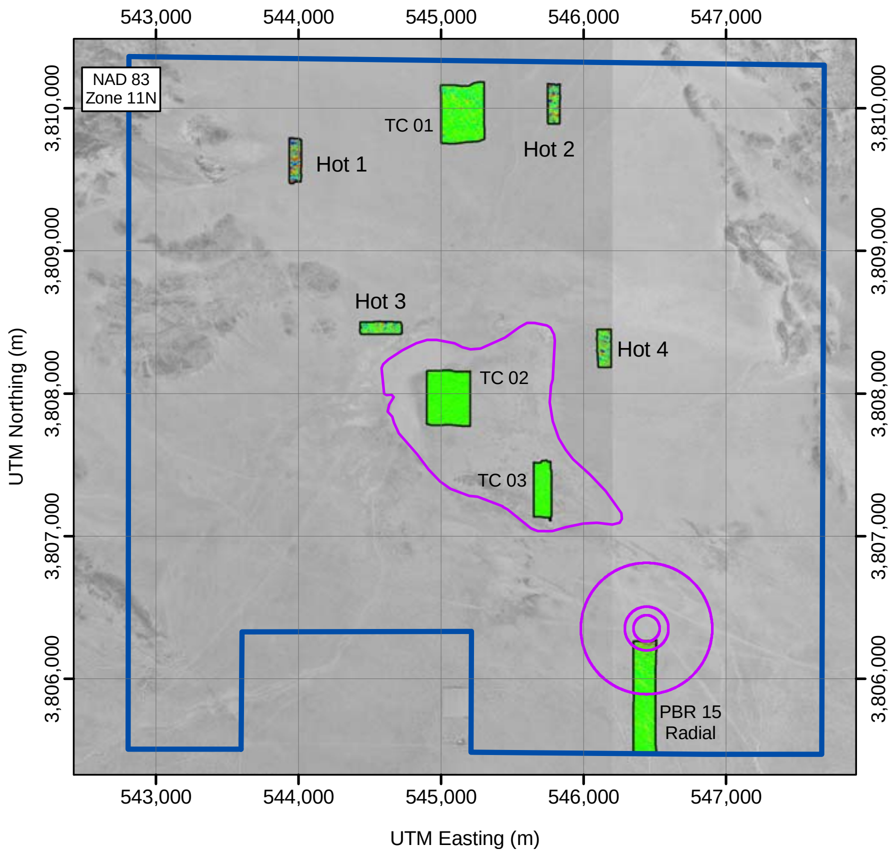


Figure 6-10. Areas of total coverage by the ground-based magnetometer system.

6.3.1.3 Target Boundary Decision

In Figure 6-11, an elliptical boundary was drawn to encompass all the craters on and adjacent to the lake bed and the areas of enhanced magnetic anomaly density associated with the target. This boundary does not imply isolated munitions or munitions debris are not present on the remaining land. In fact, two isolated munitions craters lie outside this boundary. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

The bounded area is 470 acres and contains an estimated 1,040 craters and 10,000 anomalies detectable by a ground-based sensor, which will serve as inputs to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

6.3.2 Precision Bombing Target 15

6.3.2.1 Data Analysis, Interpretation, and Evaluation

The location of PBR 15 is confirmed by all the WAA data layers. In Figure 6-12, the high-airborne data depict the inner target circles, an outer circle with a 600 ft diameter, and the central cross hair. The target circles and the cross hair are most easily seen in the LiDAR intensity and orthophotography data. Since the target markings consist of asphalt at ground level, there is very little elevation difference observable in the LiDAR elevation data.

At the other sites investigated in the first year, practice bomb targets 1,000 ft to 3,000 ft in diameter were observed. Here, circles beyond 600 ft were not seen in either high-airborne data set. This is consistent with the CSM description of this target as a low-altitude bombing target. As shown in Figure 6-13, concentrated anomalies were found in helicopter magnetometer data and the estimated anomaly densities from the ground-based transect data within a 1,000 ft diameter around the target center. The ground-based transect anomaly density in and surrounding the 600 ft target circle exceeded the threshold used to flag an area in VSP. As was encountered at PBR Y, the entire ground-based transect plan could not be surveyed with the vehicular system in this area due to soft sand. The litter-carried EM system filled in the data gaps in those areas.

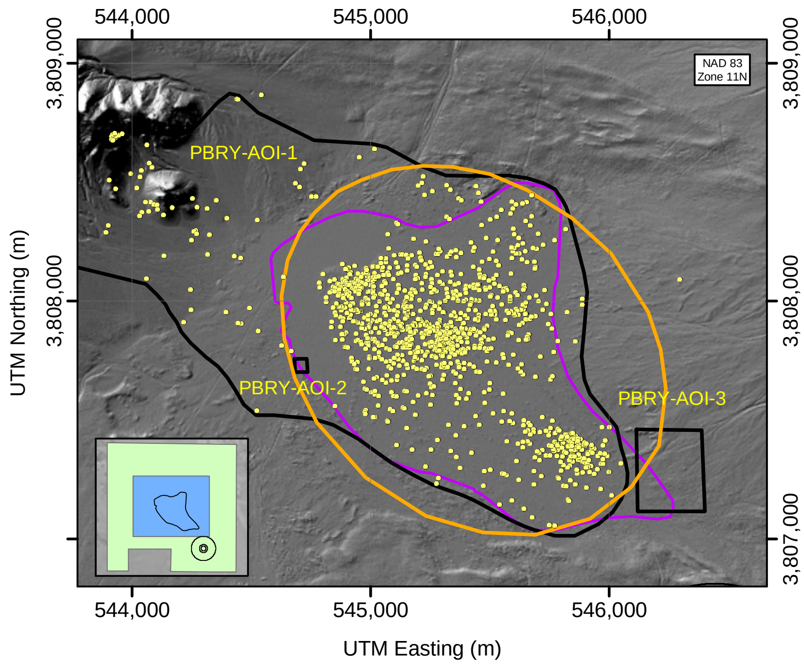


Figure 6-11. Target boundary drawn to encompass all the craters on and adjacent to the lake bed, as well as the areas of enhanced magnetic anomaly density associated with the target.

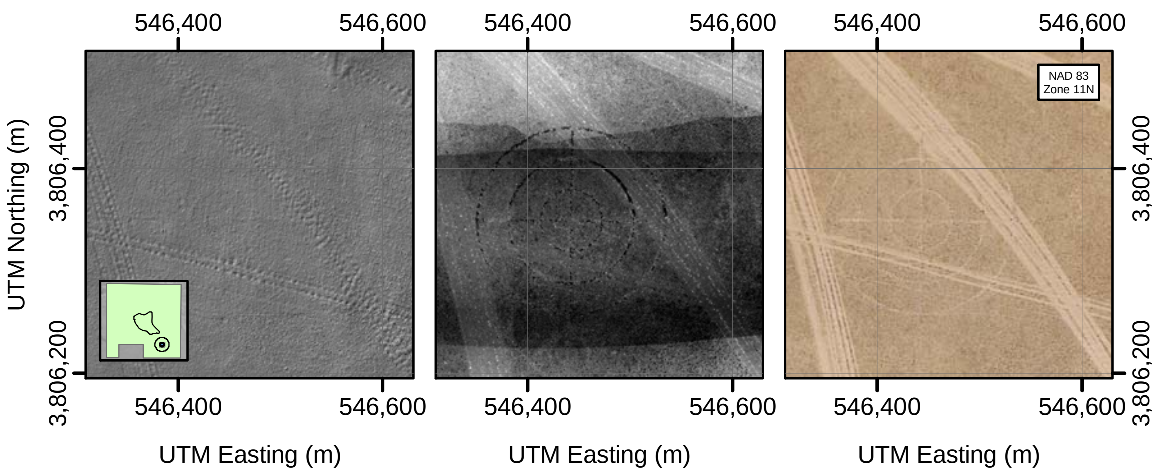


Figure 6-12. LiDAR elevation data (left), LiDAR return intensity data (center), and orthophotography data (right) from the area near PBR 15. The target circles are visible. The cross hairs are visible in the LiDAR intensity and orthophotography data.

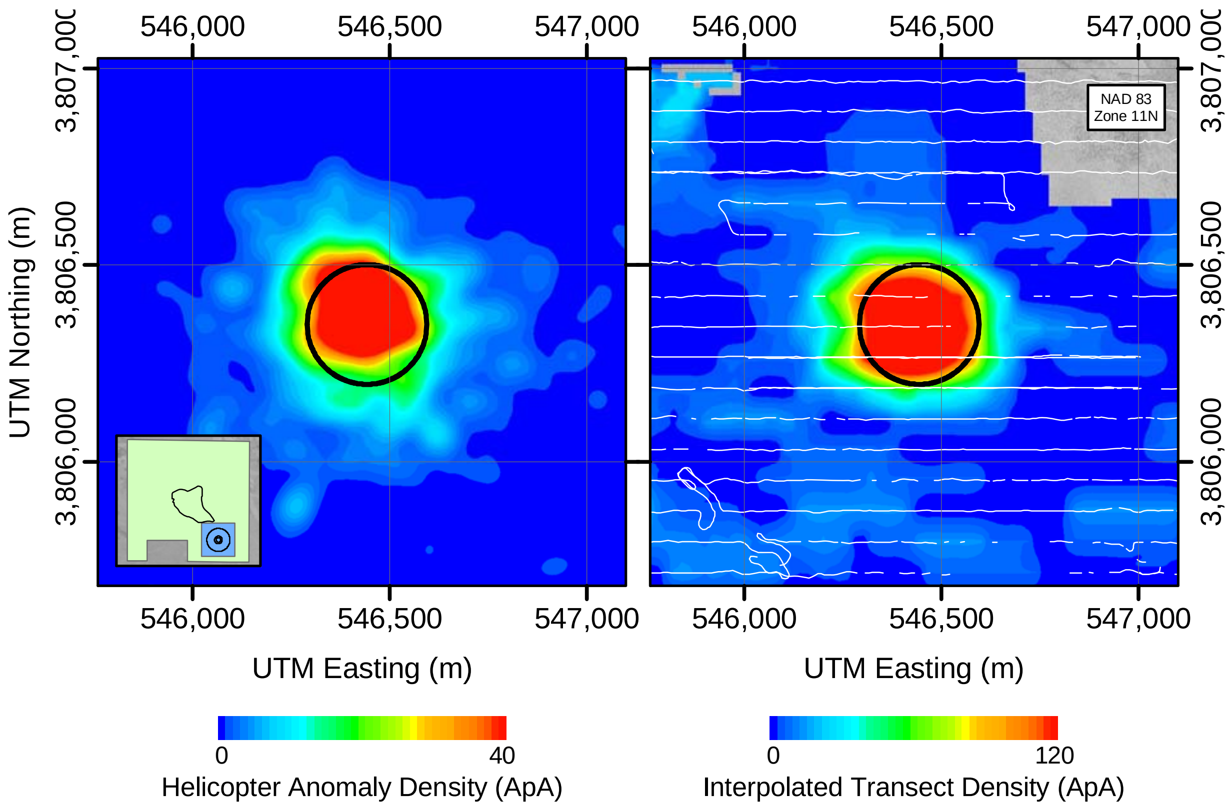


Figure 6-13. Anomaly density contours for the helicopter magnetometer data from the area near PBR 15 (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right). Elevated anomaly concentrations are seen inside the 1,000-ft circle surrounding the target in the magnetometer data sets.

During validation, a few depressions located in the target circle identified in the high-airborne data were found to be animal burrows. The absence of munitions-related craters in and surrounding this target, along with the practice bomb scrap located in the ground reconnaissance, supports the conclusion that practice bombs were used on this target. No additional AOIs were associated with this target.

6.3.2.2 Validation

Ground reconnaissance and total coverage survey areas were the two validation methods used at this site. As discussed above, an intrusive investigation was deemed to be unnecessary on this site. The validation results support the WAA data to confirm the location of the target. Practice bomb scrap was observed, and no heavy-walled fragments were encountered, consistent with the initial CSM indications that practice bombs were used on this target. However, it cannot be ruled out that a small number of HE munitions are at the site.

The ground-based magnetometer system surveyed one total coverage radial patch extending from the southern edge of the 600 ft target circle as shown on the left of Figure 6-14. The right section of Figure 6-14 shows an EM total coverage area. Because this section of the site does not have high densities of magnetic geology and does contain a number of metallic targets, this was used as a control for the EM total coverage area comparisons conducted in the north.

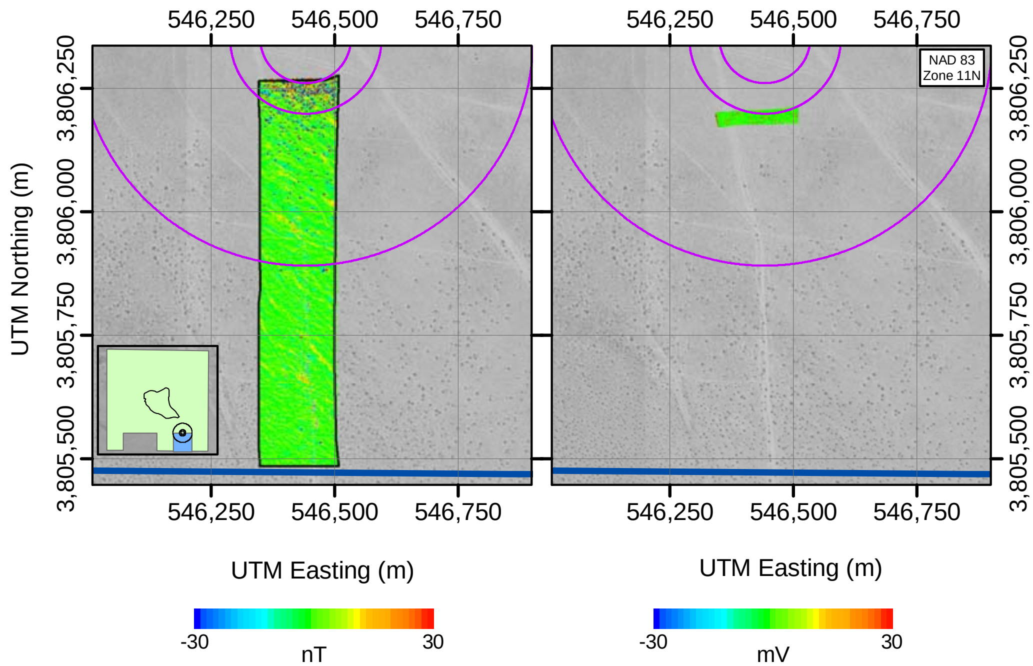


Figure 6-14. The original magnetometer ground-based total coverage area (left) and the EM data taken in the same location (right).

6.3.2.3 Target Boundary Decision

Figure 6-15 shows two methods of defining the target boundary. The left panel shows the estimated anomaly densities from the ground-transect data. The orange boundary delineates the area where the anomaly density is above the threshold of 16 anomalies per acre derived by fitting the cumulative anomaly density histogram to two distributions, representing the background and target. The right panel plots the individual anomalies observed in the helicopter magnetometer data and a boundary centered on the target that encompasses 95% of the anomalies. As can be seen from the figure, the helicopter anomalies are symmetrically arranged around the target, as is the resulting boundary. The orange boundary based on the interpolated anomaly density is less symmetric, presumably because the transects were surveyed in an east-west direction. The helicopter-derived blue boundary is larger and better reflects the anomaly distribution around the target, so it will be used to define this target area. This boundary does not imply that isolated munitions are not present on the remaining land; by definition, 5% of the helicopter-detected anomalies are outside the boundary. It is beyond the scope of WAA to identify individual munitions or munitions-related items.

The bounded area is 85 acres, and it contains an estimated 4,200 anomalies detectable by a ground sensor. At this target, the helicopter system detected a larger fraction of the ground anomalies than at most targets in this program, likely because it was a low-level practice bomb target and most remaining fragments are relatively large. The area of the target and estimated anomaly count will serve as inputs to support munitions response decisions. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity.

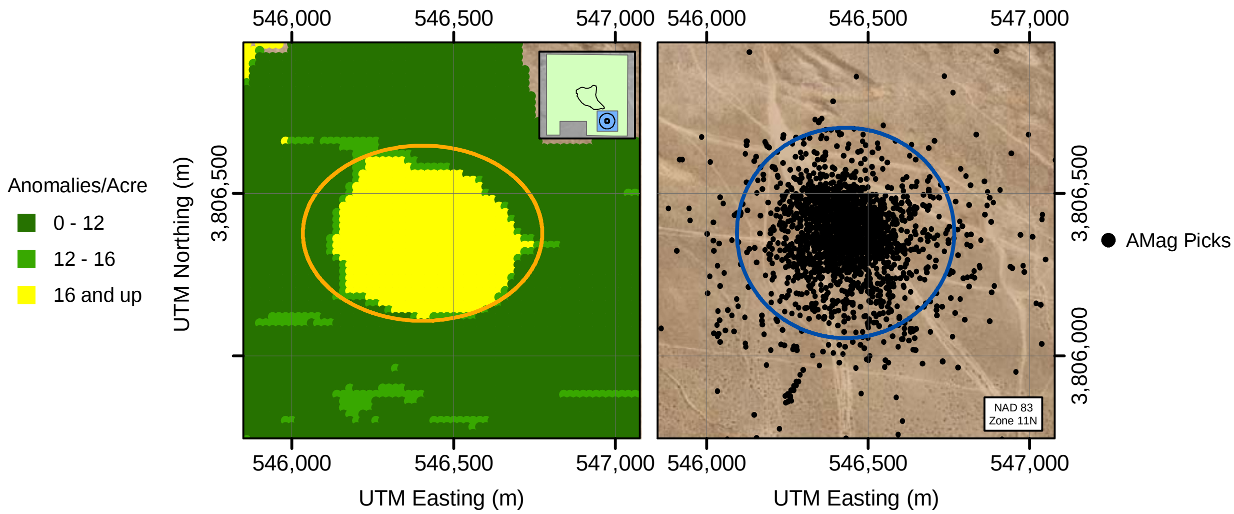


Figure 6-15. Anomaly densities from the ground-based transect data (left) and helicopter magnetic anomalies (right) around Victorville PBR 15. The bounded lines represent estimated target boundaries as discussed in the text.

6.3.3 Remainder of the Study Area

This section addresses all the other areas within the Victorville WAA study area that are not associated with specific targets identified in the initial CSM. A primary objective of the pilot program was to collect data to support decisions on areas that show no evidence of concentrated munitions use. Eleven additional AOIs were identified within the study area; all other remaining land showed no indications of munitions use. Multiple lines of evidence support the conclusion that all 11 AOIs are not munitions related. Subsequent analysis of EM data and site reconnaissance determined these areas are either due to site geology or cultural activities. The locations of the AOIs in relation to the entire study area are noted in the figure insets associated with each group of AOI.

Out of the 5,600 acres surveyed, roughly 5,000 acres were found to be free of concentrated munitions use. This information can be used to support future munitions response actions for nontarget areas, including appropriate controls or consideration of no-further-action decisions.

6.3.3.1 VPBR-AOI-1 through VPBR-AOI-5—Concentrations of Ground-Based Magnetic Anomalies

Five AOIs were identified as concentrations of ground-based magnetometer anomalies (VPBR-AOI-1 through VPBR-AOI-5; see Figure 6-16). Several depressions in the LiDAR data are also within and in the vicinity of these AOIs. The orthophotography data for VPBR-AOI-4 indicated human activity, such as camping, and several potential craters. The survey team found the areas of concentrated magnetometer anomalies correlated with the dense white rocks on the surface. The team surmised these rocks were the source of the magnetometer anomalies. The follow-on EM survey was used to confirm this hypothesis.

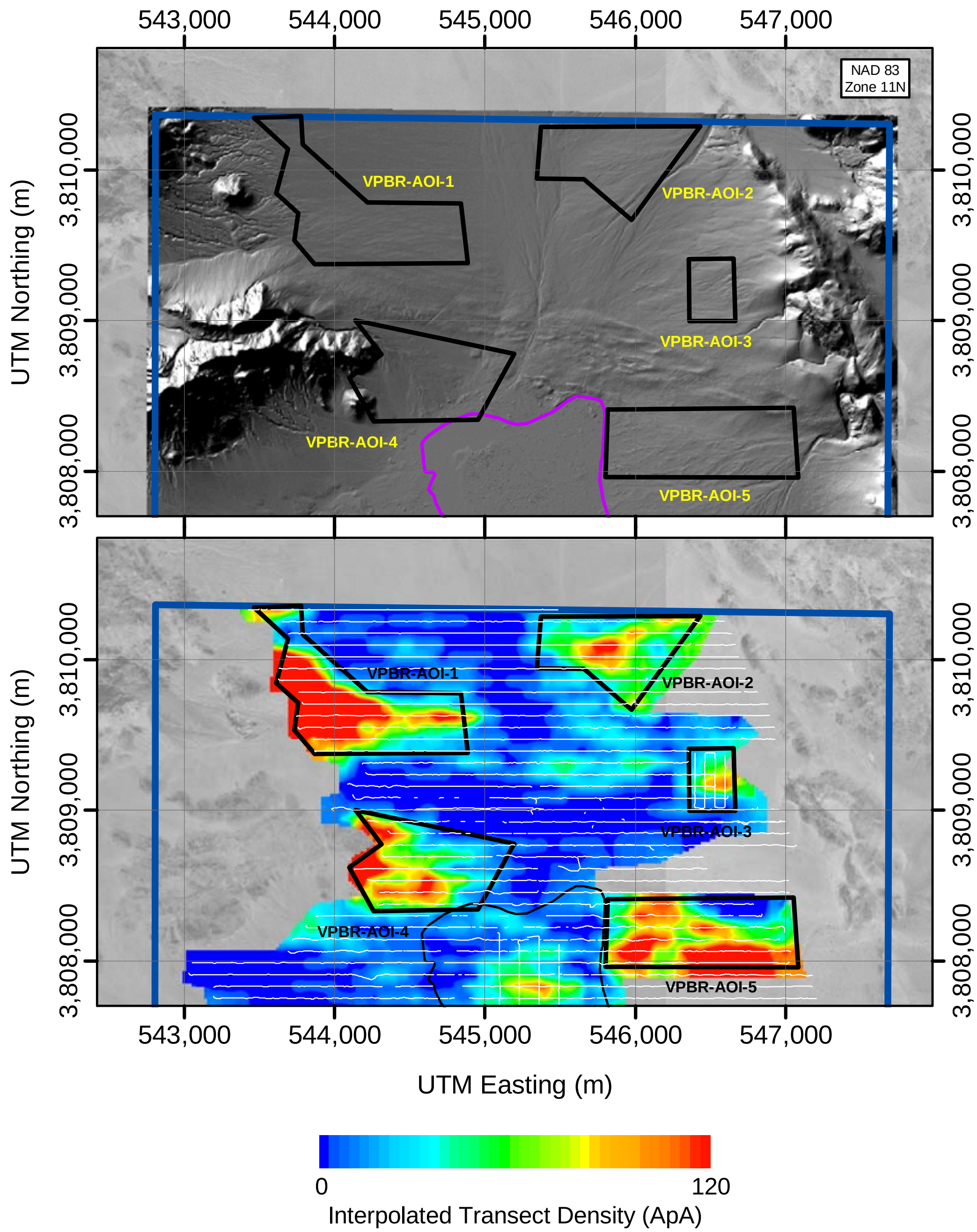


Figure 6-16. LiDAR data (top) and the estimated anomaly densities from the ground-transect data with the transects shown as white lines (bottom) for the northern AOIs.

EM total-coverage areas Hot 1 and Hot 2 were surveyed within VPBR-AOI-1 and VPBR-AOI-2. The magnetometer data show high anomaly concentrations in each area, but the corresponding EM coverage area does not show a concentration of anomalies, supporting the hypothesis that the high anomaly concentrations observed in the magnetometer data are due to geology. Figure 6-17 is a comparison of the magnetometer data and EM data from one of these areas.

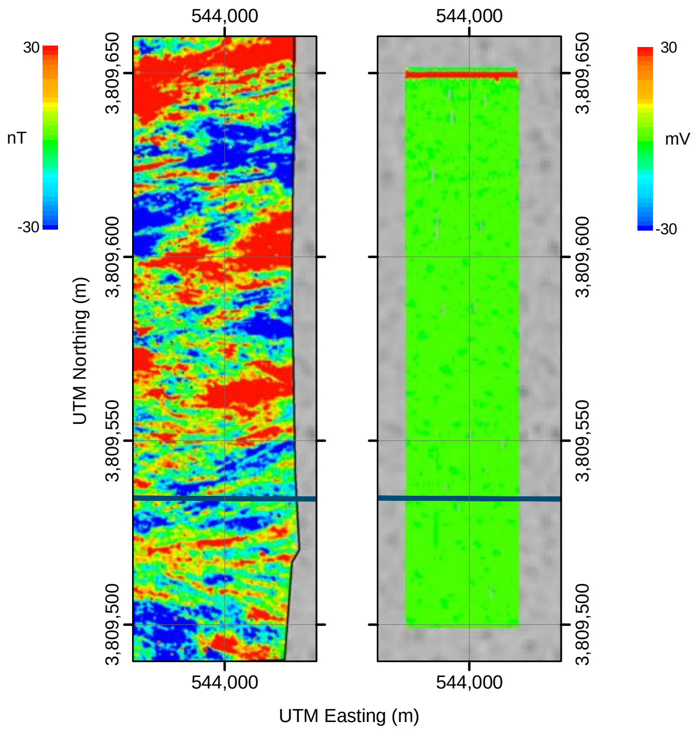


Figure 6-17. Side-by-side data sets of total coverage area Hot 1. The magnetometer data on the left clearly show interference from magnetic geology compared with the corresponding EM data on the right, where no concentration of anomalies is observed.

Ground reconnaissance was conducted on one of the areas of concentrated magnetic anomalies (VPBR-AOI-1). The team confirmed the depressions were two HE craters and found heavy-walled fragments in the southern end of the area. Figure 6-18 shows one of the craters. The validation results indicate a few isolated munitions could be present in this area, but support the conclusion this is not a separate distinct area of concentrated munitions use.

Figure 6-18. Ground reconnaissance of a depression (circled in red) identified near VPBR-AOI-1 that was confirmed as a munitions-related crater.

6.3.3.2 VPBR-AOI-6 through VPBR-AOI-11—High-Airborne Surface Features

Five AOIs were flagged from features in the high-airborne data that appeared to be man-made (VPBR-AOI-6 through VPBR-AOI-11; see Figure 6-19). Each feature was associated with either concentrated anomalies or scattered anomalies in at least one magnetometer data set.

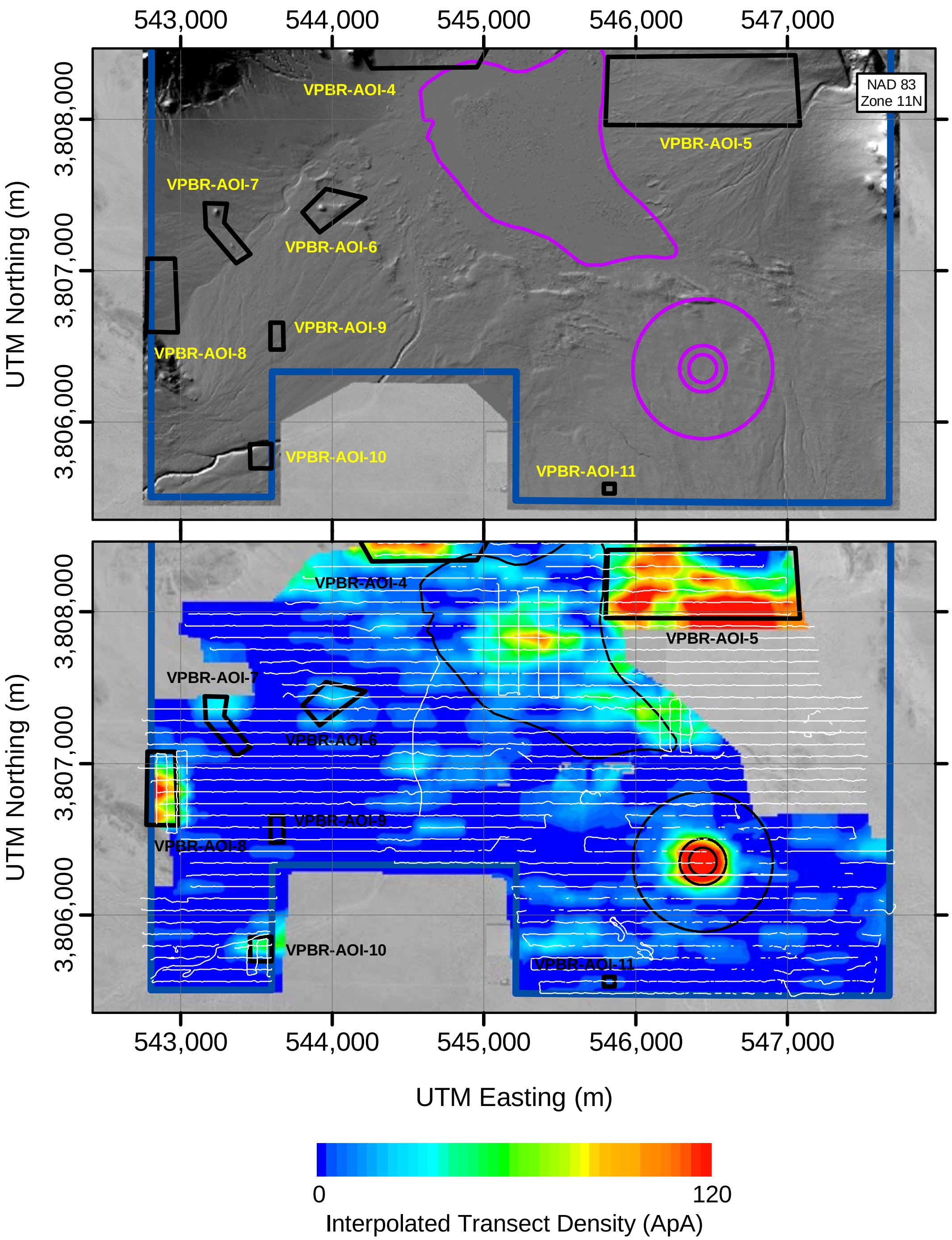


Figure 6-19. LiDAR data (top) and the estimated anomaly densities from the ground-transect data with the transects shown as white lines (bottom) for the southern AOIs.

The ground reconnaissance team did not observe any munitions-related scrap at the location of the features from the high-airborne data (VPBR-AOI-6 through VPBR-AOI-11). The team observed magnetic geology or cultural clutter, such as remains of a campground or garbage, present at these AOIs. In Figure 6-20, for example, the high-airborne surface feature VPBR-AOI-11 was confirmed to be a campground. The validation results support the conclusion that the AOIs do not represent targets or areas of concentrated munitions activity, and any munitions present are isolated.

Figure 6-20. The ground reconnaissance team visited the high-airborne feature VPBR-AOI-11 and located a camping area.

6.4 Overall Site Conclusions

The WAA study area was know to contain two target areas, PBR Y and PBR 15. Historical records indicate PBR Y was an HE target and PBR 15 was a practice bomb target. The location of PBR 15 and the historical usage were confirmed by all the WAA data layers and validation efforts. The location of PBR Y and the historical use of this target were confirmed by all the WAA data layers except the helicopter magnetometer and confirmed by the validation results. These results provide a preponderance of evidence to support the following conclusions about the site.

PBR Y

- The results are consistent with the initial CSM. The LiDAR and ground-based transects confirmed the location of target PBR Y. It is possible two sub-targets were within PBR Y based on two clusters of craters and corresponding high-density anomaly areas, but there is not enough information to confirm that hypothesis.
- The area of the target is estimated to be 470 acres with some 1,040 craters and 10,000 anomalies detectable by a ground-based sensor. Scattered potential craters are found to the north and west of the target boundary, but there are no other areas of concentrated munitions use.

- The presence of HE craters and heavy-walled fragments found during ground reconnaissance indicate HE bombs were used on this target, which is consistent with the historical records.

PBR 15

- The results are consistent with the initial CSM. All WAA data layers confirmed the location of target PBR 15.
- The area of the target is estimated to be 85 acres and to contain some 4,200 anomalies detectable by a ground-based sensor. The average background anomaly density for this part of the site is low, so there is high confidence in these acreage and density results for PBR 15.
- The historical records indicate only practice bombs were used on this target area, and the findings of this study are consistent with the initial CSM. Ample evidence of practice bombs was observed. No craters or heavy-walled fragments, which would be evidence of HE bombs, were found at this target.

Remainder of the Study Area

- WAA confirmed all the other areas within the Victorville PBR Y and 15 WAA study area not associated with specific target areas identified in the initial CSM show no evidence of concentrated munitions use.
- Out of the 5,600 acres surveyed, roughly 5,000 acres were found to be free of concentrated munitions use.

6.4.1 Technology Conclusions

The results from this site provide further insight into the capabilities and limitations of the demonstrated technologies.

6.4.1.1 High-Airborne Technology Conclusions

- The high-airborne data were effective in identifying munitions-related features and other features.
- In general, the LiDAR and orthophotography data provide complementary information for this site. The munitions-related features, AOIs, and the general terrain of the site are more clearly observed in the LiDAR data. The LiDAR was particularly useful in identifying the PBR 15 target circle and PBR Y craters. Identifying or observing the absence of craters helped support conclusions about HE bomb usage at the site.
- The orthophotography data were useful in identifying the cross hairs at the center of the PBR 15 target circle, which were not seen in the LiDAR elevation data.

6.4.1.2 Low-Airborne Technology Conclusions

- The helicopter magnetometer data were successfully used to identify elevated concentrations of surface and subsurface anomalies and to estimate the site background anomaly concentration. The helicopter magnetometer system did not detect the concentration of anomalies that identify PBR Y, presumably because the impact of demolition bombs produced primarily small fragments. Anomaly density analyses provided supporting evidence about the usage and extent of target areas.

- The helicopter magnetometer data were also affected by site conditions, including the interfering geology seen in the northern area and the challenging terrain that limited data coverage in several areas.

6.4.1.3 Ground-Based Technology Conclusions

- The ground-based magnetometer data were successfully used to identify high concentrations of anomalies and to support site background anomaly density calculations from the ground transects.
- The ground-based towed magnetometer array was challenged by the terrain of the site and the presence of magnetic geology. The towed system could not traverse all the planned transects due to both steep slopes and soft sand. In addition, the data obtained from the system showed significant interference from magnetic geology.
- A litter-carried EM system was used to collect the remaining transects to compensate for the terrain and to survey several total coverage patches to confirm the presence of magnetic geology. While the production rate is very limited, deploying the litter-carried EM system effectively resolved the gaps and interference problems presented by terrain and geology in the magnetometer transect data.
- The sparse transect design successfully identified PBR Y and PBR 15. The additional transects in the conservative design were not necessary to identify the target areas.

6.4.2 Combined Technology Conclusions

The different contributions of the various data layers at this site are primarily observed by comparing the two types of targets.

6.4.2.1 HE Target Conclusions

The most useful data layers for detecting and characterizing the HE target, PBR Y, were LiDAR and the ground-based transect data:

- The LiDAR identified the craters, which provided one method to estimate the location of the target boundary. The HE craters were less prominent in the orthophotography data.
- The ground-based transect data were useful in delineating the estimated target boundary for PBR Y. These data incorporate fragments dispersed during impact, which are features high-airborne technology cannot detect. The helicopter magnetometer was not able to detect the small fragments produced from the impact of the HE items.

6.4.2.2 Practice Bomb Target Conclusions

In contrast, all the data sets successfully detected the practice bomb target, PBR 15:

- Each of the high airborne data sets identified the aiming circle, but only the orthophotography initially detected the cross hairs. At this target, which was constructed of asphalt rings rather then berms, orthophotography yielded more definition of the target’s features than the LiDAR elevation map. The LiDAR intensity map clearly shows the target features.

- The helicopter magnetometer system and the ground-based transects were able to detect and characterize PBR 15. The soft sand posed problems for the ground-based array platform.

6.4.3 Target Boundary Decisions

Figure 6-21 shows the boundaries created for PBR Y and PBR 15 based on data from the WAA pilot program. The PBR Y boundary was created from the LiDAR crater data, and the PBR 15 boundary was created from the helicopter magnetic-anomaly data. The PBR Y boundary encompasses all the craters and ground-anomaly density associated with the target. The PBR 15 boundary encompasses 95% of the helicopter-detected anomalies in the area of the target rings. These boundaries do not imply no isolated munitions are present on the remaining land. It is beyond the scope of WAA to identify single munitions or munitions-related items.

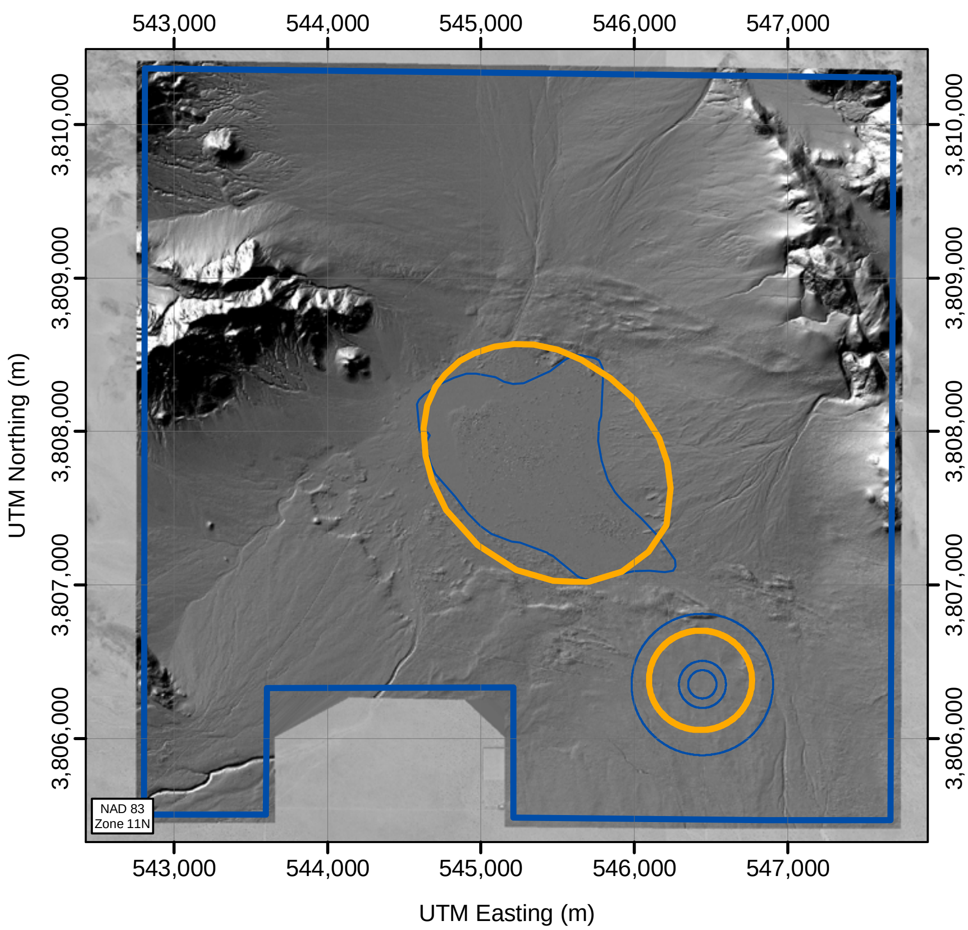


Figure 6-21. Target boundaries resulting from this study. The PBR Y boundary (center of site) is based on the LiDAR crater detections and ground-transect anomaly maps. The PBR 15 boundary (lower right) is based on the helicopter-detected magnetic anomalies in the target area.

These data have been provided to support the upcoming site inspection stage of the munitions response process. For areas that are selected to move to the investigative phase, the WAA data provides a wealth of information that is not currently available for characterizing the target areas. The calculated acreage and estimated number of anomalies in each target boundary will support munitions response planning, prioritization and cost estimation. The unbounded remaining land is considered, through multiple lines of evidence, to be outside the areas of concentrated munitions activity. Data characterizing this land can be used to support decisions on whether additional actions or controls are needed.

7.0 FORMER CAMP BEALE

The former Camp Beale was selected for this study because the site characteristics aligned with the Phase II pilot program objective to deploy the technologies on sites with more challenging conditions. The former Camp Beale has complex vegetation and terrain, and it includes flat, open areas; wooded areas; rolling hills; and steep, rocky slopes. This site contains areas of known magnetic geology. Historical records indicate mixed munitions types were used, including bombs, artillery, mortars, grenades, and small arms. The site contains multiple overlapping known target areas and ranges, and areas where there is no history of concentrated munitions use.

Currently, the former Camp Beale is scheduled for a RI/FS in the DoD munitions response process. The information from WAA could be incorporated into the RI/FS and used by site managers and regulators to support future planning, prioritization, and cost estimates. The WAA data were analyzed to bound each MRS and identify areas free of concentrated munitions use. The total acreage and estimated number of anomalies associated with the MRSs can be used to define the scope of future remediation work. The type of munitions suspected on each MRS can also be useful inputs to future planning. Characterizing the remaining land as free of concentrated munitions use will help the planning process and may guide regulatory decisions about the need for future actions.

7.1 Test Site History and Characteristics

The former Camp Beale is located approximately 10 miles east of Marysville, California, in Yuba and Nevada counties (see Figure 7-1). The 18,000 acre WAA demonstration area includes a number of historic ranges as shown in Figure 7-2. The WAA site contains a number of the targets used from 1948 through 1959. The site encompasses a wildlife refuge, scattered houses, lands used for cattle grazing, and a parcel that faces the highest development pressure of any part of this formerly used defense site.

In 1940, the Camp Beale area consisted of grassland, rolling hills, and the abandoned mining town of Spenceville. The U.S. government purchased 87,000 acres in 1942 for a training post for the 13th Armored Division. Camp Beale also held training facilities for the 81st and 96th Infantry Division, a 1,000 bed hospital, and a prisoner of war camp. As a complete training environment, Camp Beale had tank maneuver areas, mortar and rifle ranges, bombardier-navigator training, and chemical warfare classes.

In 1948, Camp Beale became Beale Air Force Base, its mission to train bombardier-navigators in radar techniques. The base established six bombing ranges of 1,200 acres each. The U.S. Navy also used Beale Air Force Base for training. From 1951 on, Beale trained navigation engineers and ran an Air Base Defense School. These additional activities led to rehabilitation of existing base facilities and construction of rifle, mortar, demolition, and machine-gun ranges. In 1958, the first runway was operational.

One year later, the installation ceased being used as a bombing range, and the U.S. Government declared portions of Beale Air Force Base as excess, eventually transferring 60,805 acres to private individuals and the State of California. On 21 December 1959, 40,592 acres on the eastern side of the base were sold at auction. An additional 11,213 acres were transferred to the State of California between 1962 and 1964 and now comprise the Spenceville Wildlife and Recreation Area. In 1964–1965, another 9,000 acres were sold at auction.

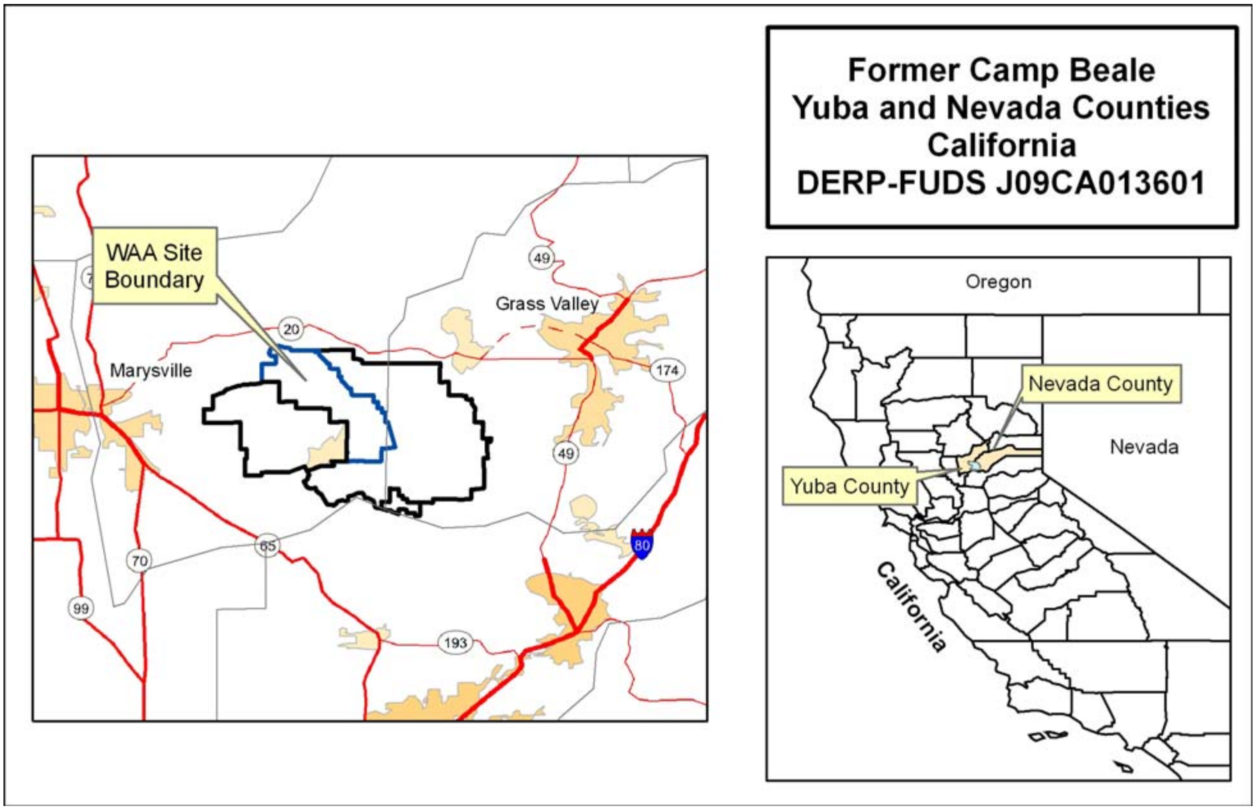


Figure 7-1. Area map showing the location of the former Camp Beale within the state of California. The location of the WAA program study area is outlined in blue.

The WAA study area contains a number of overlapping ranges that were used for multiple munitions types. These ranges are shown in Figure 7-2, and Table 7-1 summarizes pertinent information. The records are incomplete, and during the life of the base, many range number designations were used multiple times for different areas, which leaves some confusion and ambiguity about the historical use. More details can be found in the initial CSM. (Ref. 29). Ranges that were only used for small arms are not within the scope of WAA, although some of these ranges were identified during the demonstration.

7.2 Former Camp Beale Study Area Objectives and Program Design

The objectives for the former Camp Beale demonstration were to identify MRSs and areas that appear to be free of concentrated munitions use. To assess whether the conclusions aligned with the initial CSM, the WAA results were compared with the historical records. Due to the complex layout of the overlapping historical ranges it is not possible with confidence to associate concentrated areas of munitions use to specific historical ranges as was done for the Phase I demonstration sites. Individually labeled MRSs in this chapter could be associated with one or multiple historical ranges.

The technologies demonstrated at the former Camp Beale include LiDAR, orthophotography, a helicopter-borne magnetometer array, and statistical transects collected with a ground-based towed EM array and a litter-carried EM system. The high-altitude technology layers surveyed 100% of the 18,000-acre study area as shown in Figure 7-3 and Figure 7-4. In contrast to the first three demonstration sites, the two lower technology layers were deployed in a limited manner to more closely mimic a production WAA.

The low-airborne helicopter array was deployed in areas where terrain and vegetation permitted easy access. In addition, magnetic geology was expected at this site. A series of transects sampling the background geology were collected, and areas where useful data could not be obtained were avoided. The helicopter magnetometer array surveyed nearly 5,000 acres of the study area as shown in Figure 7-5.

The ground-based transects were designed using VSP. EM systems were chosen for this site to mitigate the known geologic interference. Where terrain and vegetation allowed, the transects were surveyed with the vehicle-towed system. On a significant part of the site, the vehicle could not operate and a litter carried system was used. The combined ground-based systems surveyed approximately 0.8% of the site for a total of 155 acres of transects. Figure 7-6 shows the ground-based transects and the areas that exceeded the density used to flag an area, which is 100 anomalies per acre at this site. The anomaly density contours created from the helicopter magnetometer data and the estimated anomaly densities from the ground-transect data are presented in the data analysis sections of this chapter. (Refs. 17, 18, 19, and 20)

7.2.1 Ground-Based Transect Design

The ground-based transects were planned before the survey. The transect design approach relied on historical data from the initial CSM in conjunction with assessing the AOIs identified in the high-airborne data.

The site is known to contain a variety of munitions types, which made the transect design process complex. The study area was divided into three sections based on the smallest known munitions item of interest in that area (Figure 7-7). The known munitions types used to guide the division of these areas originated from the available historical range information found in Table 2. As discussed above, the individual MRSs identified from the WAA data results cannot be associated with confidence to individual historical ranges due to their complex overlapping nature.

Transects in each of the areas were designed to have a 100% probability of traversing the specified target type. The green area is based on detecting 400 ft circular target areas created from 81-mm mortars. The yellow area is based on detecting 600 ft circular target areas created by 105-mm projectiles. The red area is based on detecting 700 ft target areas created by HE bombs ranging from 100 lb to 250 lb. Further information on the VSP transect design process and inputs can be found in Table 7-2 and the demonstrator report (Ref. 19).

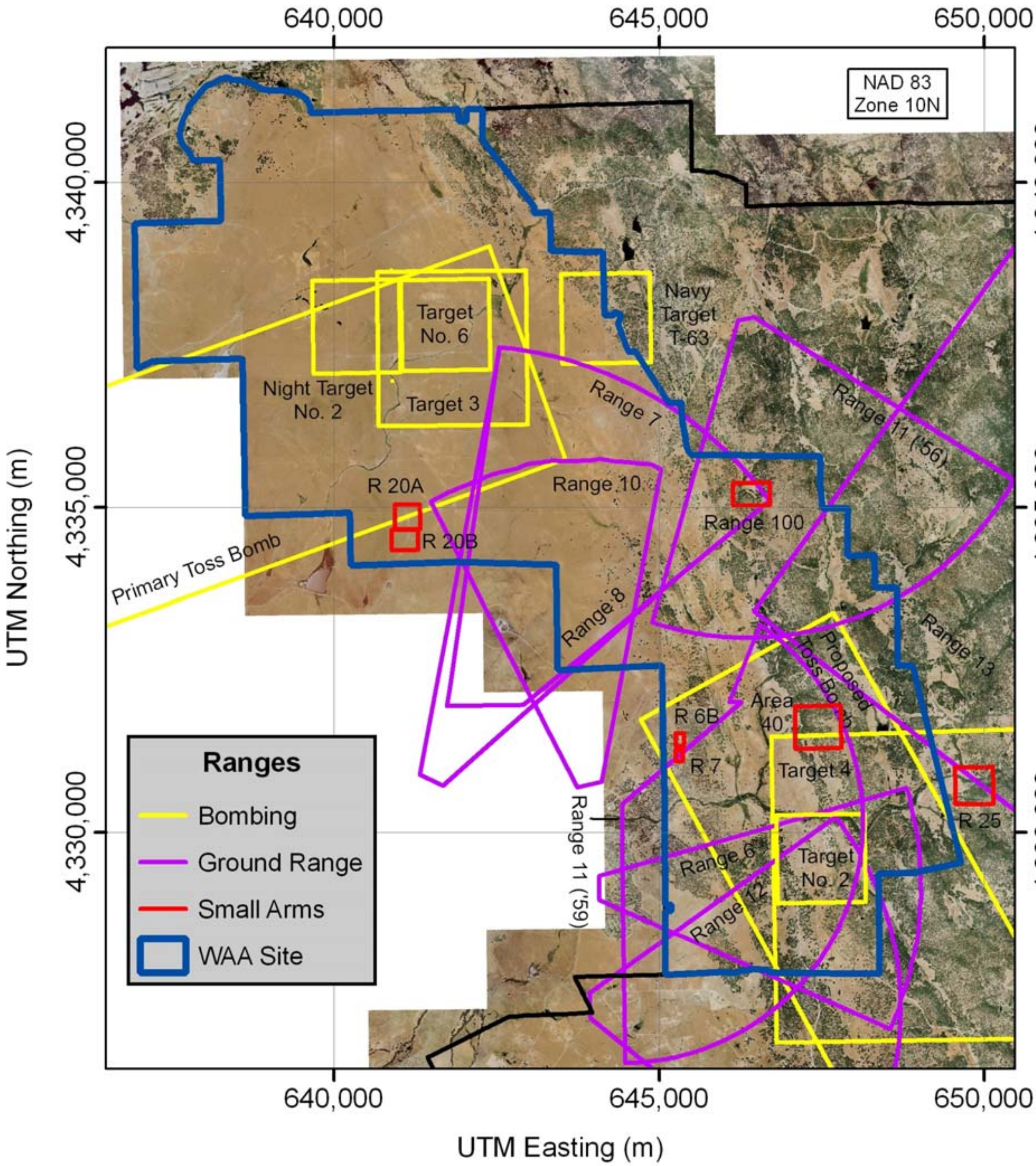


Figure 7-2. Map showing the former Camp Beale. The WAA demonstration area boundary is shown in blue, and the historic ranges are indicated.

Table 7-1. Summary of Historical Ranges within the WAA Demonstration Site (ordered roughly from north to south).

Site	Site Type	Munitions Items Used
Target 6	Bombing range	Live bomb releases for Shoran training
Night Target 2	Bombing	No information found
Target 3	Bombing	Live bomb releases for Shoran training, M38A1, 100-lb bomb
Navy Target T-63	Bombing target	Mark 76 Navy 25-lb practice bombs, possibly 250- or 500-lb practice bombs, and 1,600-lb bombs.
Primary Navy Toss Bomb Target	Bombing target	No information found
Range 7 (overlaps with Range 8)	Ground range	57-mm recoilless rifle, 60-mm Mortar, .50 caliber, shape charges
Range 8	Ground range	57mm recoilless rifle, 60-mm mortar, .50 caliber, shape charges
Range 10	Ground range	Shape charges
Range 11 (1956)	Ground range	No information found
Course 100	Infiltration courses	Machine guns, land mines, and short fused dynamite charge
Range 20A	Transition firing course	Small arms (Rifle and Carbine)
Range 20B	Transition firing course	Small arms (Rifle and Carbine)
Proposed Secondary Navy Toss Bomb Target	Bombing target	No information found; questionable whether this target was ever used.
Range 11 (1959)	Close combat range	Close combat range
Fortified Area 40	Fortified Area	No information found
Target 4	Bombing	Proposed target; apparently not used. No information found about munitions used.
Range 6B	Antiaircraft range (miniature)	No information found
Range 7	Antiaircraft range (miniature)	No information found
Combat Village 25 (R25)	Combat course	Small arms
Target 2	Demolition bombing	High-explosive charges up to 250 pounds, some information is missing
Range 6	Bombing, ground range	M38A1 practice bomb, fuze cap from 100-lb bomb, some information is missing
Range 12	Ground range	No information found
Range 13	Ground-to-air gunnery range	No information found

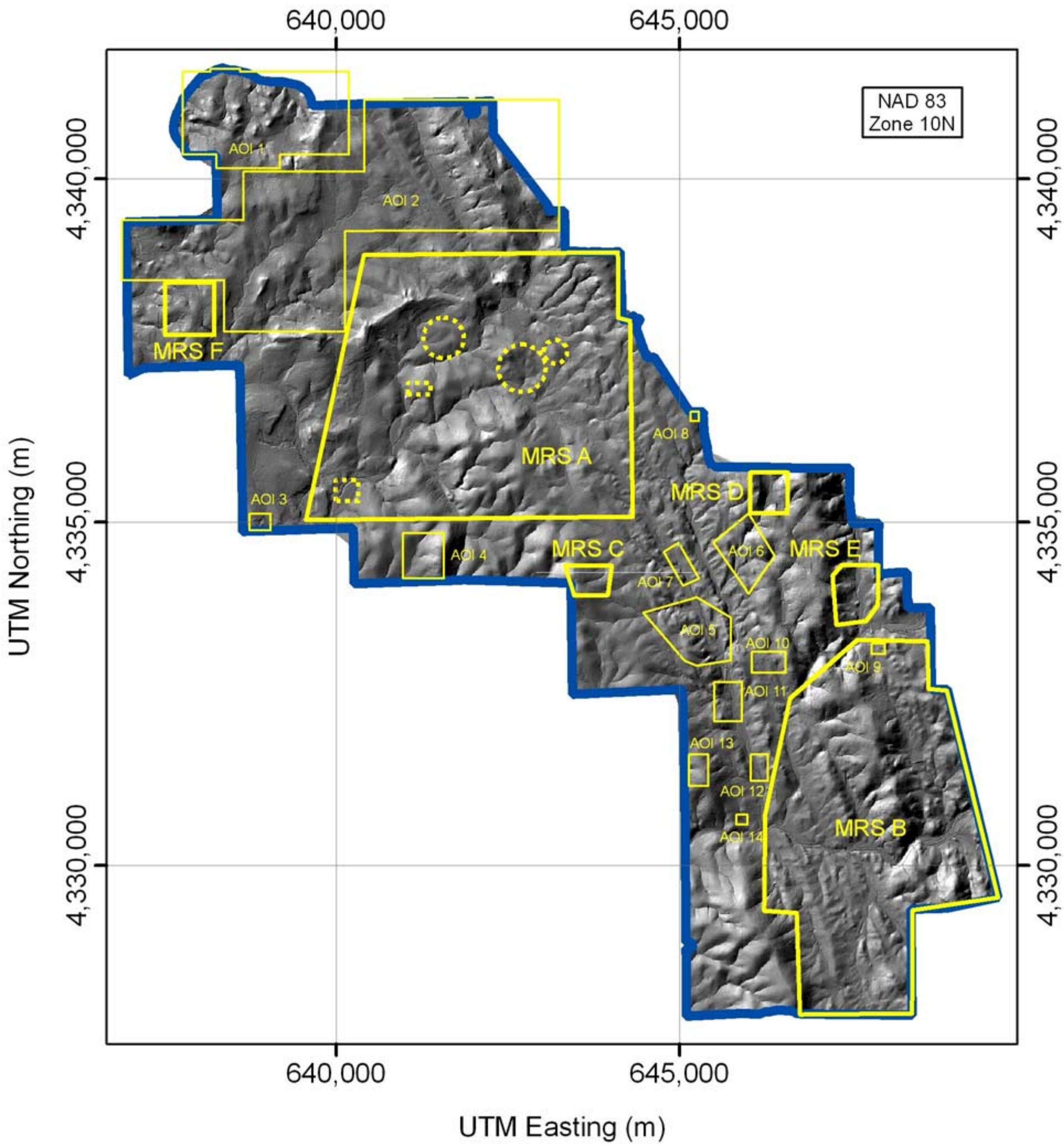


Figure 7-3. Former Camp Beale MRSs and AOIs overlain on the LiDAR data. This technology covered 100% of the study area.

Figure 7-4. Former Camp Beale orthophotography data. This technology covered 100% of the study area.

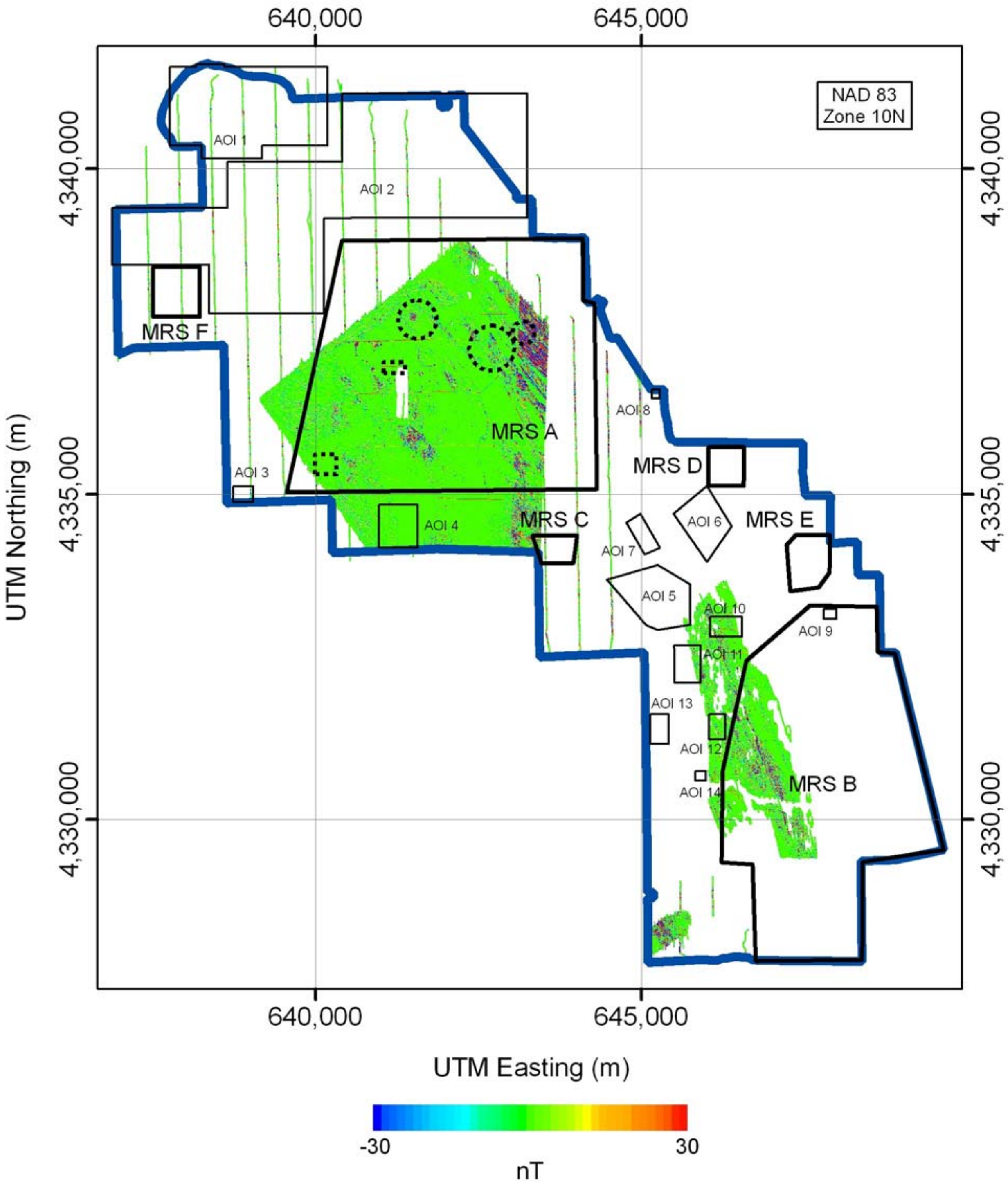


Figure 7-5. Former Camp Beale helicopter magnetometer data. Approximately 5,000 acres of the site were surveyed at 100% coverage. The long data lines are transects used to sample the site geology.

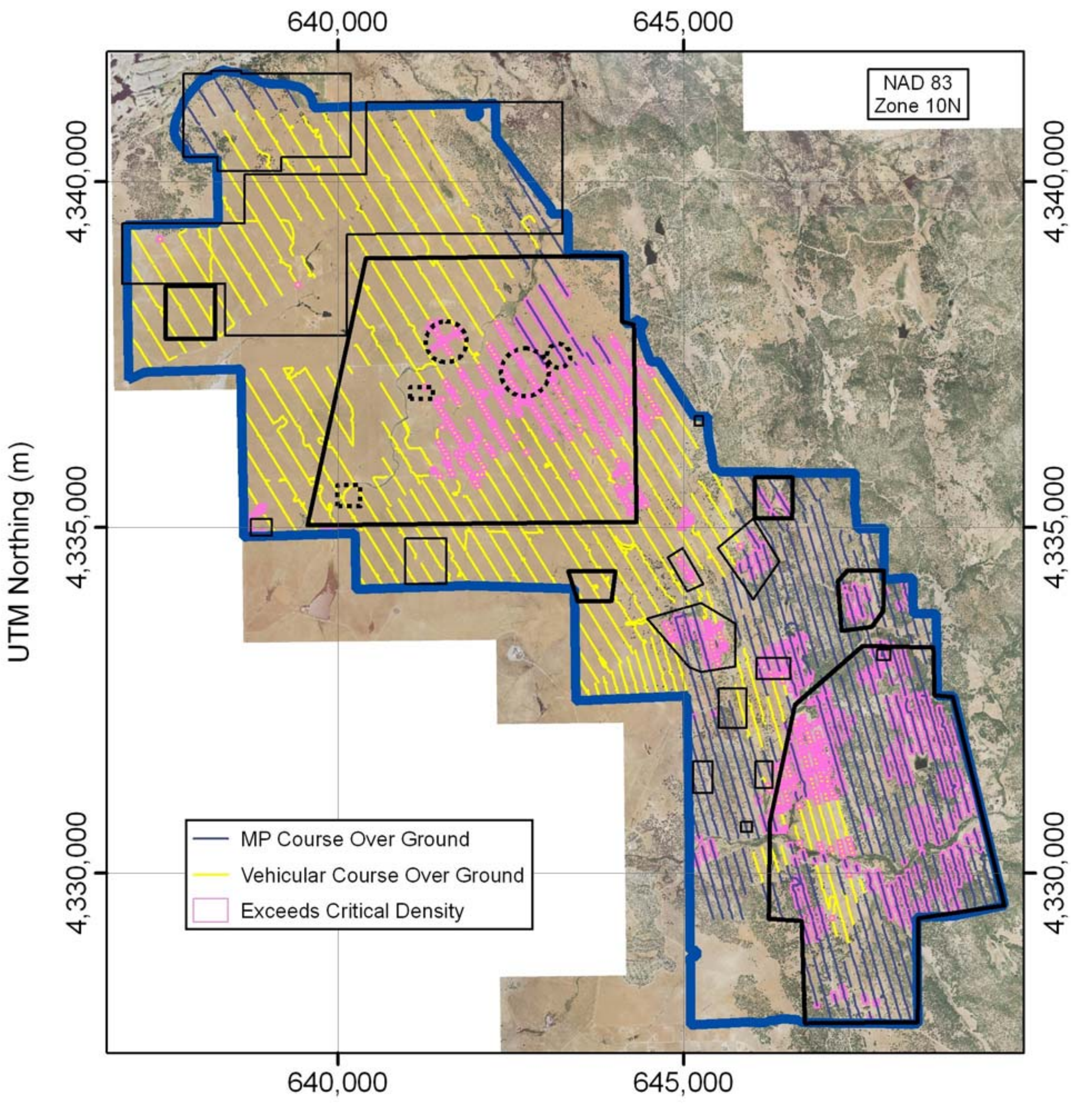


Figure 7-6. Former Camp Beale ground-transect results. The towed-array transects are shown in yellow and the litter-carried transects are shown in blue. The areas where anomalies exceed the critical density of 100 anomalies per acre used to flag an area in VSP are shown in pink.

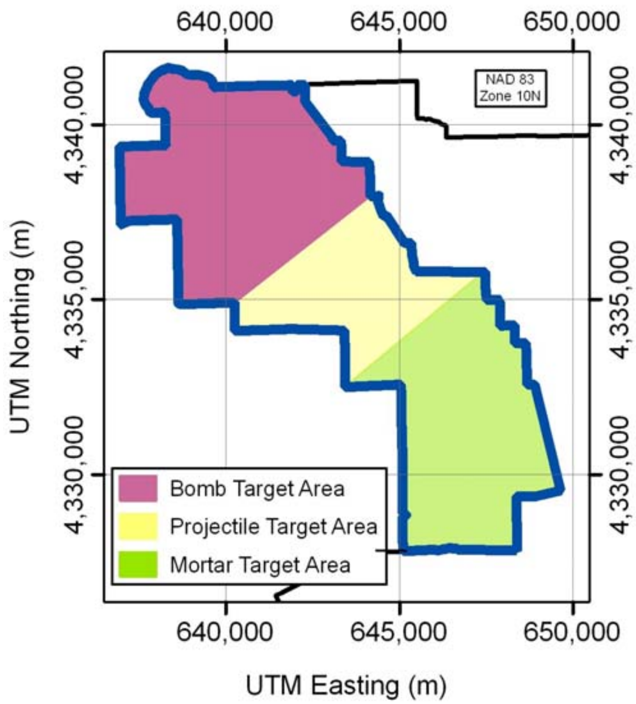


Figure 7-7. To guide the transect design, the Former Camp Beale was divided into sectors based on historical use.

Table 7-2. Summary of Transect Design Approaches for the Former Camp Beale.

	Green Area	**Yellow Area**	**Red Area**
Primary objective of design	Detect the presence of 81-mm mortar circular 400 ft (122 m) diameter target areas	Detect the presence of 105-mm and 155-mm projectile circular 600 ft (183 m) diameter target areas	Detect the presence of 100-lb to 250-lb bomb circular 700 ft (213 m) diameter target areas
Type of sampling design	Transect	Transect	Transect
Shape of target area	Circular	Circular	Circular
Diameter of target area	400 ft (122 m)	600 ft (183 m)	700 ft (213 m)
Transect pattern	Parallel	Parallel	Parallel
Transect width	1 m	1 m	2 m
Computed transect spacing	450 ft (137 m)	700 ft (213 m)	880 ft (268 m)
Required probability of traversing the target area	100%	100%	100%
Probability of detecting target area	92%	93%	98%
Number of transects	54	37	34
Transect coverage	197,172 m^2 (0.73 %)	75,034 m^2 (0.47%)	143,418 m^2 (0.47%)

7.3 Performance Assessment

The WAA data were analyzed separately and in combination. The high-airborne data were collected first and used as the starting point to identify features that appeared to be man-made but which may or may not be munitions related. As the helicopter and ground-system data were received, they were examined to identify areas of concentrated anomalies, which were then compared to the AOIs identified in the high-airborne data. Any additional areas of concentrated anomalies were either added as additional AOIs or used to modify boundaries of adjacent AOIs from the high-airborne data.

All these features were initially cataloged as AOIs and, based on comparison of all data and validation, these AOIs were then categorized as MRSs or retained as non-munition-related AOIs. A ground reconnaissance team, consisting of a UXO technician and a geophysicist, evaluated all AOIs for which the WAA data results were ambiguous. Features that were ultimately determined to be AOIs but not believed to be munitions related were retained because they provide useful information about the site that may aid future planning.

The final product contains 6 MRSs and 14 AOIs, each sequentially numbered based on the final determination. Because many of the AOIs determined to be munitions related were overlapping or closely adjacent, no credible boundary could be drawn to separate these areas. As a result, two large MRSs were drawn to encompass multiple AOIs that were clearly munitions related. They may circumscribe other AOIs that were ultimately determined not to be munitions related. Several additional isolated MRSs were also identified. For simplicity, there is no attempt to retain the numbering used in the various vendor reports. Figures 7-3 through 7-6 show the overall site investigation area, indicating the MRSs and AOIs.

7.3.1 MRS A: Northern Multi-Range Complex

The location of this MRS in relation to the entire study area is noted in the inset found in Figure 7-8. All WAA data layers confirm this area is an MRS. The area includes multiple features from the high-airborne data, including multiple groups of craters and several concentric aiming circles. Both the ground data and helicopter geophysics data indicate areas of concentrated anomaly density. The solid outline is the final combined MRS; dotted lines show the individual collections of feature concentrations from the high-airborne data.

The initial CSM indicated several ranges were located within the boundaries of this MRS. Bombing targets located in the northern half of the MRS boundary include the Navy Target T-63, Night Target 2, Target 3, Target 6, and the Primary Toss Bomb Target. The initial CSM indicated HE bombs, practice bombs, or a mix of both were used on these bombing targets. There is no information known about the use of the Primary Toss Bomb Target. Artillery and mortar ground ranges were located in the southern half of this MRS, including Ranges 7, 8, and 10. Records indicate HE munitions were used. Table 7-1 is a summary of the ranges and the known munitions use throughout the WAA study area.

7.3.1.1 Bombing Targets

Figure 7-8 shows the high-airborne data. Concentric target circles and concentrations of depressions are visible in the interior regions indicated by dotted lines and in the detail views. The remaining area in the MRS contains scattered depressions, but no apparent surface features can be directly associated with additional targets. The concentrated depressions are assumed to be munitions-related craters and support the conclusion that HE munitions were used in this MRS. The origin of the scattered depressions is less certain.

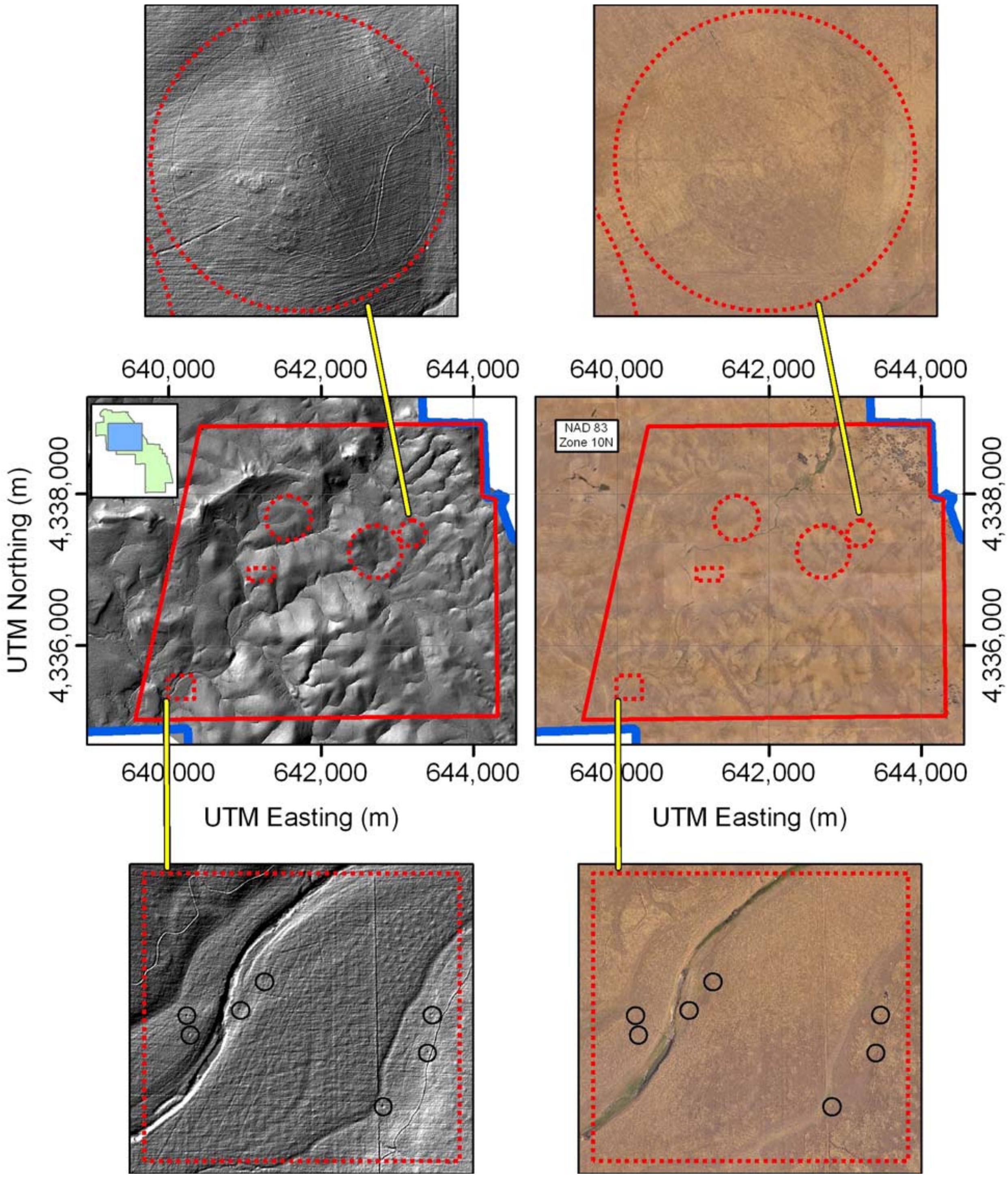


Figure 7-8. LiDAR (left) and orthophotography (right) data for MRS A. Detailed views of a bomb target and craters on the western perimeter are shown above and below the main figure, respectively.

The helicopter magnetometer array surveyed this area, and elevated concentrations of anomalies are seen throughout much of this MRS. Anomaly density concentrations are found within each of the outlined target areas shown in Figure 7-9. The ground-based towed system surveyed transects on the majority of this MRS, and the litter-carried transects surveyed the remaining portions. The estimated anomaly densities for the ground-transect data are seen in Figure 7-9. The ground-based anomaly densities exceeded the threshold used to flag an area in VSP in large portions of this MRS, including all but one of the outlined interior regions.

Due to the overwhelming evidence of concentrated munitions use, a ground reconnaissance visit was deemed unnecessary to conclude this area is an MRS.

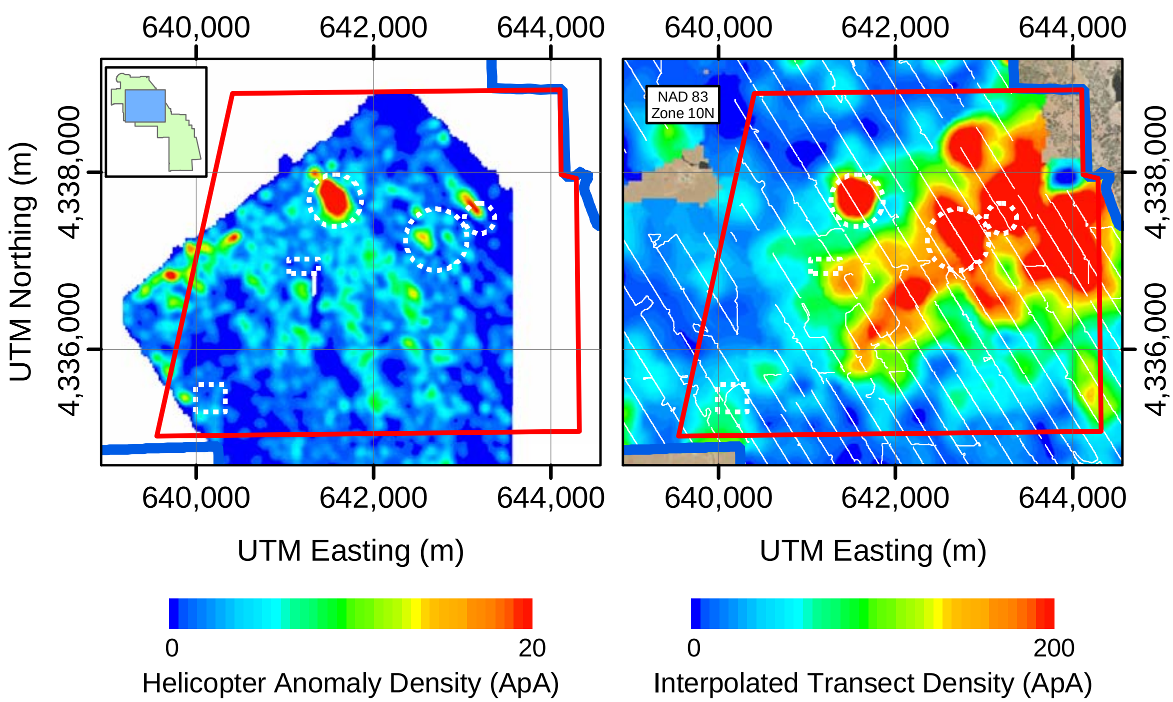


Figure 7-9. Anomaly density contours from the helicopter magnetometer data for MRS A (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right).

7.3.1.2 Artillery and Mortar Ranges

Figure 7-8 shows depressions evident in the high-airborne data. The depressions are assumed to be munitions-related craters and support the conclusion that HE munitions were used in this area.

The helicopter magnetometer surveyed this MRS, and modest concentrations of anomalies are seen in Figure 7-9. The ground-based towed system surveyed transects through this entire MRS. The ground-based anomaly densities exceeded the threshold used to flag an area in VSP in the northern half of this MRS.

Due to the overwhelming evidence of a concentrated area of munitions use in the WAA data layers, a ground reconnaissance visit was deemed unnecessary.

7.3.1.3 Craters on the Western Perimeter

Two groups of depressions were identified in the high-airborne data on the western edge of the MRS (see Figure 7-8). The helicopter magnetometer surveyed this area and did not detect a concentration of anomalies at the location of the craters, but higher density areas were found directly to their west (see Figure 7-9). The ground-based towed system surveyed transects throughout this MRS, and the anomaly densities did not exceed the threshold used to flag an area in VSP.

The reconnaissance team visited several of the depressions and the high-anomaly-density area observed in the helicopter data. The team measured and searched the depressions with a hand-held metal detector and confirmed the depressions are munitions-related craters. The high-anomaly-density area to the west of the AOI was confirmed to be geology.

7.3.1.4 MRS Boundary Decision

The high-airborne data and the geophysics data revealed that sections of this MRS had seen readily identifiable munitions use. The presence of dense craters; concentric rings indicative of aiming circles; and well-circumscribed, very high anomaly densities in the geophysics, often directly overlapping, is unambiguous. In addition, scattered depressions, some of which are likely HE craters, and other areas of elevated anomaly density are found throughout this MRS, and it is not possible to determine with any confidence that there are areas clear of concentrated munitions between the obvious targets. As such, the boundary for this area was drawn to encompass the outer borders of the aggregate of the suspected munitions indicators (see Figure 7-10). This area covers 4,100 acres and contains an estimated 375,000 anomalies detectable by a ground-based sensor.

7.3.2 MRS B: Southern Multi-Range Complex

The location of this MRS in relation to the entire study area is noted in the inset in Figure 7-11. All WAA data layers confirm this area is an MRS. The area includes multiple features from the high-airborne data, including berms, bunkers, and depressions. Both the ground and helicopter geophysics indicate multiple areas of concentrated anomaly density. The solid outline represents the final combined MRS.

The initial CSM (Figure 7-2) indicated several ranges were located within the boundaries of this MRS. Bombing Target 4 and the proposed toss bomb target are located within this MRS. There is no information on the munitions use for either target and no indication the toss bomb target was ever built in the available historical information. The WAA data does not indicate a toss bomb target is located in this area, which is consistent with the historical information. Ranges 6 and 12, ground ranges with little historical data about their use, are located in this MRS, but practice bomb parts have been found in Range 6. Range 11 (1959) was used for close-combat training.

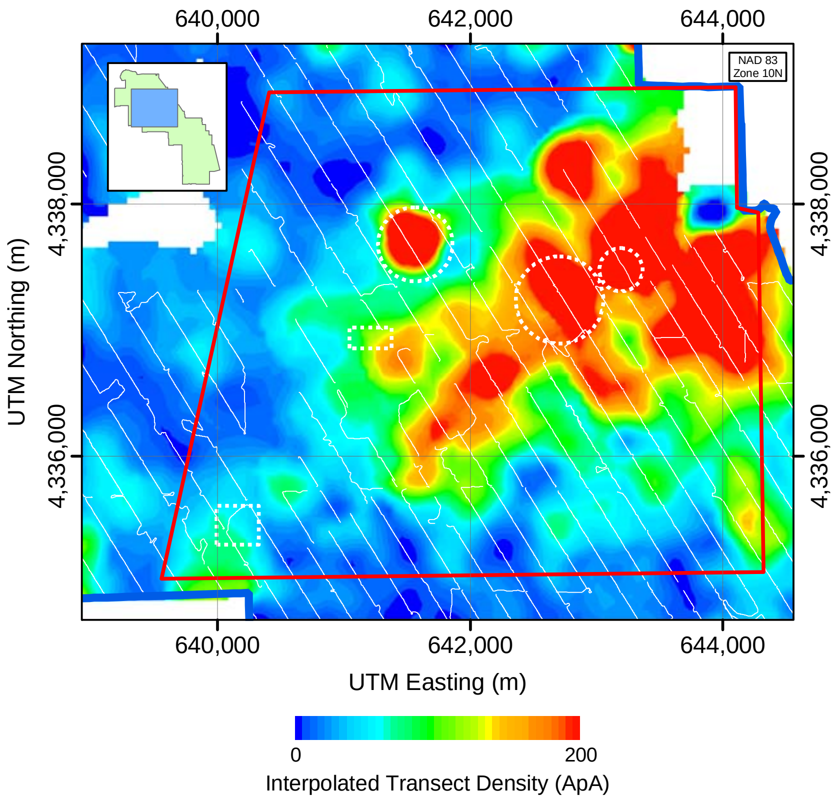


Figure 7-10. MRS A boundary with the estimated anomaly densities from the ground-transect data and the transects shown as white lines.

7.3.2.1 Firing Points

Scattered berms and adjacent trenches indicative of firing points are clearly seen in the high-airborne data (see Figure 7-11). The helicopter magnetometer surveyed a small portion of the MRS (see Figure 7-12), and several high-density-anomaly areas are seen in the west. The ground-based towed system and the litter-carried system surveyed transects throughout this area, and the anomaly densities exceeded the threshold used to flag an area in VSP in the majority of this MRS.

The ground reconnaissance team visited the high-anomaly-density areas observed in both geophysical data sets and found barbed-wire fences. Fan-shaped features were identified as firing points, and numerous bunkers were observed.

7.3.2.2 Depressions and Elevated Anomaly Density

Throughout the northern part of this MRS, areas were identified where scattered depressions found in the high-airborne data coincided with areas of elevated anomaly density in the ground data, the helicopter geophysics data, or both. The shape of the areas with high concentrations of anomalies is not uniform or circular as seen with the bombing target anomaly concentrations.

Because of the multiple lines of evidence of a concentrated area of munitions use in the WAA data layers, a ground reconnaissance visit was deemed unnecessary for three of these areas. In the fourth, the ground reconnaissance team visited, measured, and searched the depressions with a hand-held metal detector and confirmed they are munitions-related craters.

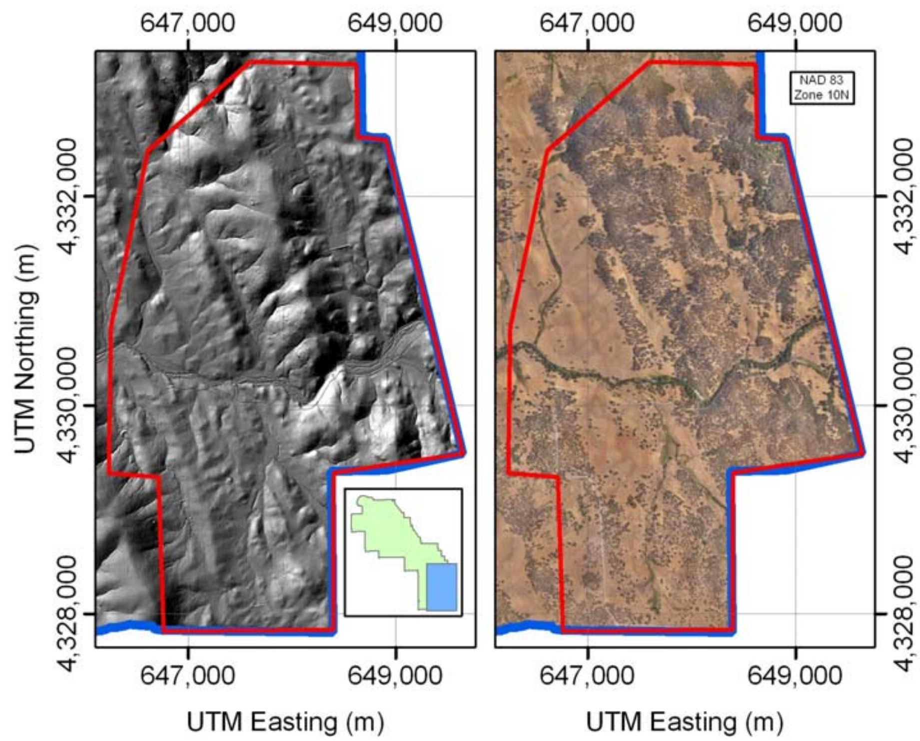


Figure 7-11. LiDAR data (left) and orthophotography data (right) for MRS B.

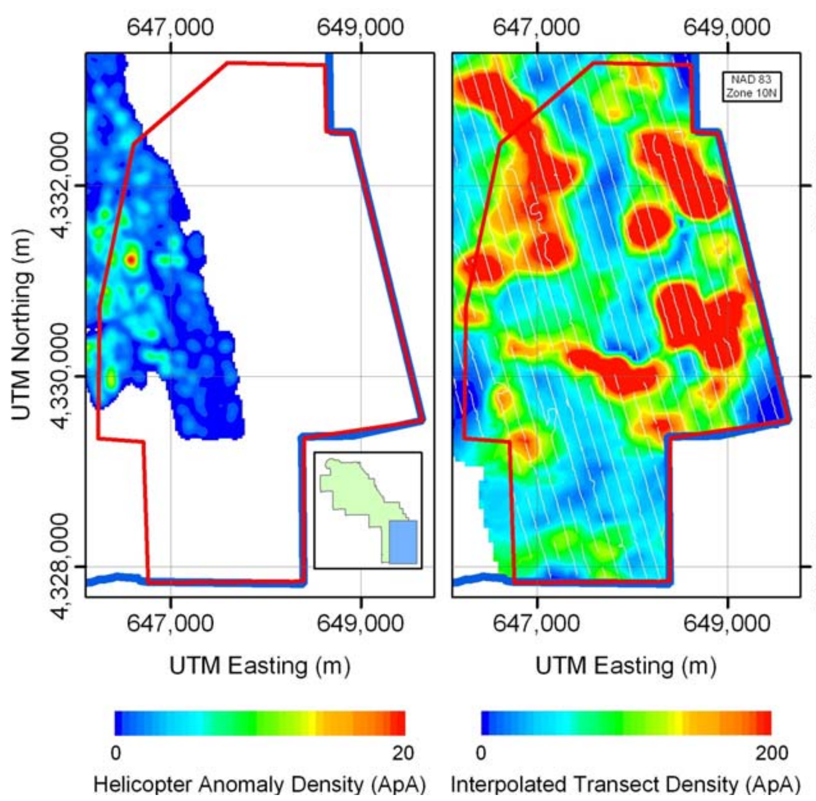


Figure 7-12. Anomaly density contours from the helicopter-magnetometer data for MRS B (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right).

7.3.2.3 MRS Boundary Decision

The high-airborne data and the geophysics data revealed that sections of this MRS had seen readily identifiable munitions use. The presence of craters, firing points, and elevated anomaly densities in the geophysics data—often directly overlapping—is unambiguous. It is not possible to determine with any confidence that there are areas clear of concentrated munitions between the obvious targets. As such, the boundary for this area was drawn to encompass the outer borders of the aggregate of the suspected munitions indicators as shown in Figure 7-13. This area covers 3,200 acres and contains an estimated 345,000 anomalies detectable by a ground-based sensor.

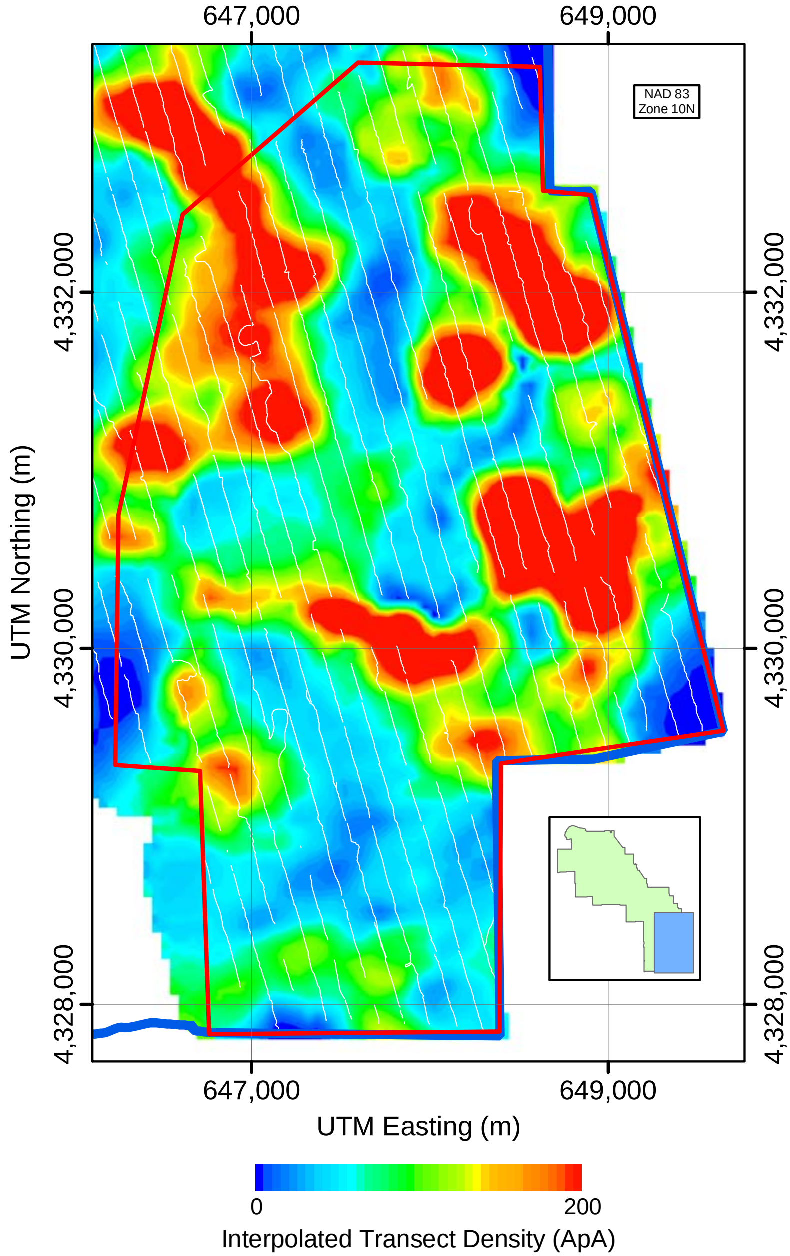


Figure 7-13. MRS B boundary with the estimated anomaly densities from the ground-transect data and the transects shown as white lines.

7.3.3 MRS C: Firing Points and Craters

The location of this MRS in relation to the entire study area is noted in the inset in Figure 7-14. The initial CSM (Figure 7-2) indicated this MRS is located within ground Ranges 7 and 10 and HE munitions were used. The WAA data provide evidence that this is an MRS.

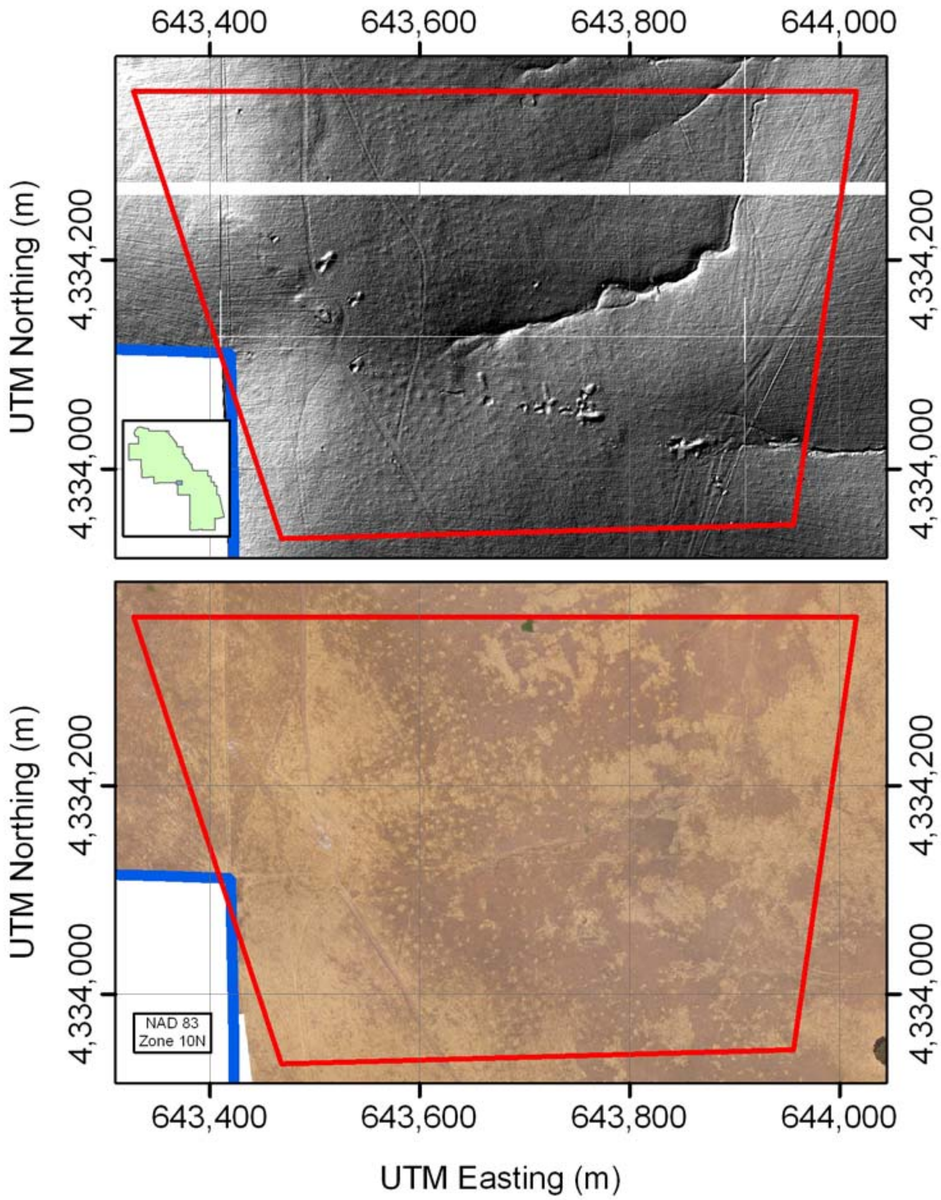


Figure 7-14. LiDAR data (top) and orthophotography data (bottom) for MRS C.

Figure 7-14 shows a series of berms and adjacent trenches resembling firing points, along with scattered depressions, identified in the high-airborne data. The helicopter magnetometer surveyed only a small western portion of this area and did not find a concentration of anomalies (see Figure 7-15). The ground-based towed system surveyed transects throughout this MRS, and anomalies were present, but their density but did not exceed the threshold used to flag an area in VSP.

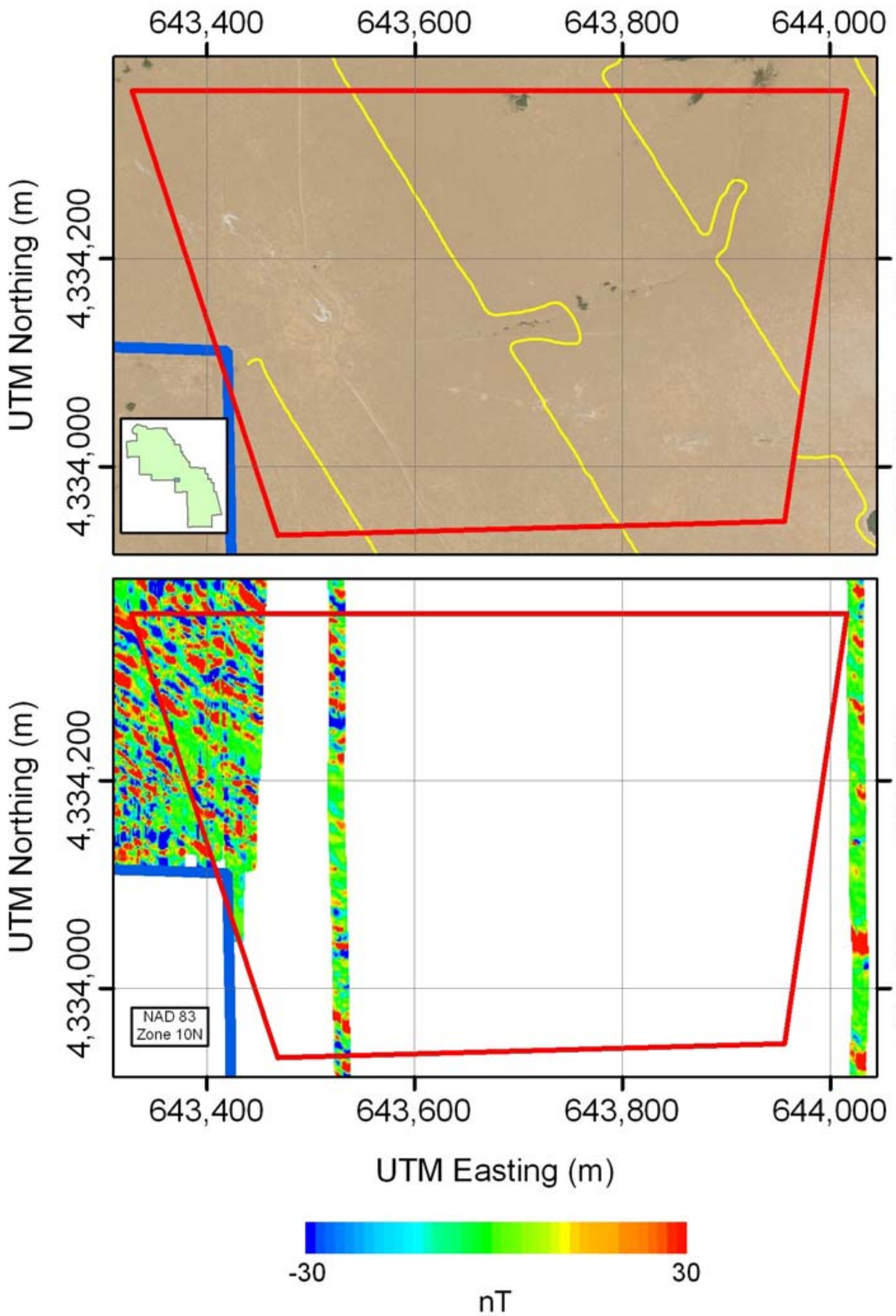


Figure 7-15. Ground-transect data (top) and helicopter-magnetometer data (bottom) for MRS C.

The reconnaissance team visited the berms and trenches (see Figure 7-16) and confirmed they are consistent with firing points. The ground reconnaissance team visited, measured, and searched the depressions with a hand-held metal detector and confirmed they are munitions-related craters. These findings support the conclusion this area is an MRS.

The MRS boundary shown in Figures 7-14 through 7-16 was drawn to encompass detected features that are related to this MRS. It covers 60 acres.

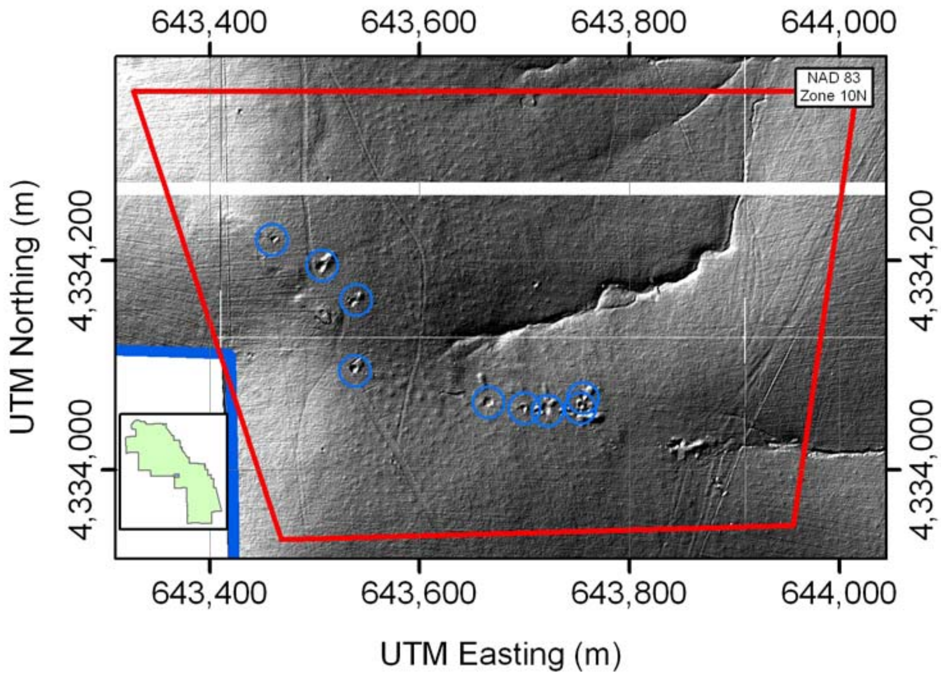


Figure 7-16. Features visited during the ground reconnaissance for MRS C.

7.3.4 MRS D: Artillery and/or Mortar Ranges

The location of this MRS in relation to the entire study area is noted in the inset found in Figure 7-17. The initial CSM (Figure 7-2) indicated this area is within Ranges 7 and 11 ('56) and on top of Range 100 and HE munitions were used. The WAA data layers provide evidence that this is an MRS.

Figure 7-17 shows a concentration of depressions, along with a possible ship-shaped feature. The depressions are assumed to be munitions-related craters and support the conclusion that HE munitions were used in this area.

The helicopter magnetometer did not survey this area. The litter carried system surveyed transects covering this MRS (see Figure 7-18). The anomaly densities exceeded the threshold used to flag an area in VSP in the majority of this MRS.

During ground reconnaissance, craters exhibited a magnetic response and were clustered in a manner consistent with a firing range. An apparent target object was found, and a flat potential firing area was noted to the north.

The MRS boundary shown in Figure 7-17 was drawn to encompass the high-airborne features. This area covers 80 acres and contains an estimated 8,800 anomalies detectable by a ground-based sensor shown in Figure 7-18.

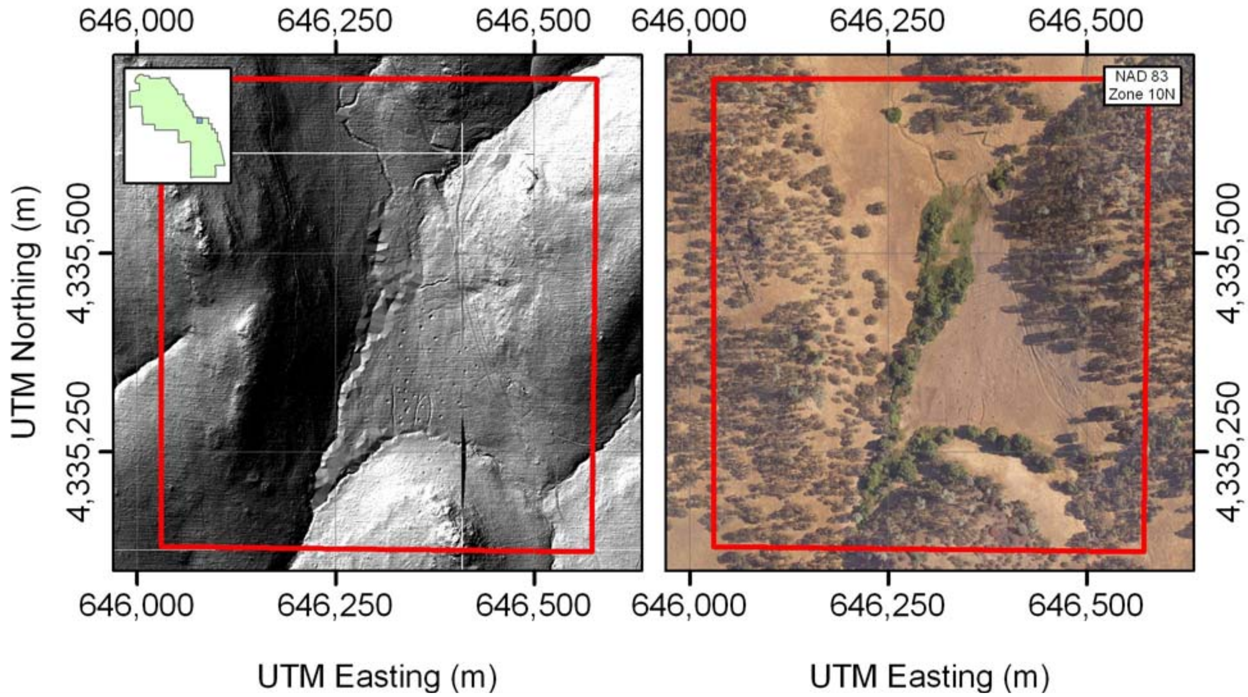


Figure 7-17. LiDAR data (left) and orthophotography data (right) for MRS D.

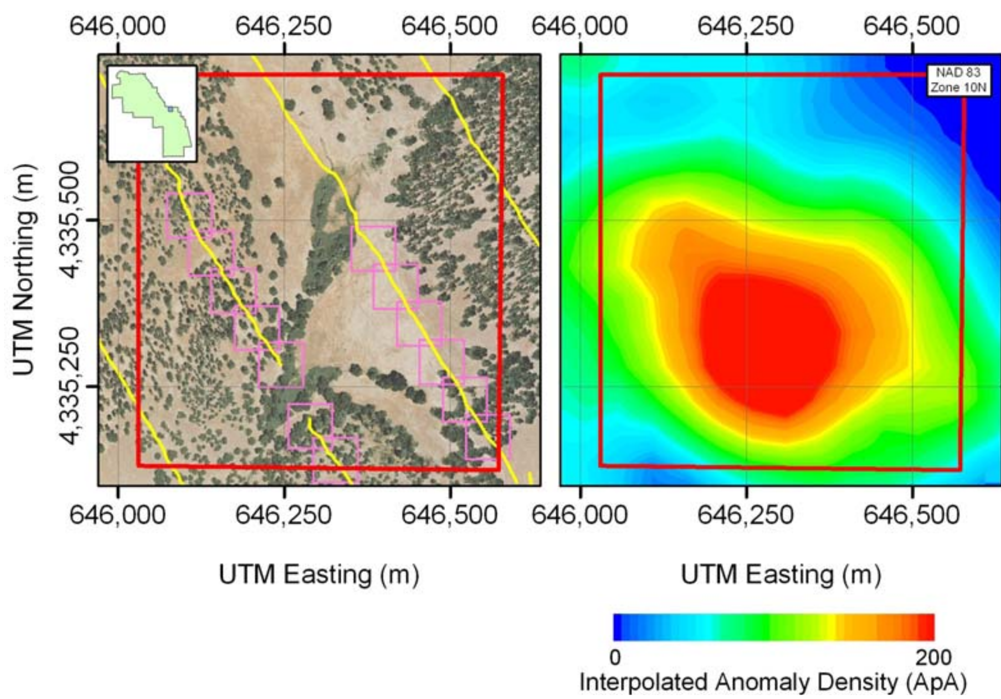


Figure 7-18. Ground-transect course (yellow lines) and areas (pink boxes) flagged as exceeding the critical density are shown on the left. Estimated anomaly densities from the ground-transect data for MRS D are shown on the right.

7.3.5 MRS E: Artillery and/or Mortar Range

The location of this MRS in relation to the entire study area is noted in the inset found in Figure 7-19. The initial CSM (Figure 7-2) indicated this MRS is within the boundaries of the ground-to-air gunnery Range 11 ('56) and no information was available in the historical records on the munitions used on this range. The WAA data provide evidence that this is an MRS.

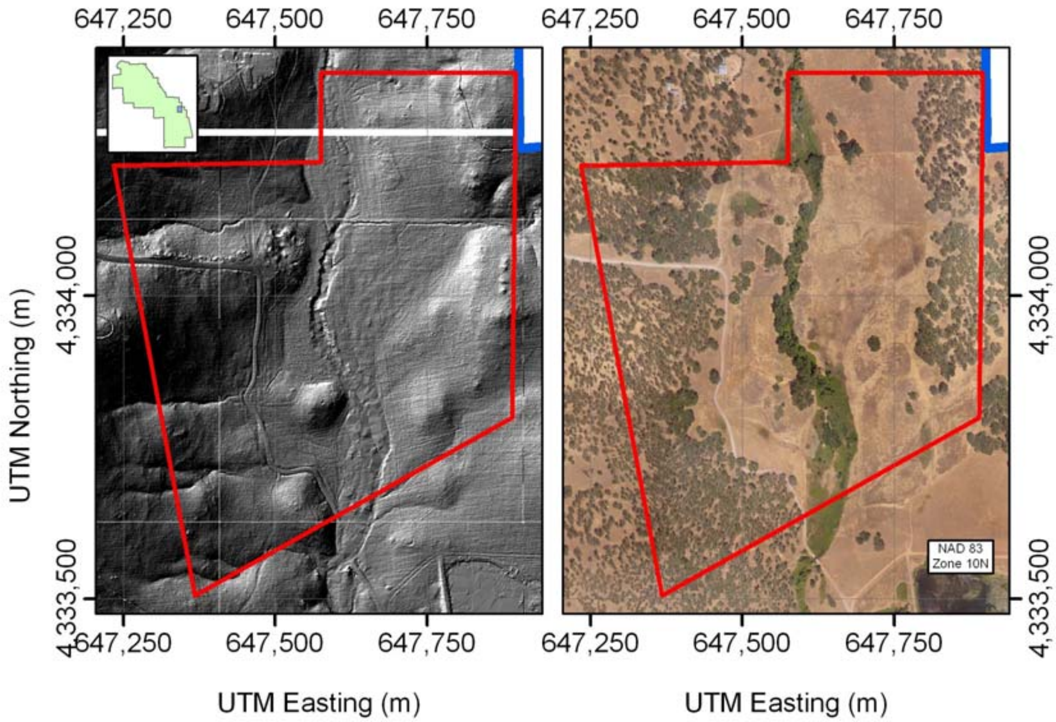


Figure 7-19. LiDAR data (left) and orthophotography data (right) for MRS E.

Scattered depressions are clearly seen in the LiDAR data as shown in Figure 7-19. The depressions are assumed to be munitions-related craters and support the conclusion that HE munitions were used in this area.

The helicopter magnetometer did not survey this area. As shown in Figure 7-20, the litter carried system surveyed transects in this MRS, and the anomaly densities exceeded the threshold used to flag an area in VSP in the majority of this AOI.

Due to the evidence of a concentration area of munitions use in multiple WAA data layers, a ground reconnaissance visit was deemed unnecessary.

The MRS boundary in Figure 7-19 was drawn to encompass the high-airborne features. This area covers 100 acres and contains an estimated 9,800 anomalies detectable by a ground-based sensor shown in Figure 7-20.

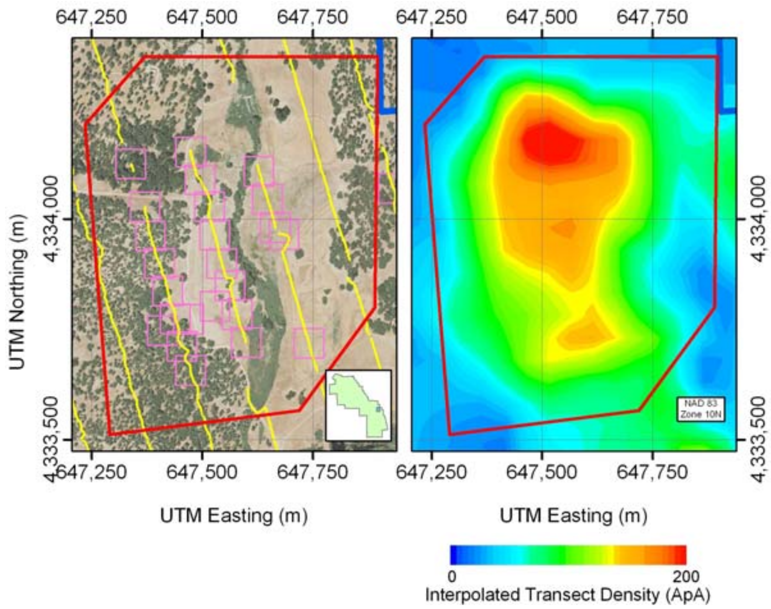


Figure 7-20. Ground-transect course over ground (yellow lines) and areas (pink boxes) flagged as exceeding the critical density in VSP are shown on the left. The estimated anomaly densities from the ground-transect data for MRS E are shown on the right.

7.3.6 Potential MRS F: Craters

The location of this potential MRS in relation to the entire study area is noted in the inset found in Figure 7-21. The initial CSM (Figure 7-2) indicated no historical ranges were located within the boundary of this potential MRS, but the primary toss bomb bombing range boundary is near the south edge of MRS F. The munitions used on the primary toss bomb range are unknown. The WAA data provided ambiguous results, and the area was deemed a potential MRS through validation and because of its proximity to a historical range.

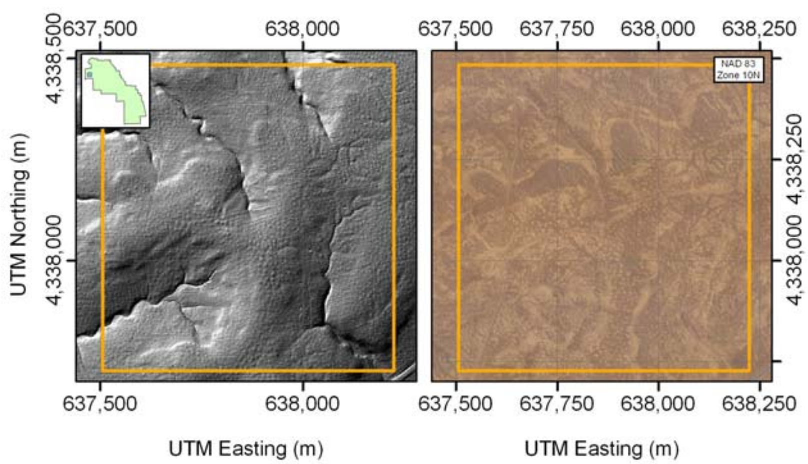


Figure 7-21. LiDAR data (left) and orthophotography data (right) for MRS F.

The high-airborne data revealed scattered depressions (see Figure 7-21). The helicopter magnetometer did not survey this area. As shown in Figure 7-22, the ground-based towed system surveyed transects in this MRS. The anomaly densities did not exceed the threshold used to flag an area in VSP.

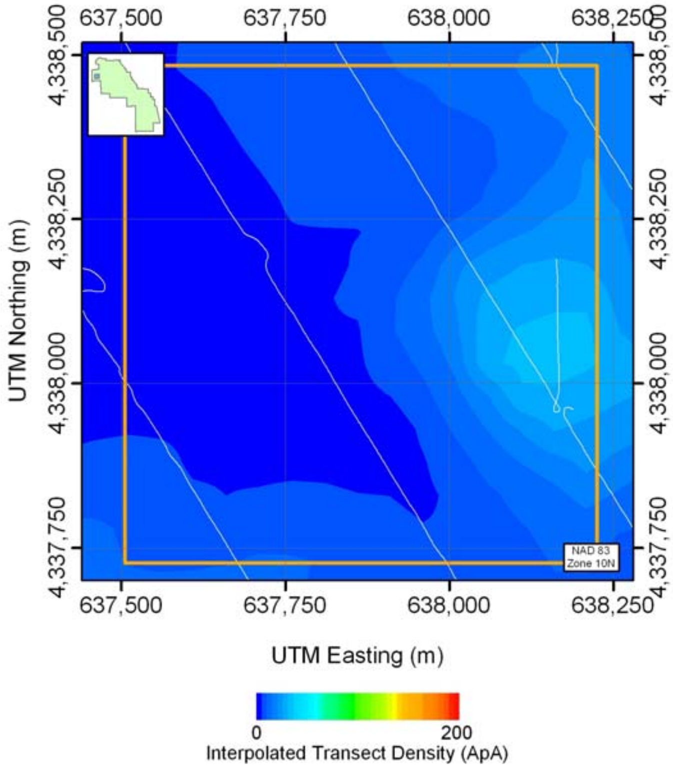


Figure 7-22. Estimated anomaly densities from the ground-transect data for MRS F. The transects are shown in white.

The ground reconnaissance team visited, measured, and searched four depressions with a hand-held metal detector and confirmed they were symmetrical depressions with magnetometer response, consistent with munitions-related craters (see Figure 7-23). Because this feature is near a historical range, these results support the conclusion that this area is a potential MRS.

The MRS boundary was drawn to encompass all features in the vicinity of the munitions-related craters and is 135 acres. No area within this MRS exceeds the background density.

7.3.7 Remainder of the Study Area

This section addresses the remainder of the WAA study area within the Former Camp Beale not associated with MRSs identified during the WAA process. The remaining land showed no indications of munitions use, and numerous AOIs observed in other parts of the site ultimately were determined not to be munitions related through multiple lines of evidence. The high-airborne results indicated 14 AOIs. Through ground reconnaissance validation, these AOIs were generally easily and unambiguously identified as features such as machine dug holes, mining artifacts, small arms ranges, geology, or man-made infrastructure. This section summarizes the disposition of each. The locations of these AOIs in relation to the entire study area is noted in the figure insets associated with each AOI.

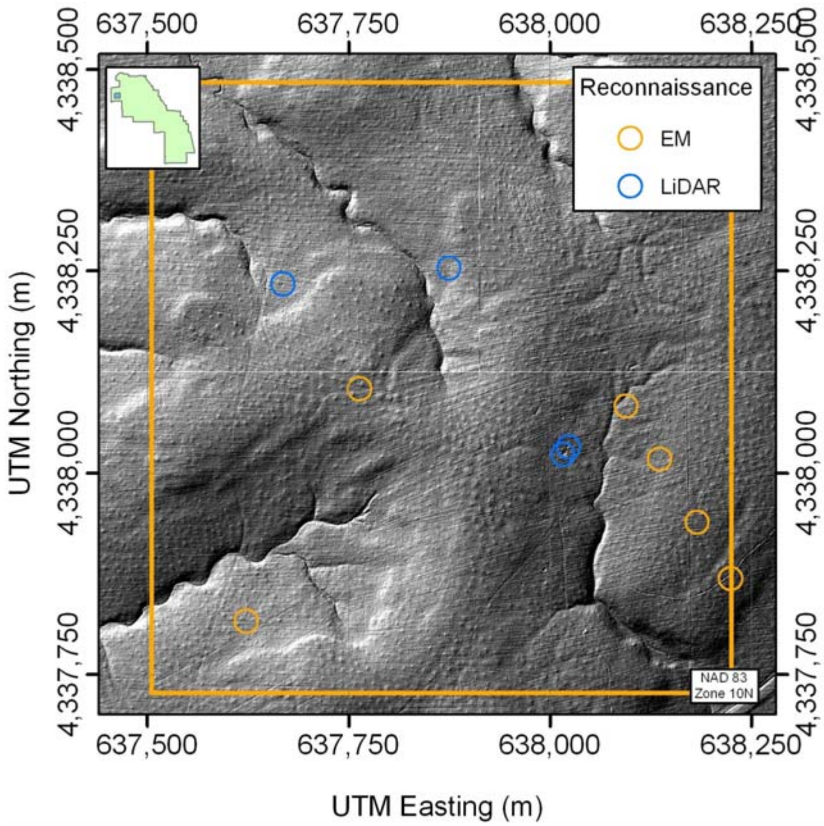


Figure 7-23. Ground reconnaissance of MRS F.

Out of the 18,000 acres surveyed, roughly 10,000 acres showed no evidence of concentrated munitions use. However, this site contains multiple overlapping historical ranges and a higher background anomaly density than the first three demonstration sites. On the Northern end of the site, where no historical targets are known to exist, this conclusion has high certainty. Most of the remainder of the study area lies within one or more of the historical ranges, and while it is not expected these areas will necessarily contain munitions throughout, there is only moderate certainty in the conclusion that no additional concentrations of munitions exist. At this site, this information can be used to support future munitions response actions for non-target areas, such as appropriate controls or consideration of no-further action decisions.

7.3.7.1 AOIs 1 and 2, Depressions and Geophysical Anomalies

Figure 7-24 shows scattered depressions identified in the high-airborne data throughout AOI-1 and AOI-2. The initial CSM did not indicate any historical ranges in AOI-1. The night bombing target No. 2 and the primary toss bomb target overlap a small southern section of AOI-2 (see Figure 7-2). The helicopter magnetometer did not survey either of these areas. The ground-based vehicle transects covered the majority of these AOIs, and the litter-carried system transects covered the remaining portion of the northern section of AOI-1. Figure 7-25 presents the estimated anomaly densities created from the ground-transect data. The ground-based anomaly densities only exceeded the threshold used to flag an area in VSP in two isolated areas, which suggests this is not an area of concentrated munitions use.

Because access to AOI-1 was difficult, the ground reconnaissance team was not able to visit that area. The reconnaissance team visited several of the depressions and EM anomalies found in

AOI-2 (see Figure 7-26). The ground reconnaissance team measured the depressions, searched them with a hand-held metal detector, and confirmed they are not munitions related. The team visited several EM anomaly locations and did not find any evidence of munitions. The validation results support the conclusion that these AOIs are likely not munitions related.

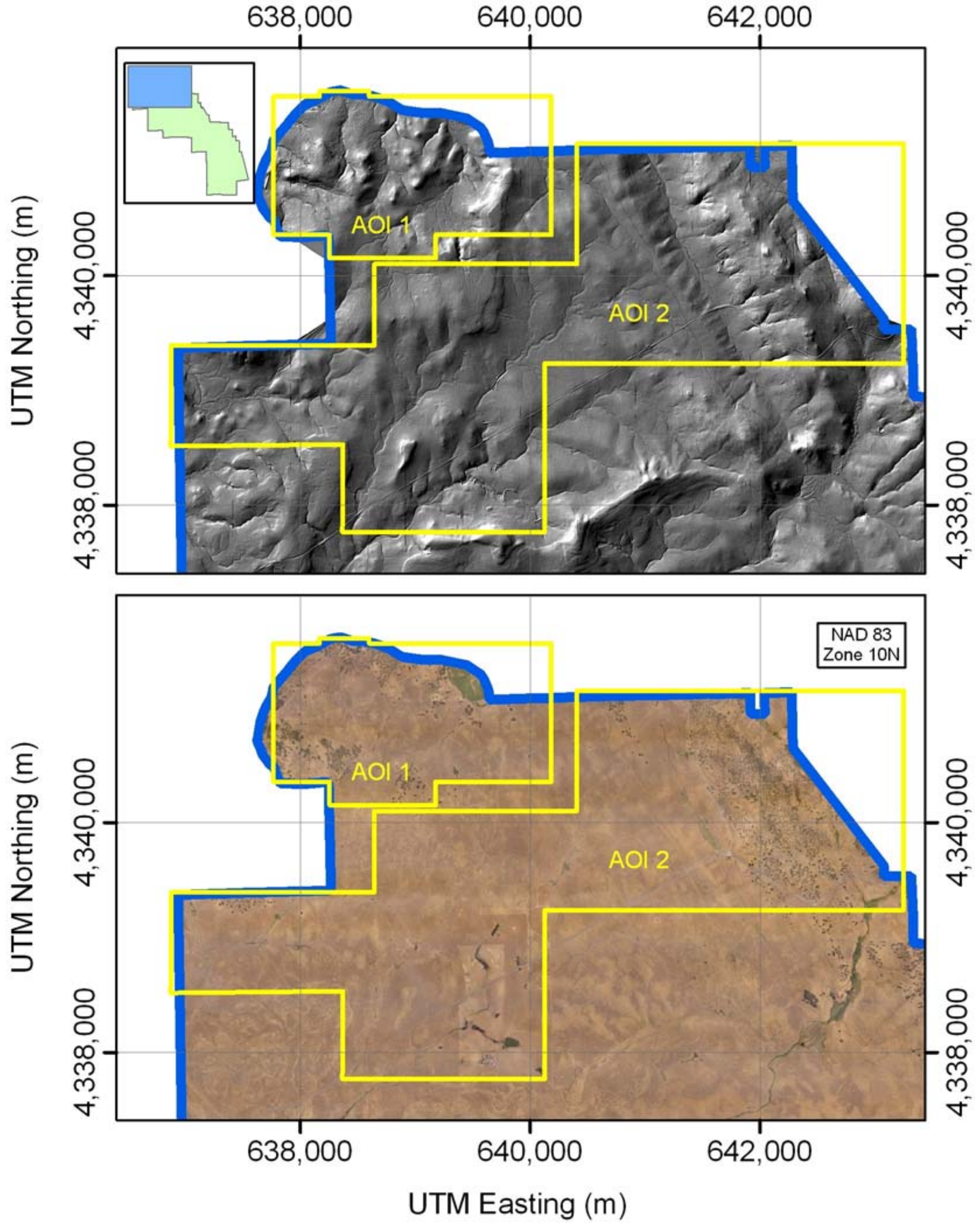


Figure 7-24. LiDAR data (top) and orthophotography data (bottom) for AOIs 1 and 2.

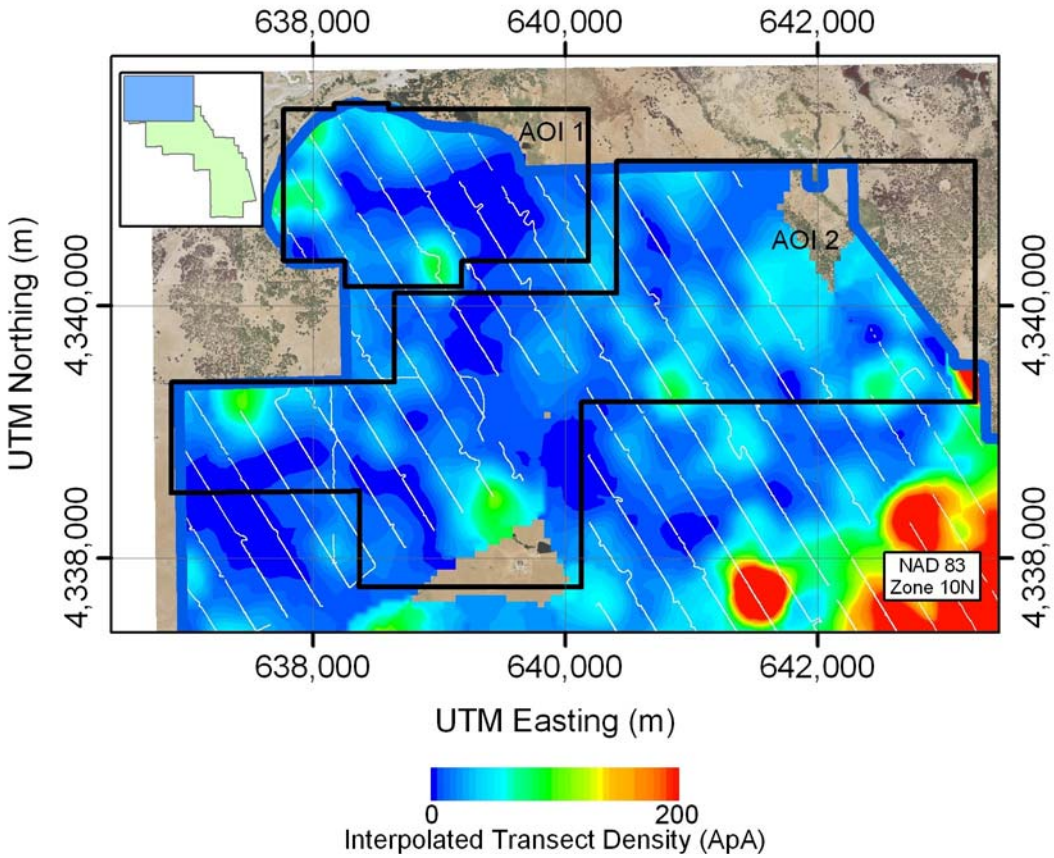


Figure 7-25. Estimated anomaly densities from the ground-transect data for AOI-1 and AOI-2. The transects are shown as white lines.

Figure 7-26. Photograph of ground reconnaissance for AOI-2.

7.3.7.2 AOI-3 Mining Artifacts

Figure 7-27 shows a large angular depression and other ambiguous features identified in the high-airborne data. The initial CSM (Figure 7-2) indicated this AOI is found within the primary toss bomb target. The helicopter magnetometer did not survey this area. Ground-based transect data were collected in the AOI. The anomaly densities exceeded the threshold used to flag an area in VSP in small areas in the southwest within this AOI corresponding to the estimated anomaly density map shown in Figure 7-28.

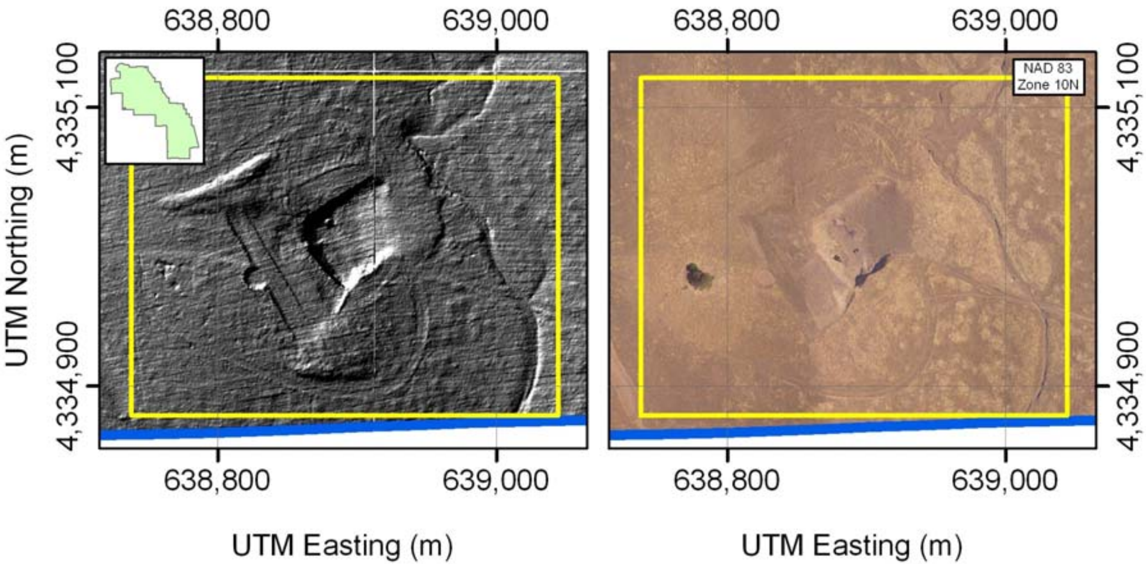


Figure 7-27. LiDAR data (left) and orthophotography data (right) for AOI-3.

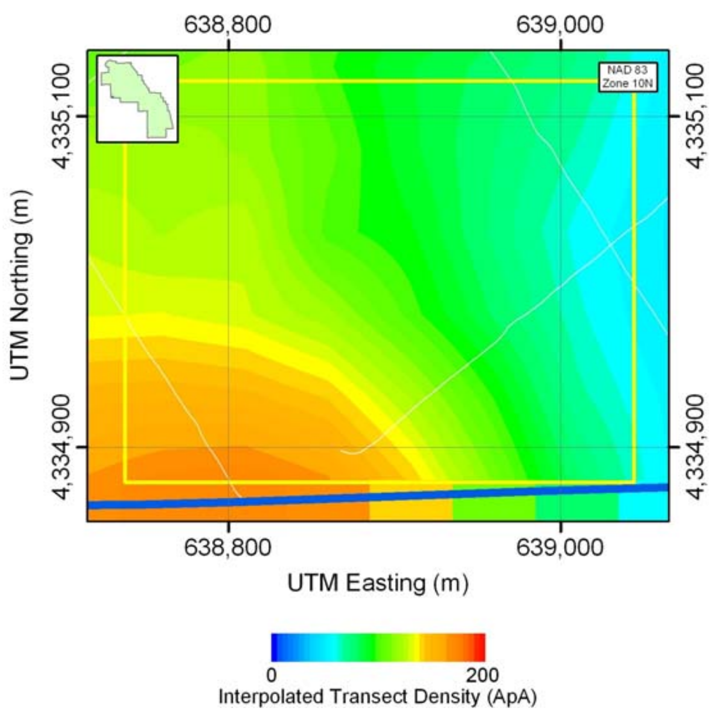


Figure 7-28. Estimated anomaly densities from the ground-transect data for AOI-3. The transects are shown as white lines.

The reconnaissance team visited the ambiguous feature shown in Figure 7-29 and confirmed this area is not munitions related. The team found evidence of mining in rock faces and mining equipment in a pit. Although the WAA data provided ambiguous findings, the validation results allow the conclusion that this is area is likely not munitions related.

Figure 7-29. Photograph of ground reconnaissance of AOI-3.

7.3.7.3 AOI-4 Small-Arms Range

Figure 7-30 shows groups of regularly spaced depressions identified in the high-airborne data. The helicopter magnetometer surveyed this area and did not show any concentrations of anomalies (see Figure 7-31). In the ground-based transects, the anomaly densities did not exceed the threshold used to flag an area in VSP. The initial CSM (Figure 7-2) indicated this AOI is found near small-arms ranges 20A and 20B. The WAA data support the conclusion this AOI is a small-arms range.

This area is a known small-arms range and was therefore not visited during ground reconnaissance.

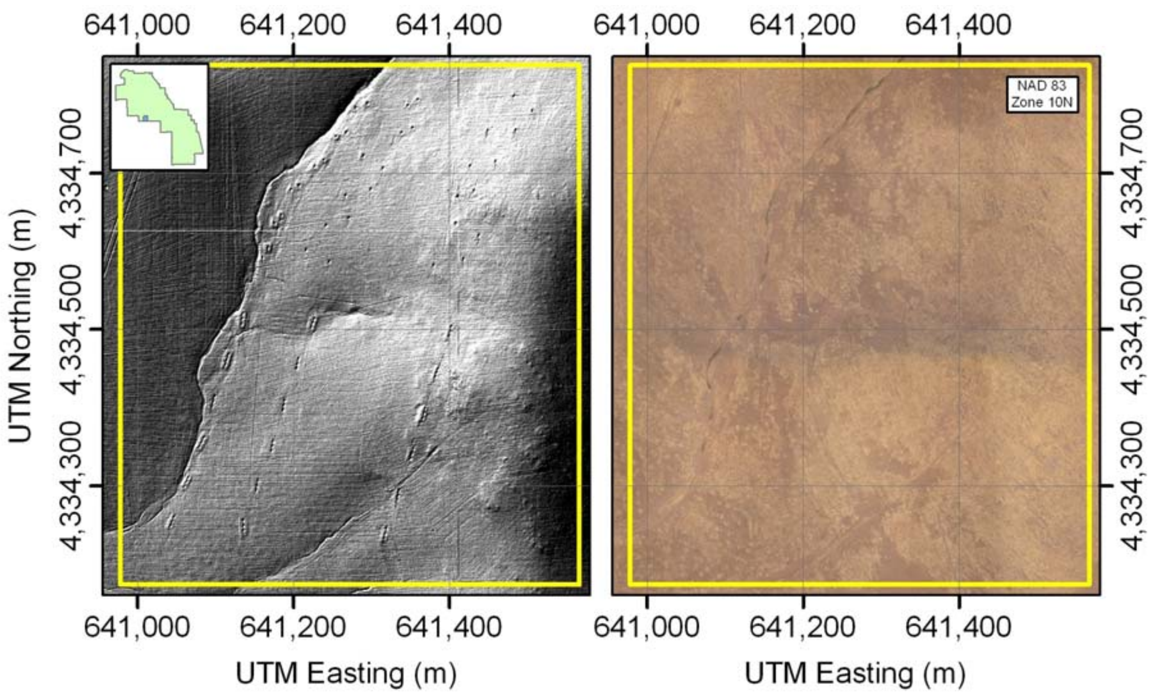


Figure 7-30. LiDAR data (left) and orthophotography data (right) for AOI-4.

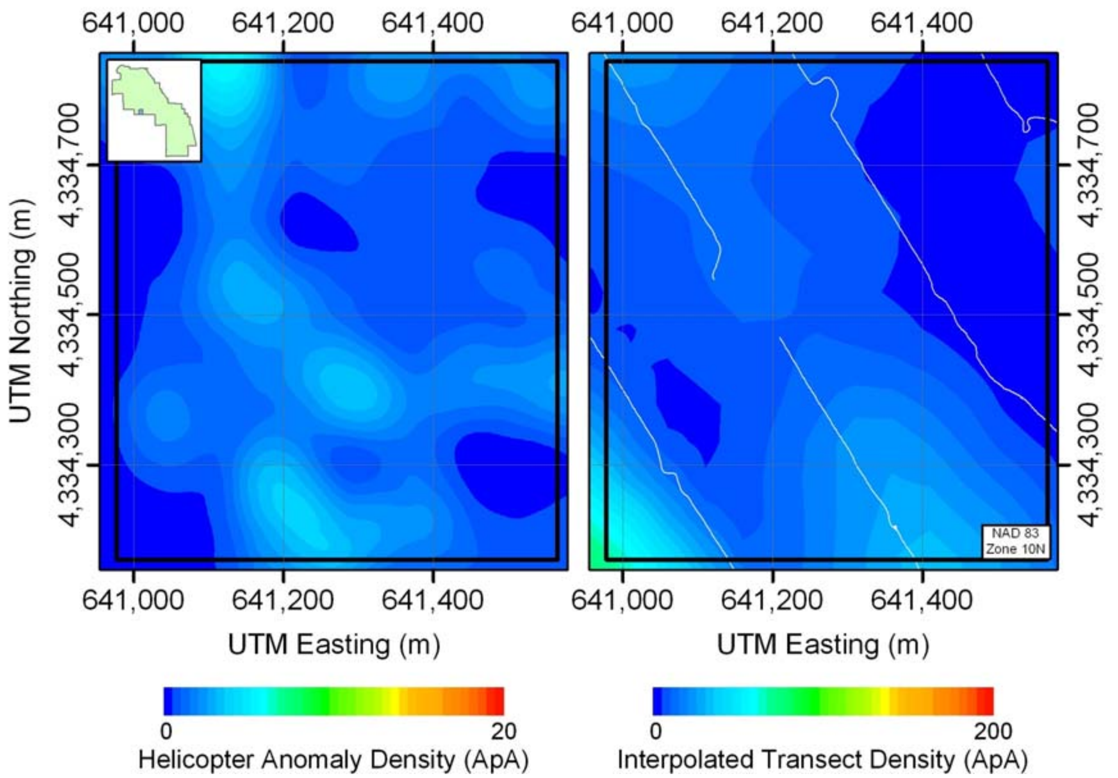


Figure 7-31. Anomaly density contours for the helicopter-magnetometer data for AOI-4 (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right).

7.3.7.4 AOI-5, AOI-6, AOI-7, and AOI-8 Nonmilitary Human Artifacts

Scattered ambiguous features identified in the high-airborne data included many depressions and disturbed surface features and are labeled AOI-5, AOI-6, AOI-7, and AOI-8 (see Figure 7-32). The initial CSM (Figure 7-2) indicates each of these AOIs is located in, or partly in, a historical range. The helicopter magnetometer surveyed only the southeast edge of AOI-5, where a concentration of anomalies was observed, and did not survey AOI-6 and AOI-8. The anomaly densities from ground-based transects exceeded the threshold used to flag an area in VSP in each of these areas except AOI-8, which corresponds to the estimated anomaly densities from the ground-transect data presented in Figure 7-33.

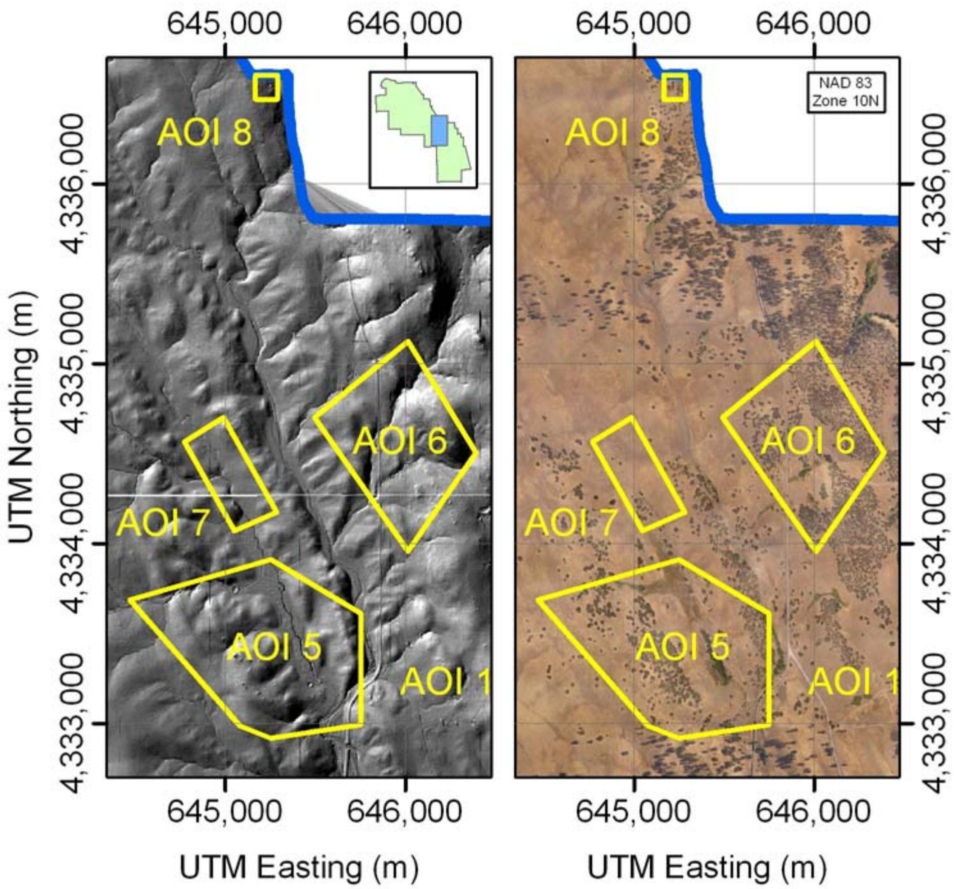


Figure 7-32. LiDAR data (left) and orthophotography data (right) for AOI-5 through AOI-8.

The reconnaissance team visited the ambiguous high-airborne features and the associated high-anomaly-density areas shown in Figure 7-33. AOI-5 was confirmed to be a camping area with a recreational shooting course. The team observed concrete pads at the location of AOI-6, and state park personnel confirmed these were part of a historic homestead. AOI-7 was observed to be a barbed-wire fence and a power line. The team visited AOI-8 and recorded it as man-made, but determined it was not munitions related. Photographs of AOI-5 and AOI-7 are shown in Figure 7-34. Despite the location of these features within the boundaries of historical ranges, the validation revealed that each is associated with human activity not related to munitions.

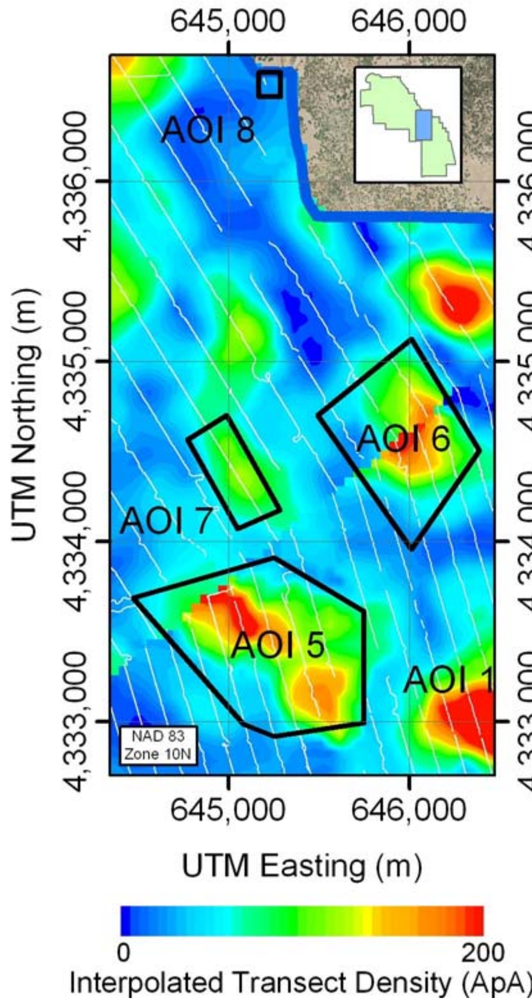


Figure 7-33. Estimated anomaly densities from the ground-transect data for AOI-5 through AOI-8. The transects are shown as white lines.

Figure 7-34. Photographs of ground reconnaissance of AOI-5 and AOI-7.

7.3.7.5 AOI-9 Small-Arms Range

Figure 7-35 is an ambiguous non-natural surface feature identified in the high-airborne data. The helicopter magnetometer did not survey this area. The anomaly densities from ground-based litter-carried system transects exceeded the threshold used to flag an area in VSP in this area. The estimated anomaly densities created from the ground-transect data are presented in Figure 7-36. The initial CSM indicated this AOI is not located in an area of known ranges, although it is on the border of Range 13.

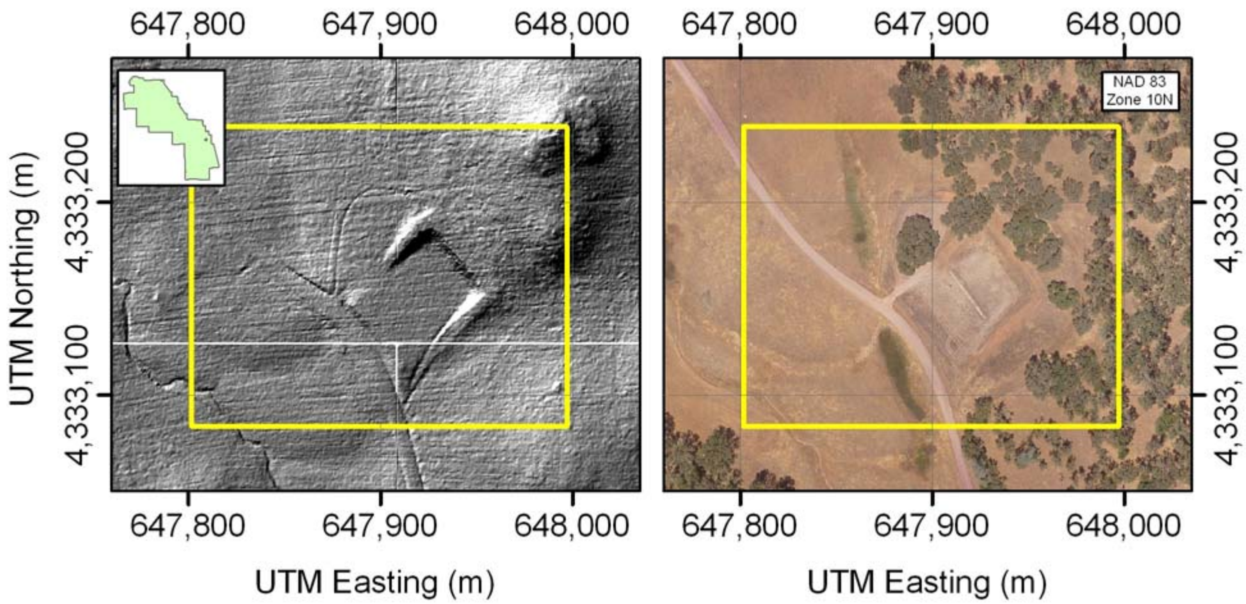


Figure 7-35. LiDAR data (left) and orthophotography data (right) for AOI-9.

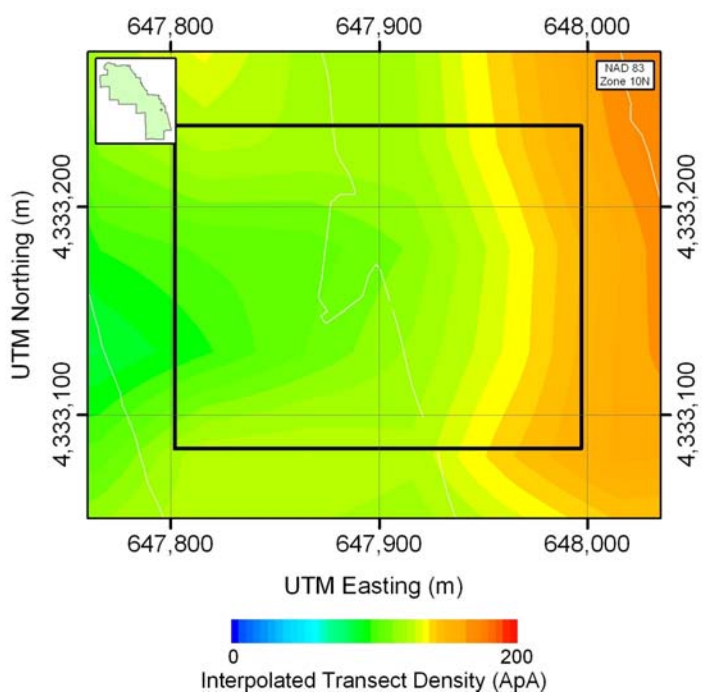


Figure 7-36. Estimated anomaly densities from the ground-transect data for AOI-9. The transects are shown as white lines.

The reconnaissance team visited this AOI (see Figure 7-37) and confirmed the area is a small-arms range. The team also observed a fence surrounding the range, which is likely the source of a portion of the high-anomaly-density areas.

Figure 7-37. Photograph of ground reconnaissance of AOI-9.

7.3.7.6 AOI-10 Public Pistol Range

Figure 7-38 shows a series of berms identified in the high-airborne data. The helicopter magnetometer anomaly density contours showed two lightly concentrated areas of anomalies (see Figure 7-39). The anomaly densities from the ground-based transects exceeded the threshold used to flag an area in VSP within this AOI and portions of the surrounding area. The initial CSM (Figure 7-2) indicated this AOI is not located in an area of known ranges.

This area is a known public pistol range and was therefore not visited during ground reconnaissance.

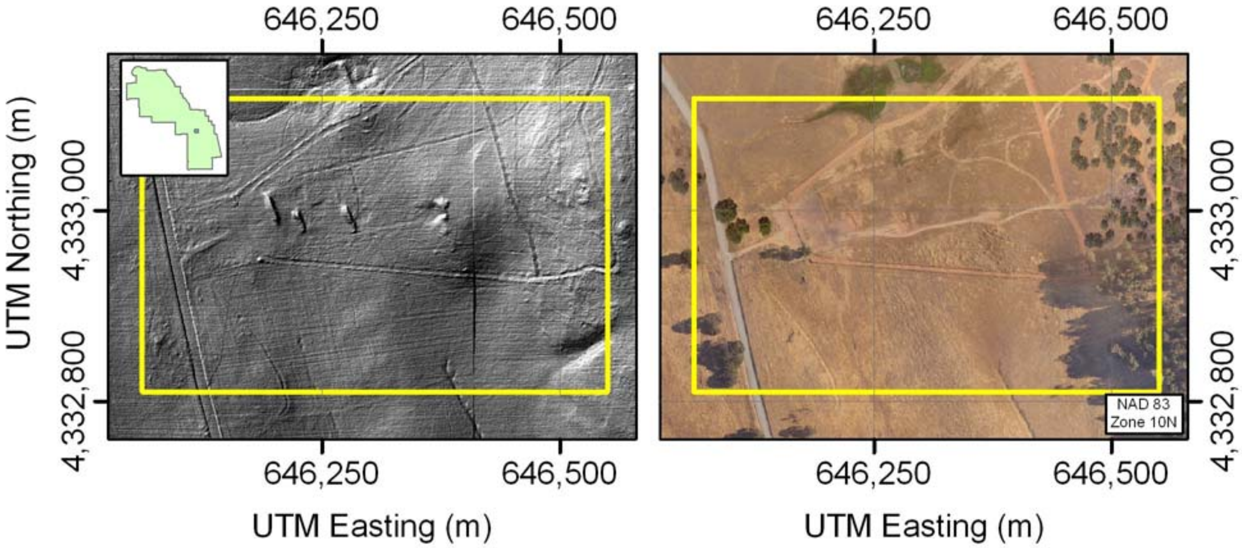


Figure 7-38. LiDAR data (left) and orthophotography data (right) for AOI-10.

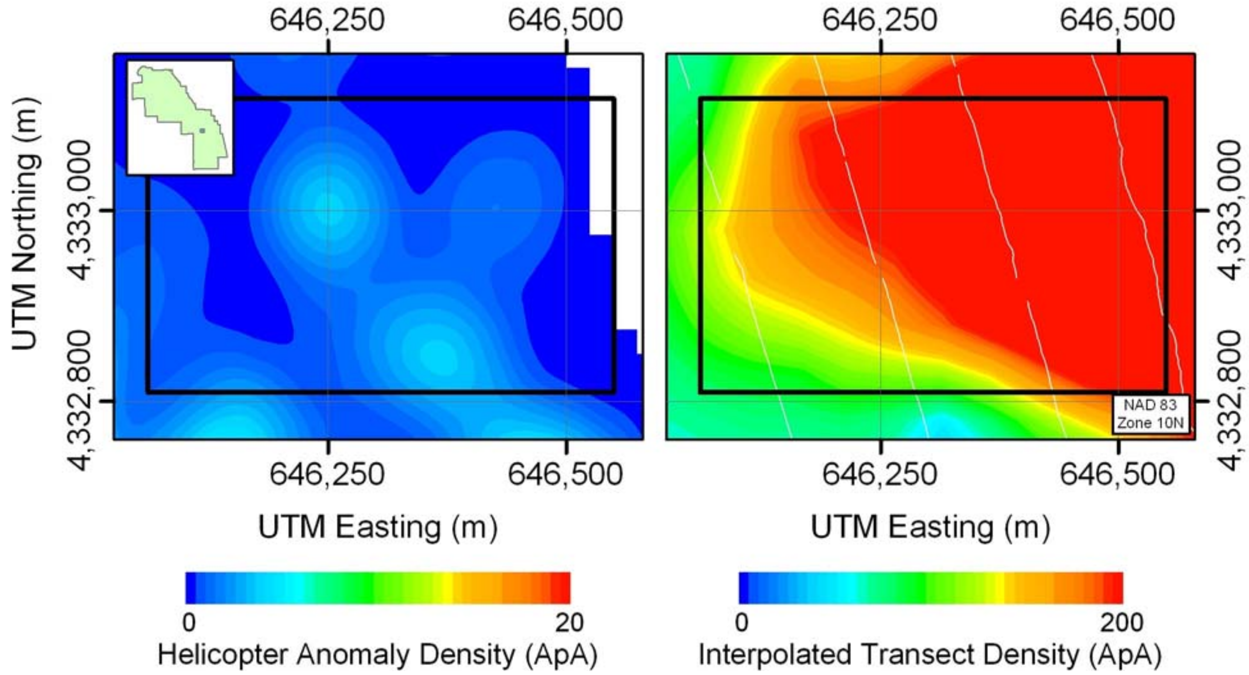


Figure 7-39. Anomaly density contours for the helicopter-magnetometer data for AOI-10 (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right).

7.3.7.7 AOI -11 Man-Made Depressions

A number of depressions arranged in a linear fashion were identified in the high-airborne data (see Figure 7-40). The helicopter magnetometer surveyed a small portion of this AOI, and no anomaly concentrations were observed (see Figure 7-41). The anomaly densities from the ground-based transects did not exceed the threshold used to flag an area in VSP. The initial CSM (Figure 7-2) indicated this AOI is not located in an area of known ranges.

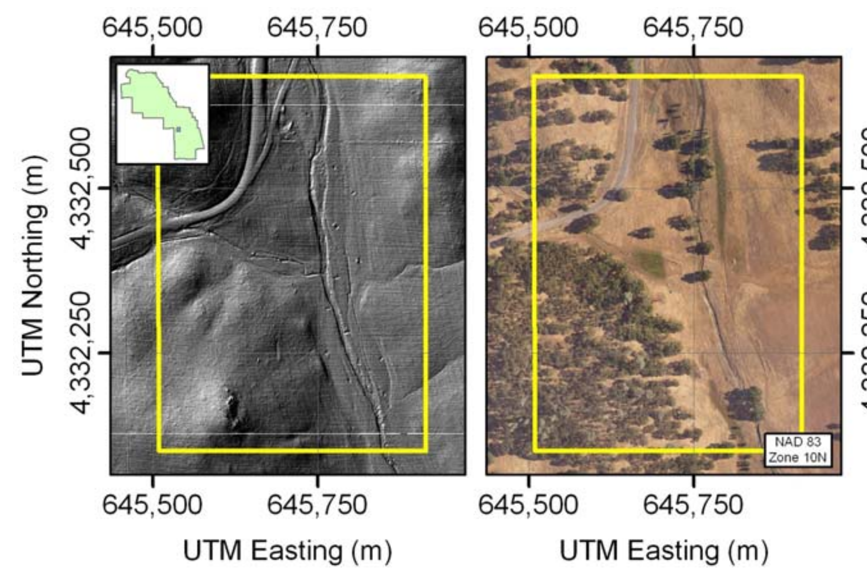


Figure 7-40. LiDAR data (left) and orthophotography data (right) for AOI-11.

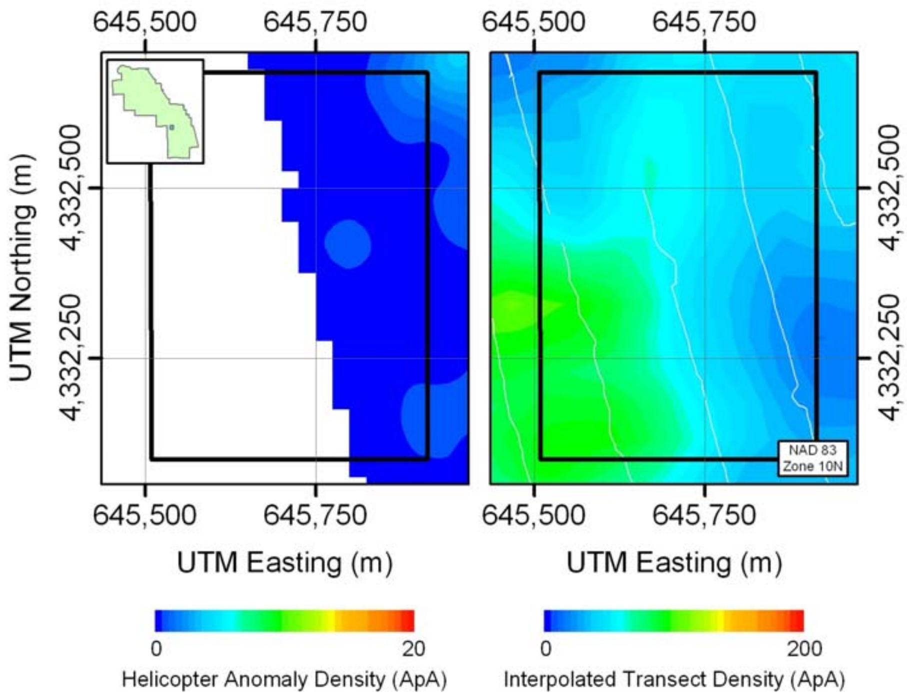


Figure 7-41. Anomaly density contours for the helicopter-magnetometer data for AOI-11 (left). The estimated anomaly densities from the ground-transect data with the transects shown as white lines (right).

The ground reconnaissance team visited, measured, and searched the depressions (see Figure 7-42) with a hand-held metal detector and confirmed that they are not munitions related. The team observed these depressions are machine-dug holes, possibly used for irrigation or exploration.

Figure 7-42. Photograph of ground reconnaissance of AOI-11.

7.3.7.8 AOI-12 through AOI-14 Surface Features and Scattered Depressions

Figure 7-43 shows the high-airborne data for AOI-12 through AOI-14. A regular pattern of berms is visible in AOI-12. In AOI-13, a linear feature with scattered depressions is apparent, which is consistent with the shape of a small-arms range. Finally, a regular line of depressions in a seasonal stream bed was found in AOI-14. The initial CSM (Figure 7-2) indicated these AOIs are located in the proposed toss bomb boundary. There is no evidence the proposed toss bomb range was ever used.

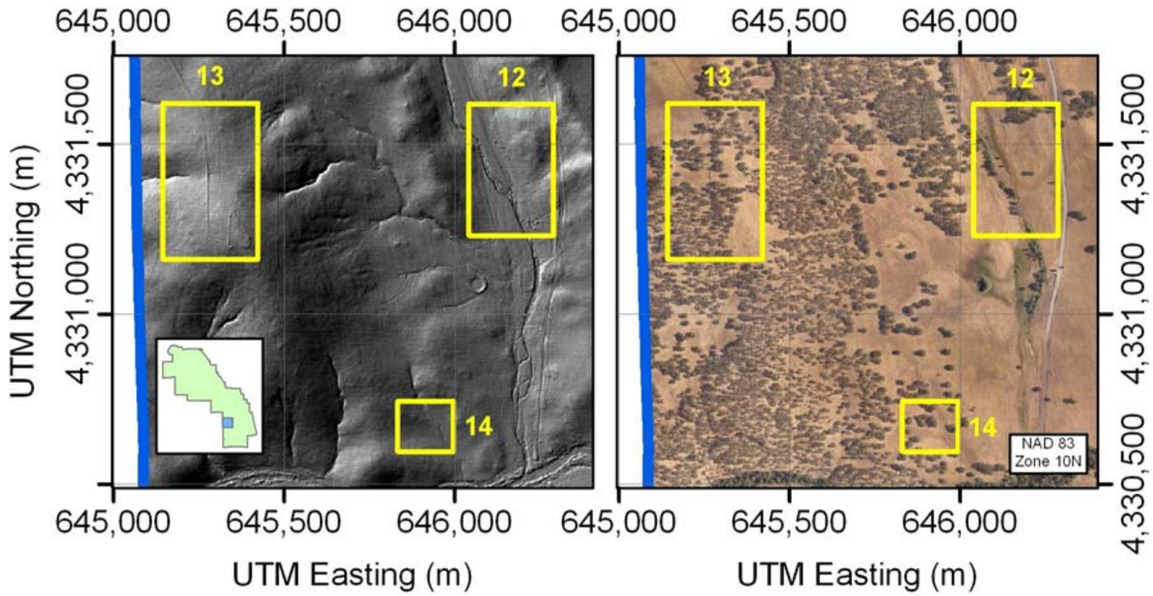


Figure 7-43. LiDAR data (left) and orthophotography data (right) for AOI-12 through AOI-14.

The helicopter magnetometer surveyed only AOI-12 and found the eastern portion of the AOI has elevated anomaly densities. The estimated anomaly densities from the ground-transect data in AOI-12, AOI-13, and AOI-14 are shown in Figure 7-44. The ground-based anomaly densities exceeded the threshold used to flag an area in VSP for one location in the southern tip of AOI-12. The anomaly densities in AOI-13 and AOI-14 did not exceed the threshold.

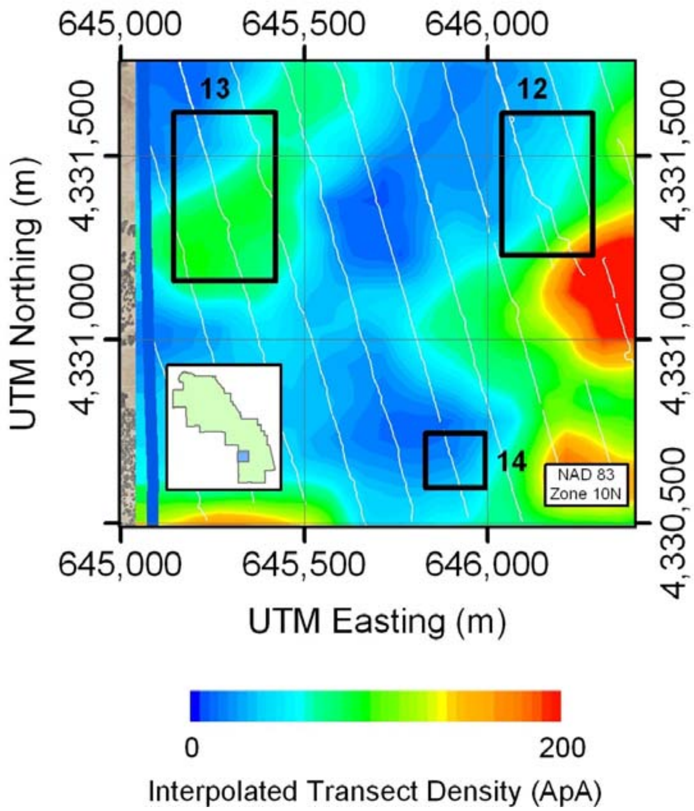


Figure 7-44. Estimated anomaly densities from the ground-transect data with the transects shown as white lines for AOI-12 through AOI-14.

The reconnaissance team visited only AOI-12 and confirmed the high anomaly density in this area is due to geology (see Figure 7-45).

Figure 7-45. Photograph of ground reconnaissance of "hot rocks" seen in AOI-12.

7.4 Overall Site Conclusions

Five confirmed MRSs and one potential MRS were identified through the WAA process. The remaining land, which shows no indication of concentrated munitions use, contains a number of AOIs that were ultimately identified in the validation phase as not munitions related. The results provide a preponderance of evidence to support the following conclusions about the site.

MRS A: Northern Multi-Range Complex

- The results are generally consistent with the initial CSM, indicating the presence of bombing targets and ground ranges throughout this area. Several confirmed areas of concentrated munitions use are embedded in a general background of apparent craters. However, it is not possible to unambiguously match an observed target area to a specific historical range.
- Using the decision boundary created by circumscribing the outer edges of all the adjacent munitions response features that could not readily be separated, the area of the MRS is estimated to be 4,100 acres, with some 375,000 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is high, resulting in a low contrast between the background and the MRS density. Therefore, there are multiple lines of evidence that support this area is an MRS, but these lines of evidence do not clearly define acreage and anomaly count. The data clearly identify distinct bomb targets and suggest some level of munitions contamination throughout the MRS, but may not delineate all of the individual target areas that make up the MRS.
- The historical record indicates both HE and practice munitions were used on this MRS, and the findings of this study are consistent with the initial CSM. Munitions-related craters were observed and indicate the use of HE munitions on this MRS. No direct evidence of practice bombs is observed in WAA data.

MRS B: Southern Multi-Range Complex

- The results are generally consistent with the historical usage of this area in the initial CSM, indicating the presence of multiple overlapping ground ranges throughout the area. No evidence was found to indicate the proposed toss bomb target was constructed or used. Throughout the bounded area, features indicating concentrated munitions use are seen in one or more of the WAA data sets. It is not possible to unambiguously match an observed target area to a specific historical range.
- Using the decision boundary created by circumscribing the outer edges of all the adjacent munitions response features that could not readily be separated, the area of the MRS is estimated to be 3,200 acres, with some 345,000 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is high, resulting in a low contrast between the background and the MRS density. Therefore, there is medium confidence in these acreage and density results.
- The historical record indicates HE and practice munitions were used on the various ranges that overlap this MRS, and the findings of this study are consistent with the initial CSM. Munitions-related craters were observed and indicate the use of HE munitions on this MRS. No direct evidence of practice bombs is observed in WAA data.

MRS C: Firing Points and Craters

- The results are generally consistent with the historical usage documented in the initial CSM, although it is not possible to unambiguously associate this MRS with a particular historic range. The high-airborne data reveal both firing points and craters, both of which were confirmed in the reconnaissance visit. Both firing points and craters are associated with ground ranges. Their presence in proximity to one another suggests this area was configured for different purposes at different points in the site history. The absence of a concentration of geophysical anomalies indicates MRS C was not the site of a heavily used target area.
- Using the decision boundary created by encompassing the outer edges of all the munitions-related features, the area of the MRS is estimated to be 60 acres.
- The historical records indicate HE bombs were used on this MRS, and the findings of this study are consistent with the initial CSM. Munitions-related craters were observed and indicate the use of HE munitions on this MRS.

MRS D: Artillery and/or Mortar Ranges

- The results are generally consistent with the historical usage documented in the initial CSM, although it is not possible to unambiguously associate this MRS with a particular historic range. The high-airborne data reveal craters and a man-made feature that appears ship-shaped, and the craters were confirmed as munitions related in the reconnaissance visit. The corresponding concentration of geophysical anomalies indicates MRS D was the site of a target area, possibly associated with Range 11 (1956) or Range 100.
- Using the decision boundary created by encompassing the outer edges of all the munitions-related features, the area of the MRS is estimated to be 80 acres, with some 8,800 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is high, resulting in a low contrast between the background and the MRS density. Therefore, there is medium confidence in these acreage and density results.
- The historical records indicate HE bombs were used on this MRS and the findings of this study are consistent with the initial CSM. Munitions-related craters were observed and indicate the use of HE munitions on this MRS.

MRS E: Artillery and/or Mortar Range

- The results are generally consistent with the historical usage documented in the initial CSM, although it is not possible to unambiguously associate this MRS with a particular historic range. The high-airborne data reveal craters, and there is a corresponding concentration of geophysical anomalies in the ground-transect data, indicating MRS E was the site of a target area, possibly associated with Range 11 (1956).
- Using the decision boundary created by encompassing the outer edges of all the munitions-related features, the area of the MRS is estimated to be 100 acres, with some 9,800 anomalies detectable by a ground-based sensor. The average background anomaly density for this site is high, resulting in a low contrast between the background and the MRS density. Therefore, there is medium confidence in these acreage and density results.
- Munitions-related craters were observed and indicate the use of HE munitions on this MRS.

Potential MRS F: Craters

- The WAA results for MRS F are not consistent with the initial CSM. This MRS is not located within the bounds of any historical ranges, but it is near a historical bombing target. The high-airborne data and subsequent validation confirm the presence of isolated craters that were validated as munitions related in the reconnaissance visit. There is no corresponding concentration of geophysical anomalies in this area, indicating that it is not a heavily used target area. Nevertheless, the WAA provides evidence this area was affected by limited or unintentional munitions use.
- Using the decision boundary created by encompassing all of the potential munitions-related features, the area of the MRS is estimated to be 135 acres. No area in this MRS exceeded the background anomaly density.
- The presence of HE craters found in validation indicates HE bombs were used in this area or were a result of spillover from an adjacent impact area.

Remainder of the Study Area

- The remaining land within the Former Camp Beale study area shows no evidence of concentrated munitions use. However, this site contains multiple overlapping historical ranges and a higher background anomaly density than the first three demonstration sites. On the Northern end of the site, where no historical targets are known to exist, this conclusion has high certainty. Most of the remainder of the study area lies within one or more of the historical ranges, and while it is not expected these areas will necessarily contain munitions throughout, there is only moderate certainty in the conclusion that no additional concentrations of munitions exist.
- Out of the 18,000 acres surveyed, roughly 10,000 acres were found to have no evidence of concentrated munitions use.

7.4.1 Technology Conclusions

The WAA results from this site provide further insight into the capabilities and limitations of each technology.

7.4.1.1 High-Airborne Technology Conclusions

- The high-airborne technologies were effective in identifying munitions-related features and other AOIs. Overall, the munitions-related features, AOIs, and the general terrain of the site are more clearly observed in the LiDAR images than in the orthophotographs. The orthophotographs were useful for identifying several features that were ambiguous in the LiDAR data. MRS C would not be picked from any technology except the LiDAR.
- There were few surface scars indicating individual target areas at this site. Craters were the most frequently observed high-airborne feature to support conclusions about munitions use at each MRS, and the remains of several firing points were also found. The presence of craters also helped support conclusions about HE bomb usage at the site.
- Trees and other vegetation obstructed the high-airborne technologies' view of the ground surface. Various levels of effect were seen, depending upon the vegetation density. Large features, such as bunkers, were visible in the LiDAR and surprisingly in the orthophotography data through scattered to moderate trees. Small features, such as craters adjacent to the bunkers, were not seen in vegetated areas, although their presence was

known from site visits. Useful LiDAR images were not obtained in areas with dense ground cover.

7.4.1.2 Low-Airborne Technology Conclusions

- The helicopter magnetometer data were successfully used to identify elevated concentrations of surface and subsurface anomalies in benign parts of the site, but much of the portion of the site suitable to low-level flight contained significant geological background. In these areas, comparing helicopter magnetometer data to ground-transect data taken with an EM system or ground reconnaissance was required to distinguish geology from concentrations of ferrous items.
- The helicopter coverage was severely limited at this site due to terrain, vegetation, and geology, but these areas were effectively avoided by incorporating site knowledge into a coverage plan before deployment. The terrain and vegetation map created from the high-airborne data was used in combination with geologic data collected from sparse magnetometer transects to select areas where the helicopter magnetometer array could be most effective.

7.4.1.3 Ground-based Technology Conclusions

- The ground-based transect data, acquired through a combination of towed array and litter-carried platforms, were successfully used to identify concentrations of anomalies.
- EM sensor selection for the ground-based systems was critical at this site where geologic interference was common.
- The background anomaly density was higher at this site compared with the first three demonstration sites. This reduces the confidence in identifying areas of concentrated anomalies.

7.4.2 Combined Technology Conclusions

- At this site, the ability to combine results from high-airborne and geophysics data layers was critical to the ability to draw conclusions in many areas where the origin of high-airborne features was ambiguous. This is particularly true for the mortar and artillery targets, where few or no persistent ground features were observed. The presence or absence of corresponding concentrations of anomalies in the geophysics data provided additional evidence that was essential to drawing a conclusion.
- Some areas of this site required additional validation from a ground reconnaissance team, even when the combined technology results were considered. The reconnaissance generally provided unambiguous identification of a feature.
- The ground-based systems proved to be more useful than the helicopter magnetometer at this site. The combined geologic interference, terrain, and vegetation constraints limited the useful helicopter-magnetometer data to a fraction of the study area. These data sets are redundant, and only one will generally be needed to provide information on the extent of the MRS.

7.4.3 MRS Boundary Decisions

Figure 7-46 is a summary of the MRSs that result from this work. The two largest areas, MRS A and MRS B, comprise a number of distinct targets and ranges that are difficult to separate, and the boundaries shown are drawn to encompass all adjacent munitions features. MRS C, MRS D, and MRS E represent smaller, distinct areas of munitions use. MRS F is included as a potential MRS because a handful of craters containing munitions fragments were observed.

Despite the CSM indicating AOIs 5,6,7,8 are in historic ranges, multiple lines of evidence in the WAA data and ground reconnaissance determined these areas are not munitions related. They were definitively identified as a camping area, historical homestead, fencing near a power line, and a man-made feature that is not munitions related respectively.

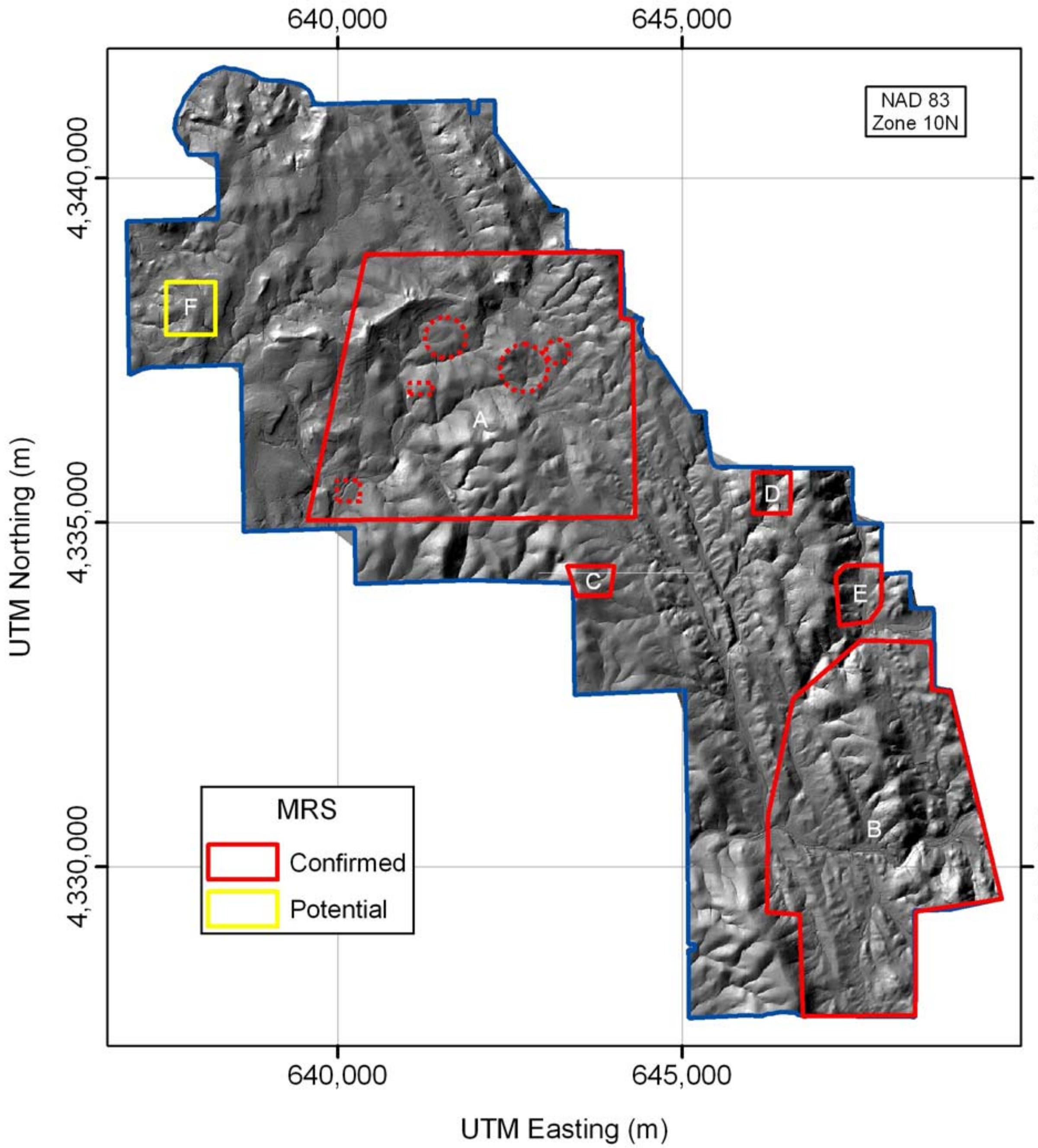


Figure 7-46. The five confirmed and one suspected MRS on the WAA site at former Camp Beale.

8.0 EXPLORING CAPABILITIES AND LIMITATIONS

The WAA program established capabilities and limitations of the various sensor platforms and approaches through the use of confirmation targets and data comparisons. During the data collection, specifically designed confirmation items were used to establish and confirm the performance of each system by measuring basic sensor operational specifications. In the analysis phase, demonstration results for each platform were compared and subjected to a number of data quality assessments and ultimately field validation. In this chapter, the first section addresses establishing the basic sensor parameters that meet data quality requirements. The remaining sections address system performance as it applies to demonstrated capabilities, site characteristics, and sensor type.

8.1 Basic Sensor Parameters—Data Requirements

Reproducing the capabilities of any of these technologies will require that the systems are operated in a way that produces data sufficient to meet the project objectives. If contracts are let to utilize these technologies for WAA, the effects of these basic sensor operating parameters must be understood and properly accounted for in data specifications. For most sensor types, data-quality requirements will generally include some measure or verification of sensor sensitivity, data density, and positional accuracy of individual measurements.

To establish that data quality was sufficient for the project objectives, the pilot program employed performance confirmation methods specifically designed for each of the sensor platforms. These specifications may not translate directly to requirements for all sites, but they give an indication of the data quality used to achieve the performance in this program—gross deviations from these ranges should be carefully scrutinized. Although operational WAA may not require this level of performance confirmation work, some means of verifying proper system performance should always be established.

8.1.1 High Airborne Technologies—LiDAR and Orthophotography

The effectiveness of LiDAR and orthophotography will depend on image quality. Factors that will affect LiDAR image quality include the point density on the ground, which will determine the size of feature that can be observed; the vertical resolution, which will determine the height of the feature that can be observed; and the horizontal location accuracy, which will affect image quality and the ability to accurately locate features. Factors that will effect orthophotography include pixel size on the ground, which will determine the size of the smallest feature that can be detected; the horizontal location accuracy, which will affect image quality and the ability to accurately locate features; and the focus and contrast qualities of the photograph.

For all the sites, arrays of fiducial targets and craters were established at surveyed locations. The fiducial targets provided a quantifiable means of measuring positional accuracy of the LiDAR points and orthophotography pixels, as well as the LiDAR vertical measurement accuracy. The craters of varying sizes provided a means of establishing the pixel size and point density needed to observe the smallest features of interest. At the Kirtland site, the LiDAR and orthophotography data were collected at a variety of altitudes, translating to a variety of pixel resolutions in orthophotography and point density (points per square meter) in LiDAR. Comparisons of these data sets allowed for the assessment of the value added of higher resolution data.

8.1.1.1 Fiducials

The fiducials for the high-airborne sensors consisted of tables of known height for LiDAR and visual cues of high contrast, generally black-and-white crosses, for orthophotography (see Figure 8-1). All fiducial locations were surveyed to centimeter-level accuracy and used to establish quantitative registration and data-quality metrics. Key data specifications included the location of pixels and LiDAR point returns, both absolute and relative to one another. LiDAR vertical precision is important since the features of interest are as small as 10 cm in relief. The reported locations of the objects and the heights of the tables were compared to the surveyed values to establish data collection was within specifications. Table 8-1 gives the basic location accuracy achieved on the Kirtland site for example.

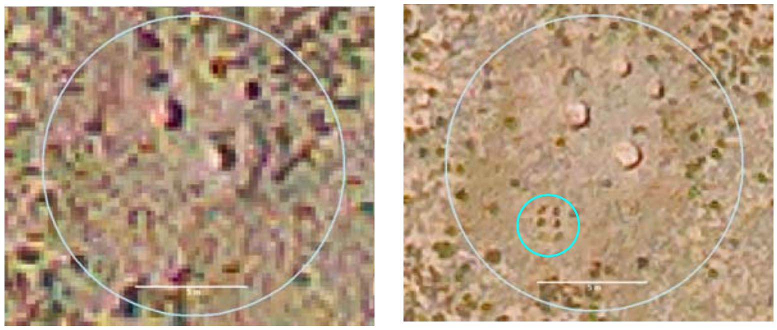
Figure 8-1. Example of fiducial targets used to verify performance of orthophotography and LiDAR systems.

Table 8-1. Location accuracy achieved for orthophotography and LiDAR.

Specification	Kirtland achieved
LiDAR	
Horizontal radial error (95%)	0.08 m in *x* and *y*
Vertical linear error (95%)	0.11 m
Orthophotography	
Horizontal radial error (95%)	0.10 m for 10-cm pixels
Cross-registration accuracy	0.14 m in *x*, 0.17 m in *y* for 10-cm pixels

8.1.1.2 Craters

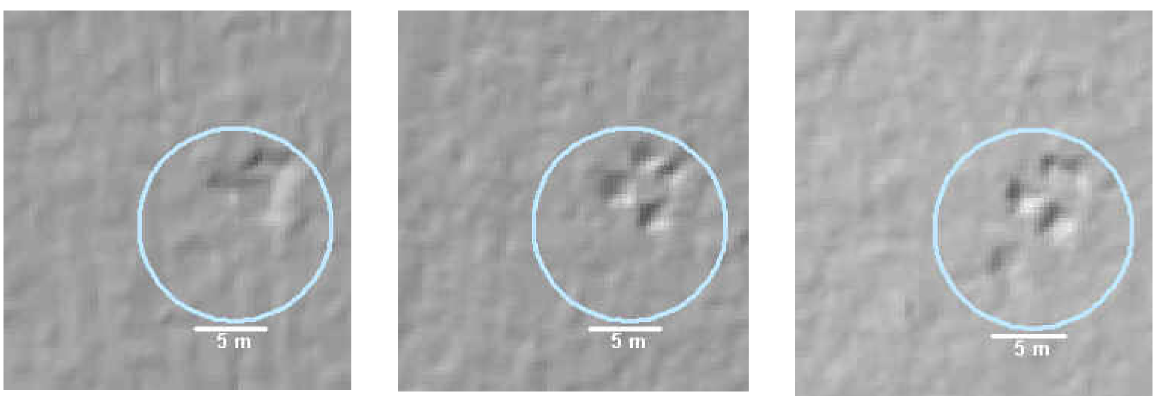
To establish the data density required to see the smallest detectable features of interest, a series of craters of varying sizes were dug. Figure 8-2 shows the craters from the Kirtland site, which included two of 1.5 m diameter, two of 1 m diameter, and six of 0.3 m diameter. The figure shows the 10-cm pixel orthophotograph detects the smallest craters, but the 20-cm pixel does not. Even for the 10-cm pixel size, however, the detectability relies to some extent on the regular arrangement of the group. In general, orthophotography is unlikely to be the sensor of choice for crater detection. These test craters are likely visible because they are freshly dug and have enhanced color contrast that would not necessarily be present in weathered craters. On some sites, craters may be detected by exploiting a difference in vegetation or shadowing. Nevertheless, this exercise illustrates the feature size that can be reliably detected for a given pixel size.



20-cm pixel orthophoto   10-cm pixel orthophoto

Figure 8-2. Orthophotography data over crater test field at Kirtland. All the test craters are visible in the 10-cm photo. The four craters prominent in the upper right quadrant of the circle include two 1.5 m in diameter and two 1 m in diameter. The inset circle indicates the six 0.3 m craters.

Figure 8-3 shows the LiDAR images over the same area at three different point densities. In the images at 4.5 and 6.0 points per m^2, the 1 m and 1.5 m diameter craters are clearly visible. However, even the highest point density of 6.0 points per m^2 is still inadequate for reliable detection of the 0.3 m craters. A depression visible at their location is only seen because the location is known and the craters grouped together.



1.5 points/m^2 4.5 points/m^2 6 points/m^2

Figure 8-3. LiDAR over crater test field at Kirtland at various point densities. Craters are as described in Figure 8-2.

8.1.2 Helicopter Magnetometer

The effectiveness of the helicopter magnetometer will depend on several factors:

- Proper absolute and relative sensitivity of the magnetometer or EM sensing elements—absolute, in the sense that measurements are consistent with the governing physics, and relative, in day-to-day consistency.
- Accurate location of the individual sensor measurements.
- Appropriate coverage with no gaps and height above ground not exceeding a few meters (actual requirement will depend on objectives).

- Meaningful interpretation of the data—target-picking thresholds and analysis using physics-based models should produce physically meaningful parameters.

Exact specifications will depend on project objectives. For the primary objective of WAA, finding target areas and determining that areas are free of concentrated munitions use, gaps in coverage and lower sensitivity and location accuracy may be acceptable. The data-collection effort is substantial even for WAA objectives, however. The data specifications should consider that secondary objectives of characterizing target areas can likely be supported with modest additional effort.

For well understood and extensively tested systems, such as the helicopter magnetometer, there is no need to conduct an extensive site-specific prove-out. This system has been the subject of numerous performance assessments that have established its detection limits. (Ref. 36) Further, it is unlikely that a prove-out sufficiently extensive to establish probability of detection, which would require hundreds of targets, could be accomplished. The probability of detection metrics of a typical prove-out are also not particularly relevant for WAA, where the goal is not to detect every item, but rather to detect enough of the munitions and scrap to identify areas of concentrated munitions use.

The pilot program used a performance confirmation strip as a means of verifying the sensor was functioning properly and the data from prior characterization accurately reflected the performance on site. This required verifying sensitivity and measuring site noise. It is a straightforward matter to calculate the expected detection capability of a magnetometer system. Figure 8-4 shows a plot of the expected signal strength versus distance from the sensor for a 105-mm projectile. The two solid lines represent the item oriented in its most and least favorable orientations. If the sensor is functioning properly, all measured values should fall between the two lines, as represented by the black dots. The signal strength is determined by well understood physics and will be site invariant. Any deviations from the expected values should be resolved before data collection. The site noise, represented by the horizontal dashed line, will be site specific. Signals that exceed the noise by a factor of about 3:1 or greater should be readily detected.

A line of targets was emplaced on the surface to verify system sensitivity and location accuracy for the helicopter-magnetometer system. The targets include 2.75-inch rockets, 155-mm projectiles, simulants of 100-lb practice bombs, and a steel cube. The magnetometer data may be analyzed using a physics-based model of a magnetic dipole to estimate parameters describing the object giving rise to each anomaly. The parameters include horizontal location of the target, depth, and dipole moment, which is related to the object's size. For the confirmation targets, these parameters may be compared to truth to verify that data and the analyses are reasonable and consistent. Table 8-2 summarizes the analysis of the confirmation targets at the Kirtland site, showing the location accuracy and precision, as well as the standard deviation of parameters derived from model-based analysis of the data.

Figures 8-5, 8-6, and 8-7 show consistency of fitted depth, fitted size, and peak signal amplitude, respectively, for individual targets in the confirmation strip. The targets were surveyed at the start and end of each data-collection day, and the individual symbols represent data from all flights. Data reproducibility was assessed by comparing the fitted parameters. In general, the fitted parameters are tightly clustered and consistent. In Figure 8-7, the measured signal strength shows somewhat more scatter, as would be expected. This value will be highly dependent on the relative location of the nearest magnetometer to the targets as the helicopter flies over them, which will vary from flight to flight.

Other factors such as height above ground and completeness of coverage are verified during the data collection. The height above ground is monitored using altimeters, and data out of specification are not used in the analyses. In cases where terrain and vegetation are challenging, data at a suitable altitude of about 2–3 m may not be obtainable. In others areas, if data collection is out of specification without a good cause, sections may need to be flown again. Completeness of coverage is verified by examining the final data product for gaps.

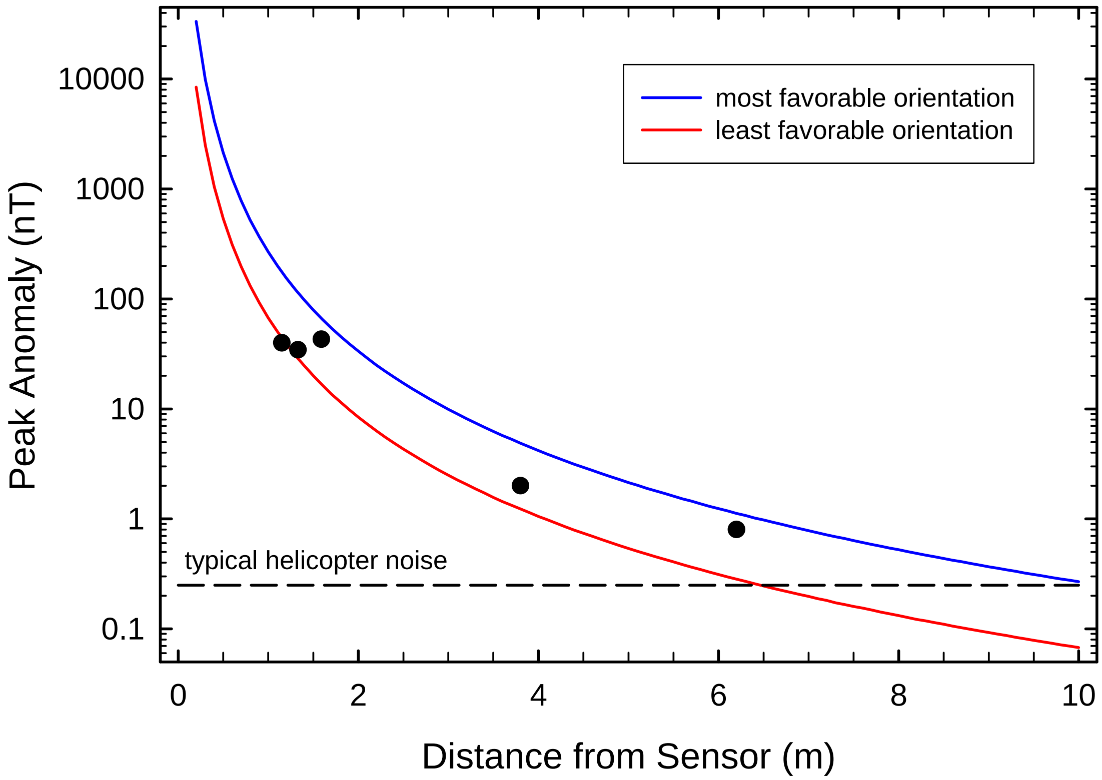


Figure 8-4. Expected magnetometer signal for a 105-mm projectile as a function of depth. The blue line represents the most favorable orientation, the red line the least favorable orientation, and the black dots the measured values from a confirmation strip. The horizontal dashed line represents nominal site noise.

Table 8-2. Kirtland Results for Confirmation Targets.

Dipole-Fit Parameter	Bias	Standard Deviation
Easting	0.02 m	0.09 m
Northing	0.06 m	0.13 m
Depth	0.15 m	0.13 m
Size	n/a	7 mm
Solid Angle	n/a	6.0°

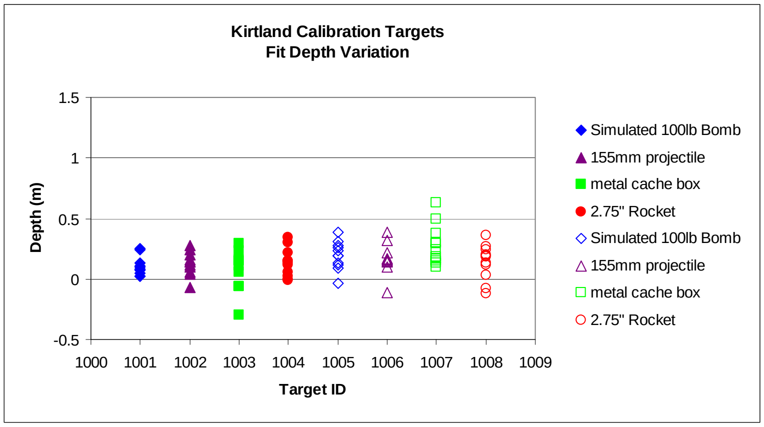


Figure 8-5. Helicopter magnetometer dipole-fit depth estimates for confirmation targets at the Kirtland site.

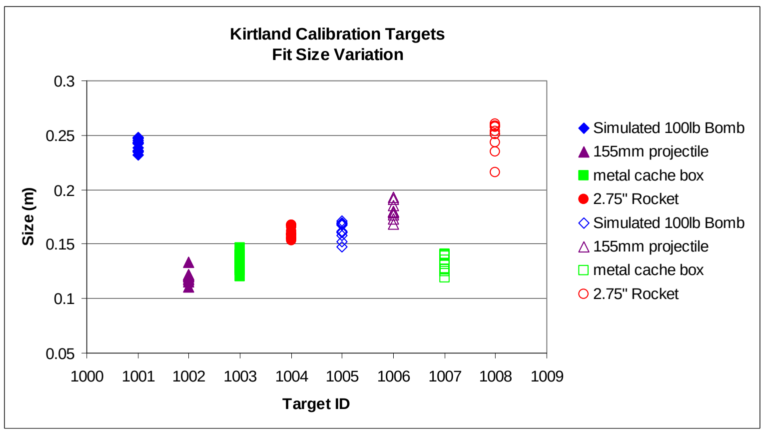


Figure 8-6. Helicopter magnetometer dipole-fit size estimates for confirmation targets at the Kirtland site.

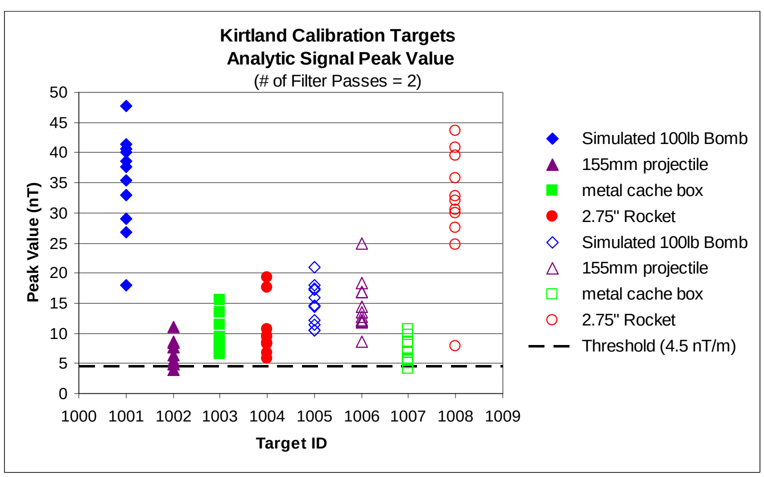


Figure 8-7. Helicopter magnetometer peak analytic signal response for the confirmation targets at the Kirtland site.

8.1.3 Ground Sensors

Like the effectiveness of helicopter magnetometers, the effectiveness of ground sensors will depend on several factors:

- Proper absolute and relative sensitivity of the magnetometer or EM sensing elements—absolute, in that the measurements are consistent with the governing physics, and relative, in day-to-day consistency.
- Accurate location of the individual sensor measurements.
- Appropriate coverage with no gaps.
- Meaningful interpretation of the data—target-picking thresholds and analysis using physics-based models should produce physically meaningful parameters.

The performance of the ground systems was verified using a line of confirmation targets. Projectiles ranging in size from 37 mm to 155 mm were buried at surveyed locations in a line that was driven over in the morning and evening of each day to verify sensitivity and location accuracy.

Figure 8-8 shows the day-to-day consistency of signal strength over the same 155-mm projectile for the VSEMS at Kirtland. The VSEMS contains both a magnetometer and EM sensor array, and the plot shows the raw data from both, as well as the fitted maximum signal strength for a magnetic dipole. Day-to-day results for this strong signature agree to within about 10%.

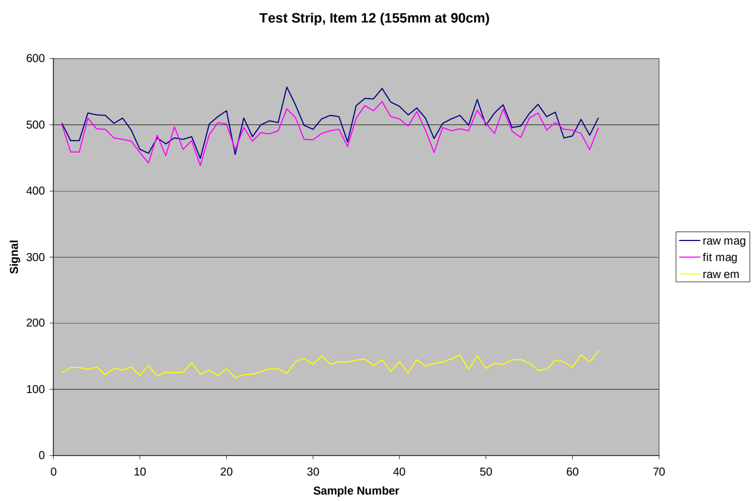


Figure 8-8. Test strip data from the Kirtland site. Plot shows raw EM value (yellow), raw magnetometer value (blue), and fitted magnetometer value (magenta) for 155-mm projectile at 90-cm depth using the VSEMS array.

Figures 8-9 and 8-10 show example results from the MTADS vehicle-towed EM array system used at the former Camp Beale site. The day-to-day variability in the signal strength and the location accuracy are plotted. The signal strength variability for most objects is less than 10% (one standard deviation), and the location accuracies are within about 5 mm.

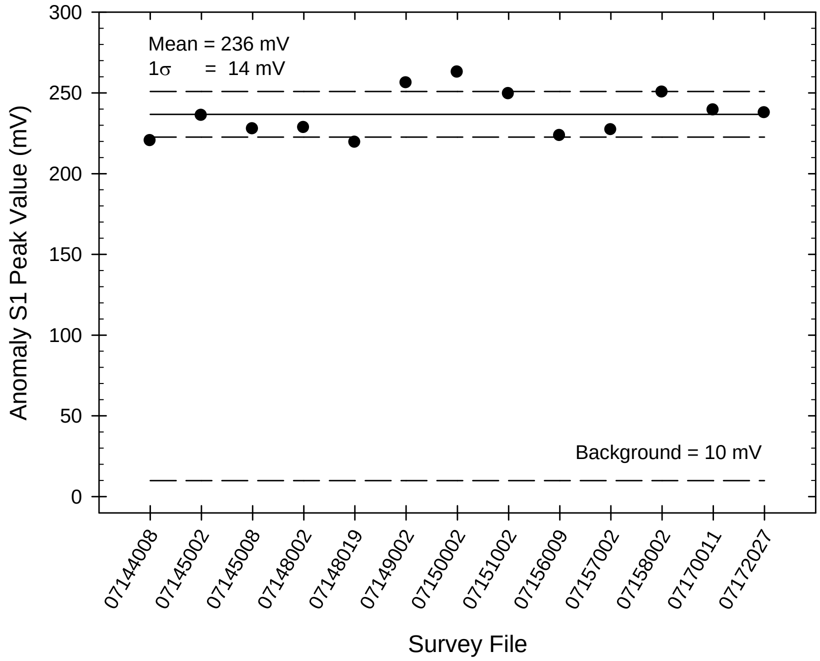


Figure 8-9. Variation of the EM61-MK2 array system (S1) for 81mm Mortar #2 at the former Camp Beale. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation, and the dashed lines represent a 1 standard deviation envelope. The lower dashed line represents the average background level for the calibration lane.

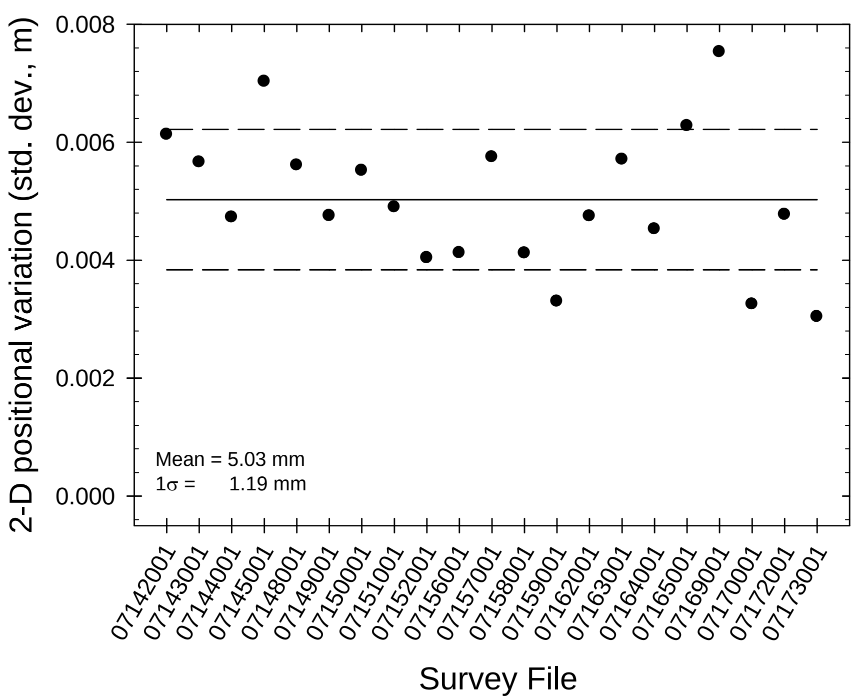


Figure 8-10. Two-dimensional position variation data runs for stationary data collected with the vehicular towed-array system at the Former Camp Beale WAA site. The horizontal axis is survey file name. The solid line represents the aggregate average positional variation, and the dashed lines represent a 1 standard deviation envelope.

8.2 Demonstrated Capabilities

The demonstrated capabilities of WAA include characterizing known targets, finding unknown targets, eliminating suspected targets that do not in fact exist, and characterizing lands that do not exhibit concentrated munitions use so decisions can be made about their future management. The pilot project examined the abilities of the suite of technologies to accomplish each of these objectives.

8.2.1 Characterizing Known Targets

In the case of target areas that are known to exist, the primary objectives of WAA are to verify the target's existence, bound the area of concentrated munitions use, and secondarily to provide information about the types of munitions used on the site and their density.

The ability to verify and characterize known bombing targets has been well demonstrated. All target areas from the historical records at all sites were seen in at least one of the orthophotography and LiDAR images, and all were seen in one or both of the geophysics data sets. The high-airborne data provide evidence of their existence. Observing craters in the LiDAR data can help verify the use of HE munitions, but the absence of craters by itself does not mean that no HE munitions were used, because post-use clearance activities or weathering on some sites may have obscured features of interest. For example, in the aiming circle at Pueblo, abundant craters are seen surrounding the circle, but none are seen in the circle itself. Geophysics confirms numerous magnetic anomalies within the circle that are validated to be munitions related, suggesting the surface had been repaired.

The ability to verify and characterize artillery and mortar targets was demonstrated at Camp Beale. In general, fewer persistent ground scars can be observed in the orthophotography and LiDAR images, but structures (bunkers), firing points, and craters were readily observed. Geophysics was useful for associating concentrations of metallic anomalies with high-airborne features, particularly where the features were ambiguous. Validation through field reconnaissance was needed to address many ambiguous features and in most cases resulted in straightforward resolution of the ambiguity.

The geophysics data led to a quantitative estimate of the number of anomalies and the area they covered. In several cases, target areas were larger and more complex than indicated in the historical record. Here, the WAA data provide valuable information to allow for more accurate cost estimates. In addition, model fits of geophysics data can give estimates of size and depth distributions, which will also contribute to cleanup decisions and cost estimates.

How estimates of the number of anomalies are interpreted will depend on whether they are based on helicopter or ground data because of the difference in sensitivity between the two platforms. The ground system will detect more anomalies associated with small targets and clutter items, so estimates of the number of anomalies will be higher in the absolute sense. For the sites in the pilot program, a scaling factor of about 3.5 between the density of helicopter anomalies and ground anomalies became evident, but the exact value will likely be site dependent. The size of the area was more consistent between the two analysis products.

8.2.2 Eliminating Suspected Targets

The example that illustrates the ability of WAA to eliminate a specific suspected target is seen in the suspected 75-mm range at Pueblo. In this case, there was a well defined hypothesis to be tested. The absence of features in the high air data and the geophysics analysis indicate with high certainty that 75-mm targets were not present in the suspected area. It is much more challenging to use WAA to eliminate all possible types of target areas, however. Transect designs are keyed to a specific target hypothesis, and helicopter sensitivity is limited for small items. The existence of features detected by the high air will depend on the type of target used, and the persistence of the features will be site specific.

8.2.3 Locating Suspected Targets

The Kirtland site afforded an opportunity to search for a target previously not located. A simulated oil refinery target was mentioned in the historical record, but its location only generally described. During the course of the pilot project, the location and extent of this target were well established in multiple data sets. Although it was helpful to have historical information that suggested its presence, for this target it was probably unnecessary. The Simulated Oil Refinery Target is a bombing target that fit within the general parameters of the known targets on the site, for which the data-quality objectives were established. Grossly different targets, such as a 20-mm range, would not necessarily be found.

8.2.4 Identifying Lands with No Concentrated Munitions Use

The historical usage of the Kirtland and Victorville sites was limited to aerial bombing. Pueblo was used for aerial bombing and possibly aerial gunnery. For these three sites, the bombing targets were evident in most of or all the data sets when they were physically present. The lack of indication of additional target areas in any data set, therefore, provides strong evidence that no additional target areas are present. Of course, this does not exclude the possible presence of isolated munitions away from target areas, such as might result from pilot error, weather or mechanical problems. In addition, many features that could not be unambiguously identified in the data required validation by ground reconnaissance. A modest effort with a field team of two was sufficient to determine these additional areas were not munitions related.

For more complex sites, the conclusions about lands with no indications of munitions use are less certain. The historical usage of the former Camp Beale was much more varied, in terms of both military and nonmilitary activities. In addition, data collection and analysis were complicated by challenging terrain, vegetation, and geology on parts of the site. Together, these factors resulted in greater uncertainty regarding conclusions about the remainder of the site, where there were no indications of concentrated munitions use. Nevertheless, there are areas with no known historical munitions use, no military features identified in the high-airborne images, and no concentrations of anomalies detected in the geophysics where there is confidence that no target area exists. For other areas within safety fans or immediately adjacent to historical ranges, no evidence of munitions use is seen in the orthophotography and LiDAR images or in the geophysics data, but because of the complex historical use and the generally higher background anomaly density, the conclusion that no areas of concentrated munitions are present comes with only moderate certainty.

8.3 Site-Specific Factors Affecting Performance

Although all the WAA Pilot sites were located in the West, they provided a range of conditions that illustrate the capabilities and limitations of the various sensors. Observations from the pilot program that will be applicable to sites planning WAA are discussed here. Additional factors that affect capabilities need to be explored, particularly for eastern sites that might include secondary growth forest, marshes, flood plains, urban encroachment, and other conditions not encountered in the sites visited.

8.3.1 Geology

8.3.1.1 High-Airborne Technologies

Geology does not affect the orthophotography and LiDAR sensors.

8.3.1.2 Helicopter Magnetometer and Ground Sensors

Complex geology can be limiting for any of the geophysics sensors, and commonly encountered magnetic soils are more problematic for magnetometers than EM. As with any geophysics investigation, the geologic background should be characterized as part of the sensor selection process. However, the difficulties encountered at the Victorville site illustrate this is not foolproof. Easily accessible areas in the center of the site were visited before deployment and found to be acceptable for magnetometers, but areas on the edges of the site near the base of the hills were challenging and needed to be reinvestigated with EM. An example is shown in Figure 8-11.

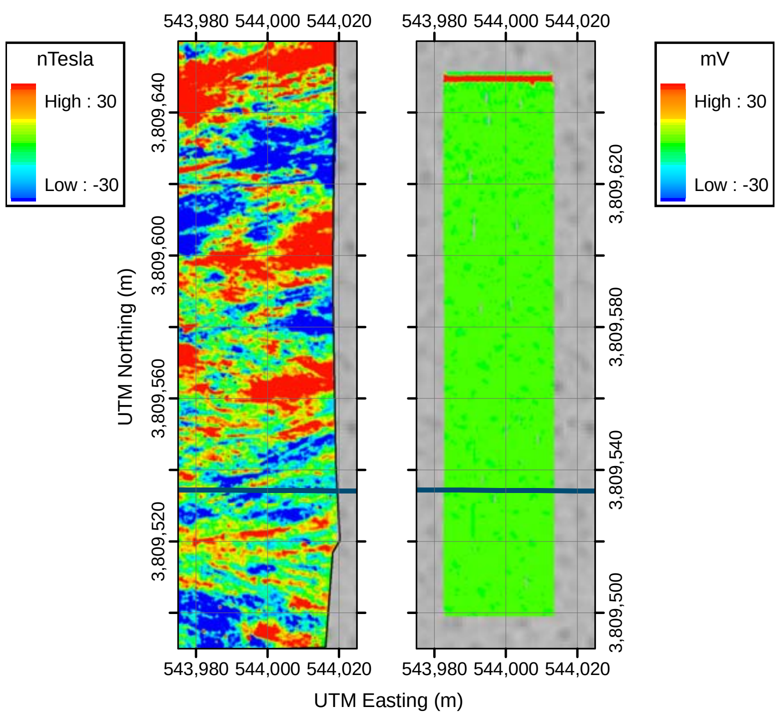


Figure 8-11. Magnetometer (left) and EM data (right) on a geologically active part of the Victorville site.

At the Camp Beale site, several long transects sampling the magnetic background across the site were collected before deployment. They confirmed magnetic background would be problematic over much of the site. These transects were used to select areas of the site where the helicopter magnetometer could collect usable data. Ultimately, its utility was severely limited on this site, with substantially higher background even in areas where geology was moderate, as shown in Figure 8-12. For the ground transects, only EM data were acquired. High-quality, usable data were obtained throughout the site, but at somewhat reduced production rates.

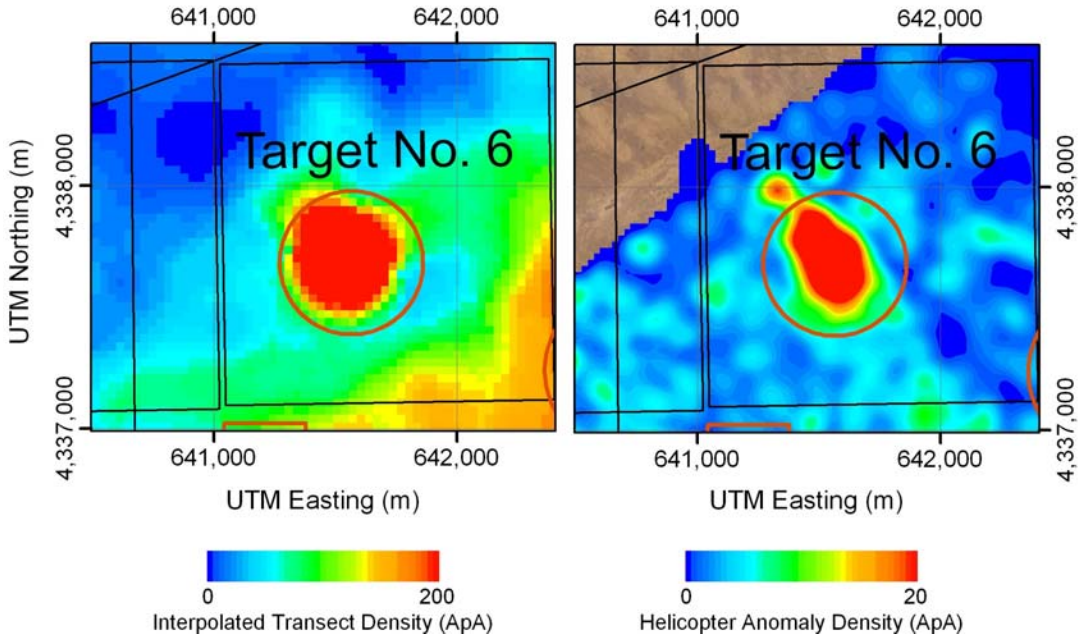


Figure 8-12. Density estimates from ground-transect EM data (left) and helicopter magnetometer data (right) for a bombing target area at the former Camp Beale. The background in the helicopter magnetometer data is higher.

In many sites, difficult geology can be mitigated by use of EM sensors instead of magnetometers. For ground transects, EM systems are available, but at slower data-collection speeds. For the low-airborne platform, no validated EM alternative currently exists.

8.3.2 Persistence of Munitions-Related Features

8.3.2.1 High Airborne Technologies

Orthophotography and LiDAR rely on detecting subtle features, such as aiming circles, craters, and berms, that persist long after a target area was used. In arid sites with minimal erosion, these features remain evident 60 years after the sites were last used, as seen at Kirtland, Pueblo, and Victorville.

Orthophotography and LiDAR data were also obtained at the Borrego Military Wash site in southern California. This project was not completed for reasons unrelated to the technologies used, and the work done is summarized in Appendix B. At this site, soft sand and washes that alter the ground surface reduced the effectiveness of orthophotography and LiDAR.

Figure 8-13 shows LiDAR data from the 6,000-acre pilot project site at Borrego. The image is dominated by a broad wash, which flows when the surrounding mountains drain off a heavy rain. The lower detail image in Figure 8-13 is from this wash area. The upper detail image shows an area of higher ground that is composed of primarily soft, shifting sand. This is a poor medium for preserving features, but a few remain. The linear feature visible in the rectangle corresponds to a mock railroad, which is raised and still contains debris from the structure. The adjacent circle contains a target area demarcated by a ring of rocks (not seen in the image). The concentric circles to the right were identified in the data by a change in vegetation. No other features remain. In short, the high-airborne technologies were found to be relatively ineffective at Borrego.

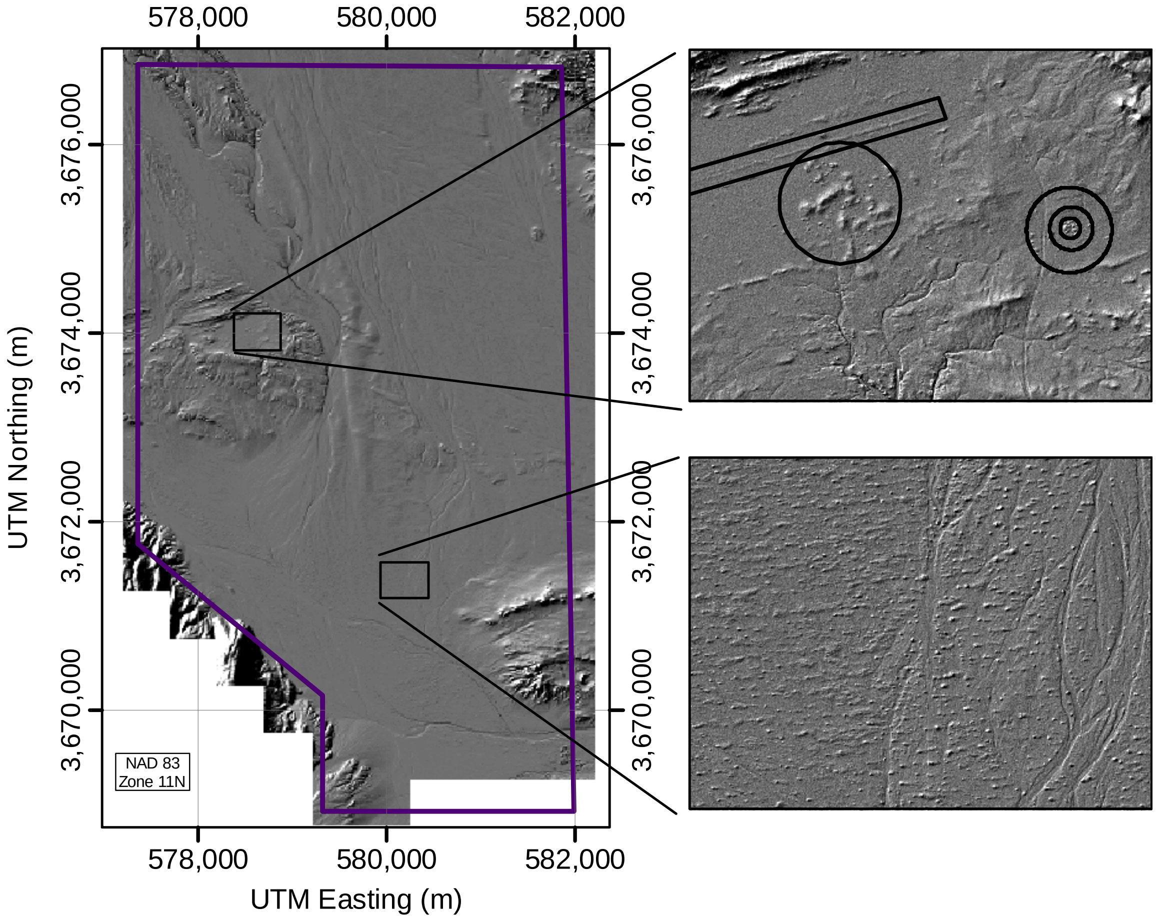


Figure 8-13. LiDAR image of approximately 6,000 acres of the Borrego Military Wash site. Detail boxes show an area where features are observed in the data (top) and the characteristics of the wash (bottom).

8.3.3 Terrain

All the demonstrated technologies work best on flat terrain. More challenging terrain will be limiting for all, although less so for the high airborne technologies. However, steep rocky terrain may mask features or be mistaken for features, as was seen in the Camp Beale demonstration.

8.3.3.1 Helicopter Magnetometer

For the helicopter magnetometer, which must fly at an altitude of about 2 to 3 m for acceptable detection of most munitions, gradual slopes up to about 12 to 15 degrees can be surveyed. But the platform cannot follow sudden, steep altitude changes such as washes and gullies, resulting in gaps in coverage at acceptable altitudes. The limitations were seen at Beale, Pueblo, and Victorville.

8.3.3.2 Ground Sensors

For ground transects, platforms exist that can survey in almost any terrain. The vehicle-towed arrays used in this program offer the advantage of great efficiency traveling at a rate of 10-20 lane-km per day. For a 2-m wide sensor, this translates to an areal coverage of 10–20 acres per day. If transects cover 2% of the site, that equates to investigating on the order of 1,000 acres per day. The towed arrays are restricted to terrain that is drivable. Extremely rough terrain can be expected to damage the vehicle beyond normal wear and tear. Additionally, system noise can be introduced by rough terrain and can degrade data quality. Wheeled carts and hand-carried systems can supplement coverage in steep terrain, but at much reduced productivity.

8.3.4 Vegetation

For all the systems tested, performance and productivity will be best for sites with minimal vegetation.

8.3.4.1 High Airborne Technologies

For the high-airborne orthophotography, thick vegetation will block the view of the ground surface. At Beale, orthophotography had very limited value in the areas with tree cover, but several large structures were observed. For LiDAR, some points will pass though gaps in vegetative cover and make it to the ground surface. The density of points forming the ground image will be reduced, but large features can still be observed. At Beale, large features such as bunkers were readily observed through moderate tree cover, but small craters adjacent to these structures were not (see Figure 8-14). More problematic than trees was dense, low brush that in some areas completely obscured the ground surface. Figure 8-15 is an example of such an area.

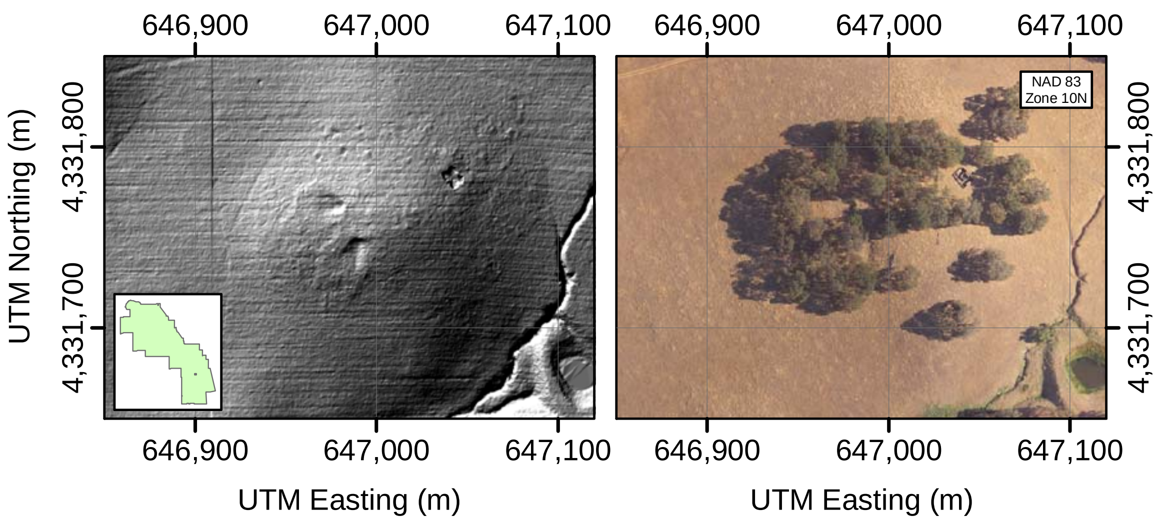


Figure 8-14. LiDAR image of vegetated areas at the former Camp Beale. The panel on the left shows features observed through tree cover. The panel on the right shows the corresponding orthophoto. The depressions readily observed in the LiDAR were identified as firing fans for close-combat exercises. A bunker is seen in the tree line in both images.

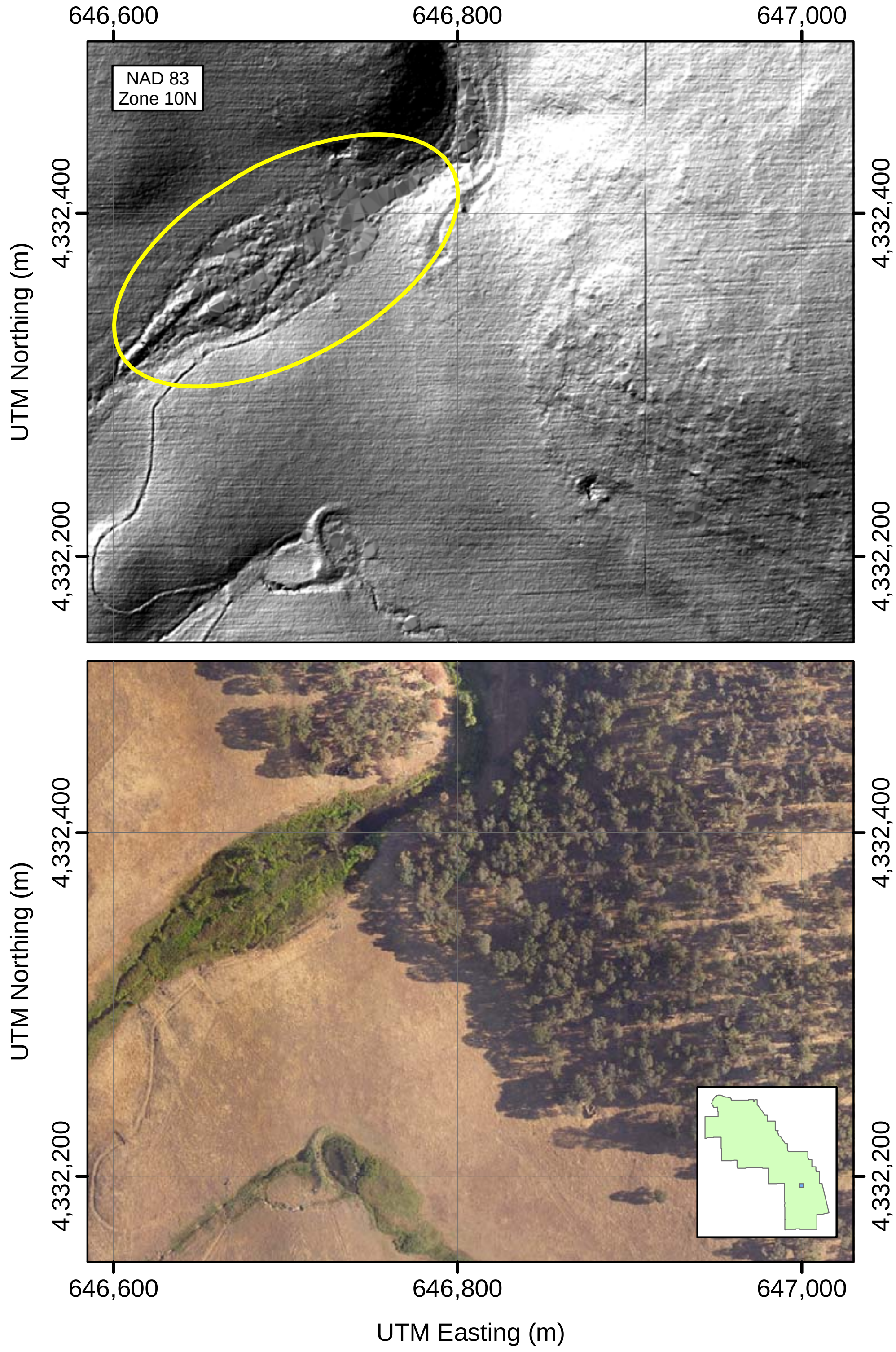


Figure 8-15. The upper panel show LiDAR data in an area with clear ground view, through trees and through dense ground cover. The lower panel shows the corresponding orthophoto. In the treed area, the LiDAR resolution is somewhat reduced, but a useful image is preserved. In the dense ground cover, the too few LiDAR points penetrate to the ground to produce a useful image, as seen in the yellow ellipse.

Multiple passes may be combined to produce higher effective point densities, and much of the success in detecting features through the vegetation at Camp Beale was attributed to the very high data density collected at this site. Ultimately, the effectiveness depends on size of features, thickness of vegetation, and point density. The presence vegetation that obscures the ground surface, such as ground leaf cover and thick grasses, have presented problems.

8.3.4.2 Helicopter Magnetometer

Helicopter magnetometer effectiveness is governed by the achievable flight altitude. Some vegetation will not allow safe, low-level flight. The helicopter can readily fly around isolated trees with minimal impact on WAA objectives. Dense shrubs will force the helicopter to fly higher and lose effectiveness. The impact will depend on the size of munitions sought. Forests currently are not approachable for airborne geophysics.

8.3.4.3 Ground Sensors

For ground transects, platforms exist that can survey in almost any vegetation. The vehicle-towed arrays used in this program offer the advantage of great efficiency, covering 10–20 acres per day. For a 2-m wide sensor, this translates to an areal coverage of 10–20 acres per day. If transects cover 2% of the site, that equates to investigating on the order of 1,000 acres per day. The towed arrays are restricted to terrain that is drivable. They can easily survey around isolated trees and small groves, with little impact on WAA objectives, but dense forests are generally impassable. Wheeled carts and hand-carried systems can supplement coverage in wooded areas, but at much reduced productivity. Most digital mapping systems rely on GPS, which has reduced effectiveness in wooded areas and eventually becomes unusable under heavy canopy. Walking systems can go anywhere that the sensor can pass.

8.3.5 Human Use Not Related to Munitions

For all the systems demonstrated, it was observed that nonmilitary human activity presents additional challenges. The impacts included basic physical access to the site, EM interference with system operation, and clutter that confused the interpretation of findings. Further, human activities such as farming and construction can obscure ground features so they are no longer detectable by orthophotography or LiDAR.

8.3.5.1 High Airborne Technologies

At all the sites, the high-altitude sensors detected man-made items that were not munitions related, but needed to be investigated. This was particularly true at the Beale site, where homesteads, mining scars, and agricultural artifacts were numerous. Although a large number of these features were identified in the LiDAR data and had to be investigated in a field reconnaissance visit, they were for the most part readily and unambiguously identified as either munitions related or not.

EM interference can cause problems for the high airborne technologies. For example, at the former Camp Beale, the Pavepaws radar at Beale Air Force Base, adjacent to the study area, corrupted the GPS data stream. Filtering the resulting interference from the data was nontrivial.

8.3.5.2 Helicopter Magnetometer and Ground Sensors

Both the helicopter magnetometer and the ground system are affected by limitations on physical access to the site. Both systems require rights of entry from landowners and may require permits. Several of the WAA sites were popular for recreational use, which affected use of the helicopter and ground systems. In particular, hunting seasons imposed access limitations on access to most of the WAA sites. Power lines can limit access for the low-flying helicopter and cause interference for ground systems. Fences must be avoided by the helicopter magnetometer, and they decrease productivity for ground transects.

The high-clutter environment at the Delacarlia Impact Area in Spring Valley (discussed in Appendix D) illustrated a significant limitation of using transects to detect a target area. The target area was hypothesized to be about 90 m in diameter within a 100-acre area. Transects were designed to detect this target in a background comparable to what was observed at other sites. The site, however, is a wooded parcel in an urban area. It contains fences, parts of fences, utility lines, and abundant other metallic non-munitions objects, all of which produce a much higher background than previously encountered. Figure 8-16 shows the detected anomalies along transect lines. No target is evident above background, but the presence of a low-density target area on a high-clutter background cannot be eliminated.

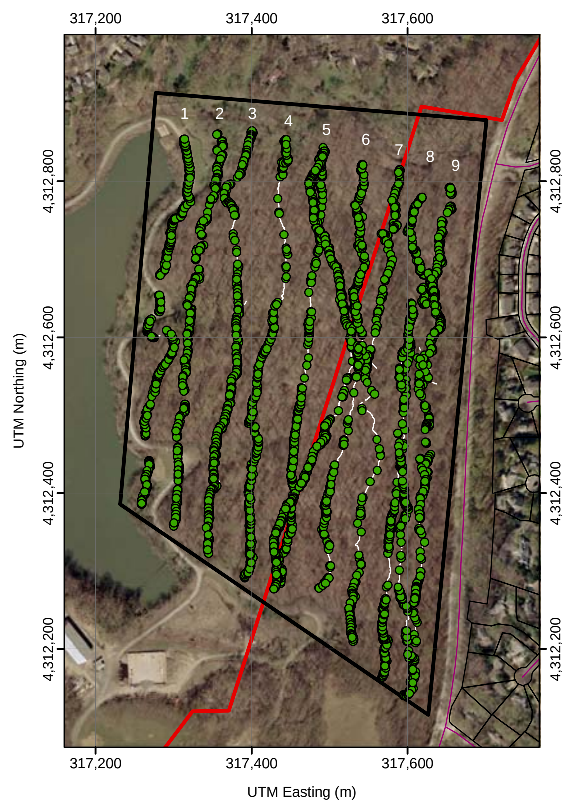


Figure 8-16. Delacarlia Impact Area in Spring Valley: Transect search for a target area in a high-clutter environment.

At the Camp Beale site, both the helicopter and ground geophysics encountered more false features that are concentrations of anomalies. Overlapping fallen fences and overhead power lines produced suspicious concentrations that later required investigation. For the most part, these were readily identified, and data-collection crews could be trained to note such features during deployment to avoid their selection in the first place.

8.3.6 Munitions Types

The WAA technologies have been well demonstrated for bombs and bombing targets.

8.3.6.1 High-Airborne Technologies

Remnants of bomb targets, which were commonly constructed as earthen berms, were readily detected at sites where these features persisted. Remnants of other munitions uses, such as artillery and mortar ranges, were not as easy to identify unambiguously from high-airborne data. The targets for these munitions types are typically structures or vehicles that are often moved around and do not leave ground scars. Remnants of firing points were detected, however.

8.3.6.2 Helicopter Magnetometer

From other studies, the probability of detection of the helicopter magnetometer on smaller targets has been established. (Ref. 36) Based on these data, the helicopter magnetometer should be sufficient to find concentrated munitions, where detection of every item is not required, for items the size or 81-mm mortars or greater. For some of the areas where historical records indicated smaller munitions used at Beale, the helicopter did not identify areas of concentrated anomalies at locations flagged in the ground-transect surveys. This is seen in Figure 8-17 in the south part of the site, where the reported munitions use included mortar and artillery.

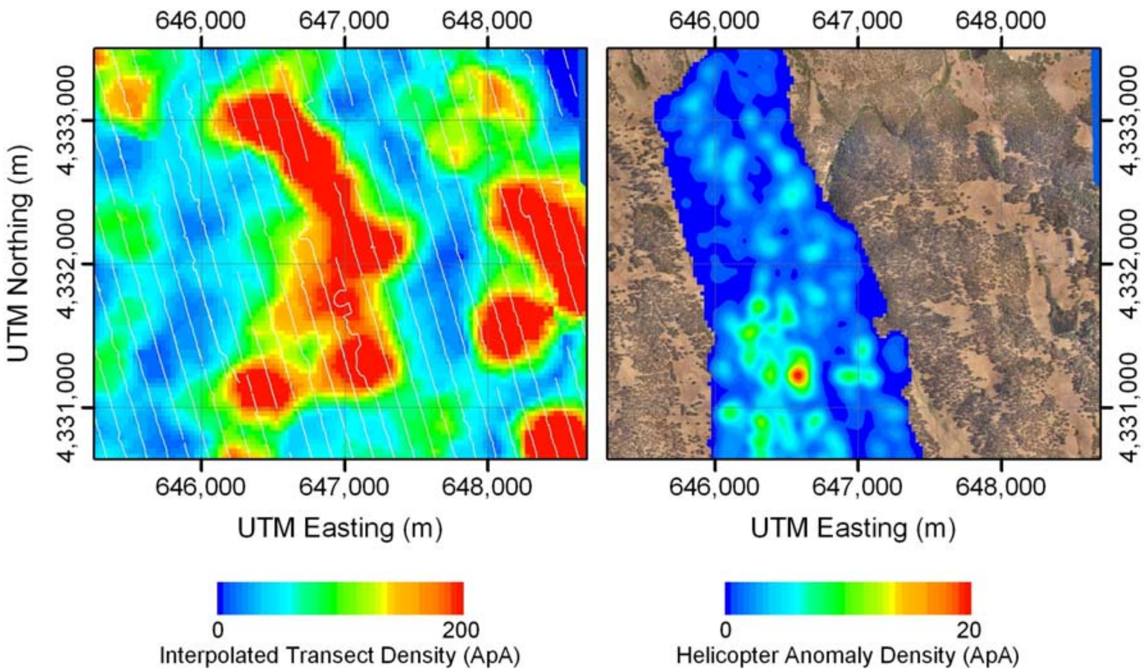


Figure 8-17. Comparison of ground-transect (left) and helicopter (right) anomaly density estimates in the southern section of the former Camp Beale, where smaller munitions types are suspected. Helicopter data could be obtained only in the valley between the tree-covered slopes. The ground transects detected extensive high-anomaly density in the north-central part of this figure. This area was surveyed by the helicopter system, but no comparable high-density area is identified. The anomaly density scales differ to account for the differences in the sensitivity of the two systems.

For targets employing HE bombs, the helicopter magnetometer results require careful scrutiny. Figure 8-18 shows the two HE targets surveyed at Kirtland and Victorville. Concentrations of anomalies are clearly visible in the Kirtland target circle, but none are seen at Victorville, despite confirmation from numerous craters that HE bombs were used there. The types of bombs used were different: at Kirtland, standard HE general-purpose bombs were used, but at Victorville, demolition bombs with a higher ratio of explosive and designed to produce smaller fragments were used. This effect may be more important on HE targets where smaller munitions were used.

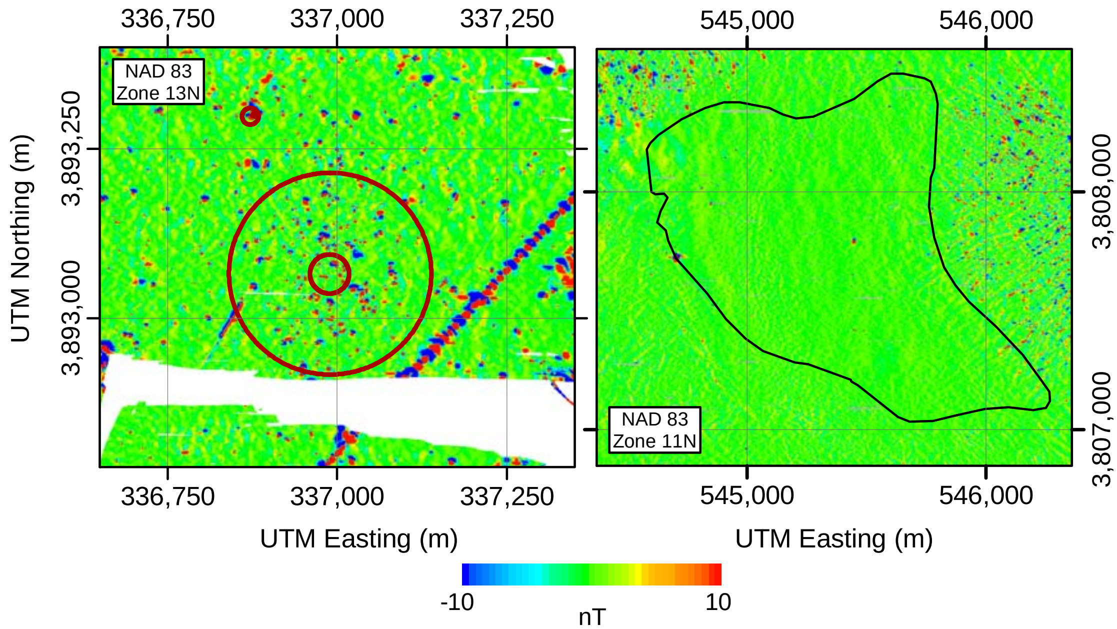


Figure 8-18. Helicopter magnetometer data from HE targets at Kirtland (left) and Victorville (right). Note the concentration of anomalies evident in the Kirtland data; no anomalies are seen in the Victorville data.

8.3.6.3 Ground Sensors

For the ground systems, sensitivity is well documented, and the smallest items of interest are detectable. (Ref. 37). To reliably detect an area of concentrated munitions use, VSP requires target characteristics as input parameters. To accurately estimate these input parameters, one must have knowledge or make reasonable assumptions about the target area, such as:

- Locations of firing points and the lines of fire.
- Type of training or testing.
- Direct versus indirect fire for artillery and mortar.
- HE versus practice.
- Low altitude versus high altitude for bombing.
- Locations of individual targets within a range.
- Quantity of munitions fired.
- Local clutter environment.

These values determine the confidence in the interpretation of the transect data. They are often unknown and must be hypothesized.

8.3.7 Underwater Sites

Currently, no analog of the high-airborne technologies has been validated for underwater sites; potentially applicable technologies such as high-resolution optical or sonar imaging techniques for munitions detection are the subject of research. The helicopter magnetometer may be applicable to very shallow water areas at some sites. The distance between the array and the targets will increase by the water depth, so only large munitions are expected to be detected at any reasonable rate.

Underwater sites can be characterized with transects like the approach used with ground-based arrays. In this program, similar methodology was applied and got similarly good results. As discussed in Appendix C, underwater WAA has been demonstrated on a large site in Lake Erie. An underwater array was used to perform a transect survey covering about 1% of 50,000 acres and the target area was successfully delineated and the number of anomalies estimated. Results were confirmed with validation using divers to retrieve selected targets.

Unlike all the technologies demonstrated for land, underwater surveying is not currently a commercial commodity product. The system deployed in the pilot program is a one-of-a-kind R&D system. Like the helicopter system, this array "flies" 1 to 2 meters off the bottom, so it has limited capabilities for detecting small munitions types (81 mm and smaller). The platform is limited to about 25 ft water depths and relatively calm seas. Other contractors have employed underwater geophysics survey systems in a small number of demonstrations and operational surveys, but high-quality data acquisition in the underwater environment is not currently routine.

8.3.8 Multiple challenges

WAA technologies have been well-demonstrated on a variety of sites. Other sites will provide combinations of many of the challenges discussed above, including vegetation up to secondary growth forests, terrain, geology, and development. Still more challenging sites may include mountains, mature trees, geology, and recreational uses. Further investigation of performance under these conditions will be needed.

8.4 Demonstrated Capabilities and Limitations by Sensor Type

This section focuses on the capabilities and limitations of the various sensors that a project team might consider for WAA. Table 8-3 (at the end of this section) discusses and summarizes conditions that should be considered when deciding what sensors are appropriate for a certain site.

8.4.1 LiDAR

LiDAR was very successful in detecting craters, aiming circles, and other large features constructed from earthen berms as was common in the WWII era. It is relatively inexpensive and can be used to screen an entire site quickly. Figure 8-19 illustrates the LiDAR image of a ship-shaped target formed from an earthen berm at Kirtland. The remnants of the feature are about 2 m wide and raised about 10 cm above the surrounding area. As shown in the photograph, it cannot be discerned at ground level, and it was difficult to locate even during validation when the ground team knew what to look for and where.

Overall, LiDAR revealed more of the large features identified in the program than the orthophotographs. For craters, a higher LiDAR point density was required, but all large features were evident at even the lowest point density.

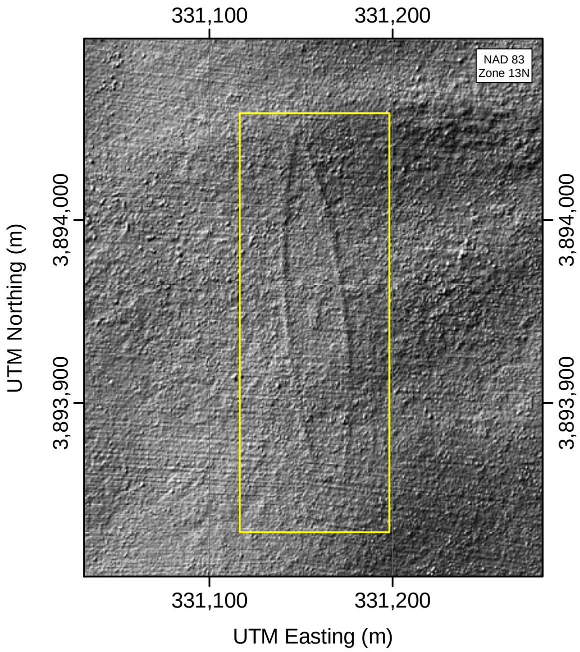


Figure 8-19. LiDAR image showing ship target at Kirtland and reconnaissance photo of the area. The field crew is standing on the location of the berm forming the ship.

LiDAR relies on the detection of telltale features left from past activities. Munitions-related features may be obscured over time by weathering, water, secondary growth, and the like. Post-use clearance activity can obliterate features either intentionally, as appears to be the case with the absence of craters in the aiming circle at Pueblo, or unintentionally, by farming or urban development. Features may be obscured by the presence of tall grasses, ground leaf cover, or other interference between the aircraft platform and the ground surface. Some target areas appear to have no visible ground scars, such as the two magnetic anomaly concentrations near Kirtland N3 Impact Area for which no surface features are evident. It is possible wooden targets were used or the areas were used for storage, but nevertheless, no high-airborne features identify it. Finally, at each site, some features that were seen in the data could not be positively identified from the data and required validation.

By itself, LiDAR may not be sufficient to declare an area free of concentrated munitions, but it provides a valuable layer of evidence that can both support and add to initial knowledge about a site.

8.4.2 Orthophotography

Orthophotography detected craters, aiming circles, and other large munitions-related features. It is relatively inexpensive, can be collected in conjunction with the LiDAR, and can be used to screen an entire site quickly. The analyst did not always cue on the feature of interest itself. Instead, concentrations of vegetation in craters, for example, were sometimes the detected features rather than the craters themselves. Overall, the orthophotographs showed fewer of the large features identified in the program than did LiDAR. However, a few features unique to the orthophoto were not seen in LiDAR at all. There is value in both data sets, which are acquired simultaneously on a single flight.

Orthophotography relies on the detection of subtle features that persist long after a site has been used for munitions. These features may weather over time, be intentionally removed in post-military clearance activities, or be destroyed by later nonmilitary uses, such as plowing or urban development. Features may be obscured by the presence of tall grasses, ground leaf cover, or other interference between the aircraft platform and the ground surface.

As with LiDAR, some features cannot be positively identified from the data and will require validation. Munitions-related features may be obscured over time by weathering, water, secondary growth, and the like. By itself, orthophotography may not be sufficient to declare an area free of concentrated munitions, but it provides a valuable layer of evidence that can support and add to initial knowledge about a site.

8.4.3 Helicopter Magnetometer

The helicopter magnetometer is effective for detecting concentrations of munitions and estimating the size of the target area requiring remediation. It can be used to screen accessible areas of entire sites relatively quickly. The helicopter magnetometer could also be used to survey only a fraction of a site using transects, although that was not done in this program.

Density estimates require careful consideration and documentation of what is estimated. Depending on the munitions type, it is unlikely the helicopter magnetometer detects all munitions of interest that would be detected by a ground system for remediation. Some conversion factor will be needed to interpret and scale the density estimates from helicopter data. In this program, it was found that a relatively straightforward and stable conversion factor could be estimated. It is likely this scale factor will be site specific, as was seen at Victorville.

The helicopter magnetometer relies on the detection of ferrous munitions or related debris from low-altitude flight. The detection capability will be lower for smaller munitions types, and the sensor will be challenged by interference from either natural geologic clutter or abundant man-made ferrous clutter. Low-altitude flight may not be possible at sites with challenging terrain or vegetation.

For HE targets, where a primary indicator is the presence of fragments from munitions that exploded, helicopter systems may not be appropriate if the dud rate is low or few munitions were used. For example, for a target that was used for general-purpose bombs at Kirtland, a concentration of anomalies was evident. On the other hand, at Victorville, for a target that was used for demolition bombs, which have a higher explosive ratio and form much smaller fragments, no concentration was evident.

8.4.4 Ground Sensors

Ground transects were effective for detecting concentrations of munitions and fragments or scrap of any size. Transect data were successfully used to estimate the size and density of the target area requiring remediation. The sensors deployed on ground-based platforms were capable of detecting all target types to common depths of interest. Anomaly-density estimates from ground-based sensors should be most accurate for typical cleanup requirements. In this program, transects were implemented using several different platforms and sensors. The strengths and weaknesses of each are discussed below. All the systems were based on the cesium-vapor magnetometer, the EM61 time-domain metal detector, or both. Other options, such as carts, man-portable magnetometers, and alternative magnetometer and EM sensors can also be used. Which sensor and platform combination is appropriate will depend on the site characteristics.

8.4.4.1 Magnetometer Vehicle-Towed Array

The magnetometer array is both sensitive and efficient. It can detect all targets of interest having ferrous content, which includes most munitions, and can cover about 20 acres per day areal coverage. If transects cover 2% of the site, that equates to investigating on the order of 1,000 acres per day. It is limited to areas where vehicle-towed arrays can operate, and it is affected by geology.

8.4.4.2 Magnetometer/EM Vehicle-Towed Array

The dual-mode magnetometer/EM array provides two independent data streams and detects all targets of interest. The magnetometer is more capable for large, deep items. The EM excels at detecting smaller, shallow items, and it will detect nonferrous metals. In areas with moderate geology, the dual-mode system may be used to eliminate some of the geologic response from the magnetometers, as was observed at Kirtland. For areas of severe geology, however, the magnetometer is unlikely to provide additional useful data. This system is limited to areas where vehicle-towed arrays can operate. Because the EM array must sample more slowly, the data-collection speed, at about 10 acres per day, is slower than the magnetometer-only platform.

8.4.4.3 EM Vehicle-Towed Array

An EM array was used at Camp Beale, where the geology was challenging enough to make the magnetometer ineffective. This system is sensitive, detects all targets of interest, and is less affected by magnetic geology than the magnetometer. The system, which is limited to conditions where vehicle-towed arrays can operate, has a slower data-collection rate (about 10 acres per day) than the magnetometer.

8.4.4.5 Man-Portable Geophysics

Like the arrays, the man-portable versions of geophysical sensors are sensitive and detect all targets of interest. The man-portable magnetometer is affected by the same geology challenges as the array, and the EM is similarly less affected by geology than the magnetometer. A man-portable platform is labor intensive and very slow (acres per day), but can survey anywhere a person can walk. At Pueblo, Victorville, and Beale, man-portable systems were successfully used to fill in areas where the arrays could not operate.

8.4.5 Statistical Transect Tool—VSP

VSP was useful for planning transects and for interpreting the data in a quantitative manner. The results can provide quantifiable determination and confidence that a postulated target area is or is not present. Analysis of the data can provide estimates of the number of anomalies that will ultimately require investigation and the size of area to be remediated.

The tool provides a transparent and real-time means of testing the effect of assumptions on the transect planning. This was illustrated in the planning for the Victorville site, where a project team met to consider various options for transect designs. Assumptions about size, density, and usage were varied, and the effects on the needed transects and costs were evaluated until the team arrived at a design that achieved the objectives and could be implemented with the available resources.

Successful application of VSP requires a good hypothesis describing the target area and the background. Historical information can provide some of these inputs. The ability to detect a target area is critically dependent on both. The size and density of a target can be hard to estimate in advance since the specific use of a target area is often not well documented. Although the background is readily measured from the collected transect data, a proper design relies on a reasonable estimate before data collection.

Transects may not provide a practical approach for detecting relatively small munitions-contaminated areas. Single burial pits on land or underwater disposal sites that result from a load dumped from a single barge will have very limited footprints. Planning transects to find such sites, particularly within vast areas to be searched, is likely to require coverage rates and resources well beyond what could be termed WAA.

Similarly, transects will not detect non-munitions features with small dimensions such as buildings, abandoned cars, watering tanks, and similar features encountered on the WAA sites. This is not an important limitation for the primary objectives of WAA—finding concentrated areas of munitions use—but a holistic picture of the site can be useful in providing a context for interpreting WAA results.

Table 8-3. Summary of factors affecting capabilities and limitations of WAA technologies.

Factor	LiDAR	Orthophotography	Helicopter Magnetometer	Ground Transects
Geology	Not affected.	Not affected.	Effectiveness will decrease in magnetic geology. Heavy geology will render useless.	Magnetometer-based systems will be affected most by geology. For moderate geology, combined magnetometer/EM systems may have an advantage. For severe geology, EM systems will be less affected than magnetometer.
Persistence of Munitions-Related Features	Weathering, intentional clearance, or subsequent land use can obscure features of interest.	Weathering, intentional clearance, or subsequent land use can obscure features of interest.	Not affected.	Not affected.
Terrain	Minimal effects. Could mask or be mistaken for features.	Minimal effects.	Only applicable for relatively flat sites (slope less than 12–15 degrees).	In principle, transect data can be collected anywhere. Terrain will dictate the platform and the data-collection efficiency.

(continued)

Table 8-3 (continued).

Factor	LiDAR	Orthophotography	Helicopter Magnetometer	Ground Transects
Vegetation	Heavy vegetation will reduce the density of LiDAR points sampling the ground surface. Presence of heavy grasses, leaf cover on the forest floor, etc will obscure features.	Heavy vegetation will block the view of the ground surface.	Isolated trees can be avoided and will have little effect. Tall brush will force higher flight altitudes and reduce detection capability. Forested areas cannot be surveyed.	In principle, transect data can be collected anywhere. Vegetation will dictate the platform and navigation.
Human Use Not Related to Munitions	Increased detection of non-munitions features requiring investigation. Alterations of the surface may obscure features.	Increased detection of non-munitions features requiring investigation. Alterations of the surface may obscure features.	Physical access to the site can be problematic (right of entry, fences, power lines, recreational activity). High density of magnetic clutter can make it impossible to locate target areas. Areas of concentrated non-munitions (scattered remnants of fence pieces, homesteads) can be confused with munitions.	Physical access to the site can be problematic (right of entry, fences, power lines, recreational activity). High density of magnetic clutter can make it impossible to locate target areas. Areas of concentrated non-munitions (fences, homesteads) can be confused with munitions.
Munitions Type	Detects visible craters or berms (cross hairs, ship targets, earthen or pebble-covered berms, etc.). Detects structural remnants of firing points, small arms ranges, etc.	Detects visible craters or aiming points. Detects structural remnants of firing points, small arms ranges, etc.	Detects individual items 81 mm or larger. Smaller munitions and fragments detected with reduced probability.	Sensors can detect all items of interest. A reasonable estimate of target size and density is needed for meaningful transect design.

9.0 COSTS

Site conditions such as topography, vegetation, geologic background, temperature and altitude can influence the costs of the data collection required for a WAA. Because the pilot program only sampled a subset of the possible conditions at the demonstration sites, bounding the costs from the data generated during this program is not possible. In fact, many of the demonstrations involved multiple data collections designed to determine which data are most useful in a WAA. For these reasons, the costs of the pilot program demonstrations are not a good guide to the costs of a production survey.

In the following sections, the survey costs are estimated for deploying each of the technologies on generic sites ranging from 1,000 to 250,000 acres. It should be noted the total technology costs per acre decreases as the acreage increases for all of the data layers. Very large sites are not included in the estimated examples for the geophysical systems because costs would be excessive. For sites larger than 10,000 or 20,000 acres, a transect survey performed with a helicopter system, would be more cost effective. Then, if the results of the transect survey warrant, a 100% coverage survey could be conducted on smaller AOIs. At the other end of the scale, per acre costs for the smallest 1,000 acre site are disproportionately higher for all the technologies. WAA may not be deemed cost effective for single sites of this size, but multiple nearby sites could be bundled to single deployment to reduce costs.

These estimates are not bids from vendors, but the numbers should serve as a good guide to fiscal year 2008 costs. This chapter considers sites with moderate topography and vegetation with environmental conditions that enable normal survey operations. To calculate mobilization costs, a distance halfway across the continental United States is assumed (16 hours); coast-to-coast or longer mobilizations will increase this component of the costs. After presenting these nominal costs, the qualitative effect of more challenging conditions for each of the technology layers is discussed. A summary of the WAA technology costs per acre is provided in Table 9-5. This section closes with a cost assessment of a few example sites that will require a combination of technology layers.

Note that the costs discussed here are costs for data collection and analysis only. Searches of historical documents, preparation of an initial CSM, and modification of the model based on the survey results are not included. Because these costs depend on prior work done at an installation and the availability of on-site support, they will have to be estimated on an installation-by-installation basis.

9.1 High-Airborne Technologies

Table 9-1 gives estimated costs for the collection and analysis of high-airborne data on the generic sites. Costs are broken out by cost category and shown as cost per acre in the final row. The costs listed are for high-airborne data as used in this program (10-cm orthophotos and greater than 4 LiDAR points per square meter) and extensive data analysis and feature selection. Per acre costs can be reduced as much as a factor of 3 if these requirements are relaxed.

Table 9-1. Estimated costs for LiDAR and orthophotography data collection and analysis covering 100% of the site.

Cost Category	1,000-acre site	10,000-acre site	50,000-acre site	250,000-acre site
Planning, Preparation, and Management	$18,000	$25,000	$55,000	$155,000
Mobilization/Demobilization*	$15,000	$15,000	$15,000	$120,000*
Data Acquisition	$25,000	$72,000	$175,000	$750,000
Data Processing, Analysis, and GIS Products	$28,000	$98,000	$400,000	$950,000
Reporting and Documentation	$8,000	$10,000	$15,000	$30,000
Total Costs	**$94,000**	**$220,000**	**$660,000**	**$2,000,000**
Cost per Acre as Demonstrated	**$94.00**	**$22.00**	**$13.20**	**$8.00**
Cost per Acre for Minimal Data Product	**$60.00**	**$14.00**	**$8.00**	**$4.00**

* Mobilization/demobilization costs increase at this acreage due to the need for crew changes to support data collection

The costs of deploying high-airborne technologies are the least affected by site conditions of any of the three data layers considered in this report. Since the aircraft flies at an altitude of 300 m or higher, site topography does not hinder data collection. Very steep slopes, however, can mask portions of the site from interrogation by these techniques. Similarly, site vegetation does not affect aircraft operations but does limit penetration of the optical wavelengths used in these technologies. As the vegetation density increases, orthophotography is affected before LiDAR; even a light canopy seriously degrades the value of aerial photography. LiDAR, on the other hand, is able to achieve some penetration of light canopy. In this case, the point density is reduced, resulting in a corresponding decrease in the ability to detect small-scale features such as craters. Larger scale features such as trenches and aiming circles are detectable under a surprisingly dense canopy.

Several lessons were learned from the Camp Beale demonstration in the pilot program. The costs of a high-airborne technology data-collection with a helicopter platform are directly affected by site altitude and excessive temperatures. These two factors decrease the lift available from the aircraft and, in the worst cases, may limit data collection to the cooler parts of the day. These concerns are less applicable to a fixed wing aircraft. This drives up the data-acquisition cost, which is a significant component of the total cost in Table 9-1. Complex sites such as Camp Beale also require extra effort in data analysis and validation, both of which will increase the technology cost.

9.2 Helicopter Magnetometer

Table 9-2 lists estimated costs for the collection and analysis of helicopter magnetometer data. These costs assume 100% coverage of the site with a helicopter-borne magnetometer array. As with the high-airborne technologies, 16 hours each way are assumed to estimate the mobilization expenses for the aircraft.

Table 9-2. Estimated costs for helicopter magnetometer data collection and analysis covering 100% of the site.

Cost Category	1,000-acre site	5,000-acre site	10,000-acre site
Planning, Preparation, and Project Management	$34,000	$50,000	$60,000
Mobilization/Demobilization	$40,000	$40,000	$40,000
Data Acquisition	$82,000	$400,000	$800,000
Data Analysis and GIS Products	$12,000	$40,000	$70,000
Reporting and Documentation	$12,000	$20,000	$30,000
Total Costs	**$180,000**	**$550,000**	**$1,000,000**
Cost per Acre	**$180**	**$110**	**$100**

The very large sites of Table 9-1 are not included here because the costs would be quite high, and 100% surveys would be conducted on only a portion of such sites as discussed above.

Several aspects of a particular site can increase the costs listed in Table 9-2. Sites with high magnetic background due to geology may not be amenable to this technique at all. This was true for large portions of the Camp Beale site studied in the pilot program. Even in the absence of geologic background, site topography limits the applicability of helicopter-borne systems. Slopes greater than about 12% limit the ability of the helicopter to maintain a low enough altitude for reasonable detection probability. The same is true for dense trees and tall brush. Because the helicopter must be flown lower than 3 meters above the ground for acceptable detection of most munitions, any vegetation of that height or higher limits helicopter operation.

As with the high-airborne technologies, excessive altitude and temperature affect the lift of the aircraft and may limit operations to the cooler parts of the day. Finally, helicopter surveys involve relatively slow flight so high winds can prohibit surveying. These factors drive up costs by extending the use of the most expensive part of the survey, the helicopter.

9.3 Ground Transects

Table 9-3 lists the estimated costs for a ground-transect survey of the standard sites. For the purposes of this estimate, a magnetometer survey covering 2% of the site is assumed. The planning and data analysis tasks include resources to support the development of transects using VSP and analysis of the detected anomalies to identify areas where the anomaly density is above the critical density.

Table 9-3. Estimated costs for ground-transect data collection and analysis covering 2% of the site.

Cost Category	1,000-acre site	2,000-acre site	10,000-acre site	50,000-acre site
Planning, Preparation, and Management	$20,000	$25,000	$30,000	$30,000
Mobilization/Demobilization	$30,000	$30,000	$55,000	$55,000
Data Acquisition and Anomaly Selection	$16,000	$30,000	$120,000	$560,000
Data Analysis and GIS Products	$10,000	$18,000	$30,000	$40,000
Reporting and Documentation	$5,000	$7,000	$15,000	$15,000
Total Costs	**$81,000**	**$110,000**	**$250,000**	**$700,000**
Cost per Acre	**$81.00**	**$55.00**	**$25.00**	**$14.00**

Two main factors can affect the cost of a ground-transect survey. If the site exhibits a large magnetic background due to geology, an EM instrument will be required for the survey. EM instruments in use today have lower data rates than magnetometers and therefore require slower survey speeds to maintain data density. This will increase the data-collection costs. The costs above also assume a vehicular system will be able to perform the entire survey. If the site includes areas with obstacles such as heavy vegetation, steep slopes, and soft sand that make a vehicular survey impossible, portions may have to be surveyed with a man-portable system. The reduced coverage of a man-portable system (5 to 10 line-km per day) compared with a vehicular system (15 to 40 line-km per day) again results in increased costs for data collection.

A number of secondary issues can also result in a small increase in the costs listed above. Some sites require escort for the survey team by a UXO technician for safety or a biologist to minimize ecological impact; these cost are not included above. Other sites are so remote that logistics items such as power, equipment storage, and site security, have to be provided separately. These costs are also not included above.

9.4 Underwater Transects

Table 9-4 lists the estimated costs for a transect survey conducted with an underwater magnetometer array. As was the case for the ground survey, these numbers assume transect planning using VSP to cover 2% of the site and analysis of the detected anomalies using the analysis modules of VSP. Mobilization costs are appropriate for a 2,500-mile transport.

Only costs for transect surveys are listed in this section because the one underwater demonstration in this program employed transects and the technology used is likely not economically efficient for a large-area total coverage survey. While appropriate to locate firing fans and other underwater targets, it may not be efficient to search for underwater dumps or other small areas of underwater munitions contamination using these surveys.

Table 9-4. Estimated costs for underwater transect data collection and analysis covering 2% of the site.

Cost Category	1,000-acre site	2,000-acre site	10,000-acre site	50,000-acre site
Planning, Preparation, and Project Management	$10,000	$15,000	$30,000	$35,000
Mobilization/Demobilization	$35,000	$35,000	$35,000	$35,000
Data Acquisition and Anomaly Selection	$25,000	$40,000	$130,000	$500,000
Data Processing, Analysis and GIS Products	$7,000	$13,000	$45,000	$60,000
Reporting and Documentation	$10,000	$15,000	$20,000	$20,000
Total Costs	**$87,000**	**$118,000**	**$260,000**	**$650,000**
Cost per Acre	**$87.00**	**$59.00**	**$26.00**	**$13.00**

The primary factors that can increase the costs estimated above are water conditions and arrangement of the survey area. The Marine Towed Array used in the Toussaint River demonstration is a developmental system designed to operate in relatively benign sea conditions. Large waves and currents dramatically slow survey progress, which correspondingly increases data-collection costs and may require the use of commercial tow vessels, further increasing costs. Because it is not optimized for transport around a site, long daily transits to and from the survey area limit survey time and thus daily productivity.

Table 9-5. Summary of estimated costs per acre for WAA technology layers.

Technology Layer	1,000-acre site	10,000-acre site	50,000-acre site	250,000-acre site
High Airborne Technologies (100% coverage)				
Cost per Acre as Demonstrated	$94.00	$22.00	$13.20	$8.00
Cost per Acre for Minimal Data Product	$60.00	$14.00	$8.00	$4.00
Helicopter Magnetometer (100% coverage)				
Cost per Acre as Demonstrated	$180.00	$100.00	N/A	N/A
Ground Transects (2% coverage)				
Cost per Acre as Demonstrated	$81.00	$25.00	$14.00	N/A
Underwater Transects (2% coverage)				
Cost per Acre as Demonstrated	$87.00	$26.00	$13.00	N/A

9.5 Example Sites

This section describes a number of typical WAA scenarios and uses the estimated costs above to derive a gross budget estimate for the assessment. As before, note that these are not vendor bids, but are intended as a rough guide to 2008 costs. Note that the costs discussed here are costs for survey data collection and analysis only. Searches of historical documents, preparation of an initial CSM, and modification of the model based on the survey results are not included. A summary of the example WAA scenarios and the associated costs are presented in Table 9-6.

9.5.1 10,000 acres, complete high airborne and partial helicopter

The first site examined is an open grassland site in the northern prairie. The historical documents suggest it contained a number of WWII-era practice bomb targets and it has been used more recently by the National Guard for artillery training. Based on this, it was expected to find features related to the bombing targets that can be detected by the high-airborne technologies such as aiming circles, observation points with access roads, light towers, etc. There may also be evidence of the artillery practice such as targets made of junk cars or old equipment. To directly detect the surface and subsurface munitions and fragments associated with the targets, the high-airborne data are used to mark 5,000 acres for survey with the helicopter system.

Using the costs from Tables 9-1 and 9-2, a cost for this WAA is estimated to be approximately $850,000. Output will be LiDAR and orthophotography image data sets and GIS layers of detected features, magnetic anomaly map, anomaly density map, and a point file of detected magnetic anomalies.

9.5.2 10,000 acres; complete high airborne and partial ground transects

This site is a broad valley in the western United States that was used for WWII bombing practice and troop training. Historical evidence suggests there may be significant contamination of smaller mortars on portions of the site. At this site, the high-airborne techniques will be used to detect features associated with the bombing targets, and ground systems will be used to ensure good detection probability is achieved for smaller mortar target areas on the 2,000 acres that might be contaminated. Transect spacing appropriate to smaller mortar targets will be used and cover 2% of the site with transects.

Using costs from Tables 9-1 and 9-3, it is estimated this survey will cost approximately $330,000. Output will be LiDAR and orthophotography image data sets and GIS layers of detected features, list of anomalies detected along the transects and transect course over ground, and an estimate anomaly density map.

9.5.3 50,000 acres, complete high airborne, mix of helicopter and transects

This site is a large mixed-use range in California. Parts of the site have significant geologic interference, so the helicopter system is not appropriate. Other parts have significant slopes and vegetation, so some mix of vehicular and man-portable transects will be required. The site team decides to survey the entire site with the high-airborne techniques and use the resulting data to make decisions on deployment of the other technologies. After seeing the high-airborne data, the team determines 7,000 acres of the site need further investigation, 5,000 acres are amenable to helicopter magnetometer surveys, and the rest will require ground EM coverage. Five percent of the ground surveys will require a man-portable system.

Using the costs from Tables 9-1, 9-2, and 9-3 and increasing the ground data-collection cost by a factor of 2 to reflect the use of an EM system, it is estimated this survey would cost approximately $1.5 million. As in the cases above, products would be GIS layers including results and analysis from all three technology layers employed.

9.5.4 250,000 acres, complete high airborne, mix of helicopter and transects

This site is a large mixed-use range in the plains states. The site team decides to survey the entire site with the high-airborne techniques and use the resulting data to make decisions on deployment of the other technologies. After seeing the high-airborne data, the team determines 15,000 acres of the site need further investigation—5,000 acres with the helicopter magnetometer system and 10,000 with ground magnetometer transects.

Using the costs from Tables 9-1, 9-2, and 9-3, it is estimated this survey would cost approximately $2.8 million. As in the cases above, products would be GIS layers including results and analysis from all three technology layers employed.

Table 9-6. Summary of estimated costs for the example WAA scenarios.

High Airborne 100% Coverage (acres)	Helicopter Magnetometer Coverage (acres)	Ground Transect Coverage (acres)	Estimated Cost
10,000 acres	5,000 acres	N/A	$850,000
10,000 acres	N/A	2,000 acres	$330,000
50,000 acres	5,000 acres	2,000 acres	$1,500,000
250,000 acres	5,000 acres	10,000 acres	$2,800,000

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GLOSSARY

Anomaly. A geophysical signal above geological background from a detected subsurface object. (Ref. 38).

Archives search report (ASR). An investigation to report past ordnance and explosives (OE) activities conducted on an installation. (Ref. 39).

Caliber. The diameter of a projectile or the diameter of the bore of a gun or launching tube. Caliber is usually expressed in millimeters or inches. In some instances (primarily with naval ordnance), caliber is also used as a measure of the length of a weapon's barrel. For example, the term "5 inch 38 caliber" describes ordnance used in a 5-inch gun with a barrel length that is 38 times the diameter of the bore. (Ref. 40).

Casing. The fabricated outer part of ordnance designed to hold an explosive charge and the mechanism required to detonate this charge. (Ref. 41).

Clearance. The removal of military munitions from the surface or subsurface at active and inactive ranges. (Ref. 41).

Clutter. Munitions-related scrap and other common metallic field debris that can mask signals of interest or generate signals not of interest, thereby affecting sensor performance.

Concentrated munitions use. A primary objective of the WAA approach is to identify areas of "concentration munitions use." In this pilot program, the phrase means an increased density of anomalous features identified through the use of WAA detection technologies that locate areas intentionally used for military activities such as impact areas, target areas, other "concentrations" such as open burn/open detonation areas. Anomalous features include ground surface features (i.e. target rings or craters) detected by LiDAR/orthophotography, or geophysical anomaly concentrations detected by geophysical systems. The concentration of anomalous features that can be detected will depend on site conditions, types of munitions, frequency of historical target usage, and the site background anomaly density.

Detonation. A violent chemical reaction within a chemical compound or mechanical mixture evolving heat and pressure. The result of the chemical reaction is exertion of extremely high pressure on the surrounding medium. The rate of a detonation is supersonic, above 3,300 ft per second. (Ref. 40).

Discarded Military Munitions (DMM). Military munitions that have been abandoned without proper disposal or removed from storage in a military magazine or other storage area for the purpose of disposal. The term does not include unexploded ordnance, military munitions that are being held for future use or planned disposal, or military munitions that have been properly disposed of consistent with applicable environmental laws and regulations 10 U.S.C. 2710 (e)(2). (Ref. 41).

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

Excavation of anomalies. The excavation and identification of a subsurface anomaly. (Ref. 41).

Explosive. A substance or mixture of substances, which is capable, by chemical reaction, of producing gas at such a temperature, pressure and rate as to be capable of causing damage to the surroundings. (Ref. 40).

Explosive filler. The energetic compound or mixture inside a munitions item. (Ref. 40).

Explosives safety. The implementation of appropriate training, policies, and procedures to minimize the unacceptable effects of an ammunition or explosives mishap.

Formerly Used Defense Site (FUDS). Real property that was under the jurisdiction of the Secretary and owned by, leased by, or otherwise possessed by the United States (including governmental entities that are the legal predecessors of Department of Defense [DoD] or the Components) and those real properties where accountability rested with DoD but where the activities at the property were conducted by contractors (i.e., government-owned, contractor operated [GOCO] properties) that were transferred from DoD control prior to 17 October 1986. (Ref. 44).

Fuze. 1. A device with explosive components designed to initiate a train of fire or detonation in ordnance. 2. A non-explosive device designed to initiate an explosion in ordnance. (Ref. 41).

Handheld. Instruments operated using the hand to collect either mag and flag or digital geophysical mapping data.

Hand carried. Another way of referring to handheld platforms.

Inert. Ordnance, or components thereof, that contain no explosives, pyrotechnic, or chemical agents. (Ref. 43).

Magnetometer. An instrument for measuring the intensity of magnetic fields. (Ref. 40).

Man-portable. Any geophysical system that can be deployed manually, either by carrying, pushing or towing.

Military munition. All ammunition products and components produced for or used by the armed forces for national defense and security, including ammunition products or components under the control of the DoD, the Coast Guard, the Department of Energy, and the National Guard. The term includes confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof. The term does not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components, other than non-nuclear components of nuclear devices that are managed under the nuclear weapons program of the Department of Energy after all required sanitization operations under the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) have been completed (10 U.S.C. 101 (e)(4) . (Ref. 41).

Munition constituents. Any materials originating from unexploded ordnance, discarded military munitions, or other military munitions, including explosive and nonexplosive materials, and emission, degradation, or breakdown elements of such ordnance or munitions. (10 U.S.C. 2710 (e)(4)). (Ref. 41).

Munitions and Explosives of Concern (MEC). This term, which distinguishes specific categories of military munitions that may pose unique explosives safety risks, means: (1) Unexploded ordnance (UXO); (2) Discarded military munitions (DMM); or (3) Munitions Constituents (e.g. TNT, RDX) present in high enough concentrations to pose an explosive hazard. Formerly known as Ordnance and Explosives (OE).[5] This document concerns the first two but not munitions constituents.

Munitions response. Response actions, including investigation, removal and remedial actions to address the explosives safety, human health, or environmental risks presented by unexploded ordnance (UXO), discarded military munitions (DMM), or munitions constituents. (Ref. 41).

Munitions Response Area. Any area on a defense site that is known or suspected to contain UXO, DMM, or MC. Examples include former ranges and munitions burial areas. A munitions response area is comprised of one or more munitions response sites. (Ref. 41).

Munitions Response Site (MRS). A discrete location within a munitions response area that is known to require a munitions response. (Ref. 41).

Noise. Noise is commonly divided into sensor noise and environmental noise. Sensor noise is the fluctuation in sensor output in the absence of an external signal and is generally dominated by noise in the sensor electronics. Environmental noise captures other external sources that also compete with the signal of interest. These sources can include electromagnetic interference, geological noise, or other types of clutter. In the case of munitions detection, environmental noise is generally the dominant contributor to the overall noise of the system. (Ref. 42).

Ordnance. Weapons of all kinds including bombs, artillery projectiles, rockets and other munitions; military chemicals, bulk explosives, chemical warfare agents, pyrotechnics, explosive waste, boosters, and fuzes. (Ref. 43).

Preliminary assessment and site inspection. A preliminary assessment/site inspection is a preliminary evaluation of the existence of a release or the potential for a release. The preliminary assessment is a limited-scope investigation based on existing information. The site inspection is a limited-scope field investigation. The decision that no further action is needed or that further investigation is needed is based on information gathered from one or both types of investigation. The results of the preliminary assessment/site inspection are used by DoD to determine if an area should be designated as a "site" under the Installation Restoration Program. EPA uses the information generated by a preliminary assessment/site inspection to rank sites against Hazard Ranking System criteria and decide if the site should be proposed for listing on the NPL. (Ref. 40).

Probability of Detection (Pd). A statistically meaningful parameter that describes the probability of detecting an item of interest. Pd is estimated as the number of emplaced munitions detected divided by the number emplaced. A true probability is calculated on a statistically significant population of items that all have the same chance of being detected and captures the random processes that affect detectability.

Production Ground Survey. Detailed geophysical characterization and mapping to detect and locate individual military munitions.

Projectile. An object projected by an applied force and continuing in motion by its own inertia, as mortar, small arms, and artillery projectiles. Also applied to rockets and to guided missiles. (Ref. 40).

Range. Means designated land and water areas set aside, managed, and used to research, develop, test and evaluate military munitions and explosives, other ordnance, or weapon systems, or to train military personnel in their use and handling. Ranges include firing lines and positions, maneuver areas, firing lanes, test pads, detonation pads, impact areas, and buffer zones with restricted access and exclusionary areas. (40 CFR 266.601) A recent statutory change added Airspace areas designated for military use in accordance with regulations and procedures prescribed by the Administrator of the Federal Aviation Administration. (10 U.S.C. 101 (e)(3)) . (Ref. 40).

Remedial investigation and feasibility study (RI/FS). The process used under the remedial program to investigate a site, determine if action is needed, and select a remedy that (1) protects human health and the environment; (2) complies with the applicable or relevant and appropriate requirements; and (3) provides for a cost-effective, permanent remedy that treats the principal threat at the site to the maximum extent practicable. The RI serves as the mechanism for collecting data to determine if there is a potential risk to human health and the environment from releases or potential releases at the site. The FS is the mechanism for developing, screening, and evaluating alternative remedial actions against nine criteria outlined in the NCP that guide the remedy selection process. (Ref. 40).

Target. Target is typically used to denote two different concepts: (1) the individual munitions item that one is attempting to detect and (2) the aim point of a weapons system at which large concentrations of munitions are typically found (i.e., an aiming circle for aerial bombing). In this document, "target" refers to definition 1.

Transferred ranges. Ranges that have been transferred from DoD control to other Federal agencies, State or local agencies, or private entities (e.g., formerly used defense sites, or FUDS). A military range that has been released from military control. (Ref. 38).

Transferring ranges. Ranges in the process of being transferred from DoD control (e.g., sites that are at facilities closing under the Base Realignment and Closure Act, or BRAC). A military range that is proposed to be leased, transferred, or returned from the DoD to another entity, including Federal entities. (Ref. 38).

Unexploded Ordnance (UXO). Military munitions that (1) have been primed, fused, armed, or otherwise prepared for action; (2) have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installations, personnel, or material; and (3) remain unexploded whether by malfunction, design, or any other cause (10 U.S.C. 101 [e][5]). (Ref. 41).

Wide Area Assessment (WAA). Rapid assessment of large tracts of potentially contaminated land to identify those areas with concentrated military munitions that require detailed characterization.

ACRONYMS

AOI	area of interest
CSM	conceptual site model
DoD	Department of Defense
EM	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GIS	geographic information system
GPS	Global Positioning System
HE	high explosive
LiDAR	light detection and ranging
MRS	munitions response site
PBR	Precision Bombing Range
RI/FS	Remedial Investigation/Feasibility Study
SI	site inspection
UXO	unexploded ordnance
VSEMS	Vehicular-towed simultaneous magnetometer/EM system
VSP	Visual Sample Plan
WAA	wide area assessment

APPENDIX A—HYPERSPECTRAL IMAGING AND SYNTHETIC APERTURE RADAR

1.0 INTRODUCTION

Two additional high-airborne sensors were demonstrated at the Pueblo Precision Bombing Range (PBR) #2 wide area assessment (WAA) site. Hyperspectral imaging (HSI) and synthetic aperture radar (SAR) use very different portions of the electromagnetic spectrum to interrogate the earth's surface. It has been proposed that each might detect munitions or munitions debris alone and that the combination might provide a false-alarm-reduction technique. In particular, SAR often suffers a large number of false alarms due to vegetation, and HSI is able to identify vegetation. Thus, the HSI results could be used to remove false alarms arising from vegetation from the SAR data.

1.1 Potential Sensor Advantages

Both SAR and HSI are amenable to data collection from fixed-wing aircraft at normal flight speed and altitude. Combined with the reasonably wide swath that can be collected on a single pass, this gives the potential for interrogation of thousands of acres per day.

In addition, ultrahigh-frequency (UHF) SAR has the potential to penetrate a certain amount of foliage or even shallowly into the earth under the right circumstances (very dry soil with little magnetic loss). Thus, the possibility exists for detecting munitions debris that is hidden from optical sensors by foliage or a shallow layer of soil. Significant stand-off is possible using focused SAR, which may ease data collection.

HSI has the potential to identify the chemical composition of items in its images through their unique reflectance spectra. Water and chlorophyll have particularly recognizable spectral signatures, and so green plants tend to stand out distinctively after appropriate data processing. Iron and iron compounds can also be identified, providing the opportunity for specifically detecting metallic debris in an image.

1.2 Potential Sensor Limitations

In actual deployment, some of the apparent advantages of SAR and HSI are difficult to realize, and other disadvantages appear. In the case of SAR, the targets of interest have scattering patterns at UHF frequencies that tend to concentrate reflected energy into a few preferred directions. Because of this, multiple passes are required over each imaged area to ensure detection of all objects of interest. In the WAA SAR data collection at the Pueblo site, eight passes in different directions over a given area were required for best detection performance. These multiple passes proportionally reduce the area that can be covered in a given time.

SAR is only able to detect fairly large metallic debris or unexploded ordnance (UXO) (e.g., plates at least 6 to 12 inches on a side) that are on or very near the surface, thus limiting the sites for which it is appropriate. As mentioned above, SAR readily detects vertical vegetation (trees and bushes), which results in a large number of false alarms on a site with significant vegetation. Finally, formation of SAR images requires intensive post-processing, and automated tools for target detection are not robust.

HSI also requires significant post-processing of the raw data to produce useful outputs. In addition, the large number of spectral bands recorded results in extremely large data sets, and this can limit the spatial resolution that is practical to pixel sizes on the order of 1 m. Because of this, the area within a pixel often contains multiple material types (e.g., munitions debris plus rocks and bushes), which reduces the effective signal-to-interference ratio of the desired signature and complicates discrimination. HSI is also sensitive to the illumination and weather, although those effects can be ameliorated in post-processing.

2.0 TECHNOLOGY DESCRIPTION

2.1 Synthetic Aperture Radar

Radars operate by transmitting pulses of radio-frequency energy into the environment and receiving returns reflected by objects in the beam path. The time it takes a pulse to reach the target and return is proportional to the distance to the target (just as is the case for LiDAR as discussed in Chapter 3), and the direction to the target is given by the radar-beam pointing direction. Range resolution (the ability to separate two closely spaced objects in range) is proportional to the bandwidth of the radar. Cross-range resolution (the ability to separate two closely spaced objects in azimuth) is directly proportional to the range and inversely proportional to the length of the antenna. To improve cross-range resolution, the SAR concept was developed in the 1950s [1]. In this concept, an effective antenna much longer than the physical radar antenna is synthesized by appropriately combining pulses collected along the radar track. Figure A-1 shows a cartoon of SAR processing, where the synthesized antenna is indicated by the series of shaded antennas in the figure. In what is known as focused SAR, the cross-range resolution can be made constant as a function of range simply by synthesizing a longer antenna as range increases. This is the process used in the WAA collection, where the figure shows the effective width of the synthesized beam to be much narrower than that of the radar footprint.

For the Pueblo site data collection, Sky Research employed an update of an ultra-wideband UHF radar originally developed by SRI for the Defense Advanced Research Projects Agency. This system, denoted the SkySAR, transmitted over the frequency band from 230 to 440 MHz and produced images with nominal 0.7 m resolutions in both range and cross range (or cross track, as the radar was side-looking). Pixel spacing for the images was 0.5 m, so the resulting images were about 30% oversampled in each dimension [2].

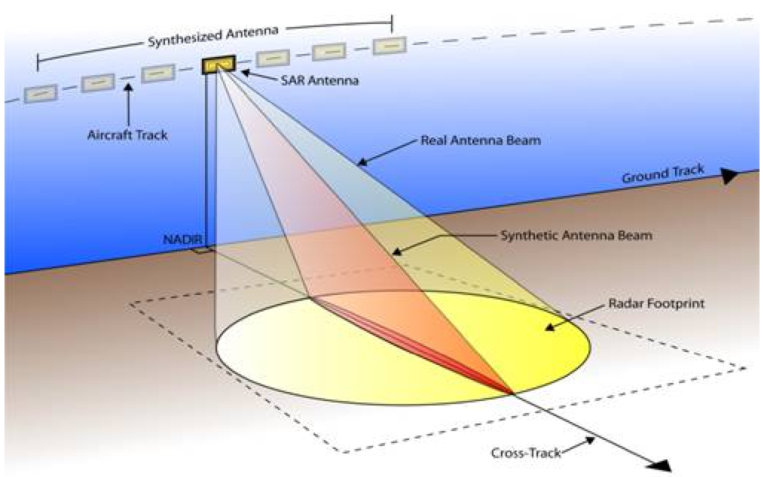


Figure A-1. Cartoon of SAR processing to generate a long synthetic antenna and hence a very narrow cross-track synthetic beam.

Figure A-2 shows an image from the Pueblo PBR #2 data collection that is the result of combining eight SAR images, each collected along cardinal and intercardinal direction flight lines. Note that SAR images bear very little resemblance to optical images. For the wavelengths employed by this radar (0.68–1.3 m), most objects that are imaged look smooth, and scattering is specular (mirror-like), rather than the diffuse scatter that provides optical images their shape and texture information. The measure of the effective scattering size of a radar target is its radar cross section (RCS), which is typically measured in square meters. In the image, pixels with a larger RCS will be brighter than ones with a smaller RCS. For any pixel in the image, the total RCS is the combination of scattering from the soil surface, which is typically fairly small, and scattering from discrete objects such as rocks, plants, man-made artifacts, and targets of interest, which can be much larger. The labeled items in Figure A-2 correspond to the emplaced UXO surrogates. Note that while many of the intact UXO placed in the test area show up very brightly (e.g., U1, U3, U9, U13), some are relatively dim (e.g., U11 and U6), and there are many non-UXO objects in the scene (unlabeled) that are very bright; these are presumably plants.

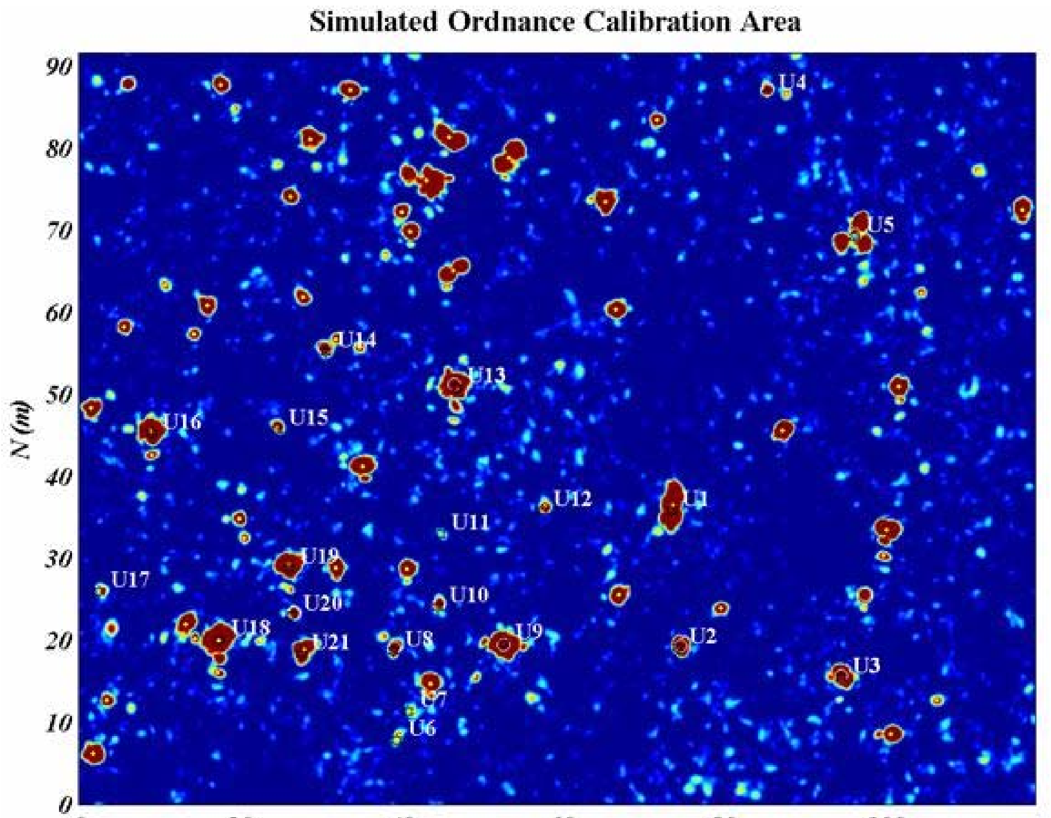


Figure A-2. Combined 8-look SAR image of the simulated ordnance calibration area at Pueblo PBR #2. Note that some of the bright items in the image are simulated UXO (those marked with U and a number), but many more are plants [2].

2.1.1 SAR Detection Limitations

SAR's potential role in the WAA process is to detect intact or partially intact UXO or munitions fragments. UHF frequencies were chosen for this application because they provide the potential for some amount of foliage or ground penetration to allow detection of objects beneath ground cover (grass or light brush) or perhaps even slightly subsurface, areas that are blocked to optical wavelengths. However, the long UHF wavelengths that make foliage penetration possible also limit the targets that can be detected. Normal surface backscatter at the frequencies and grazing angles employed leads to a background RCS in a pixel of 0.05 m^2 to 0.005 m^2, with rougher terrain having the higher background. To provide sufficient contrast for detection, we would like for a target to be at least two to four times as large as the surrounding background. For the middle frequency of this radar, Figure A-3 plots the peak RCS for a square fragment and a 155 mm diameter cylinder as a function of length. Taking 0.2 m^2 (four times the 0.05 m^2) as a pessimistic required RCS for detection and 0.01 m^2 (twice the 0.005 m^2) as an optimistic number, the figure shows that the radar is unlikely to detect plates or 155 mm diameter cylinders smaller than 15 cm in length in benign clutter. In severe clutter, it would be difficult to distinguish plates smaller than 35 cm on a side or cylinders shorter than 60 cm.

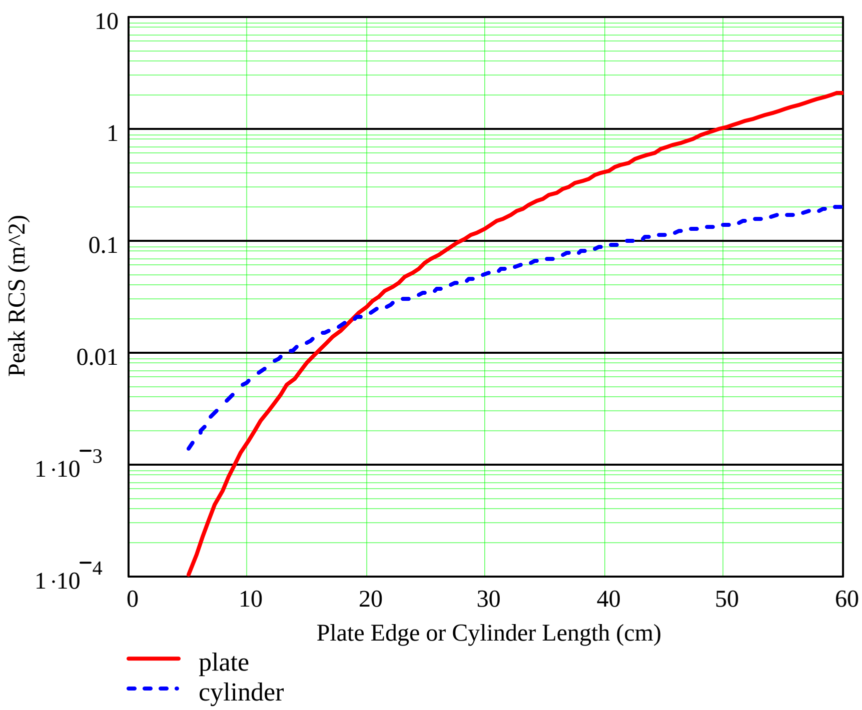


Figure A-3. Peak RCS of a square flat plate with the given plate edge length or a 155 mm diameter cylinder with the same length for the SkySAR center frequency.

In addition, radar scattering is directional. The peak RCS only occurs when the radar views the object from a specular direction. To ensure that a strong return (termed a specular flash) was obtained on the targets of interest, SAR data in the WAA demonstration were collected for a given area on eight flight legs along cardinal and intercardinal headings. Detection statistics are provided later for single-pass data and for the combination of the eight passes. Note that while the eight passes greatly increase the probability of seeing a high RCS aspect of a given target, they cut the production rate by at least a factor of 8 over what could be achieved if only single-pass imagery were required for good performance.

2.2 Hyperspectral Imaging

Unlike radar, which generates an active signal, HSI takes advantage of the ambient illumination that is reflected from objects. Different materials absorb or reflect different wavelengths to a different extent because of their detailed chemical composition. For that reason, the spectrum of reflected light can provide information regarding the object from which the light is reflected. Figure A-4 shows the reflectance spectrum for several different classes of materials as a function of wavelength over the bands covered by typical HSI systems such as the HyMap sensor used in the WAA data collection. These wavelengths cover the region from optical (wavelengths that can be seen by humans) through what are generally referred to as the near-infrared (NIR) and middle-infrared bands. Note in the figure the two regions around 1.4 and 1.9 µm for which H_2O absorption bands allow no reflected light to reach the sensor.

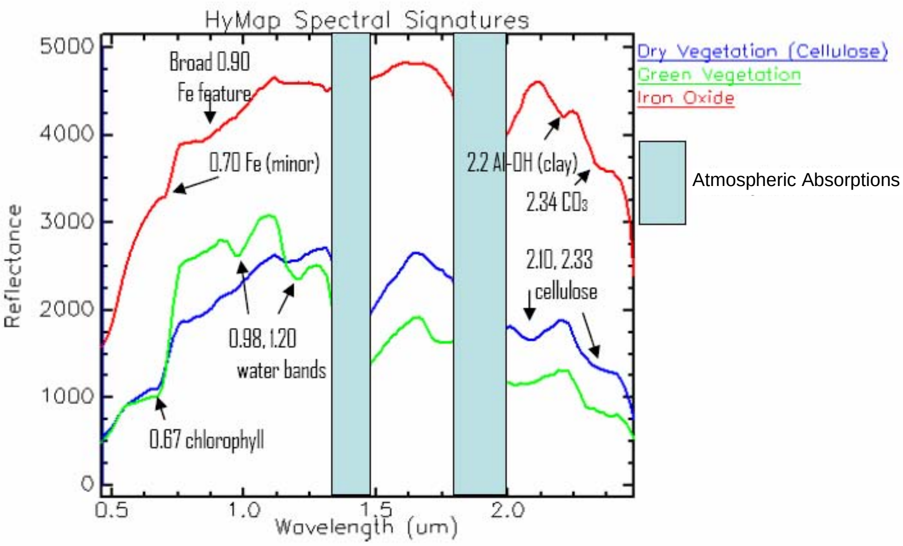


Figure A-4. Reflectance as a function of wavelength for several classes of materials [3].

HSI systems are typically flown in fixed-wing aircraft with the optics looking down and scanned side-to-side from nadir. For the WAA demonstration, pixels 1.5 to 3 m on a side were produced, depending on the aircraft altitude and speed. Absolute position accuracy of each pixel corresponded to 1 to 15 pixel widths. Note that for the demonstration, the HSI resolution was coarser than the SAR (9 to 36 SAR pixels per HSI pixel), and the poor geolocation accuracy provides additional uncertainty for registering HSI and SAR images. These factors combined to make SAR false-alarm reduction less effective than it might have been with sensors whose resolution and registration were better matched. The HyMap collects data in 126 spectral bands between 0.45 µm and 2.5 µm. Each pixel has a reflectance value recorded for each of the 126 bands. This creates a very large three-dimensional data cube (pixel down- and cross-track positions and band intensities), which complicates both data storage and processing. Figure A-5 provides a cartoon showing how data from a scene is subdivided into pixels, with each pixel having spectral samples from each of the HSI bands.

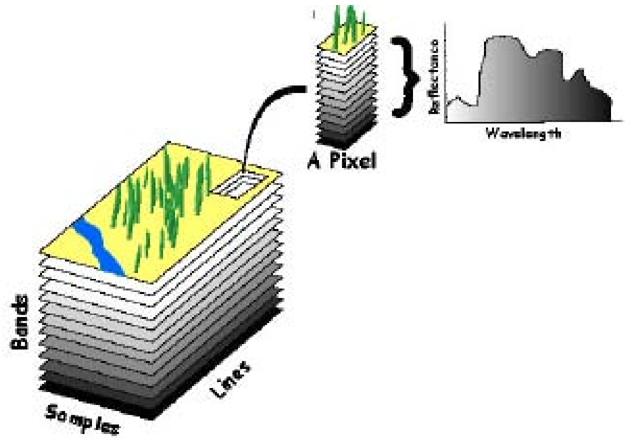


Figure A-5. Illustration of how HSI data collection sampling along scan lines is converted to pixels [3].

As the demonstration was designed, the HSI data collection had three goals: to detect bombing target features and other large munitions-related features, to detect surface concentrations of munitions-related metallic materials, and to contribute spectral information to a multiple-sensor vegetation model used to mitigate false alarms in the SAR data processing and modeling [3]. The expectation for the second goal was that the imager would be able to detect metallic debris whose mass exceeded 1.5 kg in a pixel with an 80% probability. In regard to the detection of metallic debris, the conclusion by Sky Research was that surface metal detection was not achievable at this site. Reasons for that conclusion are detailed in [3]. The detection rate for munitions-related features such as craters and berms was substantially lower than the demonstration objective and the performance achieved by LiDAR at the same site. Hence, the discussion here focuses on the SAR false-alarm reduction task.

3.0 APPLICATION OF SAR AND HSI AT PUEBLO PRECISION BOMBING RANGE #2

Sky Research gathered data to evaluate these techniques as a part of the Pueblo PBR #2 efforts in 2004 and 2005. All the data included in this appendix are drawn from the Sky reports on the results of those data collections [2], [3]. Figure A-6, from [2], shows the area of the data collection. The SAR collection area was 2,225 acres (9 km^2), and the HSI collection area, while much larger (6,710 acres in Phase 1 and 9,628 acres in Phase 2), covered most, but not all, the SAR area.

The intent of the PPBR #2 data collections was to provide sufficient data for the demonstrator and the Program Office to assess the utility of SAR and HSI for the WAA process. Thus, the site chosen was deemed to be relatively benign for the sensors, and much more effort was applied in supplying geo-registration fiducials and calibration items than would be the case for a typical collection. Hence, the results achieved in some sense are upper bounds to the utility of these particular sensors for this application.

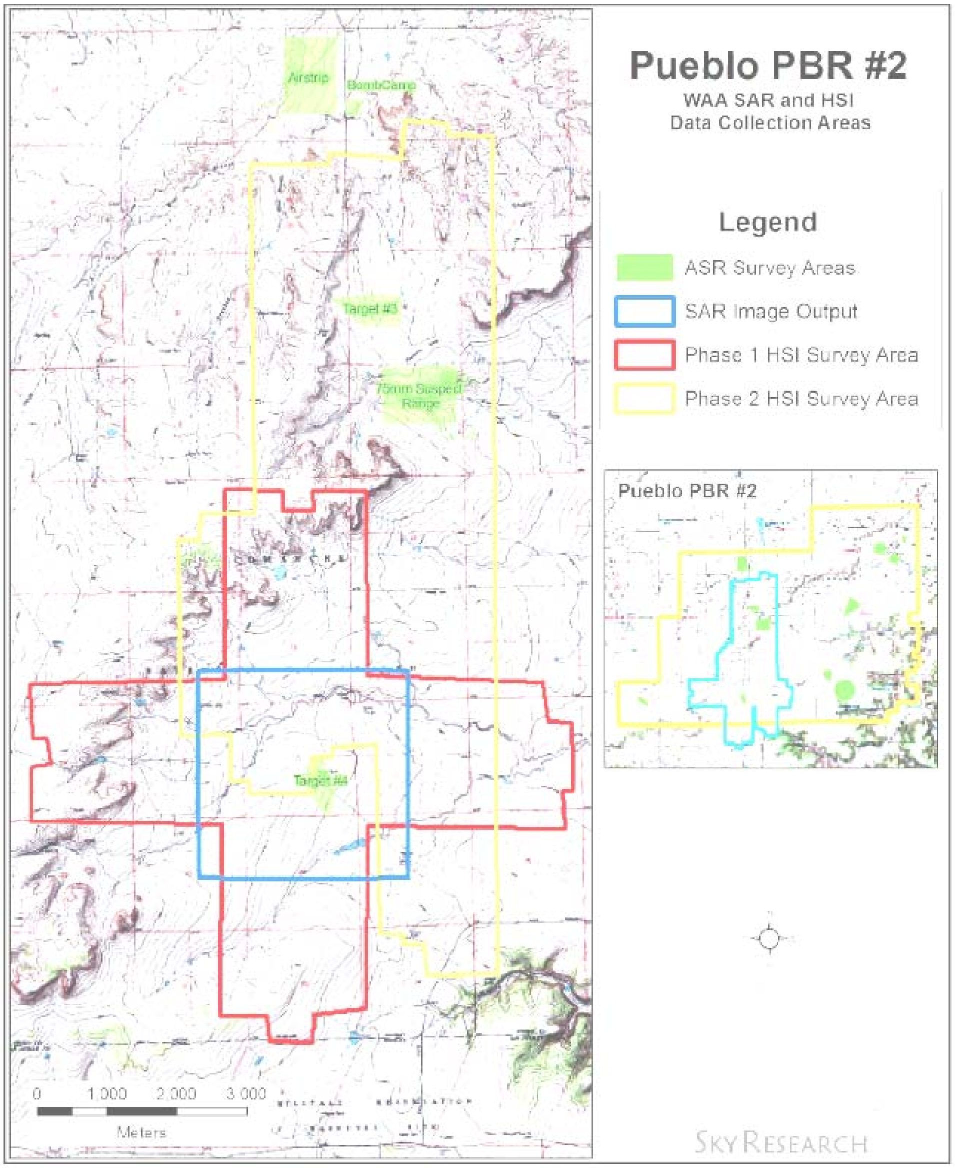


Figure A-6. SAR and HSI collections areas at Pueblo PBR #2 [1].

3.1 SAR Data Collection and Processing

While the demonstration area for SAR at Pueblo PBR #2 consisted of 2,225 acres, the focus for performance assessment was on two subareas of the site. The first was an in situ calibration area (2.46 acres) proximate to bombing target #4 that was known to contain munitions debris. The second was a simulated ordnance calibration area (3.67 acres) that was thought to be clear of munitions debris and into which 24 simulated UXO targets were placed. There was also an area containing a trihedral corner reflector used for radar calibration and to determine radar resolutions that were achieved in range and cross range. Twelve top-hat targets were emplaced at selected places in the survey scene to act as geolocation fiducials and to provide data on geolocation accuracy within the scene. For both calibration areas, field surveys were conducted to document vegetation, rocks, topographic features, and metallic debris with dimensions larger than 10 cm. Figure A-7 shows pictures of some of the items in the two areas.

Figure A-7. Items from the simulated ordnance calibration area (top row) and in situ calibration area (bottom row) [1].

Ninety-three SAR flight lines were flown in north-south, east-west, and diagonal directions across the test and calibration areas in spring of 2005. For data processing, the 9 km^2 area was broken up into nine 1 km^2 tiles, and georeferenced, complex, SAR images (amplitude and phase) were created for each pass for each tile. The magnitude in each pixel was used for target detection. The eight images for each tile from the collections at the eight angles flown were also combined. Performance results are presented for various image combinations.

3.2 SAR Performance Results

We concentrate here on the results from the two calibration areas, as those were the only areas for which ground truth was available. The emplaced ordnance-like objects in the calibration area were all cylinder-like with volumes that ranged from almost 200 liters (60″ × 18″) down to 2 liters (28″ × 3.5″). All emplaced items were on the ground surface. Even the smallest emplaced target was a significant sized object (significantly larger than an 81 mm mortar round). The targets below 6 liters were considered the “low volume” targets and were the least likely to be detected as predicted by the RCS calculations presented in Figure A-3.

Figure A-8 provides a receiver-operator characteristic (ROC) curve for the eight individual looks at the simulated ordnance calibration area, plus the combined SAR data. Note that only two of the individual looks detected all the simulated UXO items. This is because the RCS patterns are directional, and a given SAR look over a 25-degree azimuth integration angle is unlikely to see a specular return from all items. For the individual looks that achieved Pds above 0.9 (for the 24 emplaced objects), the number of false alarms to achieve the maximum Pd ranged from around 800 to 2,000. The combination of all eight looks provided significantly improved performance, as a Pd of 1.0 was achieved with 120 false alarms and Pd of 0.8 with around 50 false alarms.

As noted before, while the eight-look processing provides a very significant improvement in performance, it must be paid for in a much reduced area coverage rate and eight times the data processing that would be required if a single look image sufficed. In addition, to achieve the gains, very precise registration among the eight individual images is required.

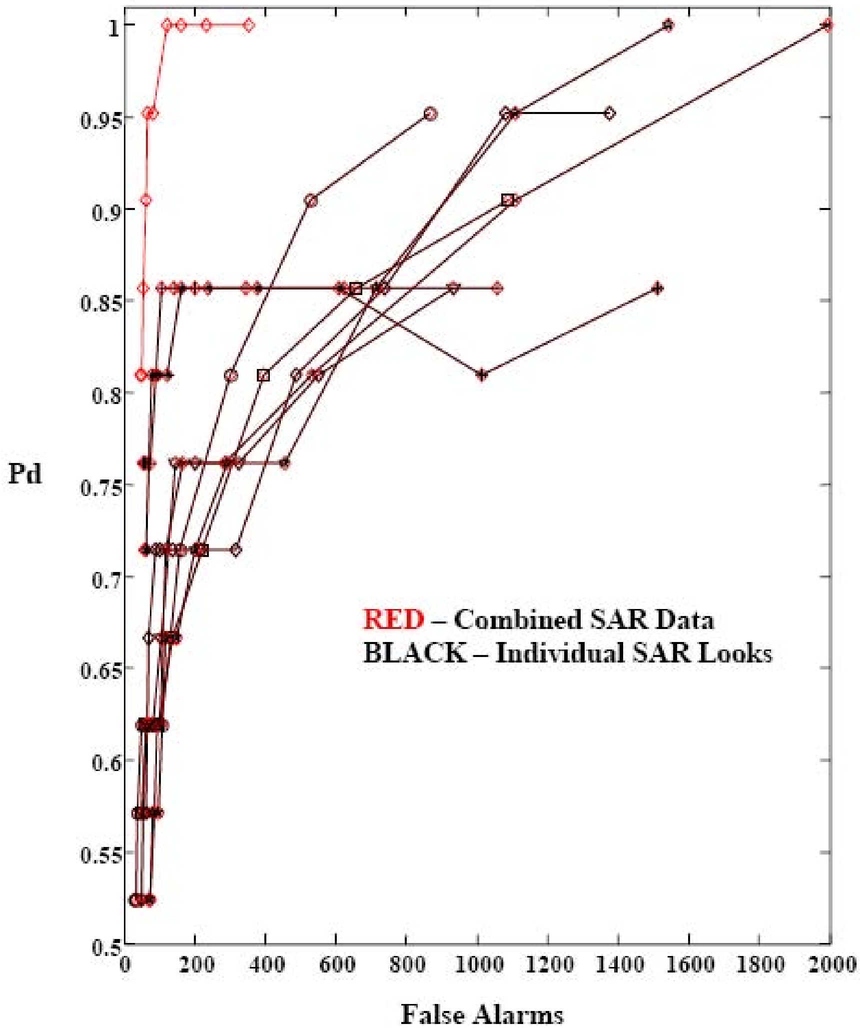


Figure A-8. ROC curves for detection of simulated ordnance on the surface [2].

In the in situ calibration area, 29 metal items had volumes above 1 liter. The maximum volume was 24 liters, but only 6 were above 10 liters, and only 4 of the 29 items had average signal-to-noise ratios above 2.0 in the images. All these items are of substantial size, as even the smallest have at least two dimensions that are 6 inches or greater. Figure A-9 provides a ROC curve for these items. Note that performance was not nearly as good for these items as for the simulated UXO items. Even the combined-look curve does not reach a Pd of 1.0, and most of the individual look curves have a Pd below 0.8. This detection performance comes with false-alarm numbers between a low of 650 for the combined-look curve and a high of almost 1,800 for a look that only reached a 77% Pd. Thus, the SAR showed much reduced performance against scrap items that might be typical of a large percentage of those found on a range of interest than it did against the simulated ordnance items, which would be significantly less common.

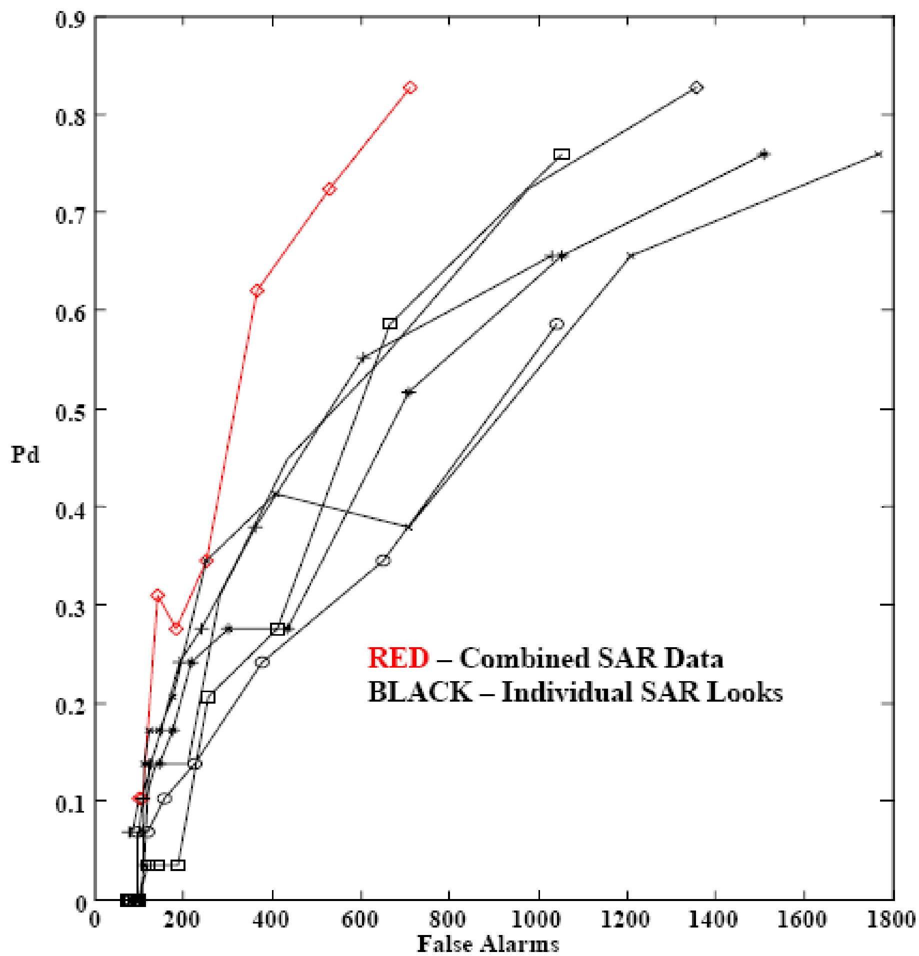


Figure A-9. ROC curves for the in situ calibration area [2].

3.3 SAR Summary

The results shown in Figures A-8 and A-9 reinforce the observation drawn from Figure A-3 that a UHF SAR will only be able to reliably detect relatively large munitions fragments or intact munitions on the surface. Because of the directional nature of the RCS patterns, multiple passes on different courses will have to be run to ensure that peak RCS is observed. Assuming some pattern symmetry in azimuth (certainly true for cylindrical objects), and with the 25-degree-wide azimuth collection angle that is typical of these systems, the eight passes on each tile collected by the SkySAR is nearly the minimum that would guarantee observation of the peak RCS direction.

As is typically the case, detection is not the major concern. Even if lower probabilities of detection on individual items can be tolerated for WAA than in UXO surveys, the number of false alarms is of concern. For the best case in the simulated-ordnance calibration area (eight combined images) and 80% Pd, there were still twice as many false positives as there were real detections on an area where the number of items of interest is artificially high because it was seeded. That problem was recognized coming into this demonstration, and it was hoped that HSI could provide a false-alarm mitigation mechanism that would result in useful SAR performance. That effort is discussed in the next section.

3.4 HSI Data Collection and Processing

Phase I data image strips were collected by covering the site with orthogonal swaths at both 3 m (4 strips) and 1.5 m (6 strips) resolutions. Note from Figure A-6 that most of the SAR collection area has strips from both the Phase 1 north-south and east-west collections. For the Phase II data collection, a total of 11 flight strips were collected at 1.5 m pixel resolution.

Processing for HSI data is relatively complex. The ultimate desire is to produce an output value for each pixel in each spectral band that accurately replicates the actual reflectance of the imaged area. This requires several steps to account for the effects of the illumination spectrum, the atmosphere, and the sensor on the signal received. An atmospheric correction is applied to take out dispersive atmospheric effects (absorption differences as a function of frequency). A second calibration removes sensor transfer-function effects. The solar spectrum is well understood and can be accounted for in the calibration.

A number of different algorithms were then applied to the data to attempt to detect munitions-related features and surface metal. Finally, for the SAR false-alarm-reduction effort, the 14 cm red-green-blue orthophoto data were resampled to 25 cm pixels to match a subsampled SAR image resolution. The 126-band HSI data were fused with the red orthophoto band to generate 126-band spectral data at 0.25 m resolution that could be more accurately registered with the SAR data. This was required because of the poor inherent registration of the HSI data.

Because the results depend on the in situ reflectance parameters, a ground-based data collection was accomplished before the airborne data collection to acquire spectral signatures of the types of materials of interest. Data were collected on the various vegetation types and soils in the scene. Details on the spectral signatures are provided in [3].

3.5 Performance Results for HSI fused with SAR, LiDAR, and Orthophotography Data

A broadband normalized difference vegetation index (NDVI) was computed from the high-resolution spectral data to provide a detection of canopy chlorophyll content. The NDVI strongly correlates with the green yucca, cactus, juniper, and other SAR-responsive vegetation species on the site. Canopy water content indices corresponding to spectral water absorption features at 0.97 μm and 1.2 μm were computed to generate high-resolution measures of vegetation water content, which is again highly correlated with SAR signal response from vegetation. These vegetation indices were used in combination with LiDAR-derived canopy height models and slope models to discriminate terrain and vegetation-related SAR targets from those generated by metal objects on the terrain surface. The following bullets from [3] provide a better description of the indices used:

- Normalized Difference Vegetation Index. NDVI is broadband normalized difference vegetation index computed from high resolution spectral data using (RED-NIR) / (RED +NIR) to provide a robust detection of canopy chlorophyll content.
- Water Band Index 970. WBI970 is a canopy water content index computed to exploit the spectral water absorption features at 970 nm to generate high-resolution measures of vegetation water content.
- Water Band Index 1175. WBI1175 is a canopy water content index computed to exploit the spectral water absorption features at 1175 nm to generate a second measure of vegetation water content.

- Canopy Height Index. This index is developed directly from the LiDAR-derived digital elevation models that exploit the elevation differences estimated from the “first-return” and “ground-return” LiDAR models and represent the top of the vegetation canopy.
- Slope Index: Also derived from the LiDAR data this index provides a metric of the roughness of the surface and indicates areas where SAR scattering occurs from craters, gullies and other topographic features.

A set of discrimination masks were produced using the above indices, and these masks were used for false-alarm reduction. Each SAR target that appeared in an image was successively reviewed relative to each of the masks. Any target that fell within 1 meter of a mask was declared vegetation, rather than a possible metallic target. Note that this procedure would likely discard actual metallic targets that were close to vegetation, particularly because of the 1-meter mask halo that was used to allow for registration problems.

Figure A-10 provides ROC curves for the simulated-ordnance calibration area for the SAR data, the SAR data with the above masks individually applied, and the SAR data with all the masks applied. Of the individual masks, NDVI provides the largest reduction in false alarms, reducing the number from the SAR image alone from 50 (with a Pd of 0.8) to below 20, but with a reduction in Pd to about 0.57. The reduction in Pd is likely to have been caused by the proximity of some of the simulated UXO to sufficient vegetation to trigger the NDVI mask.

The other HSI-based mask, the water-band mask, was less effective than NDVI in reducing false alarms. In this case, false alarms were reduced by about a factor of 2, and Pd was essentially unaffected. Of the remaining two masks based on LiDAR, canopy height was the more effective, but the slope mask had no effect because of the gentle terrain in the measurement area. The combined mask was modestly better than NDVI alone in reducing false alarms, but with an attendant additional 5% reduction in Pd.

No similar data were provided for applying the masks to the in situ calibration area. Detection statistics for SAR were much poorer in that area, so it would have been of interest to assess whether the masks would have been effective in drastically reducing the false alarms while still maintaining a useful Pd.

4.0 CONCLUSIONS

HSI at this site proved unable to detect metallic fragments on the ground and was much less successful at detecting munitions-related features than had been hoped. It did prove successful in reducing SAR false alarms due to vegetation. The application of the water-band mask reduced such false alarms by about a factor of 2 while leaving Pd virtually unchanged. The NDVI index was more successful at false-alarm reduction, reducing such alarms from about 50 to below 20, but with an accompanying reduction in Pd from around 80% to about 57%. However, with the very high false-alarm rates provided by the SAR, a reduction by even a factor of 3 may not be sufficient to provide a tool that would reliably differentiate munitions contaminated from uncontaminated areas.

In this testing, SAR showed the capability of detecting relatively large metallic items on the surface of the ground and unshielded by foliage. Detection was less reliable on items with volumes of less than a few liters. To provide reliable detection, however, the SAR had to collect data on eight passes in the cardinal directions. Even for the large items in the simulated ordnance calibration area (minimum volume of 2.35 liters), single passes rarely resulted in 100% detection, even with thresholds providing false-alarm numbers approaching 2,000. For the in situ calibration area, where target volumes were smaller (but still exceeded 1 liter), only 1 of the 8 single passes exceeded Pd of 0.8, and that was with over 1,600 false alarms. Even the combined pass image failed to reach 100% Pd for the in situ site.

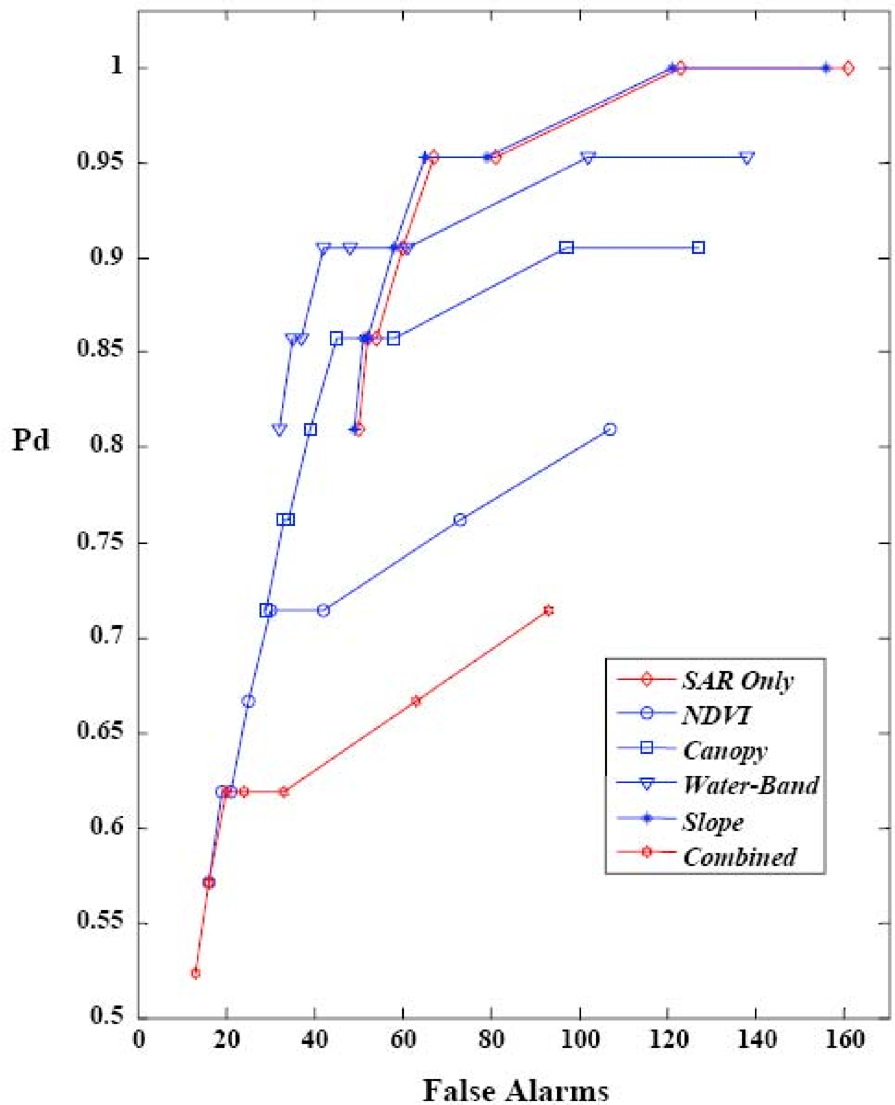


Figure A-10. ROC curves for SAR data with various masks applied for the simulated ordnance calibration area [3].

Fusing SAR data with HSI does provide a reduction in false alarms, as was hoped, but not by a large enough factor to make the results useful. In fact, the ordnance calibration area provides an optimistic view of potential performance, because the threshold would have to be set much lower to detect typical munitions debris than it was to detect the simulated ordnance, and a lower threshold would come with a commensurate increase in false alarms.

Thus, the current generation SAR and HSI sensors appear unlikely to unambiguously delineate areas contaminated with ordnance debris among the remaining very large numbers of false alarms. The best performance demonstrated in this program required data collection and analysis efforts that far exceeded what was needed for the other technologies.

5.0 REFERENCES

1. C. A. Wiley, “Pulsed Doppler Radar Methods and Apparatus,” U.S. Patent no. 3,196,436, 1965 (originally filed in 1954).
2. “Wide Area Assessment Using Synthetic Aperture Radar at Pueblo Precision Bombing Range, Colorado,” Project No. ESTCP-200416 Phase I Interim Report by Sky Research, 20 April 2006.
3. “Demonstration of Airborne Wide Area Assessment Technologies at Pueblo Precision Bombing Ranges, Colorado – Hyperspectral Imaging,” Project No. ESTCP-200416, Draft Final Report by Sky Research, 31 January 2007.

APPENDIX B—BORREGO MILITARY WASH

The Military Wash area of the Borrego Maneuver Area was selected for this study because (1) it is representative of a large number of munitions sites associated with the nearby California-Arizona Maneuver Area and (2) the site characteristics aligned with the pilot program objective to deploy the technologies on sites where capabilities and limitations could be demonstrated with limited interference from site-specific factors. Borrego Military Wash has limited vegetation and minimal interfering geology. The site contains a variety of targets and munitions-related features, including contained bombing, strafing, and rocket targets with rake (observation) stations that are firing points for 40 mm and 90 mm antiaircraft weapons systems. There also may have been an air-to-ground railway strafing target, as well as a bermed area for ground-to-ground firing as part of an Army anti-mechanized target.

The majority of the WAA demonstration site at Borrego Springs lies within the Anza-Borrego Desert State Park, a unit of the California Parks system. Personnel from this park were involved in initial project planning and, although there were restrictions on vehicular access to off-road areas, it was understood that permits for three layers of WAA surveys would be granted. A portion of the demonstration area is within the Ocotillo Wells State Vehicular Recreation Area, however, and separate permits are required from this park unit. The permit for the helicopter survey in this park was not granted. The high-altitude survey was underway at the time, so it was completed, but the remainder of the planned activity at this site was transferred to Victorville Precision Bombing Range Y (see Chapter 6).

Currently the USACE, Los Angeles District, is conducting a Remedial Investigation and Feasibility Study for munitions and explosives at the former Borrego Maneuver Area. The information from the WAA on this site has been shared with the Remedial Investigation and Feasibility Study team and is being incorporated into their study.

1.1 Test Site History/Characteristics

The former Borrego Maneuver Area is a parcel of desert land located in the eastern portion of San Diego County and the western portion of Imperial County, west and southwest of the Salton Sea in California (see Figure B-1). The area is a combination of desert, mountains, and badlands, with negligible amounts of arid climate vegetation species. The Federal Government acquired Borrego Maneuver Area by use permit from the State of California in 1942 for use as a force-on-force maneuver area. The Army closed its portion in 1944, but the Navy continued to use its areas through 1953. The Anza-Borrego Desert State Park has numerous historical, archeological, and paleontological sites, in the form of village sites and tool construction sites. Since site closure, the former Borrego Maneuver Area lands have consistently been under State, Federal, and private ownership, with the predominant portion used by California as State park land. Usage is expected to remain consistent in the future.

Figure B-2 shows the location of Borrego Military Wash within the larger Borrego Maneuver Area in more detail. The Military Wash study area lies approximately 3 miles due north of the town of Ocotillo Wells and Benson Dry Lake. The study area had two distinct military uses. The area designated as E-1 in the Archive Search Report (ASR) contained bombing and strafing targets, as well as potential firing points for 40 mm and 90 mm antiaircraft weapons systems. In addition, the ASR shows the location of a mile-long wooden track that may have been a simulated railroad target. The area the ASR designated as E-2 served as a safety buffer area.

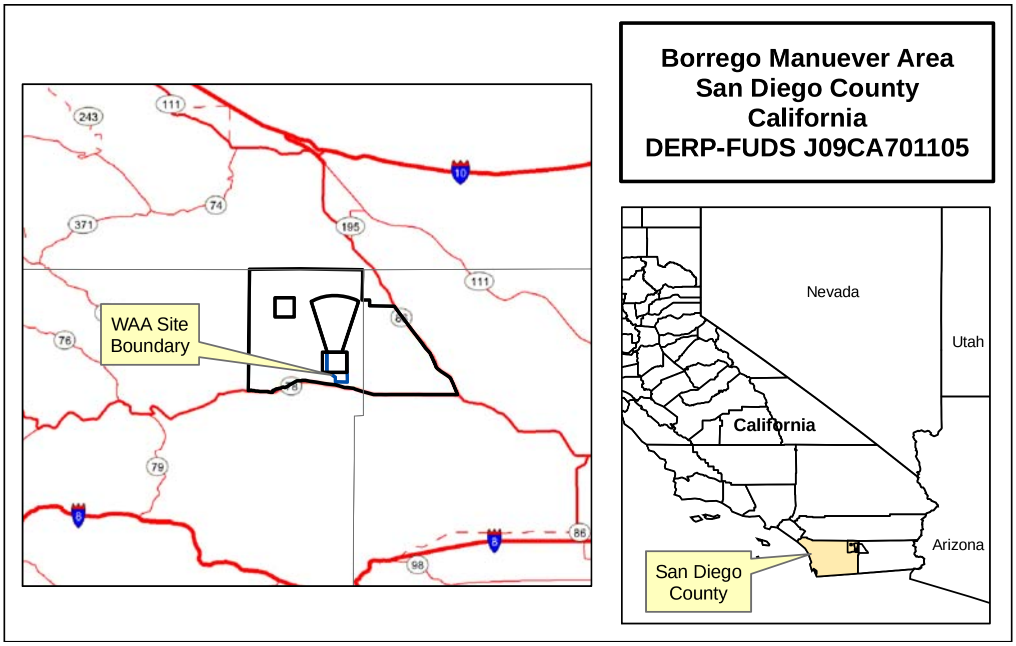


Figure B-1. Map showing the location of Borrego Maneuver Area within Southern California (right) and the location of the WAA program study area within the Military Wash Area (left).

The Military Wash targets are presumed to have been used from 1943 through late 1953. A Certificate of Clearance for the Navy areas was issued on 22 January 1954 (surface only). Expected or observed military improvements at the bombing targets include remains of rake stations, remains of potential mobile target tracks, and remains of targets and a bermed area.

A considerable amount of surface evidence of Naval targets and munitions and explosives of concern was discovered in the Borrego Military Wash area. Naval target or target-related evidence and debris were found in the form of two rake stations, one concentric circle bombing target, and three vehicular strafing/rocket targets. The ASR site inspection team discovered 5-inch-high explosive rocket fragments, 2.25-inch practice rockets and related debris, MK 15MOD3 and M38A2 100-pound practice bomb and spotting charge debris, MK 23 3-pound practice bomb debris, a substantial amount of 20 mm M95 and M99 armor-piercing and target practice projectiles, and a substantial amount of .50-caliber bullets. The munitions expected in the Borrego Military Wash area may be present in the form of 100-pound photoflash bombs, 5-inch-high explosive rockets, MKII 40 mm and M71 90 mm high-explosive projectiles, Ml 3-pound black powder spotting charges (incorporated in the M38A2 100-pound practice bombs), MK4 smokeless powder/stabilized red phosphorus spotting charges (incorporated in the MK23 3-pound and MK15 MOD4 100-pound practice bombs), and MK7 8-pound black powder spotting charges (incorporated in the MK15 MOD3 100-pound practice bombs). (Refs 1 and 2)

An approximately 7,500-acre WAA study area was selected. In Figure B-2 it is shown overlain on the Military Wash site.

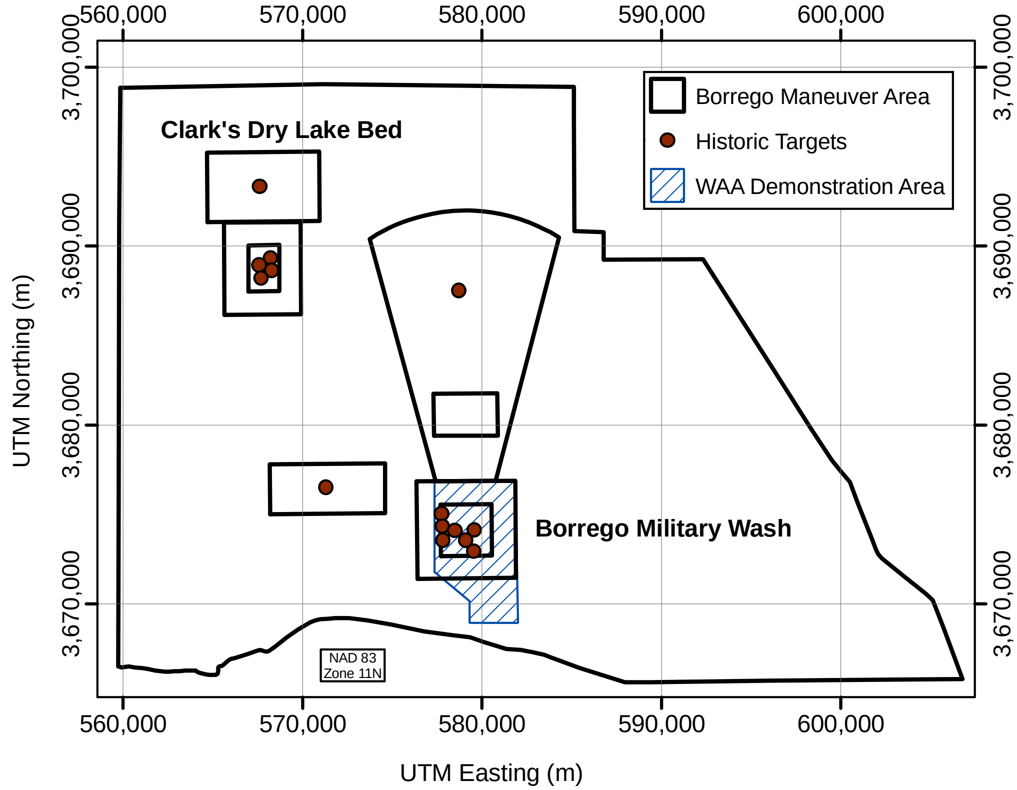


Figure B-2. Map showing Borrego Maneuver Area and the major historical targets. The WAA demonstration area is shown in blue and encompasses the area known as Borrego Military Wash.

1.2 Borrego Military Wash Study Objectives and Program Design

The Borrego Military Wash objectives included confirming the presence of the targets located in the ASR and assessing the remaining land in the study area to determine if there is evidence of any unknown targets. As noted above, the original program plan for Borrego Military Wash included a demonstration of LiDAR, orthophotography, a helicopter-borne magnetometer array, and a ground-based magnetometer array. The high-altitude technology layers surveyed 100% of the 7,500-acre study area as shown in Figures B-3 and B-4. (Ref 3) Because of permitting issues, the other layers were not able to survey at the site, and the remaining effort was transferred to the Victorville site (see Chapter 6).

1.3 Performance Assessment

The results from the two high-airborne data sets were analyzed separately and in combination to identify munitions response sites and areas of interest. Both data sets and the validation results confirm the locations of the naval targets. The remaining land in the WAA study area shows no evidence of concentrated munitions based on the WAA data, although any evidence that did exist may have been obscured by running water and blowing sand.

1.3.1 Target Area

The target area (referred to as Area E-1 in the ASR) is in the north-central part of the WAA study area, as shown in Figures B-3 and B-4.

Data Analysis, Interpretation, and Evaluation

Several of the features identified in the ASR are clearly seen in both the LiDAR data (Figure B-5) and orthophotography (Figure B-6) data sets. Highlighted in the figures are the railroad target and two target circles. The eastern-most target circle is recognized as an aiming circle most clearly in the orthophotograph and was identified by the high-airborne analyst and confirmed by the reconnaissance team. The western target circle is less obvious from the data sets shown but can be identified from the ground and so is included in the figure.

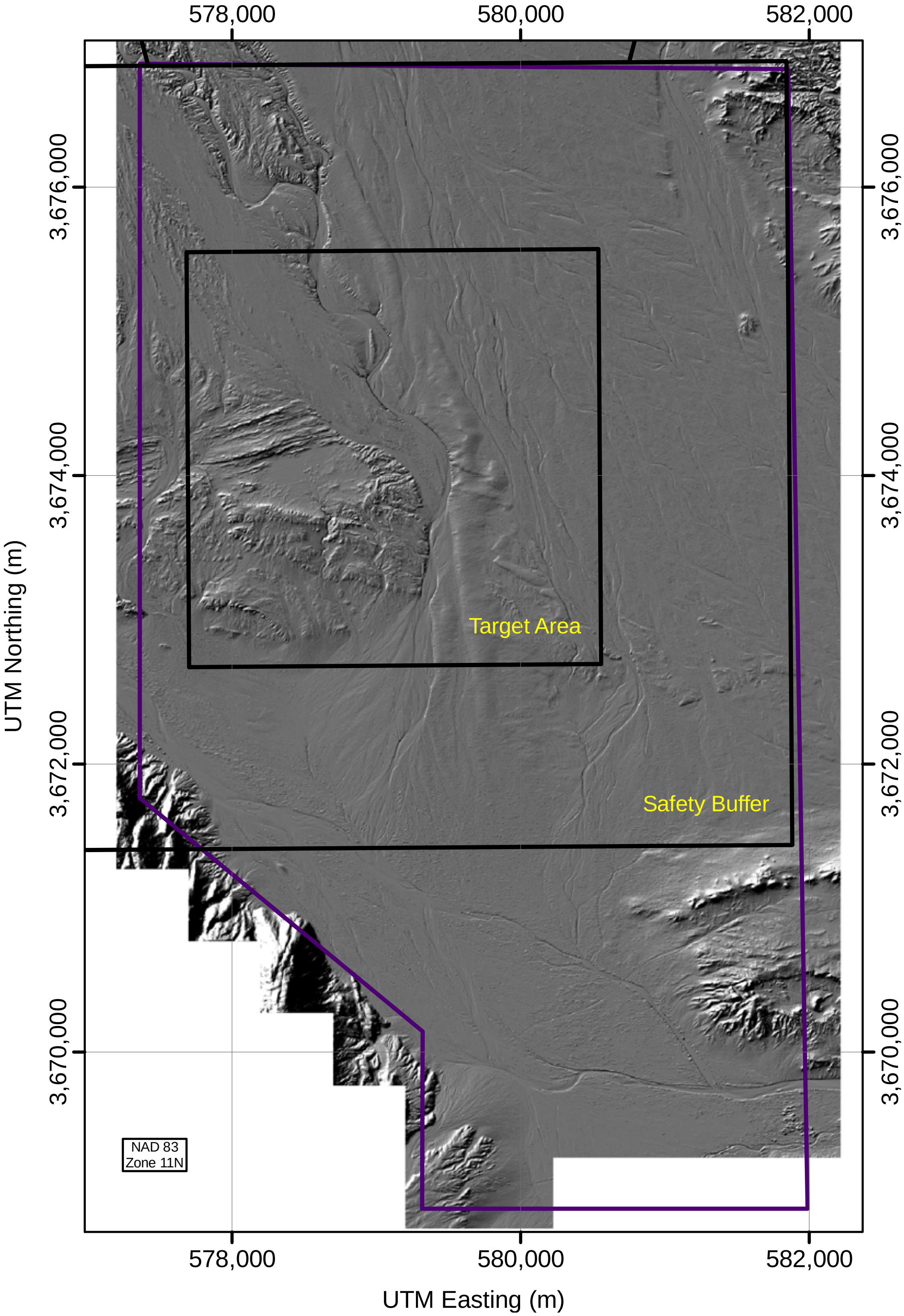


Figure B-3. The locations of the Borrego Military Wash target area and safety buffer overlain on the LiDAR data. The technology covered 100% of the site.

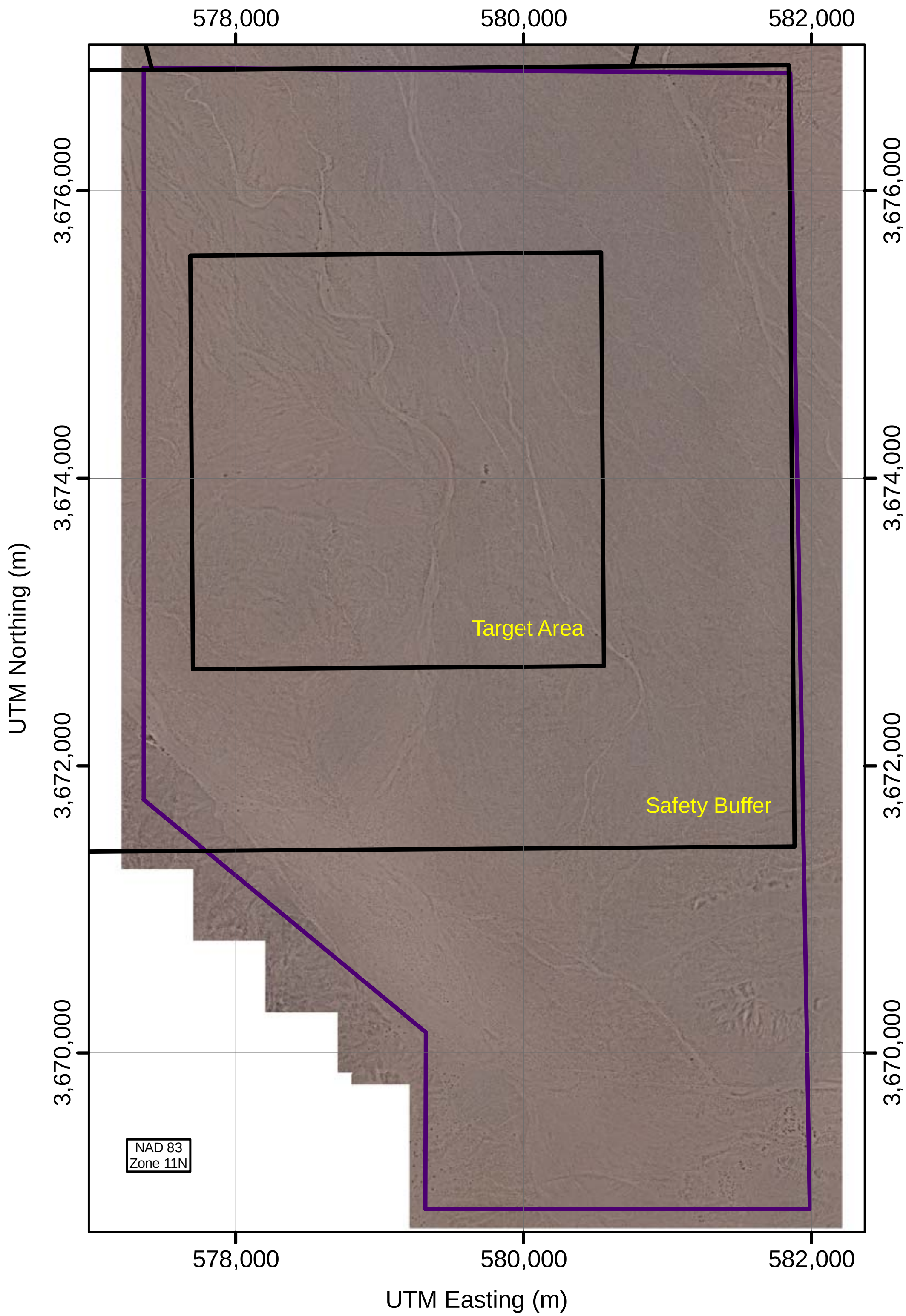


Figure B-4. Borrego Military Wash orthophotography data. This technology covered 100% of the site.

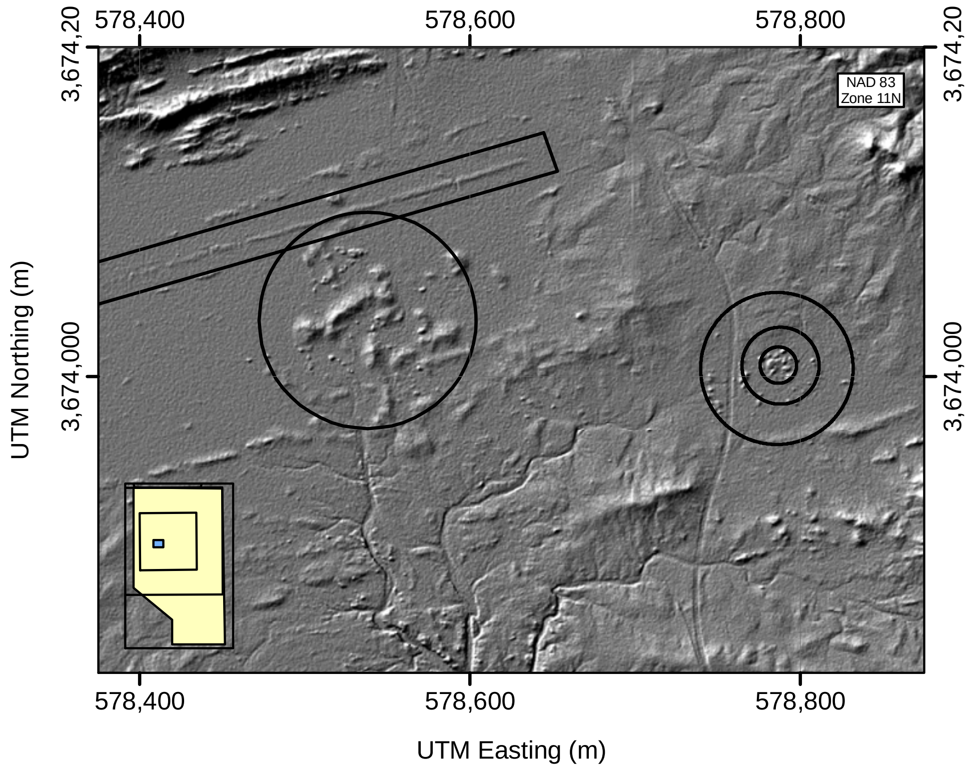


Figure B-5. LiDAR data from an area within the Borrego Military Wash target area. Three munitions-related features are outlined.

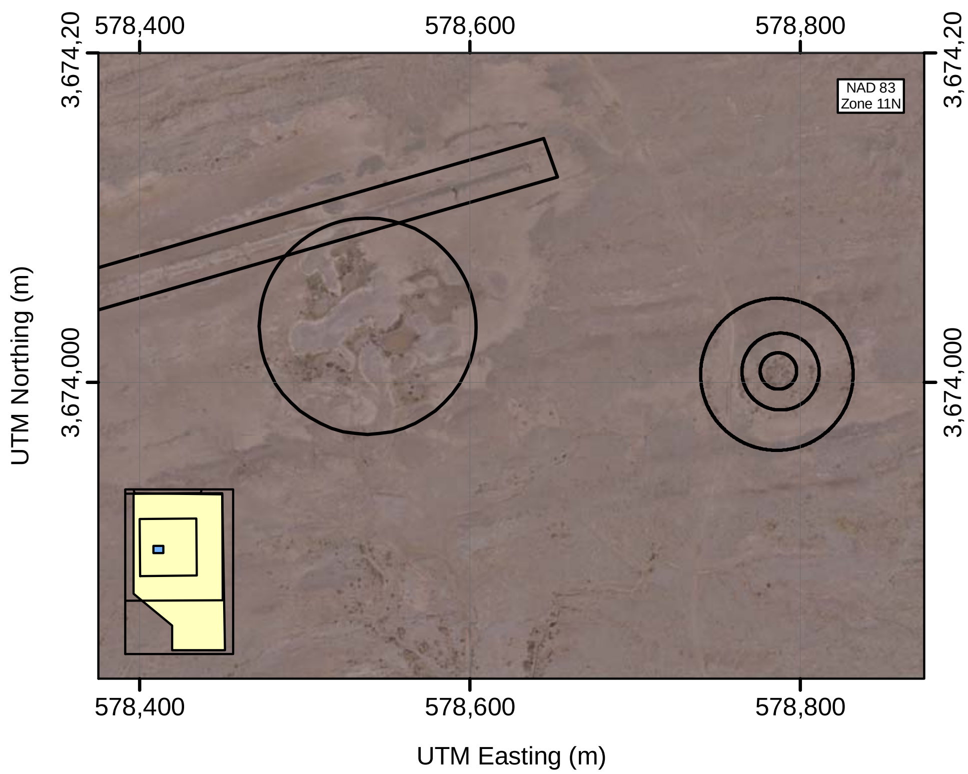


Figure B-6. Orthophotograph from an area within the Borrego Military Wash target area. Three munitions-related features are outlined.

Validation

Validation activity at this site consisted of a reconnaissance survey by a team comprising a geophysicist with a hand-held magnetometer and a UXO technician. They visited each of the features identified from the high-airborne data or the pre-demonstration site visit to assess the likelihood that they were munitions related. In addition, they performed a transect survey of the entire target area to search for additional munitions-related features.

Figure B-7 shows two photographs of the eastern target circle taken during the reconnaissance survey. Notice that the vegetation seems to be arranged in a circular pattern, which is why the feature was most clearly seen in the orthophotograph. Figure B-8 shows a photograph of the widely-spaced stones that comprise the western target circle. Although this feature is easily recognized from the ground, the wide spacing of the stones makes it difficult to definitively identify in the high-airborne data. Finally, Figure B-9 shows two photographs of the raised area that remains from the railroad target and a close-up of the hundreds of nails that are left on the surface.

Figure B-7. Photographs of the eastern target circle from Figure B-5, denoted MW-4 in the reconnaissance survey.

Figure B-8. Photograph of the stones that comprise the western target circle from Figure B-5, denoted MW-10 in the reconnaissance survey.

Figure B-9. Photographs of the remaining evidence of the railroad target, denoted MW-3 in the reconnaissance survey.

Figure B-10 shows the transect path covered during the reconnaissance survey. Numerous pieces of bomb scrap and parts of .50 cal. belt links were observed during the transects, but no evidence of other aim points was observed.

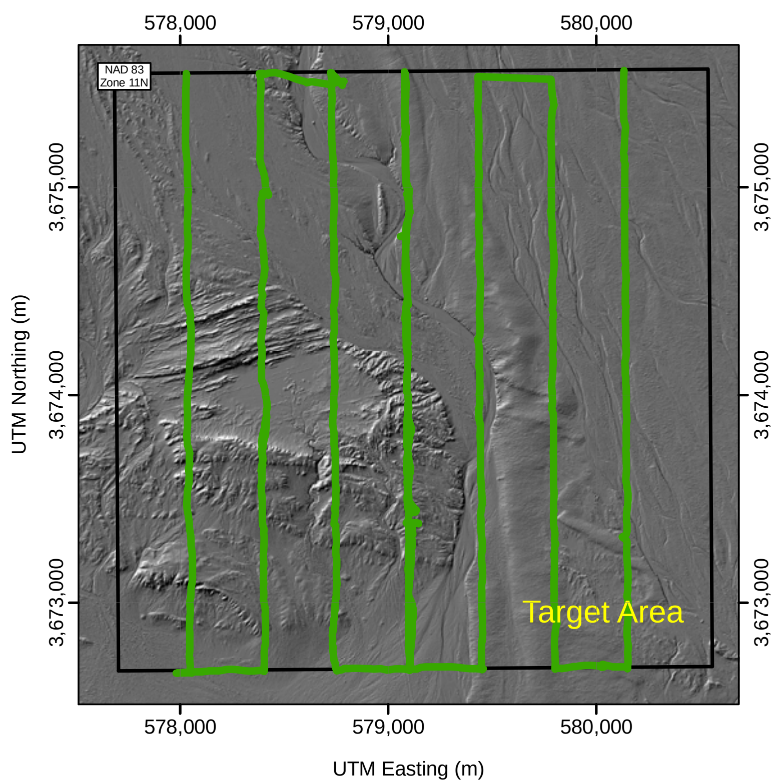


Figure B-10. Transect path for the reconnaissance survey in the Borrego Military Wash target area.

1.3.2 Other Areas

Figure B-11 shows LiDAR data from an area outside the target area in the wash. It is clear that in this area running water and blowing sand have obscured any evidence of munitions activity that may have been present. With the exceptions of the remains of two rake (observation) stations located on the edge of the target area, no evidence of munitions-related activity was found within the WAA demonstration site outside the target area.

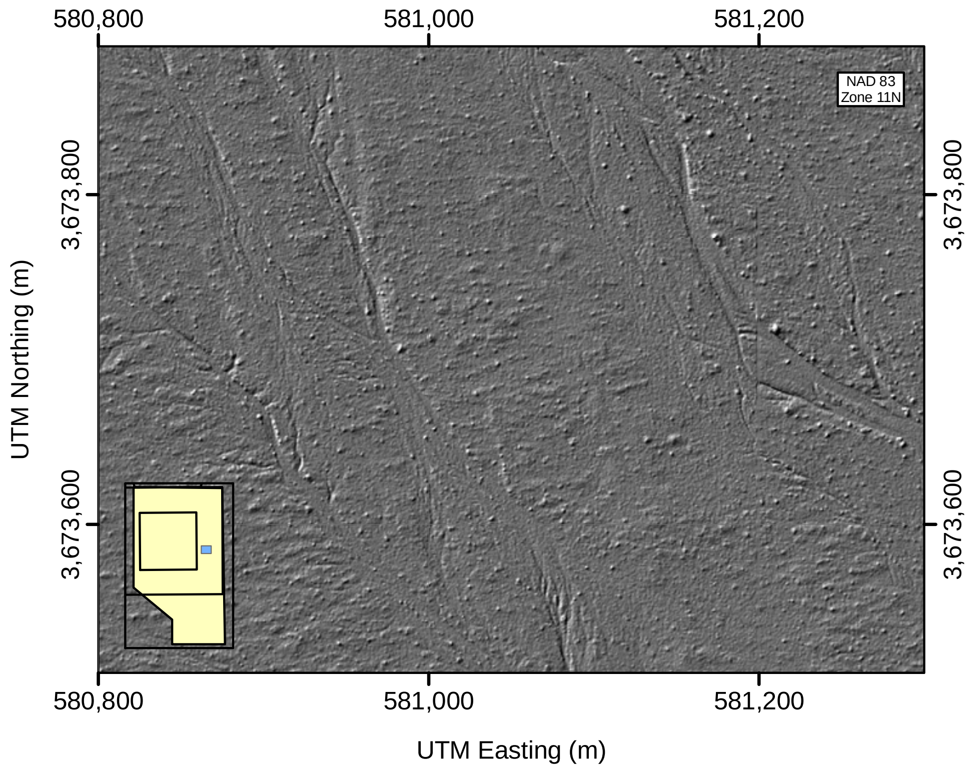


Figure B-11. LiDAR data from an area in the Borrego Military Wash buffer area.

1.4 Overall Site Conclusions

Borrego Military Wash was known to contain several Naval targets and a wide variety of munitions scrap. The location of the major targets was confirmed from the high-airborne data and the reconnaissance survey. Numerous scrap items and munitions-related debris were observed during the reconnaissance survey. Since we were unable to perform the geophysical surveys at this site, no data are available regarding the presence of subsurface munitions and munitions debris on this site.

No evidence of concentrated munitions use outside the target area was found in the high-airborne data sets or the reconnaissance survey, although running water and blowing sand may have obscured any evidence that once was present.

Appendix C

Environmental Security Technology Certification Program (ESTCP)

Final Report

Assessment of Munitions Contamination at the Former Erie Army Depot Lake Erie Impact Area and Toussaint River

CONTENTS

Acronyms

ASR	Archive Search Report
CSM	Conceptual Site Model
DERP	Defense Environmental Restoration Program
DoD	Department of Defense
DQO	Data Quality Objective
EE/CA	Engineering Evaluation/Cost Analysis
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GIS	Geographic Information System
GPS	Global Positioning System
MRA	Munitions Response Area
MTA	Marine Towed Array
MRS	Munitions Response Site
nT	Nanotesla
Pd	Probability of Detection
PNNL	Pacific Northwest National Laboratory
TCRA	Time Critical Response Action
USACE	US Army Corps of Engineers
UXO	Unexploded Ordnance
VSP	Visual Sample Plan
WAA	Wide Area Assessment

ACKNOWLEDGEMENTS

Several individuals and organizations contributed to the success of this project. The underwater geophysics work was performed by the former AETC, Inc. (now SAIC) led by Dr. Jim McDonald. The transect planning and analysis were performed by a team from Pacific Northwest National Lab and Sandia National Lab, led by Mr. Brent Pulsipher and Dr. Sean McKenna. The helicopter magnetometry work was performed by a team from Sky Research, led by Dr. John Foley. The validation of targets was performed by a team from Explosive Ordnance Technologies, Inc., led by Mr. Wayne Lewellyn.

In addition, we would like to acknowledge the assistance and support of the US Army Corps of Engineers, Louisville and Buffalo Districts, the ARES Corporation, and the Ohio Environmental Protection Agency. We are particularly grateful to the Ohio National Guard at Camp Perry for invaluable assistance and coordination that made the data collection possible.

EXECUTIVE SUMMARY

The former Erie Army Depot, Ottawa County, OH, is located along the southern shore of Lake Erie. This site and the associated impact areas are classified by the United States Government as a Formerly Used Defense Site (FUDS) under the Defense Environmental Restoration Program (DERP). This property was formerly used for artillery testing, resulting in impact areas on land and in Lake Erie. Unexploded ordnance (UXO) has been found on the lake bottom, in the Federal navigation channel in the Toussaint River, in the marshland adjacent to the firing ranges, and along beaches fronting the former Depot. The impact areas were located in and near Lake Erie, extending offshore from the beaches for several miles. Ordnance found on or near the shore of Lake Erie appears to be mobile and may have originated from offshore or near shore impact areas.

The Department of Defense Environmental Security Technology Certification Program (ESTCP) is charged with promoting innovative, cost-effective environmental technologies through demonstration and validation. In FY2006, ESTCP was directed by Congress to conduct a demonstration to comprehensively characterize UXO contamination impacting the Toussaint River area. The project objectives were:

- Identification of areas of concentrated munitions
- Characterization of site conditions that will support future investigation, prioritization and cost estimation, including:
  - bounding the munitions-contaminated areas in Lake Erie,
  - estimating density and distribution of munitions types and sizes,
  - locating areas where munitions are likely to migrate to the river channel, and
  - determining the extent of munitions contamination in the Toussaint River.

The overall investigation area encompassed approximately 50,000 acres, and included the current impact area in Lake Erie, the adjacent beach, and areas of the Toussaint River where munitions have been reported.

All geophysics investigations were performed with magnetometer systems, which detect surface and buried munitions, as well as other ferrous objects.

- A helicopter-based magnetometer array system, shown in Figure E-1, surveyed 3,300 acres along the beach, shallow water and river areas.
- A marine magnetometer array towed behind a pontoon boat, shown in Figure E-2, surveyed 46,000 acres of the lake impact area and deeper portions of the river. This platform operates in water depths from 3 feet to about 25 feet, so nearly the entire area of interest was accessible to it.
- The marine survey was conducted as a series of statistically-planned evenly spaced sampling paths, or transects, sampling the impact area in the lake and 100% surveys of the accessible parts of the river up to the Route 2 bridge.

Figure E-1. Helicopter magnetometer system.

Figure E-2. Marine towed array.

The primary result of this work is a comprehensive and detailed characterization of the munitions present in the vicinity of the Toussaint River. Figure E-3 shows the extent of the munitions detected and an estimate of the density of items per acre. From this analysis, we estimate approximately 300,000 anomalies will require investigation in an area encompassing approximately 8,000 acres, if the impact area were to be cleaned up. Validation of a sampling of more than 200 targets yielded munitions in the impact area in Lake Erie ranging in size from 37 mm to 155 mm, with one general purpose (GP) bomb discovered near West Sister Island. A limited number of anomalies were investigated in the river. Although all proved to be non-munitions clutter, the possibility of munitions in the river cannot be ruled out due to the small sample size.

This document provides a summary of the data collection, analysis and results. Technology specific reports prepared by the vendors provide additional details.

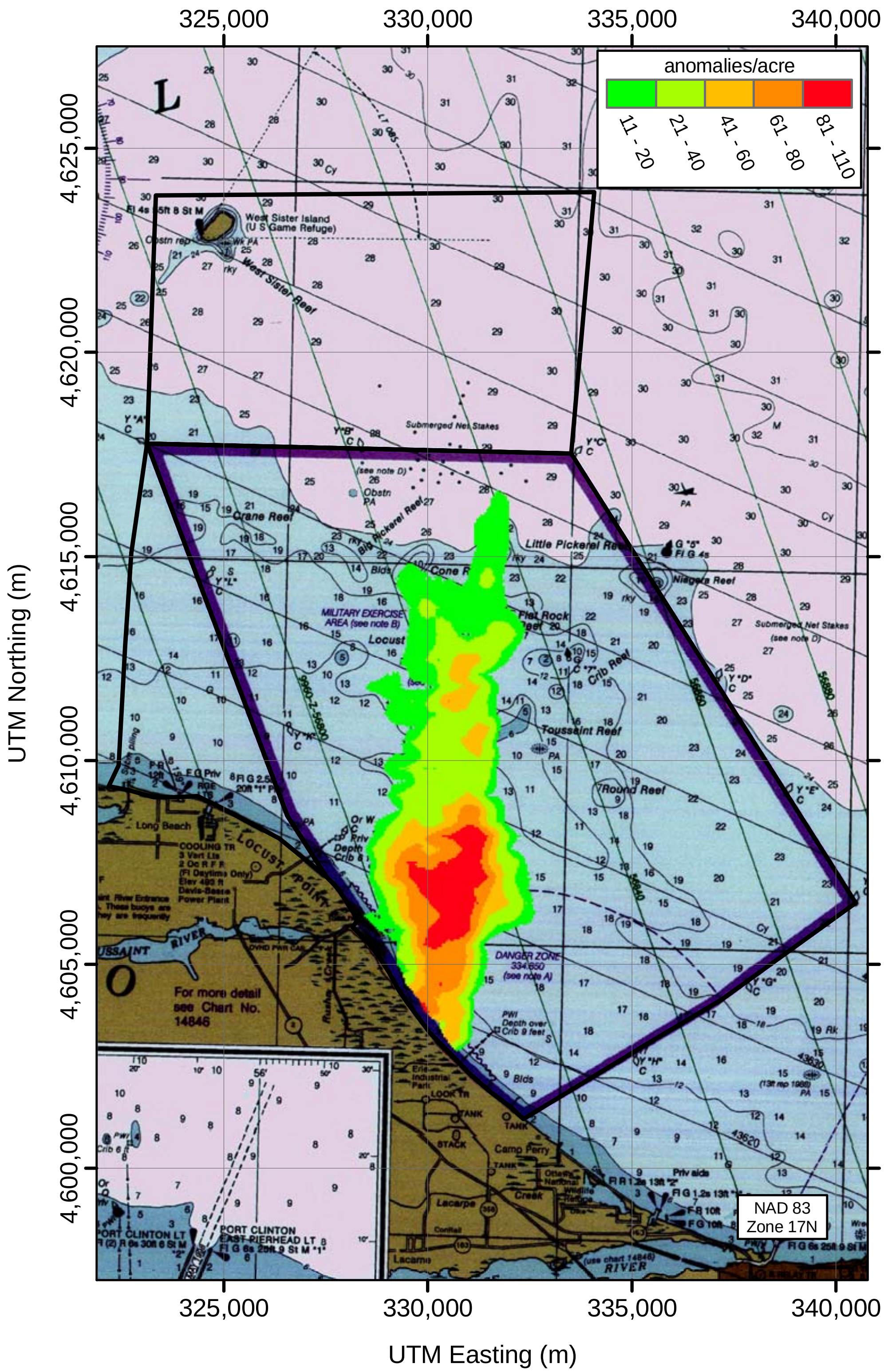


Figure E-3. Estimate of the extent and density of munitions contamination in Lake Erie.

1.0 INTRODUCTION

1.1 Background

The former Erie Army Depot, Ottawa County, OH, is located along the southern shore of Lake Erie. The study area includes sections of Lake Erie and the Toussaint River (Figure C-1). This site and the associated impact areas are classified by the United States Government as a Formerly Used Defense Site (FUDS) under the Defense Environmental Restoration Program (DERP). This property was formerly used for munitions testing, resulting in impact areas on land and in Lake Erie. Unexploded Ordnance (UXO) has been found on the lake bottom, in the Federal navigation channel at the Toussaint River, in the marshland adjacent to the firing ranges, and along beaches fronting the former Depot. The impact areas were located in, near, or offshore of the beaches adjacent to Lake Erie. Ordnance found on or near the shore of Lake Erie appears to be mobile and may have originated from offshore or near shore impact areas. (Refs. 1–4)

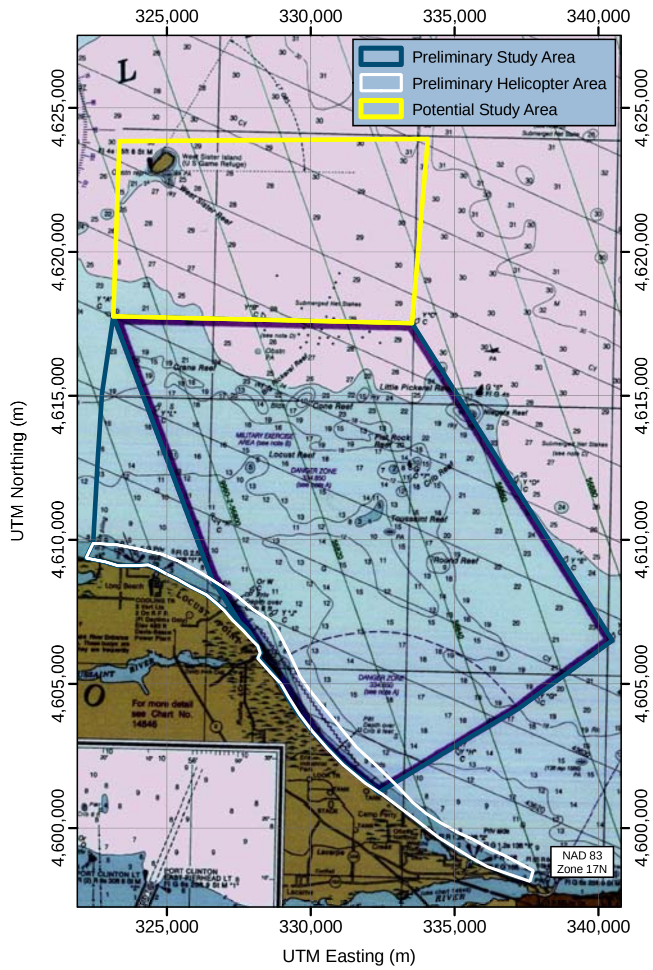


Figure C-1. Study area in Lake Erie near the Toussaint River.

In FY2006, ESTCP was directed by Congress to conduct a demonstration to characterize UXO contamination impacting the Toussaint River area. This document provides a summary of the data collection, analysis and results. Technology specific reports prepared by the vendors provide additional details. (Refs 3–7)

1.2 Objective of the Demonstration

The purpose of this demonstration was to use technologies suitable for wide area assessment (WAA) of suspected munitions contaminated sites to characterize the areas in and around the Toussaint River that are contaminated with munitions from historical activities at the Erie Army Depot and Camp Perry. The technical objectives were:

- Identification of areas of concentrated munitions
- Characterization of site conditions that will support future investigation, prioritization and cost estimation, including:
  - Bounding the munitions-contaminated areas in Lake Erie,
  - Estimating density and distribution of munitions types and sizes,
  - Locating areas where munitions are likely to migrate to the river channel, and
  - Determining the extent of munitions contamination in the Toussaint River.
  - The information will be provided to the US Army Corps of Engineers (USACE) and local stakeholders to assist them in developing a site management or remediation strategy.

1.3 Regulatory Drivers

The Toussaint River is situated immediately north of the former Erie Army Depot. The river includes several small craft and commercial fishing marinas. The USACE - Buffalo District is responsible for maintaining a navigable waterway. The area is periodically dredged, either by the USACE or local private interests. These dredging activities are often affected by munitions encounters. Figure C-2 shows the mouth of the Toussaint River, the maintained navigation channel, and the areas where previous dredge spoils have been disposed.

1.4 Stakeholder/End-User Issues

UXO is present on thousands of sites covering millions of acres. The characterization technologies demonstrated in this project can provide data that will improve prioritization, planning, and cost estimation, providing decision makers with information on which to base decisions regarding future site management or cleanup efforts. Widespread implementation of these technologies will require broad acceptance by government, contractors, and regulators, as well as availability of funds in the programs that execute munitions response activities. Their application would be integral to a comprehensive approach to the munitions response problem.

2.0 TECHNOLOGY DESCRIPTION

This demonstration employed of a number of technologies, each of which contributed to the overall goals of the demonstration. These technologies include

- a **marine-towed magnetometer** array to survey the impact area in Lake Erie and the deeper parts of the river
- a **helicopter-mounted magnetometer** array to survey the beach, shallow water, and marshy areas
- a **statistical tool** to aid in planning transects for the marine array and interpreting the data gathered.

The main detection sensor used in this study was the magnetometer, which detects all ferrous metal.

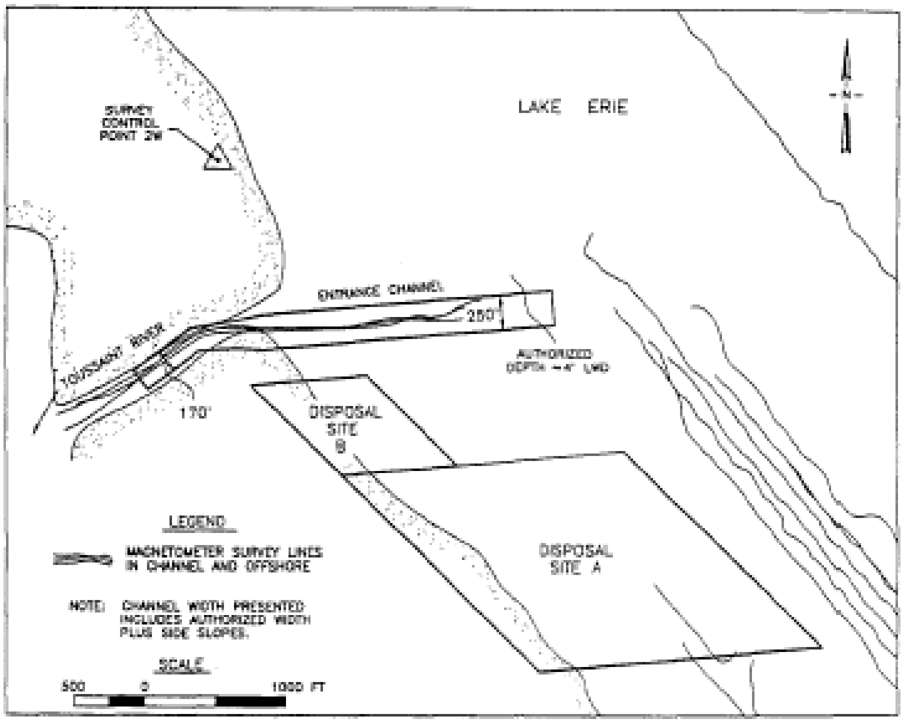


Figure C-2. Authorized Toussaint River federal navigation channel and disposal areas.

2.1 Marine Towed Array (MTA)

The marine array houses both magnetometers and electromagnetic induction sensors. For this demonstration, the magnetometers were used. Figure C-3 shows a schematic of the system design and Figure C-4 shows a photograph of the system. Eight Cesium vapor full-field magnetometers are deployed across a platform that measures nearly 5 m in width. The platform is towed behind a pontoon boat, supported by a cable. The location of the boat is precisely known from a cm-level accuracy Global Positioning System (GPS). The location of the platform is determined by careful measure of the length and angles of the tow cable. The platform is controlled using the control fins shown on either end. The control system maintains the platform at a fixed distance off the water bottom. A detailed description of the technology is found in the demonstration report of the marine array demonstrator. (Ref. 5)

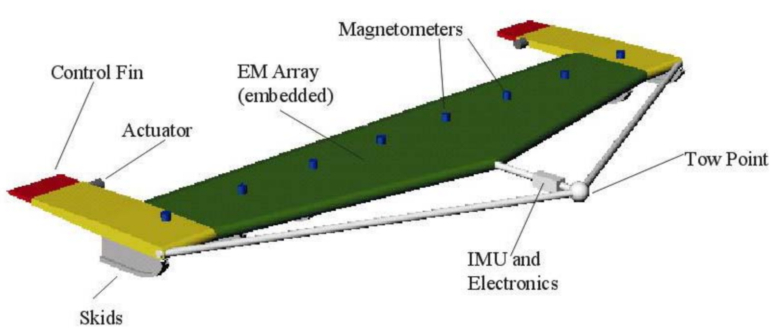


Figure C-3. Schematic of the marine towed array system. The platform is nearly 5 m wide.

Figure C-4. Photograph of the marine towed array system.

This system was deployed to collect data following planned transects in the lake area and to survey as much of the river as was accessible, providing characterization of the areas where munitions are present.

2.2 Helicopter Magnetometer Array

The helicopter-borne magnetometer array consists of seven Cs-vapor full-field magnetometers mounted in a boom that is carried on the front of a helicopter. Figure C-5 shows a photograph of this system. Like the marine array, the location of the helicopter is determined using a cm-level GPS. Because the magnetic signal falls off quickly with distance, the helicopter must fly 1 to 3 m above the ground surface to detect objects the size of the munitions of interest. A detailed description is found in the demonstration report for this system. (Ref. 6)

Figure C-5. Photograph of the helicopter-borne magnetometer array.

This system was used to survey the beach, shallow water and river areas. Since the size of these areas is moderate, 100% of each area was surveyed, except where access was limited by trees and other obstructions.

2.3 VSP Statistical Planning Tool

Visual Sample Plan (VSP) is a statistical sampling software package designed by Pacific Northwest National Lab (PNNL) to provide site investigators a simple to use, defensible method of gathering and analyzing site characterization data. VSP contains a module to aid in transect sampling to identify areas where the likelihood of UXO presence is elevated. For a given set of experimental design parameters (transect width, anomaly detection efficiency, false alarm rate), VSP will compute the required spacing of widely separated sample paths, referred to as transects, to achieve a specified probability of traversing a target area. It also calculates the probability of detecting a target area of specified size and density if it exists. (Ref. 7)

After the data have been collected, VSP's target identification algorithm calculates the density of anomalies and marks areas of high density. Geostatistical estimation using a kriging algorithm is used to interpolate information in the unsurveyed areas between transect locations. From these analyses, both the probability that an area is within a target and the anomaly density can be estimated. The MTA transect data were used for this statistical analysis.

2.4 Magnetometer Data

The magnetometer data from both platforms were analyzed to estimate distributions of magnetic anomalies which can be used to locate and bound targets, aim points, and other areas of concentrated munitions. In addition, physical characteristics of objects giving rise to individual anomalies were estimated using physics-based analysis. Estimates of location, depth, and rough size were used in conjunction with validation of more than 200 targets by divers to confirm the results of the magnetometer survey.

3.0 DEMONSTRATION DESIGN

3.1 Selecting the Test Site

ESTCP received Congressional direction to study the Toussaint River area. From historic activities at Camp Perry and the former Erie Army Depot, it is known that there is a large impact area in Lake Erie and there are other impact areas in the swampy land adjacent to the large impact area and Lake Erie. The primary interest of the community is in the UXO that affects dredging the navigation channel to the river. A study area consisting of ~50,000 acres was selected based on these factors, as illustrated in Figure 6.

3.2 Test Site History/Characteristics

The subject study area consists of the beach and area of the Lake Erie fronting the former Erie Army Depot (now called Erie Industrial Park), between Camp Perry Ohio National Guard Training Center and the mouth of the Toussaint River in northwest Ohio (Figure C-6). This FUDS site is located in rural Carrol Township, Ottawa County, OH, on Lake Erie, approximately 37 miles east of Toledo, Ohio, and 6 miles west of Port Clinton, Ohio. The Erie Army Depot was initially established in 1918 as the Camp Perry Proving Grounds, then redesignated as Erie Proving Grounds. For almost a half century (1918–1966) this site was used by the Department of the Army for testing and proof-firing of artillery and as an ordnance storage and issue center. (Ref. 2) Proof testing of projectiles and the gun barrels that were designed to fire them took place from a series of 15 fixed gun emplacements located adjacent to one another in a line about 2000 meters inland from the beach.

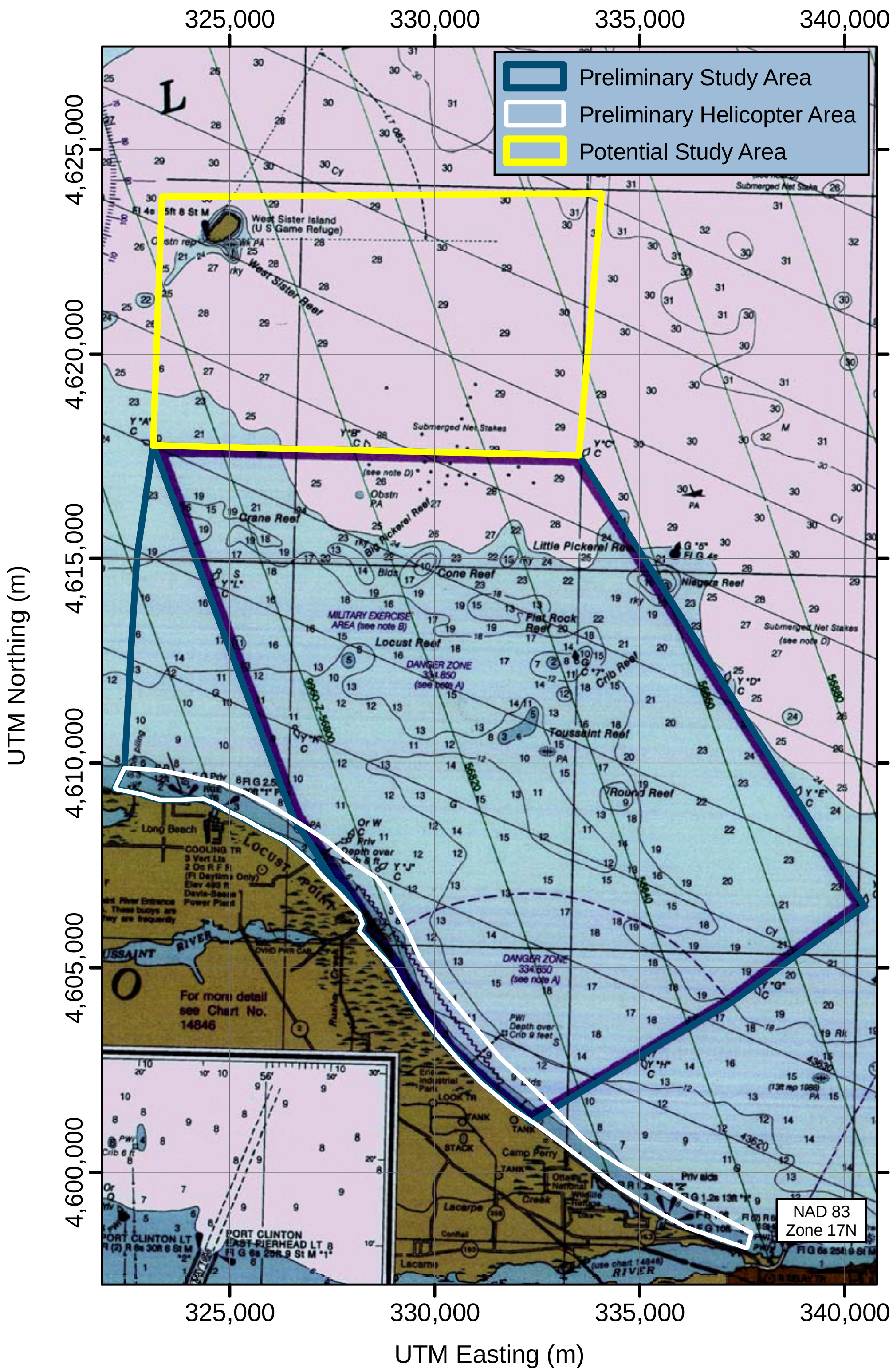


Figure C-6. Study area for the Toussaint River demonstration.

Camp Perry was established in 1907 by the state of Ohio for the training of the state National Guard. Part of the camp was used to establish the Erie Army Depot in the spring of 1918. During the next 2 years, the site was used to proof fire (verify the cannon will withstand the pressure of firing) thousands of pieces of artillery. Between World Wars I and II, the site was less active and was used primarily to warehouse and issue various items of ordnance. In 1941, the artillery test firing mission of the site was reactivated in support of World War II and the name of the facility was changed to the Erie Proving Ground. During the next 5 years, 70 percent of the mobile artillery used by the U.S. Army or provided to Allied armies was tested and proof-accepted at Erie Proving Ground. Between 1946 and 1951, the site reverted to a peace-time role and was renamed the Erie Army Depot. Late in 1951, the depot assumed the additional roles of anti-aircraft support testing and the overhauling of surface-to-air guided missiles in support of the Korean Conflict. Additional activities included logistical support to Regular Army and National Guard anti-aircraft units training at Camp Perry. Test firings of Vietnam-era munitions continued into the mid-1970s.

Figure C-7 illustrates 1965 period firing fans and target zones related to the present Erie Industrial Park. Discussions with previous employees of the Erie Army Depot and present officials of Camp Perry indicate that the firing source and range patterns have been similar for other periods. The Erie Army Depot was excessed by the General Services Administration in 1966 and closed in 1967. However, ARES, Inc., under contract to the Federal Government, has continued to manufacture and test fire artillery and other large-caliber barrels on this property as a commercially owned and operated enterprise. ARES reportedly fires inert rounds into the land targets and collects the rounds. The majority of acreage encompassing the former Erie Army Depot site is no longer Federal property and is now classified as a FUDS. Approximately 5.7 km^2 (1,400 acres) of property at the former Erie Army Depot is leased from the State of Ohio to private land owners.

Several impact areas in Lake Erie were established by the Erie Army Depot in order to test artillery by proof firing. The boundaries of these areas are generally known for the World War II era and well known from the 1960’s to present (Figure C-7). The heavy caliber lake impact areas, which are currently used by Camp Perry, are significantly smaller in size than those documented as being active by Erie Army Depot in the earlier years (Figure C-7). Approximately 388 km^2 (96,000 acres) of Lake Erie and 5.78 km^2 (1,427.75 acres) of land are classified as formerly used target areas. The currently maintained impact/safety zone used by Camp Perry includes 145.8 km^2 (36,033 acres) of the FUDS Lake impact zone. (Ref. 1 and 2) In addition to the test firing conducted by the Erie Army Depot, these impact areas were extensively used in training missions by the Navy, Air Force, National Guard, and Army Reserves. These multiple uses and 75-year history of ordnance firings is reflected by the wide range in type and caliber of ordnance recovered on or near the former impact areas. Ordnance recovered or identified on the FUDS beaches include a broad variety of direct fire and indirect fire munitions currently or formerly maintained in the arsenals of U.S. military forces. Shells range in size from the largest World War I 240-mm and more recent 155-mm artillery rounds to smaller World War II 45-mm armor-piercing projectiles and 1960’s 60-mm mortars.

Several previous activities have uncovered a variety of munitions types. These activities have included dredging, a time critical removal action (TCRA) and a beach removal action. The munitions types are listed in Table C-1. (Refs. 1–4) In addition to those items known to have been fired over the life of the range, it has been anecdotally reported, but not confirmed, that munitions were dumped from barges in the vicinity of the impact area during the 1960s. If this in fact occurred, types of munitions and quantities were not documented.

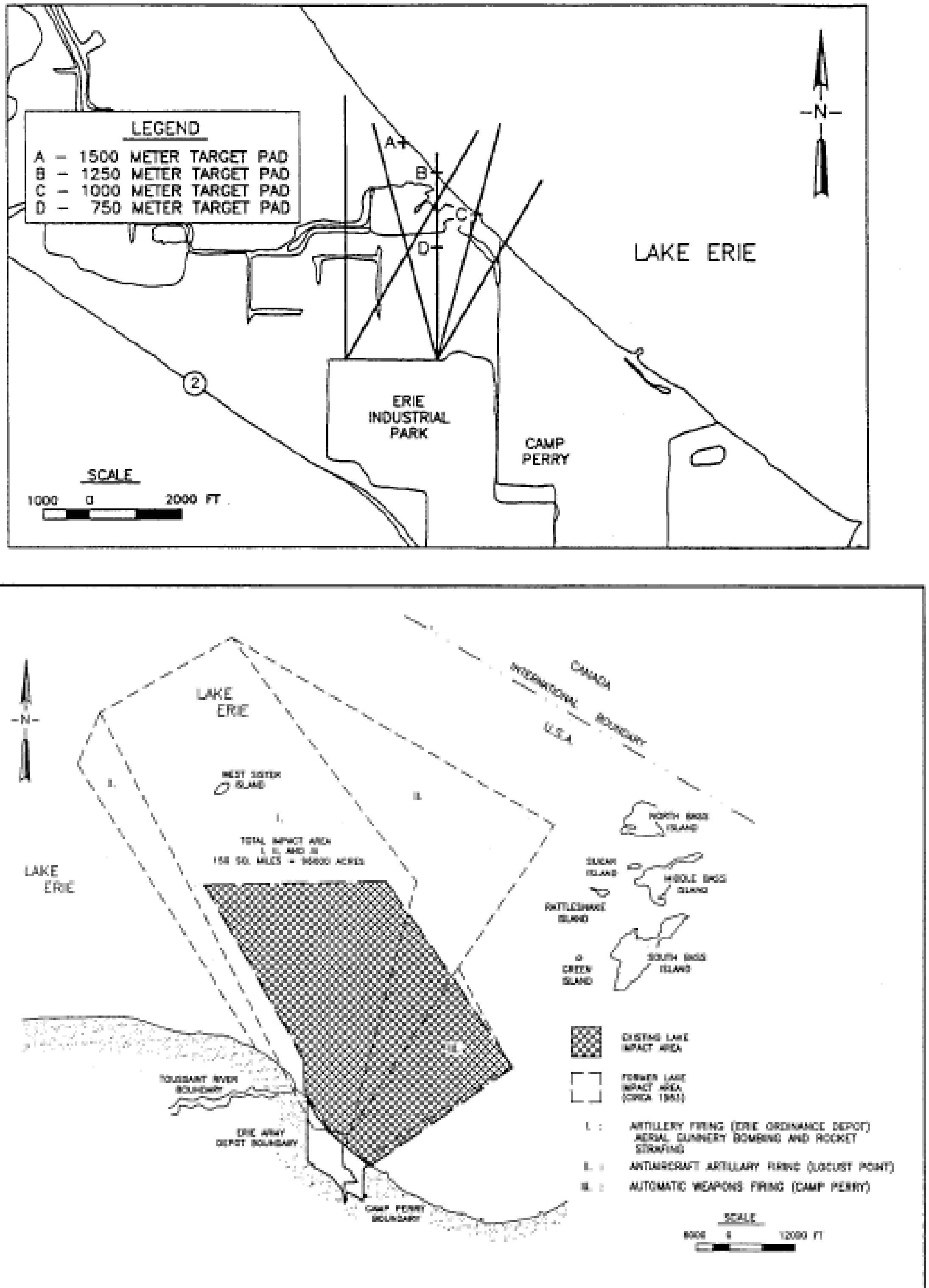


Figure C-7. Firing fans and historic target locations for Erie Army Depot in 1965.

Table C-1. Compilation of munitions found in previous activities.

Munition Type	Comments
3.5 inch rocket	Found during dredging
60 mm mortar	Found during dredging, beach removal action and TCRA
106 mm projectile	Found during dredging, beach removal action and TCRA
M52 fuze	Found during dredging
M15 Smoke Grenade	Found during dredging
105-mm projectile	Found during dredging, beach removal action and TCRA
90-mm projectile	Found during dredging and TCRA
20 mm projectile	Found during Beach Removal Action
165 mm	Pieces found during Beach Removal Action
40 mm	Found during TCRA
75 mm	Found during TCRA
81 mm	Found during TCRA
155 mm	Found during TCRA

3.3 Present Operations

At present, the site is used for limited firing from Camp Perry and the ARES facility in the former Erie Army Depot. The immediate area near the Toussaint River is used for recreational and commercial boating. The land area north of the former Depot is owned by the Toussaint Shooting Club and maintained for recreational hunting. Security is present at Camp Perry and the ARES facility, but there are no restrictions on public access to the water and beaches.

3.4 Sensor Calibration Targets

The operation of the two sensor platforms on site was verified using common calibration targets. The calibration targets for the two magnetometer systems are listed in Table C-2. The helicopter calibration targets were placed on the ground surface at a spacing of 50 m. Each day, the system was flown over the targets and the resulting signatures compared to calculated responses to confirm that the system was operating at its expected sensitivity. (Ref. 6)

The marine calibration targets were emplaced in a line in the river channel near the base marina at a spacing of 20 m. The targets were tethered to a long rope, which was anchored by rebar driven into the sediment at either end. Locations of the rebar and the target were surveyed. The marine system surveyed the calibration line several times during the deployment and recorded signal strengths were compared to archived data for common items to confirm the system was operating properly. (Ref. 5)

3.5 Period of Operation

The schedule for the demonstration at Toussaint River is given in Table C-3. Details of the individual technology demonstrator's schedules can be found in their respective reports. (Refs. 5 and 6)

Table C-2. Calibration targets emplaced for the Toussaint River demonstration.

Helicopter-borne Magnetometer			Marine Array		
Item	Depth	Orientation	Item	Depth	Orientation
8″ steel cube	ground level		16-lb shotput	proud	
100-lb bomb simulant	ground level	1 N-S 1 E-W	105 surrogate	proud	N-S 45°
155mm projectile	ground level	1 N-S 1 E-W	155 surrogate	proud	E-W 45°
2.7″ warhead	ground level	1 N-S 1 E-W	Re-bar	Flush with sediment	N-S E-W
			81 mm surrogate	proud	E-W 45°

Table C-3. Schedule for the demonstration at Toussaint River.

Date	Action
23 May 2006	Initial site visit by ESTCP
19 July 2006	Overall demonstration plan
1 August 2006	Draft demonstration plans from contractors
12 August 2006	Demonstration plans final
17 August 2006	Marine survey begins
9 September 2006	Helicopter magnetometry survey begins
16 September 2006	Helicopter magnetometry survey ends
21 September 2006	Marine survey ends
1 October 2006	Marine targets selected for validation
10 October 2006	Helicopter mag data targets selected for validation
October 2006	Validation on site in Lake Erie
January 2007	Draft reports from contractors
April 2007	Final reports from contractors

4.0 RESULTS

4.1 Marine Towed Array

The lake area that has been historically used for munitions activity is too large to survey at 100% coverage with the available resources. Selected areas deemed most likely to contain UXO that could migrate to the dredge area and river mouth were selected for characterization. As such, the land-based impact areas were not studied. The study was focused on the current-day exclusion zone, shown in heavy outline in Figure C-8, but the scope included the lake areas out to West Sister Island, as well as the beach and river.

PNNL, using VSP, designed the survey approach and transect sampling plan for the Lake Erie project. The VSP requires a hypothesis describing the target area sought, including the size, shape and anomaly density of the target. In this case, there was little historical information to construct such a model with high confidence. The transect survey plan was developed to cover the maximum area possible at relatively sparse coverage, with the intention that initial data could guide adjustments, if needed.

The survey transect plan is shown in Figure C-8. The main impact area was expected in the lower section outlined in purple. This corresponds to the exclusion zone used throughout the history of the base and is in closest proximity to the mouth of the Toussaint River. This area was deemed highest priority and surveyed first. The east/west transects are spaced 165 meters apart in the main survey area. The extended area shown in yellow was once part of the historical impact area. In the event that resources allowed, additional sparser transects were planned in the extended area, with the spacing increased to 330 meters.

The marine survey was carried out between August 17, and September 21, 2006. Figure C-9 shows the transects as they were actually surveyed. Because the size of the target area was uncertain, initially every other transect was surveyed. As initial data were analyzed and it became apparent that the target area was more extensive and dense than the planning assumptions, it was decided that the alternate transect approach was sufficient for target characterization and would allow a larger area to be investigated. In the south part of the main survey area, the odd numbered transects were surveyed. In the north part of the main survey area, every fourth transect was surveyed. Upon completion of the main survey area, additional transects were sampled in the extended area out to West Sister Island, shown in the northwest corner of Figure C-9. Five roughly equally spaced transects were surveyed.

Several additional lines were surveyed parallel to the shoreline. These passes were intended to overlap with the airborne survey to provide some common survey areas and targets for comparison of the MTA and the Airborne systems.

An automated target picker was used to select likely targets. The threshold was chosen to exclude very small targets (those likely too small to be projectiles) and the target picker was run to exclude targets that did not have more than half of the target signature included in the survey data. The automatic target picker choices are shown in Figure C-9 as yellow circles superimposed on the survey transects. Approximately 5,500 targets were identified in the transect areas.

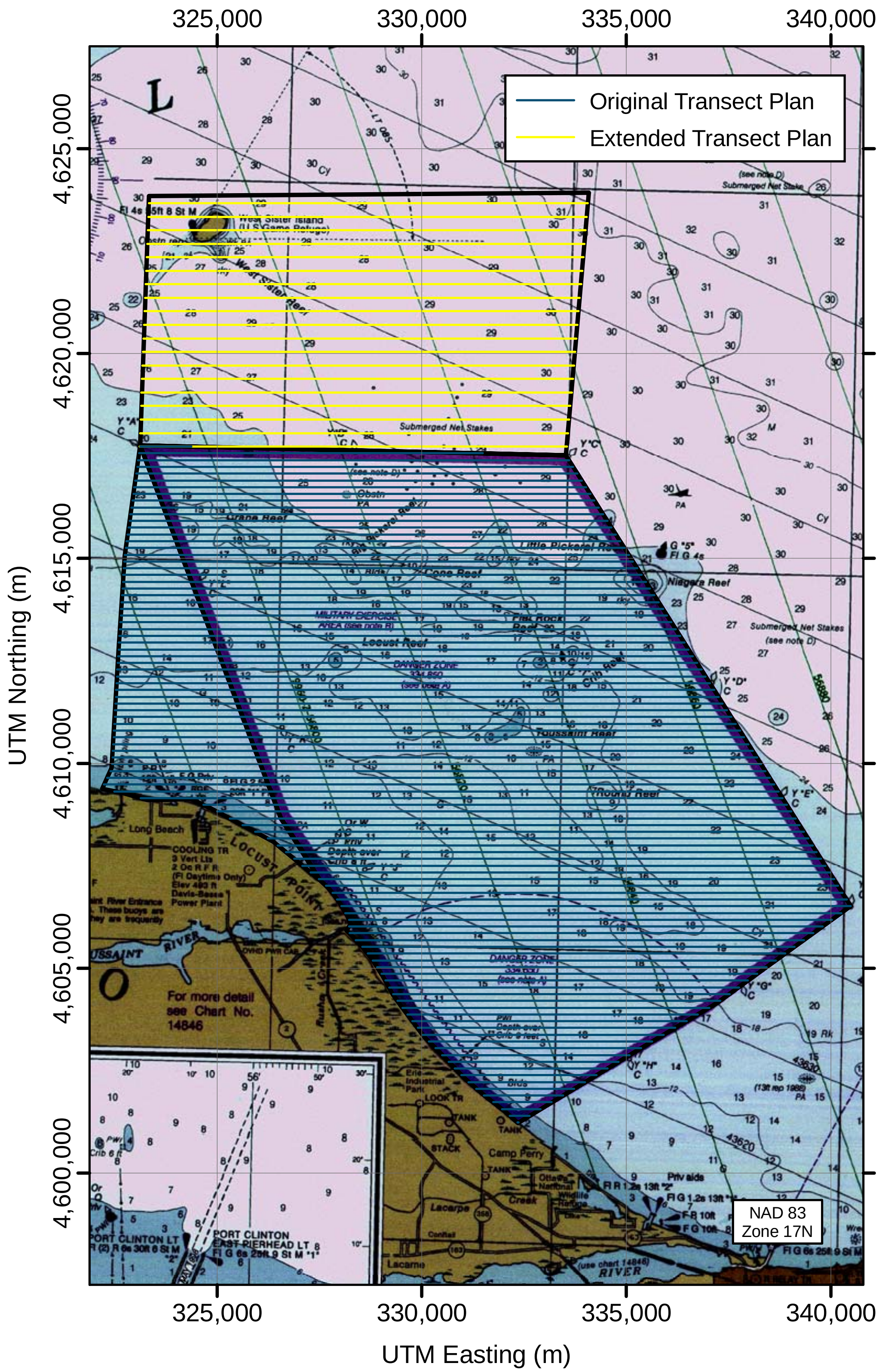


Figure C-8. Lake Erie map with planned transects.

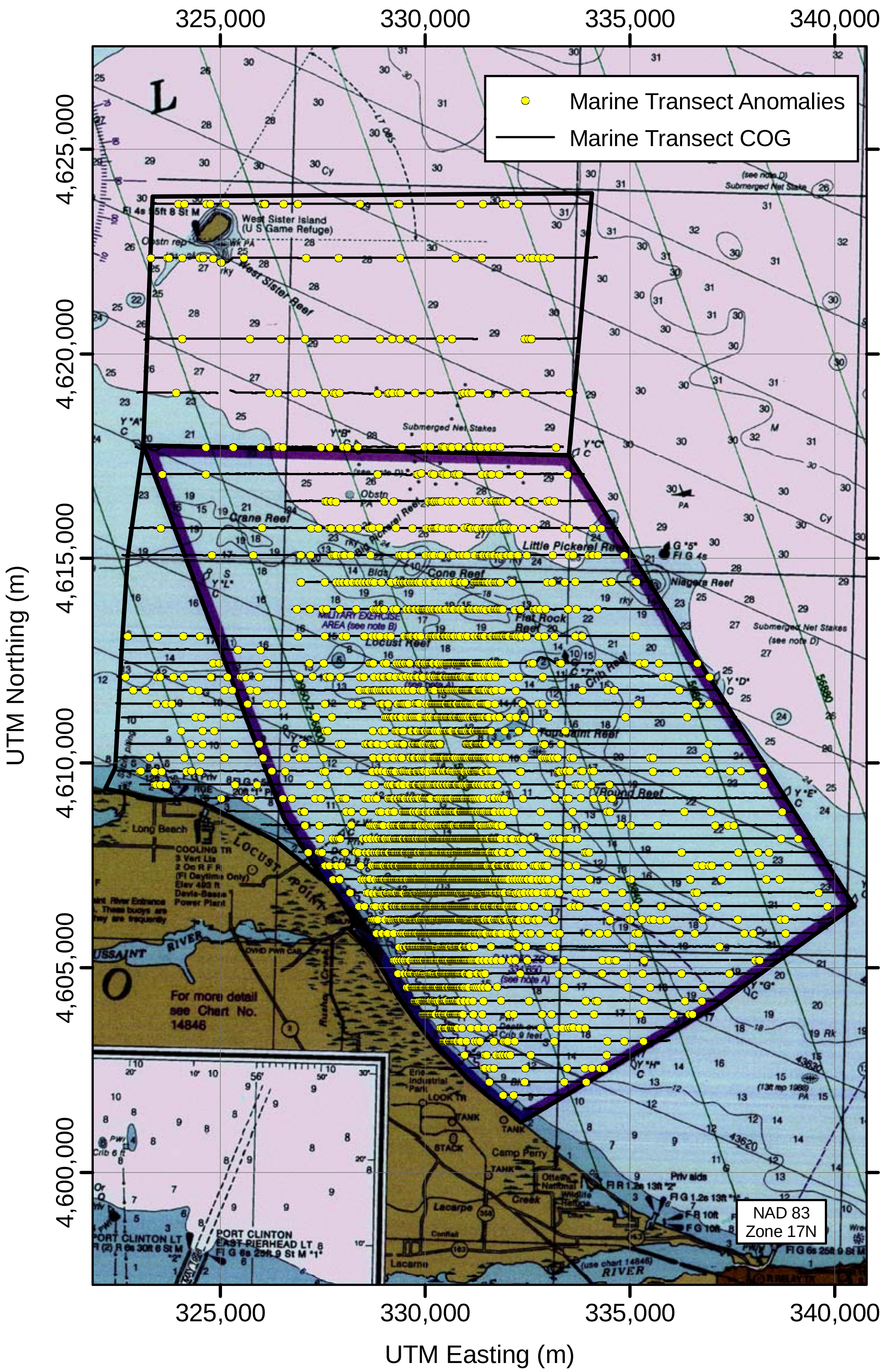


Figure C-9. Marine transects as surveyed.

Figure C-10 shows a magnetic anomaly image composed of data clips from a single transect. The green represents the background magnetic measurements and the red and blue are positive and negative deviations from background. Typically, compact metallic objects, such as munitions, exhibit a dipolar signature with positive and negative lobes. The analyst's target identification number is shown in white. The white polygons are those drawn by the analyst to define individual targets. The data within the boxed area are used to estimate target characteristics for the targets that were selected for validation by the divers. As shown in Figure C-10, not all magnetic anomalies were chosen for analysis. In general, targets that were identified as lying less than 3 meters from an adjacent target were not chosen for analysis. This was done to reduce the likelihood of the diver mistaking the intended target for another one nearby. In general, targets were not chosen for analysis if the majority of their signatures were not included in the 8-sensor measurement track.

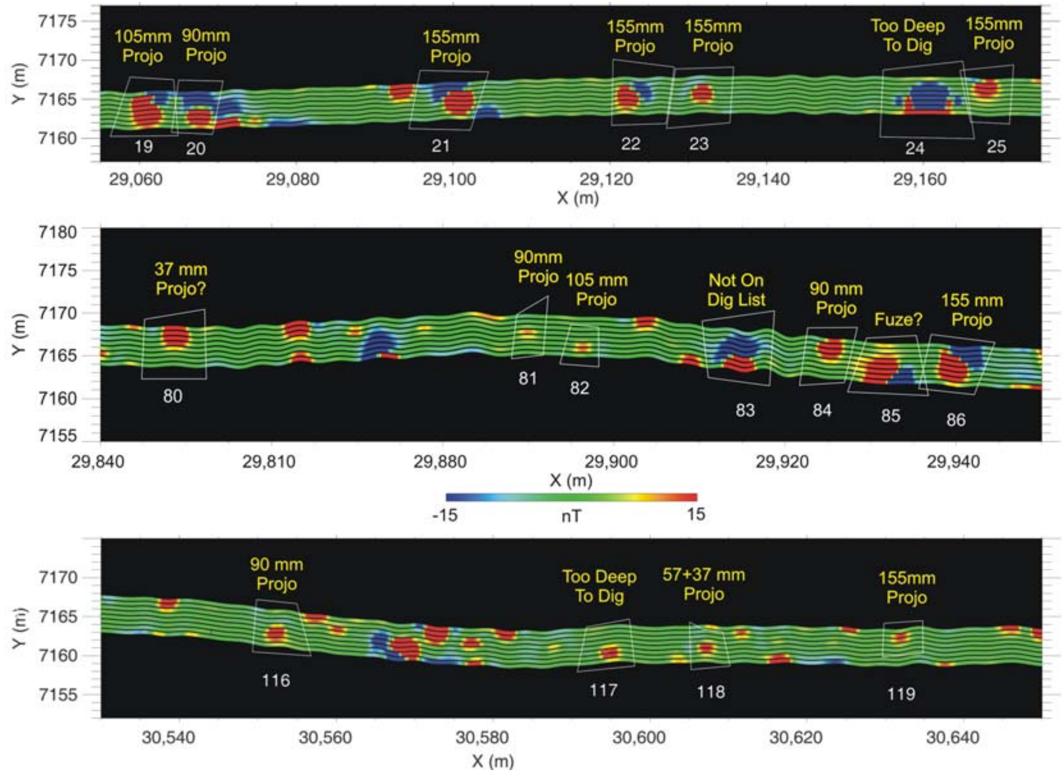
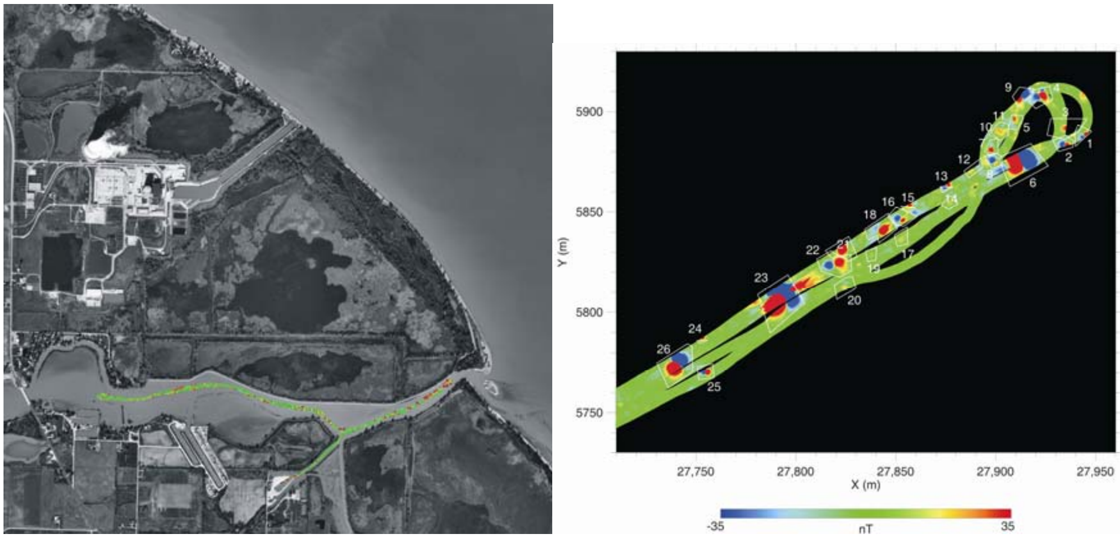


Figure C-10. Magnetometer data from a single transect in the main impact area in Lake Erie, showing targets selected for validation and their validation results.

Areas of the Toussaint River were surveyed by the MTA, as shown in Figure C-11 (a). In general, the system surveyed areas where the water depth and the width of the channel permitted operation. This was limited to a narrow swath in the deepest part of the river. Twenty-eight targets were identified for validation in the river as shown in Figure C-11(b).



(a) (b)

Figure C-11. (a) Magnetometer data collected in the Toussaint River using the MTA and (b) a close up view of the data showing the individual targets selected for validation.

4.2 Helicopter Magnetometer

Helicopter Magnetometer surveys began on 9 September 2006. The initial area surveyed was within the Camp Perry exclusion area to coordinate with dates that Camp Perry suspended firing activities to accommodate the survey. Surveying continued through the morning of 16 September 2006; on the morning of the 16th, the survey ended when pilot error caused an incident resulting in the helicopter landing in the water. While the helicopter was severely damaged, the pilot and sensor operator escaped without injury. Approximately 80% of the planned surveys were completed prior to the accident.

At the Toussaint River site, the distance of the sensor above potential targets was increased by the water depth. This resulted in significant reduction of anomaly amplitudes compared to surveys conduct over land (particularly in deeper water). There was a corresponding reduction in signal to noise of the targets. A total of 1,904 anomalies were selected from the data to assess the distribution of metal objects across the study area. Figure C-12 illustrates the locations of these anomalies and their densities over the WAA study area. Scattered anomalies are seen throughout and several concentrations are identified in the very near shore area.

Of the 1,904 anomalies detected, 1,155 had sufficient signal to be analyzed to estimate target parameters. The size estimates for the vast majority of these targets corresponded to objects of 150 mm or larger. These size estimates are consistent with the large projectiles known to have been fired on the site, which are expected to be within the detection capability of the helicopter system.

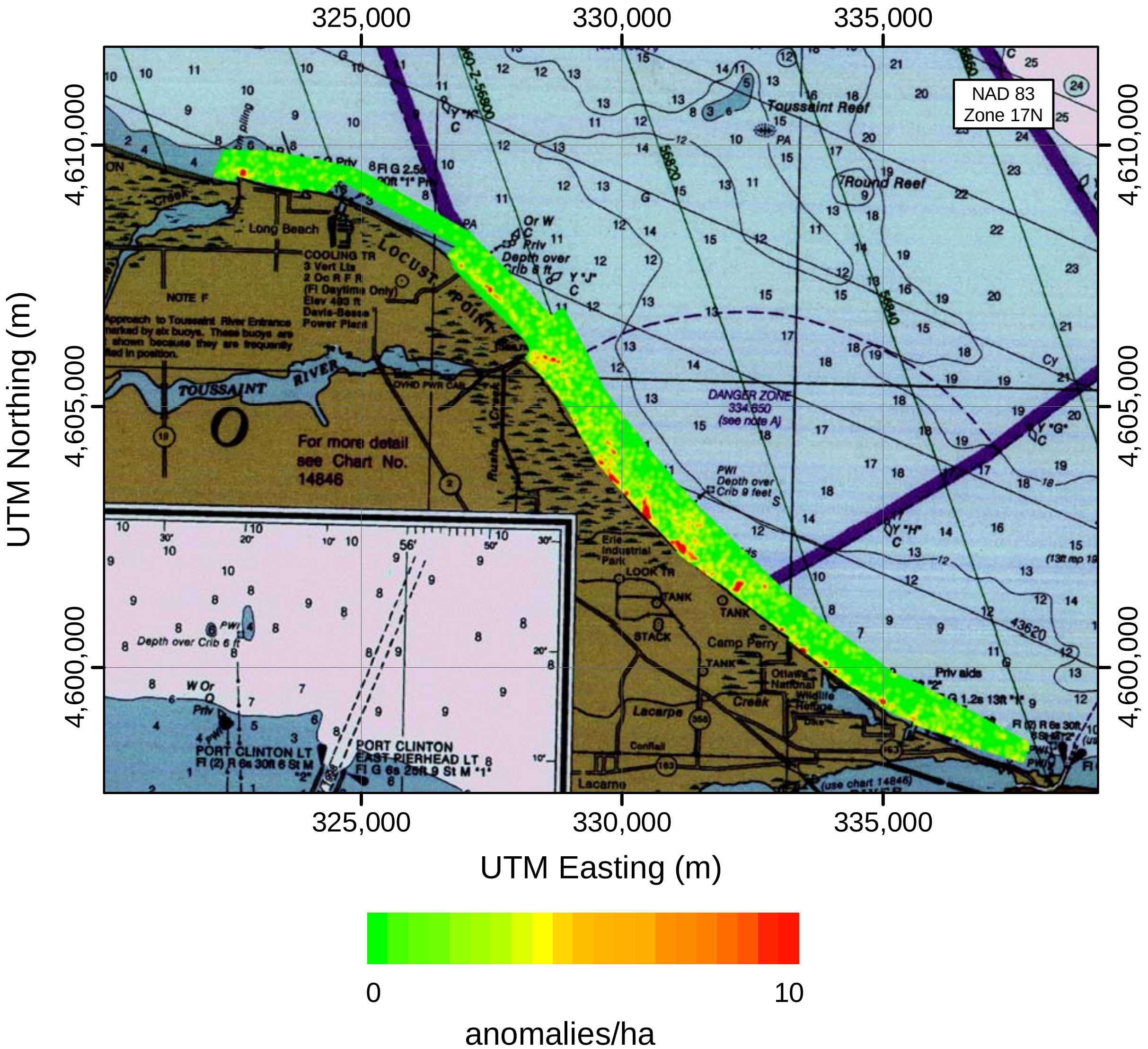


Figure C-12. Magnetic anomaly density estimates from the helicopter magnetometer survey.

4.3 Validation

Based upon the analysis of the MTA survey and the Airborne survey, 255 targets were selected for validation. Divers were directed to the locations of these targets to investigate the objects that gave rise to the detections. Where possible, each anomaly on the dig list was carefully uncovered so that it could be examined to identify the item, its condition, and to determine if it could be brought to the surface. Figure C-13 shows an example of ordnance recovered from Lake Erie. In some cases, the bottom composition precluded access to and/or identification of the anomaly. In other cases, the bottom composition allowed enough access to identify the anomaly, but recovery of the item was not feasible. In a few cases, the items were deemed unsafe to move.

Figure C-13. Ordnance recovered from Lake Erie during validation.

During the intrusive investigation phase of this demonstration project, a total of 229 anomalies were reacquired, investigated, and documented. Figure C-14 summarizes the results from the main impact area in the Lake. Of 186 items investigated in this area, 141 were munitions or munitions debris, ranging in size from 37-mm projectiles to 155-mm projectiles, with one general purpose bomb identified near West Sister Island. Many of the recovered items were never fuzed and contain the eye-bolts used for shipping, but scoring on the rounds provides evidence that they were fired. The two 37-mm projectiles are likely the result of the divers retrieving the incorrect target, since it is unlikely that either detection system has the sensitivity to detect these small items under the conditions of this survey. Approximately 25% of the targets validated produced inconclusive results because the targets were too deep, the bottom conditions did not permit identification, or the original signal was a results of naturally occurring geology.

No high-explosives (HE) filled projectiles were recovered during the intrusive investigations at Lake Erie. However, 33 items were identified that could not be recovered either because of the way they were fuzed or because they were not sufficiently accessible to determine their fuzing. Eleven of the intrusive investigations resulted in identification of shrapnel that resulted from high order detonation of projectiles. It appears that a fraction of projectiles fired on this range were HE filled.

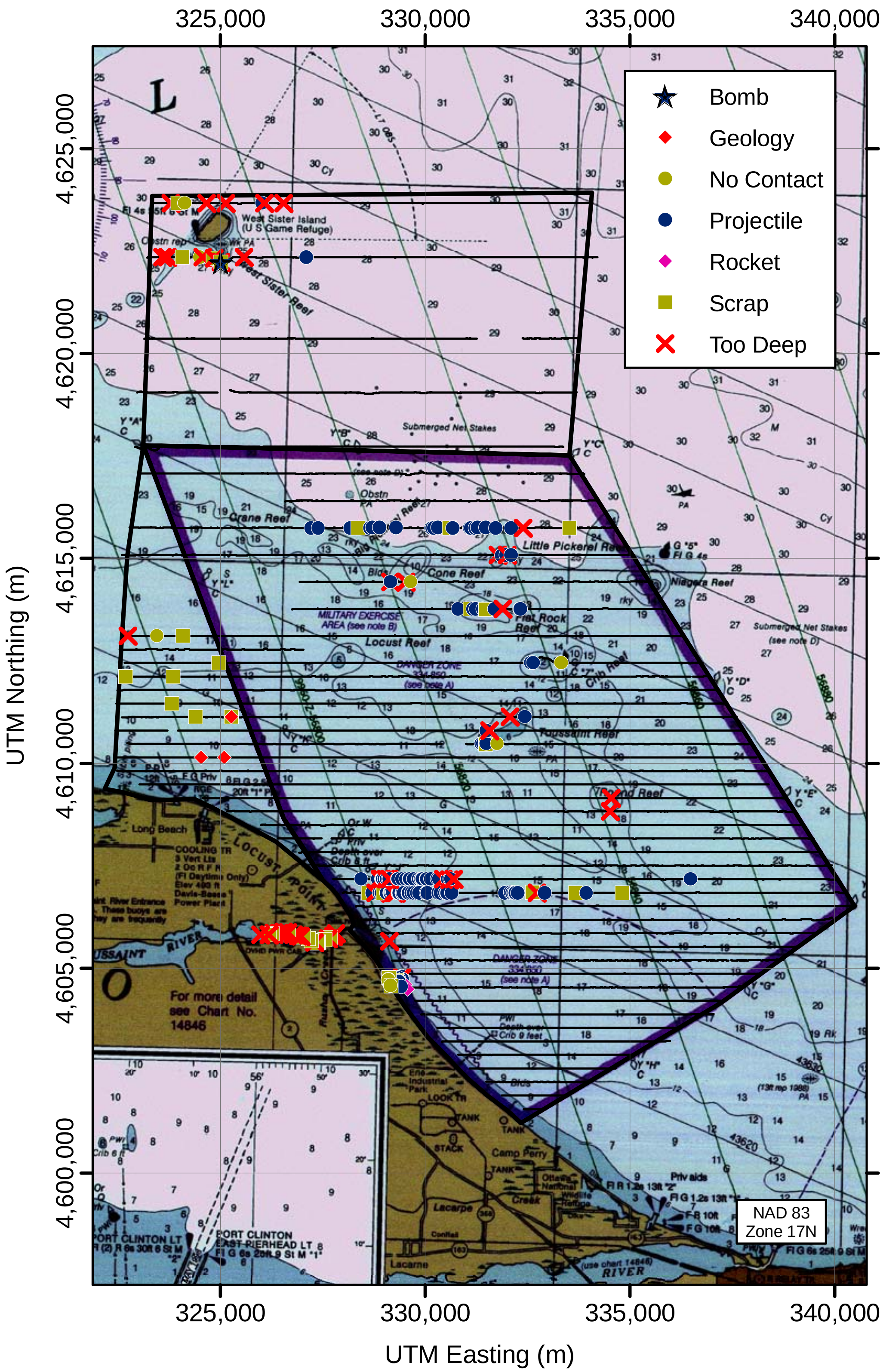


Figure C-14. Validation results.

Of the 28 intrusive investigations made in the Toussaint River, there were no UXO recoveries or identifications. However, for 21 of the 28 targets that were investigated, the diver either failed to identify any target or the analyst concluded that he recovered a target different from the one specified in the target list. There is insufficient information resulting from the investigations in the Toussaint River to determine whether UXO is present.

One item of note is the GP bomb recovered near West Sister Island. It likely resulted from an air drop, and thus tends to confirm the speculation that the island might have been used as a bombing target. However, one bomb recovery does not establish a bombing target. Investigations on the island proper would likely prove much more useful for resolving this issue. A simple surface inspection might be adequate to establish the presence of air dropped weapons. In addition, one would also expect to find 155 mm projectiles on the island, which is within range for this ordnance.

An itemized list of all objects recovered during the validation is contained in Reference 5.

4.4 Discussion and Conclusions

The primary result of this work is a comprehensive and detailed characterization of the munitions present in the vicinity of the Toussaint River, including the locations and estimated densities from the analysis of the transect data.

Lake Erie

Figure C-15 shows the extent of the main impact area and an estimate of the density of items per acre. The dark green colored boundary represents 95% of the anomalies above background and is not intended to be a rigid boundary beyond which no munitions are present. Additional anomalies present outside this main area arise from a combination of non-munitions metallic clutter and scattered munitions that fall off in density as the distance from the aim points increases. From this analysis, more than 300,000 anomalies will require investigation in an area encompassing approximately 8,000 acres, if the impact area were to be cleaned up. Validation of a sampling of more than 200 targets yielded munitions in the impact area ranging in size from 37 mm to 155 mm, with one general purpose bomb discovered near West Sister Island.

In summary, the density and general distribution of ordnance found in this demonstration survey and from the intrusive recovery of selected anomalies is consistent with the long and intense use of these ranges for proof testing a range of projectiles and guns. More than 70% of the ordnance recoveries were 90 mm, 105 mm, and 155 mm projectiles.

The demonstration produced no evidence that parts of these ranges were used to dump large caches of ordnance from barges when the range was closed for proof testing. However, the overall anomaly density in the impact area is quite high and the transects, particularly on the northern half of our survey, were quite widely spaced. It is possible that barges of ordnance could have been dumped and not detected by our transect surveys.

Toussaint River

Accessible areas of the Toussaint River were surveyed by the MTA. In general, the system surveyed areas where the water depth and the width of the channel permitted operation. This was limited to a narrow swath in the deepest part of the river. Twenty-eight targets were identified for validation in the river. All anomalies in the river that were investigated proved to be non-munitions clutter.

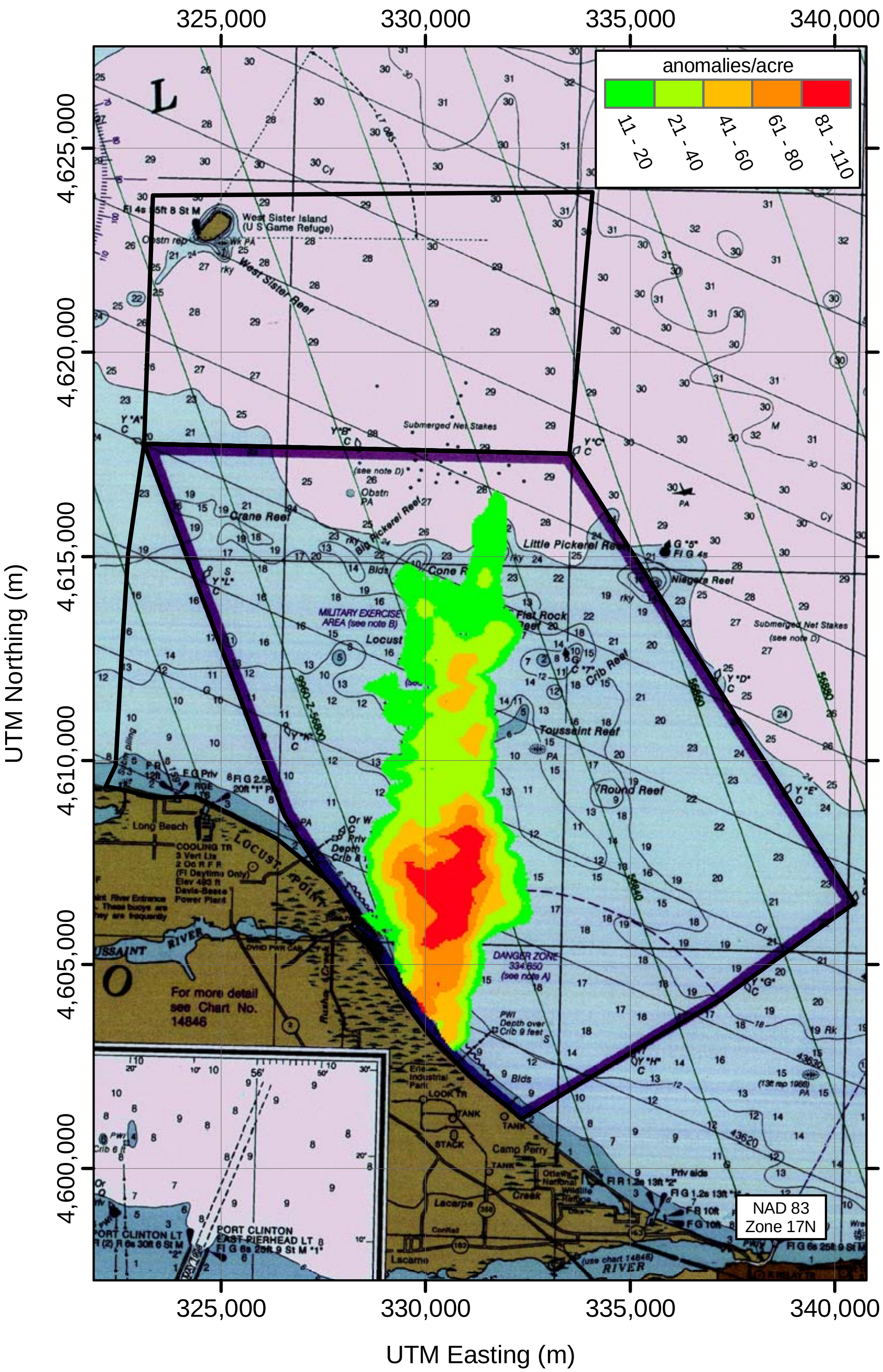


Figure C-15. Estimate of the extent and density of munitions contamination in Lake Erie. The highlighted area contains approximately 300,000 targets and encompasses about 8,000 acres.

Beach and Near Shore

The helicopter magnetometer array surveyed the beach and near-shore, shallow-water areas. Coverage on the beach was minimal, since it is very narrow and lined with trees. Nearly 2,000 targets were identified in the data, with several concentrations very near the shore line. All of the targets that could be characterized are consistent in size with large projectiles. Smaller objects may be present, but they would not necessarily be detected with this system. Validation of 18 targets in this area produced 9 munitions items (155-mm projectiles and 2.75-in rockets), as well as 4 non-UXO objects, 2 items too deep to identify and 3 no contacts, which may be a result of mobility between the time of the survey and the recovery.

5.0 REFERENCES

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Appendix D

Environmental Security Technology Certification Program (ESTCP)

Final Report

Magnetometer Transect Survey of AOI 6 – Dalecarlia Impact Area, American University Experiment Station
December 2006

Contents

Acronyms

AAPP	Abbreviated Accident Prevention Plan
ASR	Archive Search Report
CSM	Conceptual Site Model
DoD	Department of Defense
DSB	Defense Science Board
DQO	Data Quality Objectives
EE/CA	Engineering Evaluation/Cost Analysis
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Sites
GIS	Geographic Information System
ha	hectare
LiDAR	Light Detection and Ranging
MRA	Munitions Response Area
MRS	Munitions Response Site
OB/OD	Open Burning/Open Detonation
USACE	US Army Corps of Engineers
UXO	Unexploded Ordnance
VSP	Visual Sample Plan
WAA	Wide Area Assessment

Acknowledgements

This demonstration would not have been possible without the assistance of personnel from the US Army Corps of Engineers. In particular, we acknowledge the assistance of Mike Peterson of the Washington Aqueduct and Andy Schwartz and Ken Shott of the U.S. Army Engineering and Support Center, Huntsville. We acknowledge the survey assistance from Ms. Katherine Kaye, Mr. Jeff Fairbanks, and Mr. Tony Buschur from HGL, Inc. We thank Sky Research of Ashland, OR for loan of the magnetometer array and Brent Pulsipher and John Hathaway of Pacific Northwest National Laboratory for assistance with the VSP analysis.

Executive Summary

In December 2006, the Environmental Security Technology Certification Program (ESTCP) Program Office and the Chemistry Division of the Naval Research Laboratory conducted a transect magnetometer survey of the Federal Property on the western edge of the Spring Valley, DC Formerly Used Defense Site (FUDS). The purpose of this demonstration was to evaluate the use of statistically-guided ground transects, previously validated for wide area assessment (WAA), to locate and bound an artillery fan and suspected disposal site associated with the former American University Experiment Station in the Spring Valley neighborhood of Washington, DC. These techniques have been successfully demonstrated on aerial bombing targets during the 2005 ESTCP Wide Area Assessment Pilot Program. Specific goals of the demonstration included:

- investigate the suspected range fan on Federal property west of Dalecarlia Parkway,
- search a 1-ha area around a suspected disposal area for any evidence of a concentration of munitions, and
- characterize site conditions for future work - provide information about the Muntitions Response Site (MRS) conditions to support future investigation, prioritization and cost estimation tasks.

A statistical planning tool, Visual Sample Plan (VSP), was used to design transects calculated to give a 100% change of traversing and a high likelihood of detecting a 45-m radius area of concentrated magnetic anomalies. Additional transects were planned for a 1-ha area that may contain a disposal area. The survey was conducted using a 1.5-m wide, four sensor magnetometer array on loan from Sky Research, Inc. Additional characterization surveys were conducted at the Naval Research Laboratory's Ordnance Classification Test Field at Blossom Point, MD.

Using data collected at Blossom Point, we demonstrate that the array and deployment method are capable of detecting the target munitions and fragments. Survey results however, show that the background density on the site is substantially higher than estimated during the planning process. We conclude that it is not reasonable to expect to find a lightly-used target on a site with this background density using statistical methods. From the data we collected, we can conclude with 80% confidence that there is no 45-m radius target with a density of 250 anomalies per acre or greater on this site. These results do not imply that there are no munitions on the site; they do demonstrate that there is not a 45-m radius area of concentrated magnetic anomalies on this site. Similarly, the results from the 1-ha sub-area do not show the large, extended anomaly that would be expected from a disposal area.

During the course of this survey, we collected high-quality geophysical data that will be useful in the planning process for future investigations on this site. These data have been transmitted to the site team.

Magnetometer Transect Survey of AOI 6 – Dalecarlia Impact Area, American University Experiment Station December 2006

1. INTRODUCTION

1.1 Background

Unexploded ordnance (UXO) contamination is a high-priority problem for the Department of Defense (DoD). Over the past ten years, the Environmental Security Technology Certification Program (ESTCP) which is charged with promoting innovative, cost-effective environmental technologies by demonstrating and validating those technologies, has sponsored a number of demonstrations of technologies to detect UXO [1].

In December 2003, a Defense Science Board (DSB) Task Force on Unexploded Ordnance issued a series of recommendations about the UXO problem [2]. In response to the DSB Task Force report and recent Congressional interest, ESTCP sponsored a Wide Area Assessment Pilot Program beginning in FY 2005 to validate the application of a number of recently developed and validated technologies as a comprehensive approach to Wide Area Assessment.

One of the technologies demonstrated as a component of the Wide Area Assessment Pilot Program was statistically-guided ground transect surveys to locate areas of concentrated munitions contamination such as firing points, target rings, burial pits, etc. Although the typical Wide Area Assessment site was thousands of acres, the transect methods are applicable to any size site.

1.2 Objective of the Demonstration

The purpose of this demonstration was to evaluate the use of statistically-guided ground transects technologies, previously validated for wide area assessment (WAA), to locate and bound an artillery fan and suspected burial site associated with the former American University Experiment Station in the Spring Valley neighborhood of Washington, DC. These techniques have been successfully demonstrated on aerial bombing targets during the 2005 ESTCP Wide Area Assessment Pilot Program. Specific goals of the demonstration include:

- confirm the presence of the suspected range fan on Federal property west of Dalecarlia Parkway,
- search a 1-ha area around a suspected disposal area for any evidence of a concentration of munitions, and
- characterize site conditions for future work - provide information about the MRS conditions to support future investigation, prioritization and cost estimation tasks.

A secondary objective was to develop an understanding of the effects of site specific factors such as terrain, vegetation, proximity to an urban area, and ordnance type that will affect applicability and limitations of the technologies used.

1.3 Regulatory Drivers

The Department of Defense (DoD) is responsible for environmental restoration of properties that were formerly owned by, leased to or otherwise possessed by the United States and under the jurisdiction of the Secretary of Defense. Such properties are known as Formerly Used

Defense Sites (FUDS). The Army is the executive agent for the program and the U.S. Army Corps of Engineers is the organization that manages and directs the program's administration. A significant portion of the remediation required at a typical FUDS site involves UXO. As noted above, a task force of the Defense Science Board has recently studied the UXO problem and has issued a series of recommendations for improvements in the assessment process. If proven valuable, these procedures will have a large impact on the FUDS restoration program.

1.4 Stakeholder/End-User Issues

ESTCP plans to use a process that will ensure that the information generated by WAA technologies is useful to a broad stakeholder community (e.g., technical project managers and Federal, State, and local governments, as well as other stakeholders). ESTCP demonstration team personnel presented a preliminary demonstration plan to a regularly-scheduled meeting of the Spring Valley Partners (a working group consisting of Army Corps of Engineers, national and local regulators, and community representatives) for their input and concurrence. Several features in this demonstration plan were added or modified based on feedback obtained during the presentation and a final version of the demonstration plan was published in mid-November 2006. This same group was briefed in late-February 2007 on the results of the demonstration.

2.0 TECHNOLOGY DESCRIPTION

The Wide Area Assessment Pilot Program consisted of a number of technologies, each of which contributed to the overall goals of the demonstration. These technologies can be thought of in a layered fashion. The top layer consisted of the various sensors deployed from (relatively) high-flying fixed- or rotary-wing aircraft. These were referred to as “high-airborne” technologies. These sensors include Light Detection and Ranging (LiDAR) sensors for measuring variation in surface elevation and orthorectified photography. These sensors are designed to detect anomalies that can be referred to as “ordnance-related features.” These are features such as target rings, craters, and possibly surface metal that can be associated with the presence of UXO.

The next layer was a helicopter-borne magnetometer array. This technology is designed to detect subsurface ferrous metal directly. The magnetometer data can be analyzed to extract either distributions of magnetic anomalies which can be used to locate and bound targets, aim points, and OB/OD sites or individual anomaly parameters (location, depth, rough size, etc.) that can be used in conjunction with target remediation to validate the results of the survey.

The final layer of the Pilot Program was a ground survey of portions of the demonstration site using a vehicular-towed array of magnetometers. These ground surveys were deployed in two modes. The first was in conjunction with statistical transect planning with the goal of defining target locations and bounds. Additional ground surveys were conducted to validate the results of the airborne layers. These validation surveys consisted of 100% coverage of selected areas with emphasis on areas that have been declared to be outside a target by the airborne systems.

Of these technologies, only the ground-based techniques are applicable to this relatively small, heavily-treed site. In fact, the tree coverage is so dense that a vehicular system is not feasible; this demonstration was conducted with a man-portable sensor system. Details of the two components of the demonstration are presented in the following sections.

2.1 Statistical Transect Planning

Visual Sample Plan (VSP) is a statistical sampling software package developed by Pacific Northwest National Laboratory (PNNL) to provide the site investigators a simple to use, statistically-defensible method of gathering and analyzing their data for site characterization. VSP contains a module to aid in transect sampling to identify areas where the likelihood of UXO presence is elevated [3]. For a given set of design parameters, VSP will compute the required spacing of transects to achieve a specified probability of traversing a target area of a specified size and density, calculate the probability of both traversing and detecting the target zone if it exists, display the proposed transects on the site map and output the x,y coordinates of the proposed transects. The user can then conduct a sensitivity analysis by evaluating the effects of varying the input parameters and their required Data Quality Objectives. These methods and tools allow the project team to balance DQO objectives against costs and other site constraints.

After survey data have been collected, VSP's target identification algorithm uses a circular window that systematically moves along each transect surveyed and marks points where the window has a greater anomaly density than expected from background. Because there is often no prior estimate of background anomaly density, VSP provides the capability of examining the distribution of densities found during the survey. The user can then determine an optimum critical value above background density for target detection. The effect of window size on target area detectability can be determined iteratively. With the optimum window size and appropriate background density determined, cells along the transects belonging to potential target areas are identified.

This is shown schematically in Figure D-1. Visual Sample Plan has been used to define transect spacing on the site shown outlined in blue. The suspected targets, along with an estimate of their size, were inputs to VSP which calculated the transects shown to meet the user-specified probabilities of traversing the various targets and recognizing that traversal.

An example of the application of this process at Pueblo Precision Bombing Range #2, CO is shown in Figures D-2 through D-4. Figure D-2 shows the transects that were planned to characterize the two bombing targets (known from historical records) indicated by the circles and the anomalies detected along those transects. Figure D-3 shows the areas flagged by VSP as being above a threshold of 60 anomalies/acre and Figure 2-4 plots the geostatistical probabilities of exceeding that threshold over the LiDAR data collected on the site. Plots such as this can be used to define the boundaries of areas of concentrated munitions use for remediation.

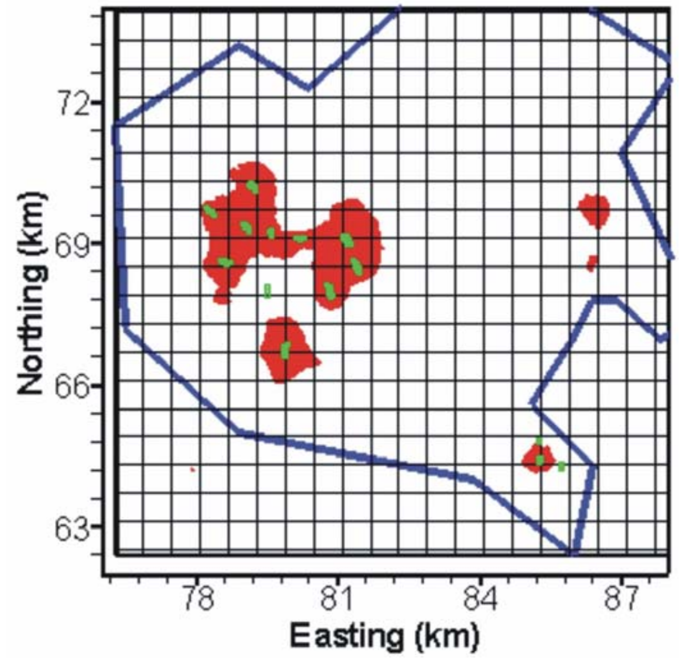

Figure D-1. Example of planned transects resulting from the use of Visual Sample Plan.

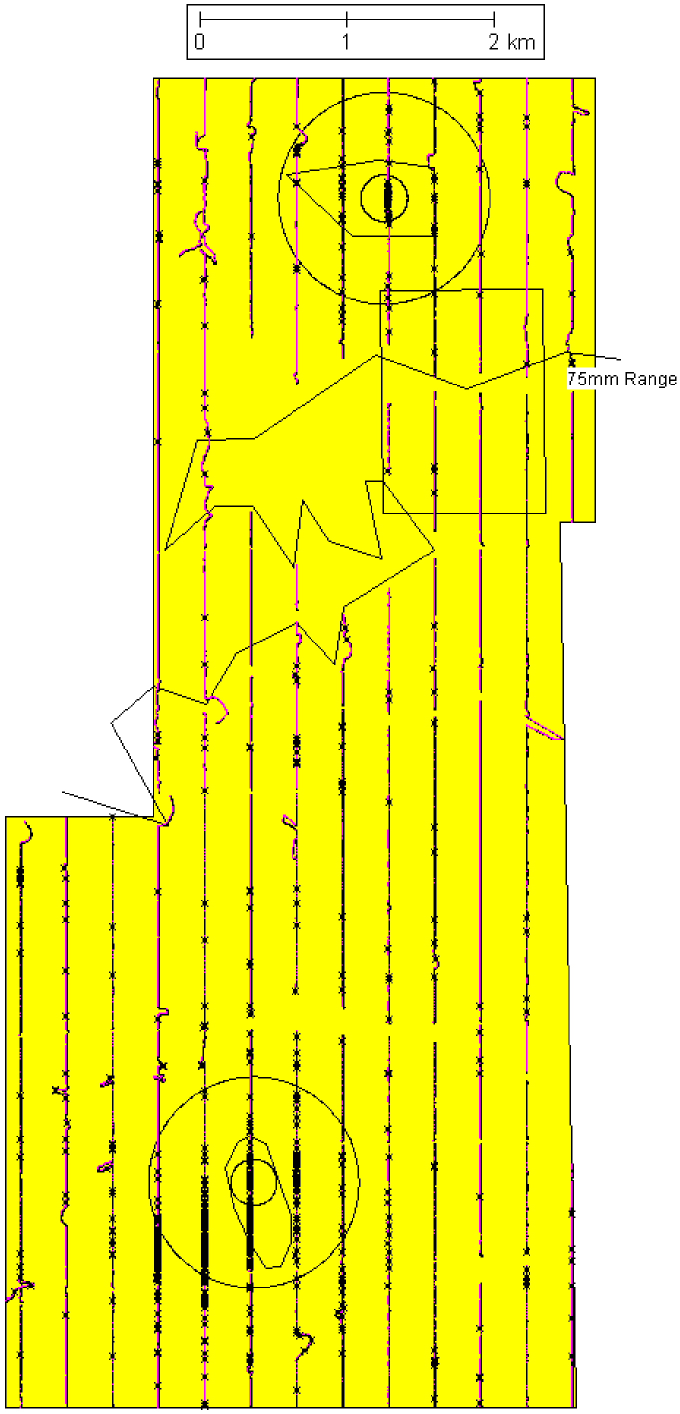

Figure D-2. Transects and detected anomalies from the WAA demonstration at Pueblo Precision Bombing Range #2, La Junta, CO. The two bombing targets known from historical data are indicated by the circles.

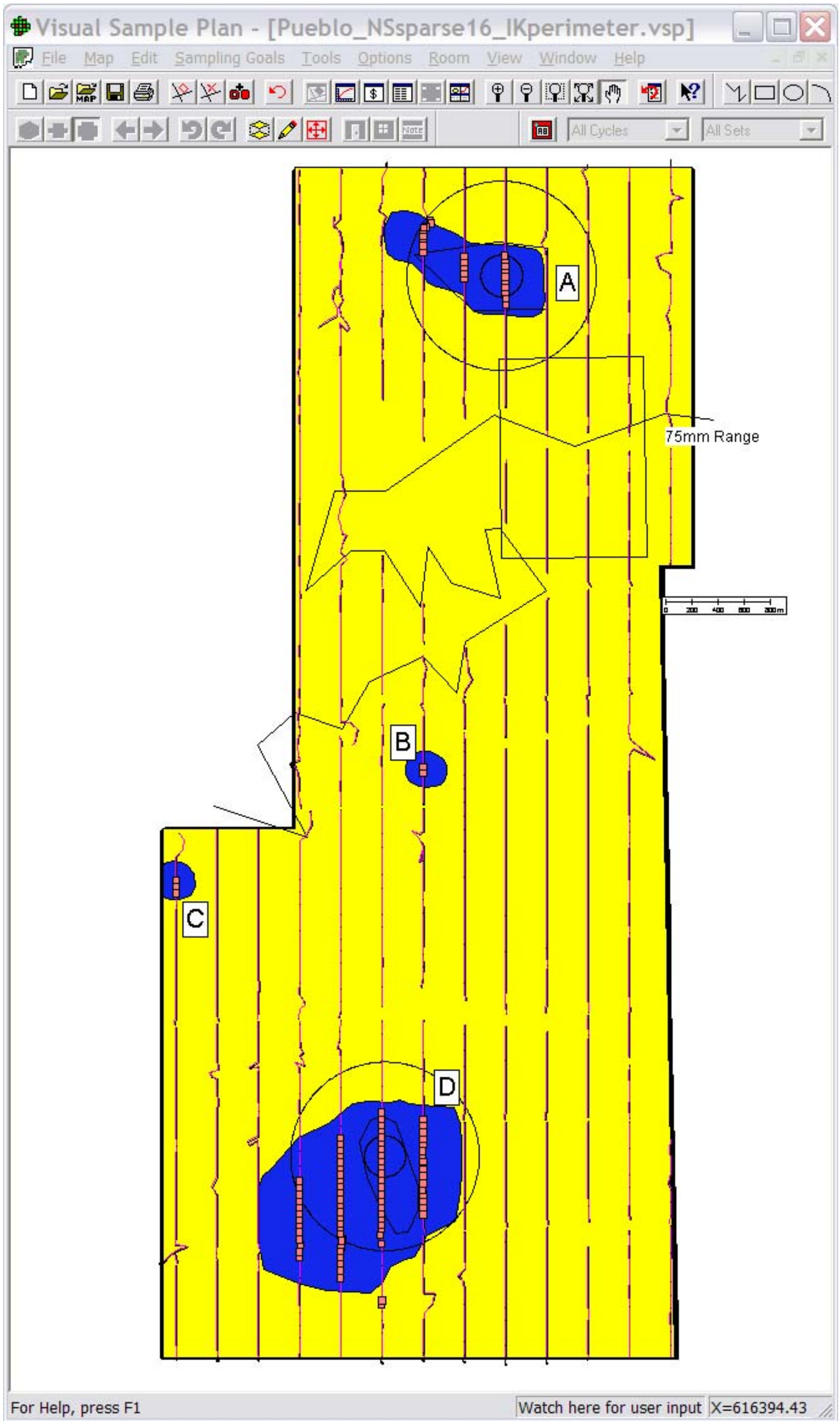

Figure D-3. Screen shot showing the VSP analysis of the data from Figure D-2. Note that the two bomb targets are flagged as areas of interest along with two additional areas with elevated anomaly density.

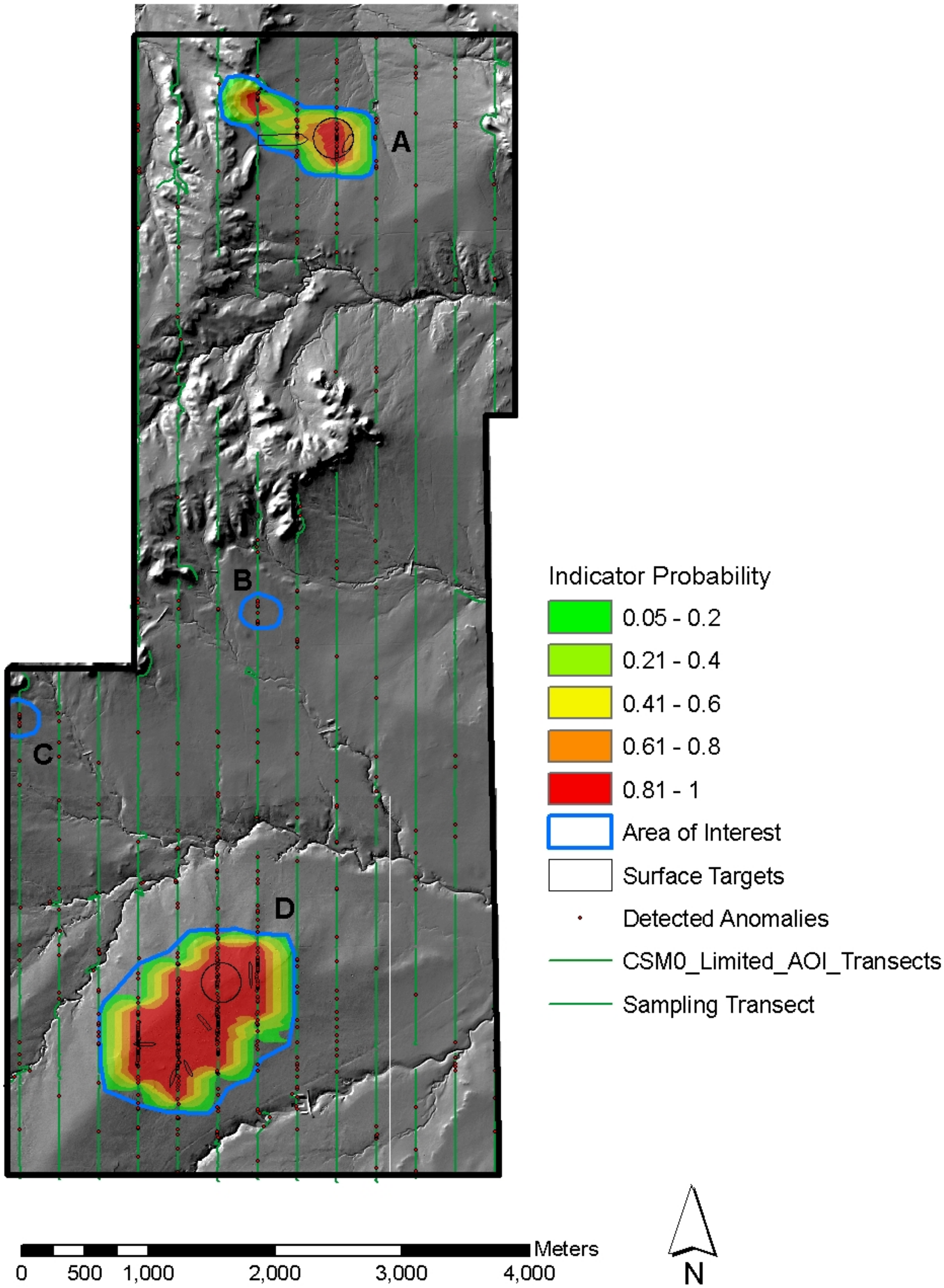

Figure D-4. Results of geostatistical analysis of the flagged areas from Figure D-3 showing the probability of a parcel having an anomaly density above a threshold of 60 anomalies/acre and a first cut at defining the extent of the areas of interest. The background is the LiDAR data collected during the demonstration.

2.2 Man-portable Magnetometer Array

The man-portable magnetometer array that was used in the demonstration is shown in Figure D-5. It consists of four Cs-vapor, total-field magnetometers arranged as a 1.5-m wide array. The sensor readings are recorded at 10 Hz which, combined with a survey speed of 0.5 to 1 m/s achieved in this demonstration, results in a down-track sampling interval of ~5 to 10 cm with 50 cm across track.

Figure D-5. Man-portable magnetometer array in use during the demonstration.

Use of the array involves two operators, the front operator carries the sensors (in front in the figure) and associated electronics (bottles behind the operator). The second operator trails with the data recording electronics. The sensor array is shown with a low-magnetic signature GPS antenna mounted over the center of the sensor boom for array positioning. We were able to use sub-meter GPS for array positioning in this demonstration.

The sensor array has been used extensively in support of the Montana Air National Guard [4]. Its characteristics and operation are well understood. In conjunction with the work at Spring Valley, we conducted additional calibration and characterization tests of the system at our Test Field in Blossom Point, MD [5]. The results of these characterization tests are presented in Section 3.4.

3. DEMONSTRATION DESIGN

3.1 Selecting the Test Site

The site for this demonstration is part of a long-term project of the Corps of Engineers, the American University Experiment Station, or Spring Valley, in Northwest DC. The specific area for the demonstration is referred to as AOI 6, the Dalecarlia Impact Area. It became of interest after the discovery of a Livens Gun Pit in August 2002. A map of the western portion of the FUDS site with the relevant points of interest marked is shown in Figure D-6.

3.2 Test Site History

The Spring Valley Formerly Used Defense Site (FUDS) consists of approximately 661 acres in the northwest section of Washington, DC [6]. During the World War I era, the site was known as the American University Experiment Station (AUES), and was used by the U.S. Government for research and testing of chemical agents, equipment and munitions. Today, the Spring Valley neighborhood encompasses approximately 1,200 private homes, including several embassies and foreign properties, as well as the American University and Wesley Seminary.

On 5 January 1993, while digging a utility trench in Spring Valley, a contractor unearthed buried military ordnance. The U.S. Army Technical Escort Unit initiated an emergency response. This response was completed on 2 February 1993, and resulted in the removal of 141 ordnance items (43 suspect chemical items) from a past burial pit.

On 3 February 1993, the U.S. Army Corps of Engineers, Baltimore District, began a remedial investigation of the site. Using historical documentation-reports, maps and photos, the Corps focused its investigation on specific sites that were determined to have the greatest potential for contamination. These sites were referred to as Points of Interest or POIs.

During the extensive, two-year investigation that followed, geophysical surveys were done at POIs considered to be potential ordnance burial locations, plus a selection of approximately 10 percent of all properties outside of the POIs. These additional properties served as a check on the historical information that had been gathered. A total of 492 properties were surveyed. Most were surveyed with a state-of-the-art electromagnetic device called an EM-31. This device is useful in identifying large metallic objects under the ground, such as ordnance burial pits. Some properties had a magnetometer survey due to the difficult terrain or other limiting conditions.

In the years since 1995 there have been a number of investigations performed at this site. A full history of this work is available at the Spring Valley web site [6].

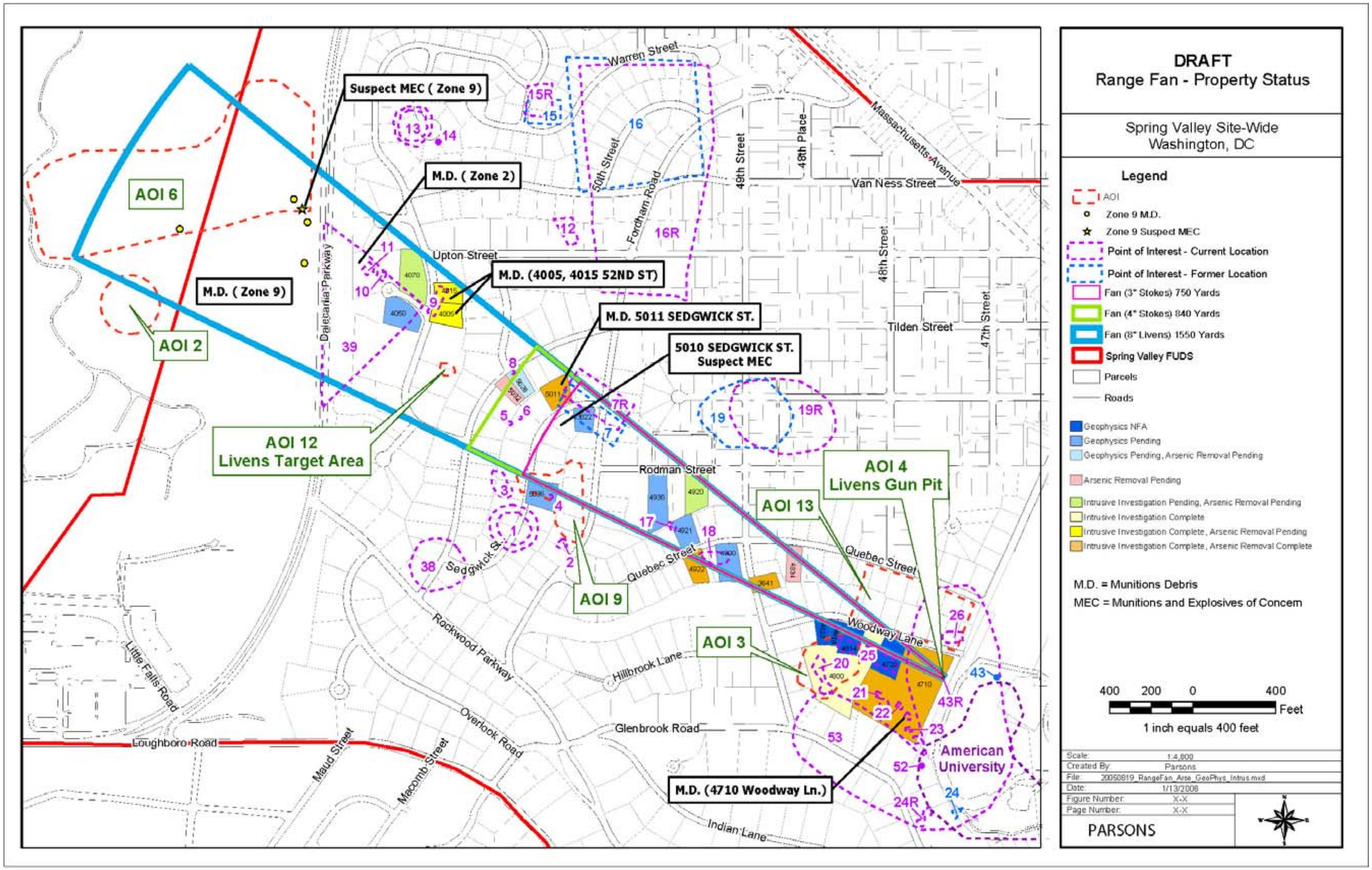

Figure D-6. Map of the western portion of the Spring Valley FUDS site with the relevant areas of interest for this demonstration marked.

The precipitating event for this demonstration was the discovery of a Livens Gun Pit in August 2002 on Woodway Lane. After discovery of the gun pit, Corps of Engineers personnel were able to determine the exact direction of fire. This direction of fire confirms other historical evidence about the use of this range. Based on historic maps and aerial photos it is believed that there were only three impact areas associated with this range. Two of these, POI 18 and AOI 12, are located east of Dalecarlia Parkway. The possible impact area west of Dalecarlia Parkway has been designated "AOI 6 - Dalecarlia Impact Area." Confirming this assumption, munitions debris has been previously identified in this area west of Dalecarlia Parkway on the Federal Property.

According to historical evidence, it is thought that only 3" Stokes, 4" Stokes, and Livens Projectors were ballistically fired on this range. Based on the maximum range of these munitions, we would only expect to find Livens west of Dalecarlia Parkway.

3.3 Site Characteristics

The demonstration site is primarily gently rolling hills with some steep banks at the edge of streams. There is moderate tree cover on the site but aerial photos show that there is substantial sky view after leaf drop, Figure D-7.

Figure D-7. Screen shot from Google Earth© showing the sky view available at the demonstration site after leaf drop.

3.1.1 Climate Data

Climate data for a reporting station on the Federal Property in NW DC is given in Table D-1. The demonstration was conducted during the first week in December so that the trees would be bare while still having moderate daytime temperatures for the field work. The actual conditions on the days of the demonstration were somewhat colder than average with daily highs in the lower 40s.

Table D-1. Climate Data for NW Washington, DC.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature (in degrees Fahrenheit)													
Avg. Temperature	32.9	36.0	45.5	54.9	64.8	73.0	77.2	75.7	69.1	57.4	47.3	37.4	55.9
Avg. Max. Temperature	43.0	46.8	57.6	67.6	77.2	84.9	88.2	86.7	80.2	69.4	58.5	47.3	67.3
Avg. Min. Temperature	23.0	25.5	33.4	41.9	52.2	61.2	65.8	64.8	57.7	45.0	36.0	27.3	44.4
Precipitation													
Precipitation (inches)	2.9	3.0	3.8	3.6	4.2	3.9	4.5	4.1	3.9	3.5	3.5	3.4	44.3

Source: Data from http://www.worldclimate.com/ for Washington, DC.

3.3.2 Present Use

The demonstration area is unused at present.

3.4 Pre-Demonstration Testing and Analysis

Each of the individual technologies to be demonstrated as part of this Wide Area Assessment demonstration has been previously demonstrated and validated. The details of this prior testing can be found in recent publications by the technology developers [3, 4].

3.4.1 Demonstration Set-Up and Start-up

There were two major components of demonstration set-up. The first was to plan the transects that will be surveyed. This task consumed the majority of the pre-demonstration effort and will be discussed in detail in the following section. The second was the additional characterization of the magnetometer array at our Test Field in Blossom Point, MD

Transect Planning: At this site, the direction of the firing fan has been establish from historical data and the discovery of the firing point (Figure D-6) so there is little uncertainty on this point. Figure D-8 shows the firing fan plotted over an aerial photo of the western portion of the Spring Valley FUDS site with the demonstration area outlined in black. This area encompasses all of the Federal Property west of Dalecarlia Parkway. As can be seen in the figure, the demonstration area included a large buffer area on either side of the historic range in case the historical information is in error.

Figure D-8. Historic firing fan (white) and proposed survey area (black) for this demonstration.

The first step in planning transects is to establish the parameters of the target area to be located. We have been told that an aiming error of ± 2° is reasonable to expect for a Livens Projector. It is approximately 1,325 m from the firing point to the middle of the survey area. Coupled with the ±2° aiming area this translates to a target area approximately 90-m wide. A notional area of this size, assuming we know nothing about the down-range aim point, is shown in Figure D-9.

There are two steps in the transect planning process using Visual Sample Plan, calculating the probability of traversing the target area and the separate probability of detecting the target area if you traverse it. For this demonstration, we require a 100% probability of traversing the target area with our 1.5-m wide array as shown in Figure D-10. We then make some reasonable assumptions about the background anomaly density at this site and the instrument false negative rate (also highlighted in Figure D-11). In this context, the background anomaly density is the anomaly density expected to be found on the parts of the site outside any target. We have chosen a value of 10 anomalies per acre for a background based on results obtained at a number of the WAA sites. The instrument false negative rate (fraction of anomalies missed) is set to a conservative 5%. This leads us to a nine-transect survey for which the probability of detecting the target area as a function of anomaly density is shown in Figure D-11. Also plotted in the figure is an equivalent calculation for the case of a well-defined down-range distance that results in a 45-m radius circular target area.

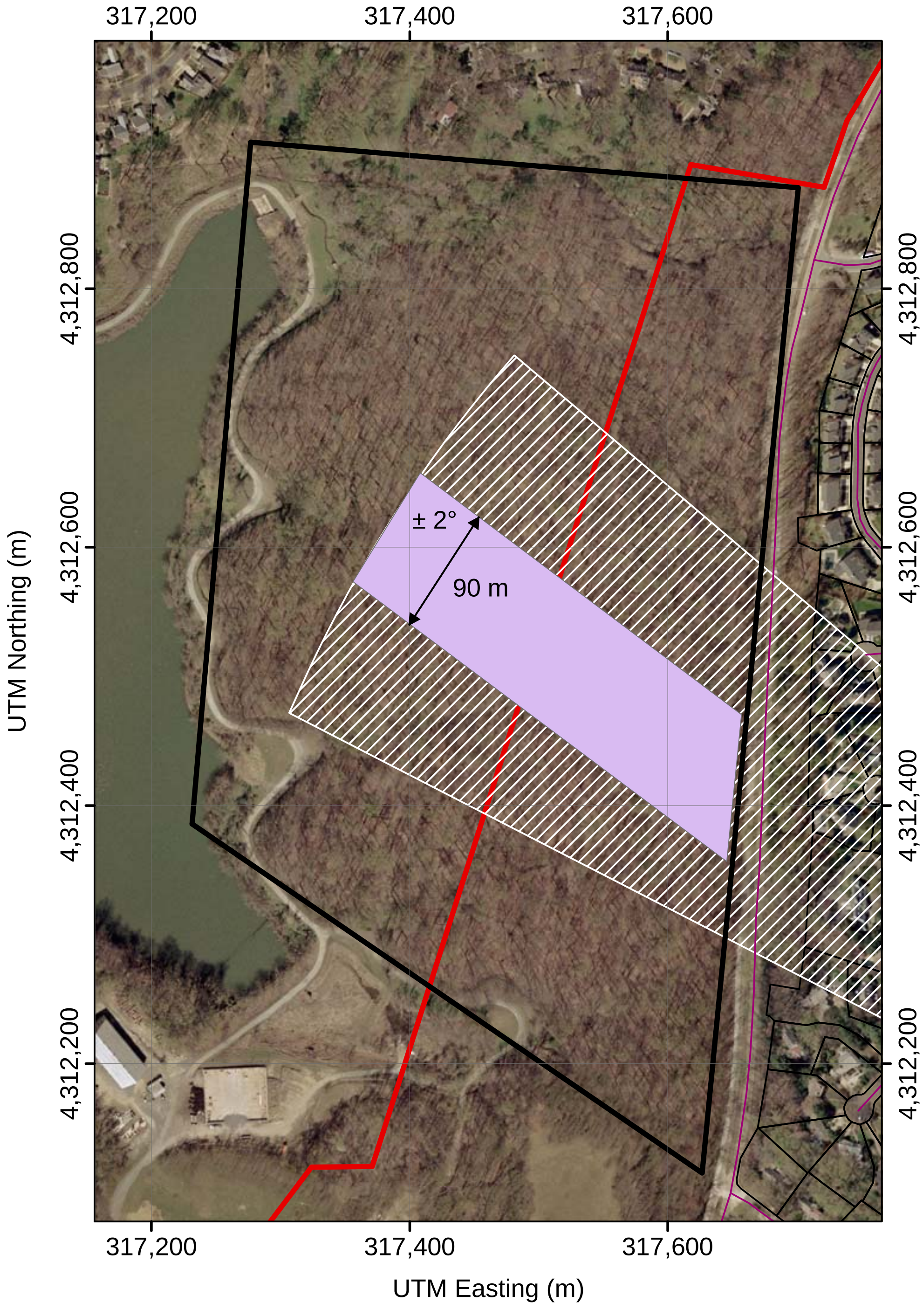

Figure D-9. Detail of demonstration area with notional target area highlighted as discussed in the text.

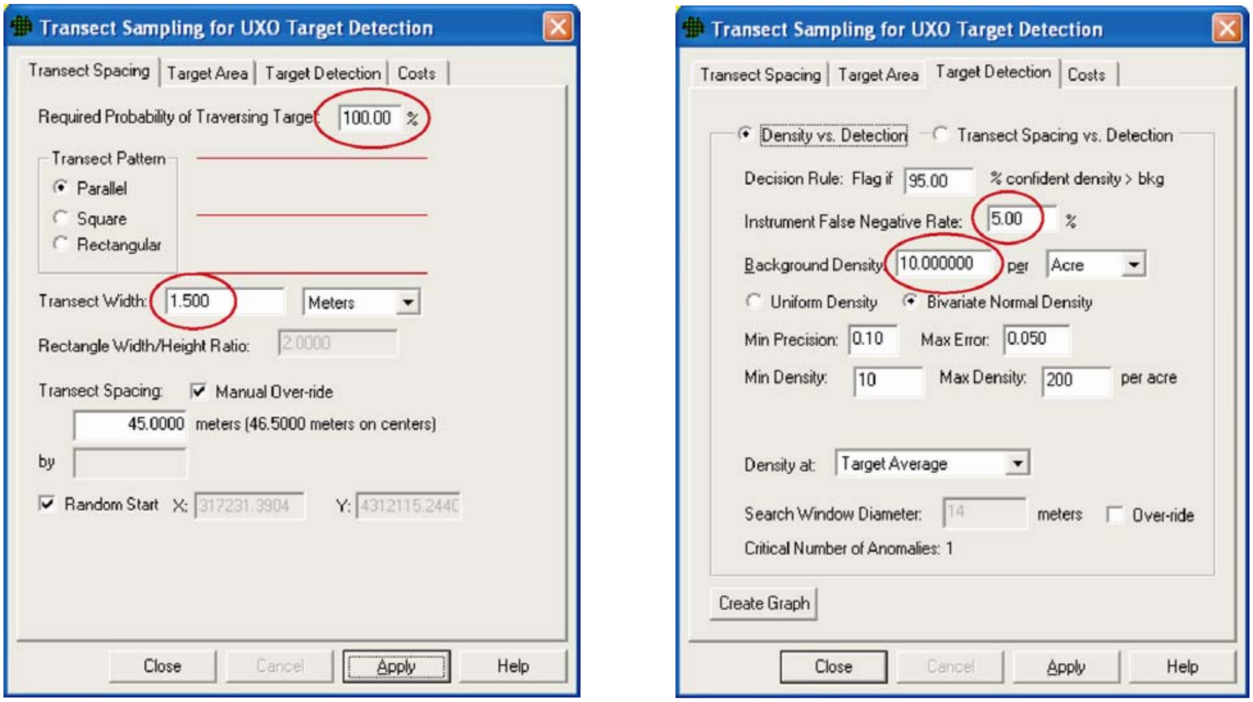

Figure D-10. Screen shots from Visual Sample Plan showing the input parameters discussed in the text.

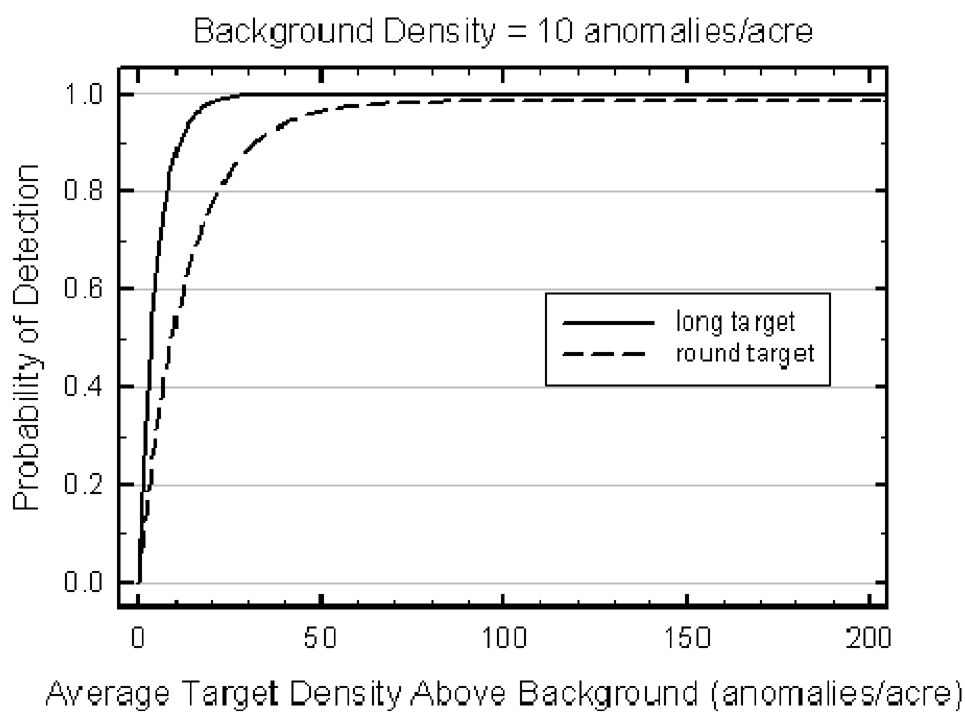

Figure D-11. Probability of detecting a 90 m × 200 m target area or a 45-m radius circular target area as a function of anomaly density.

As can be seen in Figure D-11, even for the worst case assumption of a 45-m radius circular target area, the probability of detection approaches 100% for target densities above 50 anomalies per acre. The transects that result from this analysis are shown in Figure D-12.

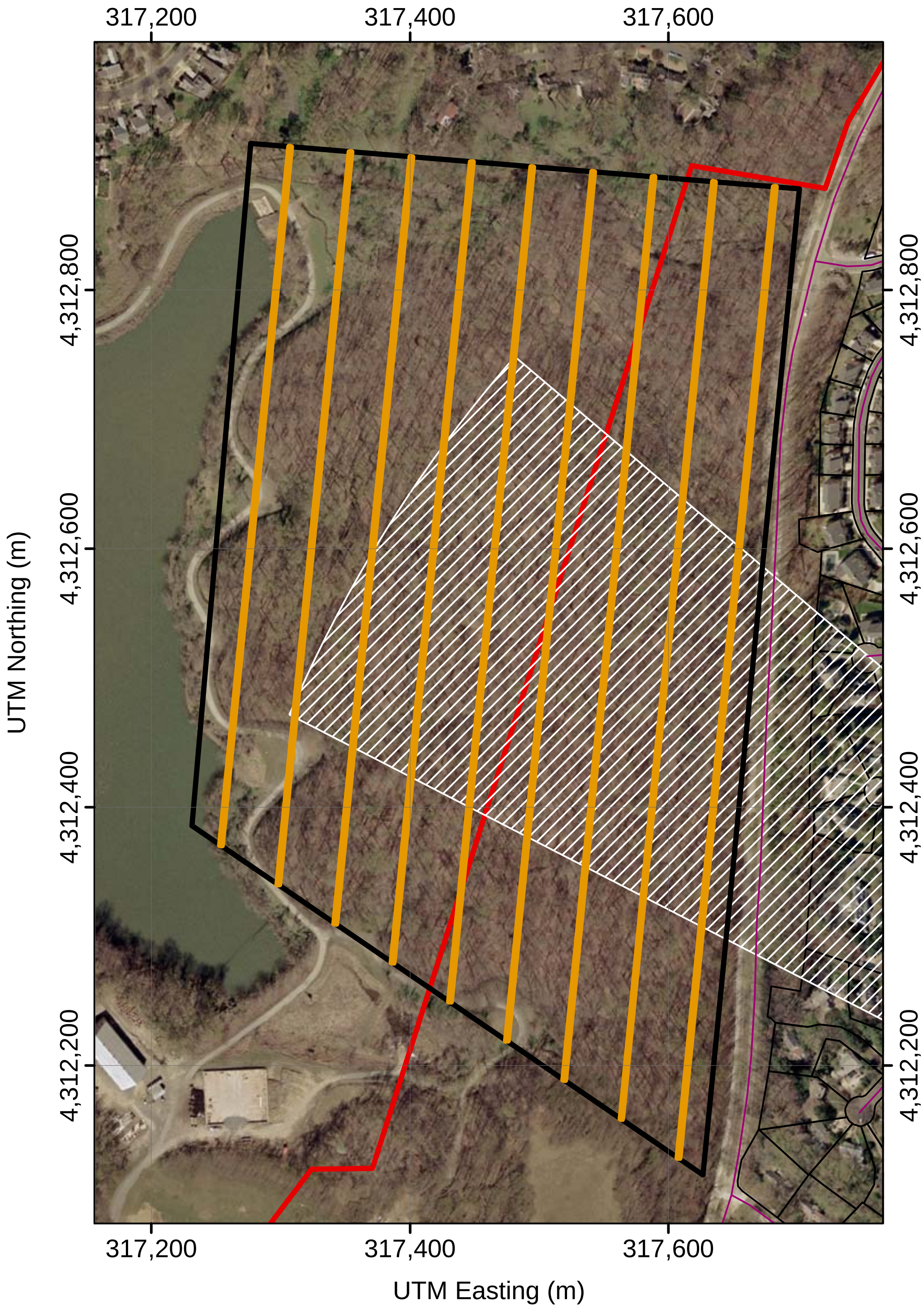

Figure D-12. Nominal transects surveyed in this demonstration.

The second objective of this demonstration was to search for a possible burial site marked AOI 2 in Figure D-6. To accomplish this, we surveyed a 1 ha (100 m × 100 m) area around the presumed location of the burial site using a 10-m transect spacing. To maximize our probability of detecting the suspect disposal area if it exists, the transects were perpendicular to the main transects as shown in Figure D-13.

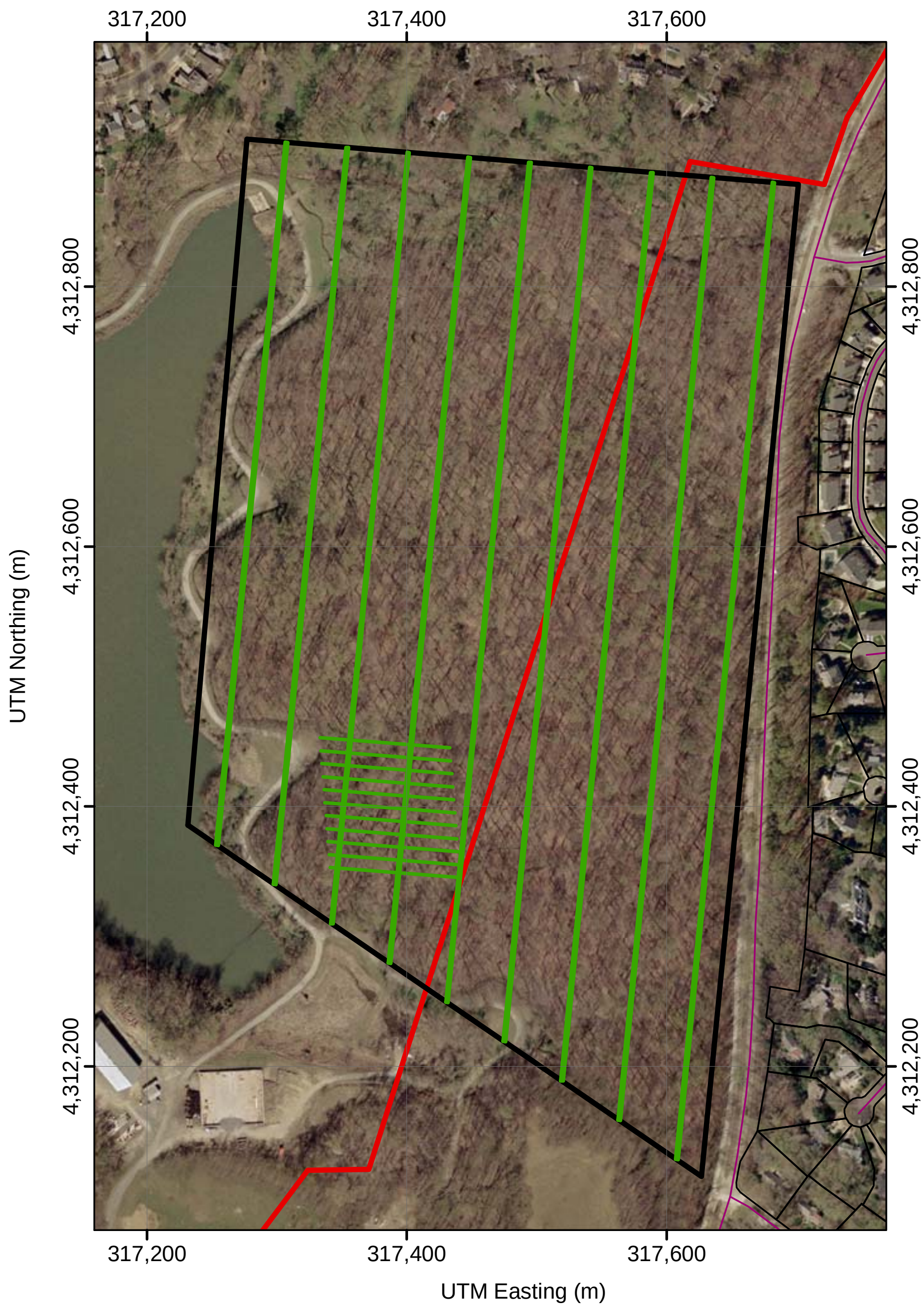

Figure D-13. One hectare disposal area search area transects shown over the main target search transects.

Magnetometer Array Characterization: As part of the demonstration, we undertook to characterize the magnetometer array at our Test Field at Blossom Point. Figure D-14 shows the magnetometer data collected as we walked transects over the five original lines [5] of emplaced targets at the site. A more quantitative presentation of the data will be given in the next Section.

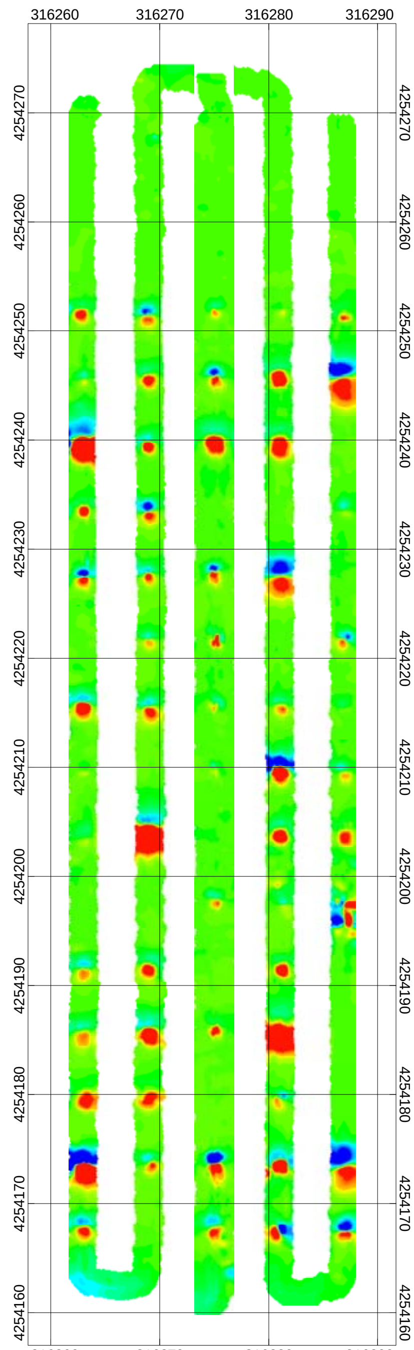

Figure D-14. Demedianed magnetometer data collected on our Blossom Point Test Field.

Initial Field Activities: One week prior to the start of the field work, we made a visit to the demonstration site to locate the survey monuments we would use and make a quick traversal of the demonstration area to confirm that the sub-meter GPS system was appropriate for use after the trees had undergone leaf drop. We had originally planned to use one of a pair of survey monuments which we had installed in 2001 in conjunction with a vehicular survey of a portion of the Federal Property [7]. These monuments were no longer available so we used a Corps of Engineers monument, details of which are given in Table D-2.

Table D-2. Control point used for this demonstration.

Station	Latitude	Longitude	HAE
P3, 2004	38° 56' 15.75534" N	77° 06' 22.64438" W	36.872 m

The survey equipment and all spares were deployed to the site in the vehicles of the survey team. The equipment was stored each evening in the conference room of the site trailer and the various batteries were charged in the trailer.

The first order-of-business after arriving at the site was to lay out rough transect lines using light string. The ends of each transect, located using the sub-meter GPS system, were marked by driving a wooden stake into the ground and our best approximation of the desired line was marked with string. An example of this process is shown in Figure D-15. After the transect lines were laid out, we walked the lines and performed light brush and obstacle removal to facilitate passage of the 1.5-m wide array. This process is shown in Figure D-16.

Figure D-15. The transect path is marked by running light string from the two surveyed ends of the transects.

Figure D-16. Light brush and obstacles were removed to facilitate the passage of the magnetometer array.

3.4.2 Period of Operation

The performance schedule for the demonstration is given in Table D-3

Table D-3. Performance schedule for the demonstration at Spring Valley.

Date	Activity
22 August 2006	Initial Site Visit by ESTCP Team
3 October 2006	ESTCP Program Office briefing to Spring Valley partners
3 November 2006	Draft Demonstration Plan submitted for comment
17 November 2006	Final Version of the Demonstration Plan published
27 November 2006	Site visit to confirm applicability of sub-meter GPS system
29 November 2006	Obtain magnetometer array from Sky Research
4 December 2006	Initial transect survey begins
6 December 2006	Initial transect survey ends
18 December 2006	Characterization of magnetometer array at Blossom Point
20 December 2006	Second collection on transect 5. Remove stakes and strings.
8 February 2007	Draft demonstration report submitted for comment
22 February 2007	Brief Spring Valley Partners on demonstration results
30 April 2007	Final Report Submitted

3.4.3 Scope of Demonstration

The overall demonstration area was ~27.5 ha or 68 acres. This was a detection survey only, no targets were remediated.

3.4.4 Health and Safety Plan

An Abbreviated Accident Prevention Plan (AAPP) for this demonstration was prepared with the assistance of personnel from US Army Corps of Engineers, Huntsville. All activities at the site were conducted in accordance with procedures in that plan. Mr. Glenn Harbaugh, of Nova Research, a UXO Tech III (former Army EOD Tech) with 5 years supervisory experience served as Site Safety Officer for this demonstration. He and Mr. Ken Shott of the Army Corps of Engineers conducted daily tailgate briefings before the start of work. Cellular telephone service was good on the site; in case of emergency all personnel were directed to dial 911. Sibley Hospital is adjacent to the Federal property and was available for emergency medical attention. George Washington University (GWU) Hospital was the dedicated facility for chemical response. Maps and directions to GWU were maintained in each vehicle on the site.

3.5 Management and Staffing

On-site supervision duties were shared by Dr. Anne Andrews of the ESTCP Program Office and Dr. Herb Nelson of the Naval Research Laboratory. Mr. Glenn Harbaugh of Nova Research served as Site Safety Officer. Dr. Dan Steinhurst, also of Nova Research, served as Quality Assurance Officer. Contact information for all survey personnel can be found in Section 8.

4.0 RESULTS AND DATA ANALYSIS

4.1 Geophysical Data Collection

The actual survey course-over-ground is shown in Figure D-17. Compare these results with the planned transects from Figure D-13. As can be seen from the figure, the middle transect of the main survey, Line 5, was laid out incorrectly for the original deployment (note the large bulge to the east) and was repeated on our follow-up deployment. The survey lines are less straight than in the characterization survey at Blossom Point due to the presence of obstacles and rough terrain in places during this survey. The range of conditions at this site is illustrated in Figure D-18.

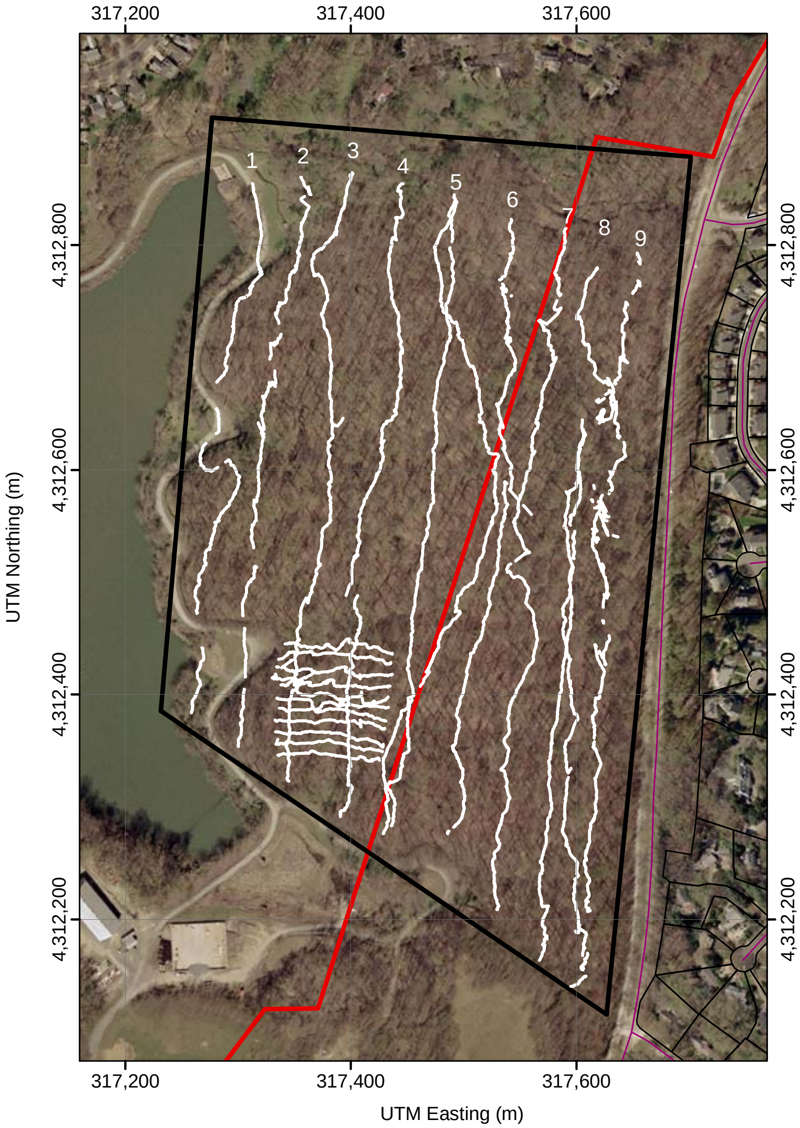

Figure D-17. Actual survey course-over-ground for this demonstration with the main survey transects numbered.

Figure D-18. The conditions at this site ranged from steep slopes (upper photo) to relatively mild inclines (bottom photo).

4.2 Data Analysis and Interpretation

Individual data sets are collected using a custom software package developed at NRL. The raw data, which are comprised of several files, each containing the data from a single system device with unique data rates, are processed on site for quality assurance purposes using standard MTADS procedures and checks. The data are merged and imported into a single Oasis montaj (v6.3, Geosoft, Inc.) database using custom scripts developed from the original MTADS DAS routines which have been extensively validated. An example of a working screen from Oasis montaj is shown in Figure D-19. As part of the import process any data corresponding to a sensor outage, a GPS outage, or a COG stop / reverse, is defaulted or marked so as not to be processed further. Defaulted data are not deleted and can be recovered at a later time if so desired. Any long wavelength features such as the diurnal variation of the earth's magnetic field and large scale geology are filtered from the data (demedianed).

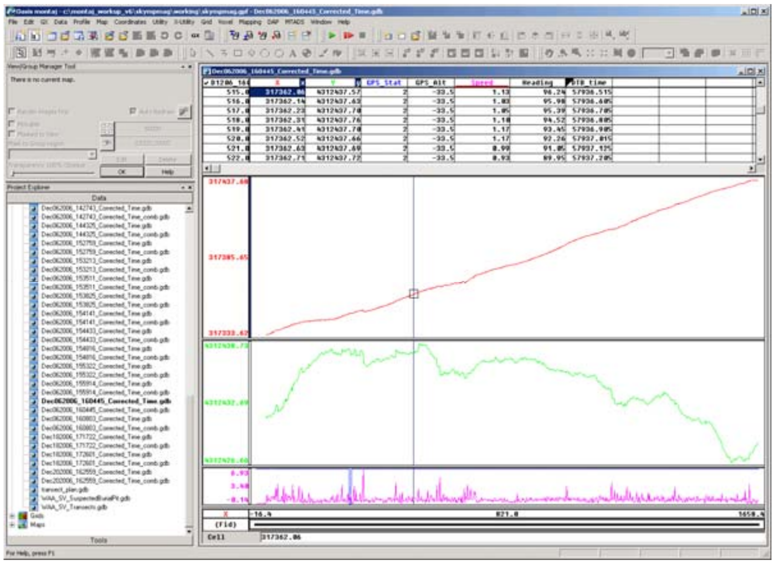

Figure D-19. Screenshot of the working view using Oasis montaj.

Magnetometer data anomaly features exhibit a dipolar response having both positive and negative peaks. It is difficult to robustly pick anomaly locations from this type of data as the anomaly location is best described by the zero crossing between the negative and positive peaks. We have previously demonstrated [8,9] a technique for WAA applications where the demedianed magnetometer data are converted to the analytic signal where a dipolar magnetometer anomaly is represented by a single positive peak. Due to the degraded positioning under the tree cover using sub-meter GPS rather than full RTK GPS, the results using this technique were not satisfactory. An alternate method was adapted from our man-portable EM61 survey at the WAA Victorville site [10] where anomaly selection was done using the down-track EM data profiles. A one-dimensional function similar to the definition of the analytic signal was used to convert the dipolar magnetometer data into a form more easily used for anomaly selection. The Peak Extraction function is defined as

$$PE = \sqrt{\left(\frac{d}{dx}\right)^2}$$

where d/dx represents the horizontal derivative down-track along the profile. Then a built-in feature of Oasis montaj was used to extract peaks above a given threshold from the PE profile data from each sensor. The detected anomalies from all sensors were then clustered together using a custom piece of software and a 1.5-m selection radius to eliminate duplicate selections among all four sensors. The detected anomaly locations along with the PE amplitude at the peak of the anomaly were provided as a deliverable. The down-sampled transect COG (every tenth sample, approximately 2m separation) was also provided.

The application of this analysis to a portion of the Blossom Point characterization data is illustrated in Figure D-20. The bottom panel shows the demedianed total field magnetometer data from one sensor as the array traverses the middle, or "C", line of the test field. The upper panel shows the Peak Extraction function for these data along with an indication (+) of the targets detected using a threshold of 25 nT/m. Details of the emplaced items on the "C" line are given in Table D-4. The only seed item missed (×) was the Al plate in position 3 which, of course, should not be detected by a magnetometer system.

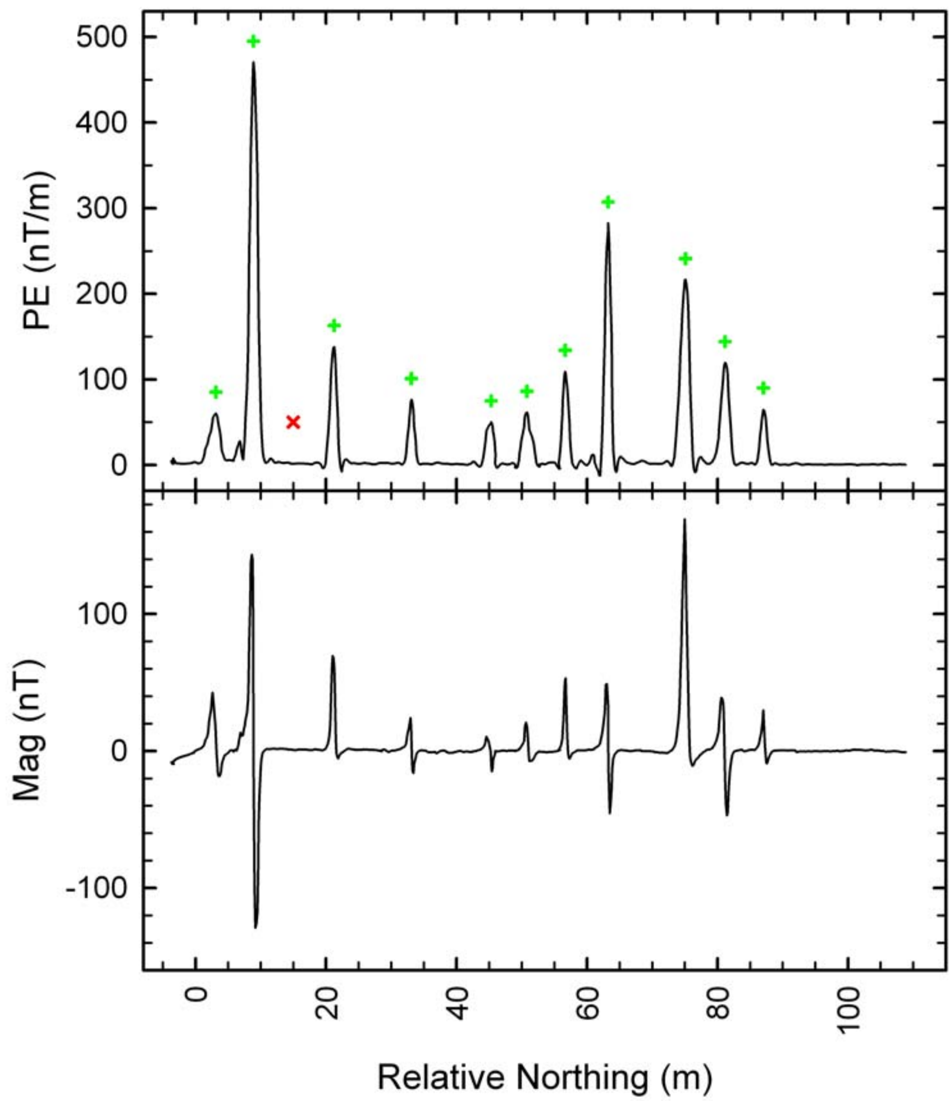

Figure D-20. Demedianed total-field magnetometer data (lower panel) collected over the "C" line at Blossom Point and the Peak Extraction function calculated from these measurements (upper panel). The emplace items detected using threshold of 25 nT/m (+) and the Al plate not detected (×) are marked.

Table D-4. Details of some of the emplaced items in the Blossom Point Test Field.

Position	Relative Northing (m)	Description	Depth (cm)	Azimuth (°)	Inclination (°)
C1	3	3″ × 12″ steel cylinder	50	0	0
C2	9	clump of barbed wire	10	0	0
C3	15	4″ × 4″ × ¼″ Al plate	5	0	0
C4	21	1½″ × 6″ steel cylinder	20	0	90
C5	27	blank			
C6	33	1½″ × 6″ steel cylinder	10	0	0
C7	39	blank			
C8	45	1½″ × 6″ × ¼″ steel plate	5	90	0
C9	51	horse shoe	5	0	0
C10	57	4″ × 4″ × ¼″ steel plate	5	0	90
C11	63	banding material	10	0	0
C12	69	blank			
C13	75	3″ × 12″ steel cylinder	5	0	90
C14	81	8″ × 8″ × ¼″ steel plate	25	45	0
C15	87	1½″ × 6″ steel cylinder	20	0	0

The average background level was higher at the demonstration site than at Blossom Point (2.5 to 5.5 nT/m at the Federal Property vs. 1.6 nT/m at Blossom Point). The levels at both places are far below the 25 nT/m used as a threshold in the characterization tests. For that reason, we chose to use the same threshold for the Federal Property data.

Primary Range Fan: A map of the magnetic anomalies encountered during the survey of the nine primary NS transects is shown in Figure D-21. Most of the anomalies detected fall into the smallest size bin. A number of the larger anomalies result from easily identifiable features such as manhole covers, monitoring wells, etc. There is no obvious concentration of anomalies evident in Figure D-21. Reference to Figure D-21 shows that a majority of the items the size of intact munitions falls between 100 and 250 in the Peak Extraction Function. Figure D-22 shows only this subset of anomalies plotted. As in the case of all anomalies, there is no obvious area of concentrated anomalies present in this image.

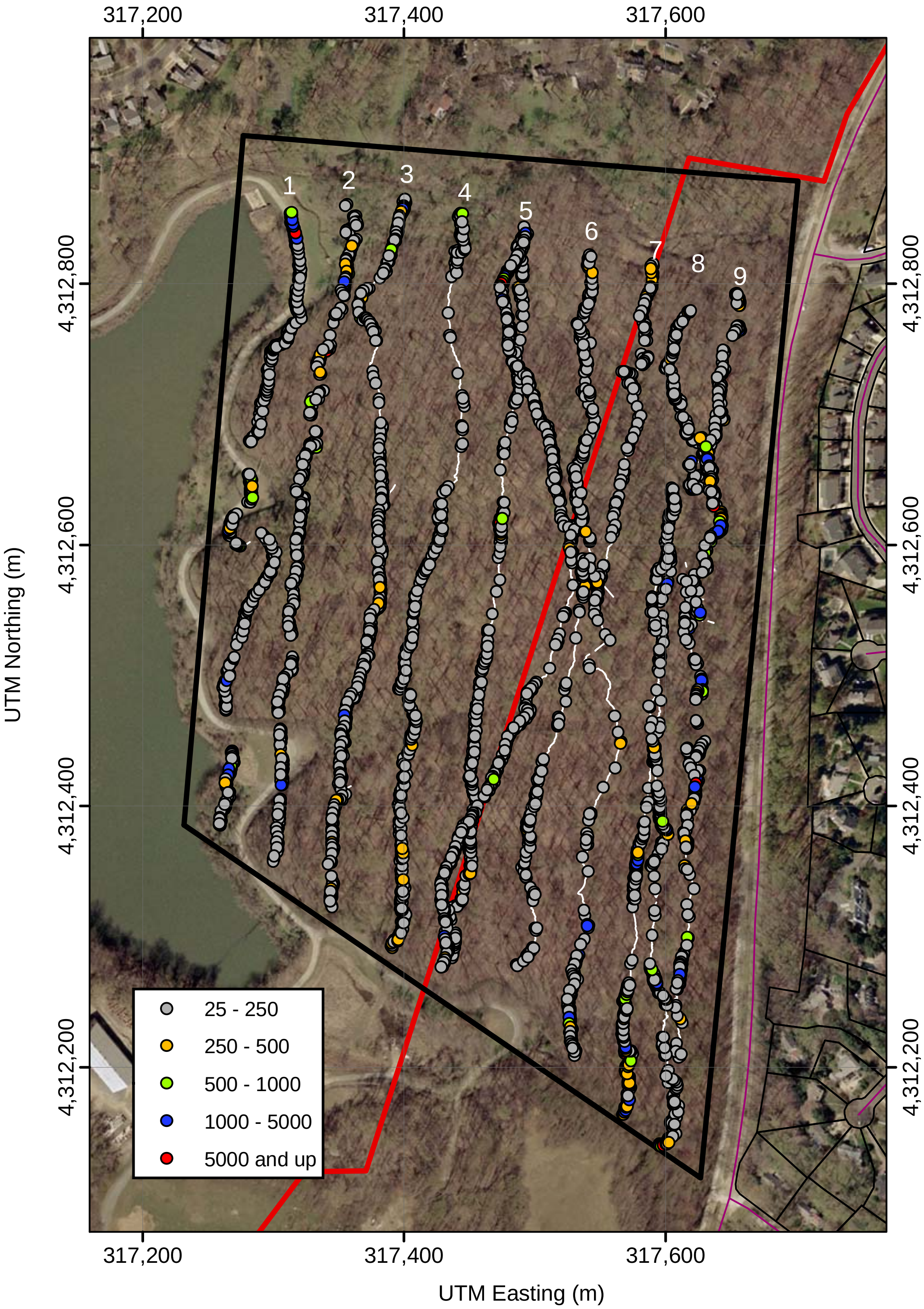

Figure D-21. Magnetic anomalies detected during the primary survey at the Federal Property. Anomalies are color coded by peak amplitude of the Peak Extraction function discussed in the text.

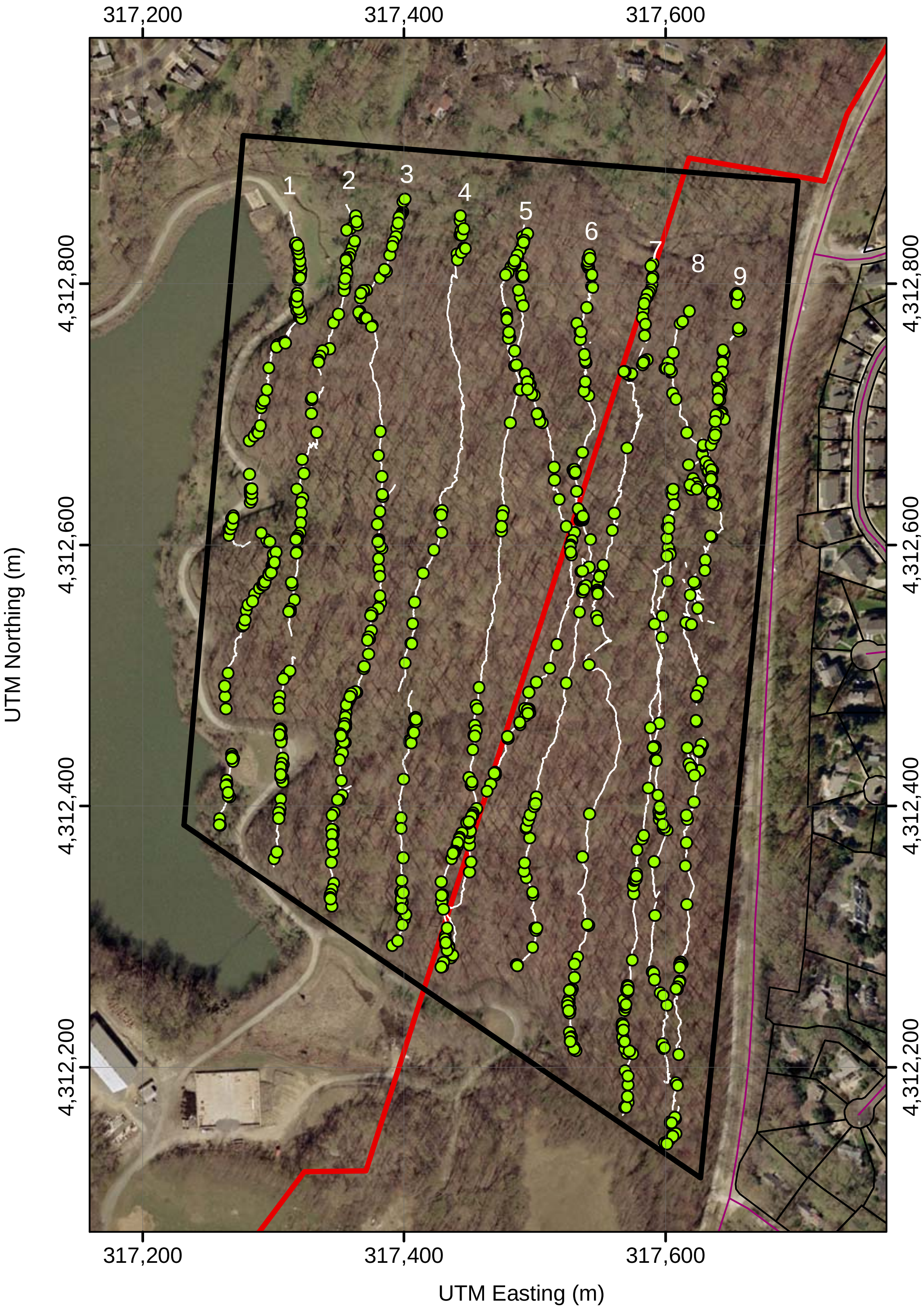

Figure D-22. Subset of anomalies from Figure 4-5 having maximum Peak Extraction function values between 100 and 250.

Potential Disposal Area: Plots analogous to Figures D-21 and D-22 for the area around the potential disposal area are shown in Figures D-23 and D-24. If there were a disposal area present, we would expect to observe a small number of large, extended anomalies. Although there is a concentration of anomalies in the lower three or four transects there do not appear to be any large, extended anomalies so we conclude there is no disposal area at this location.

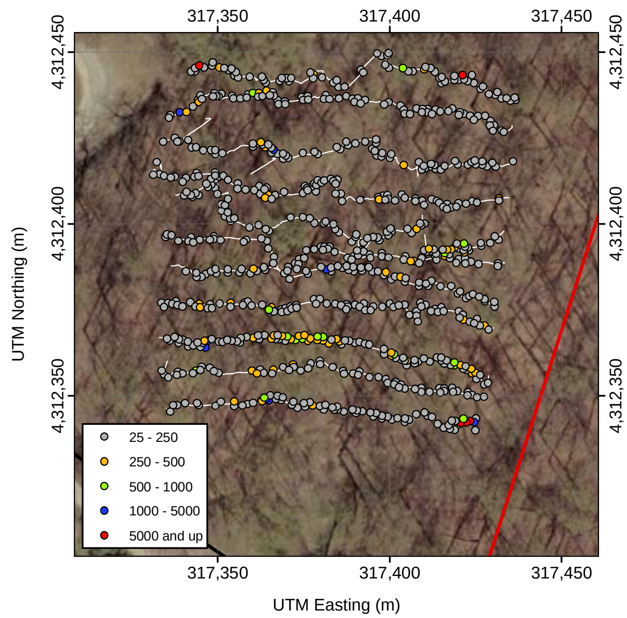

Figure D-23. Magnetic anomalies detected during the search for a potential disposal area color coded by peak amplitude of the Peak Extraction function.

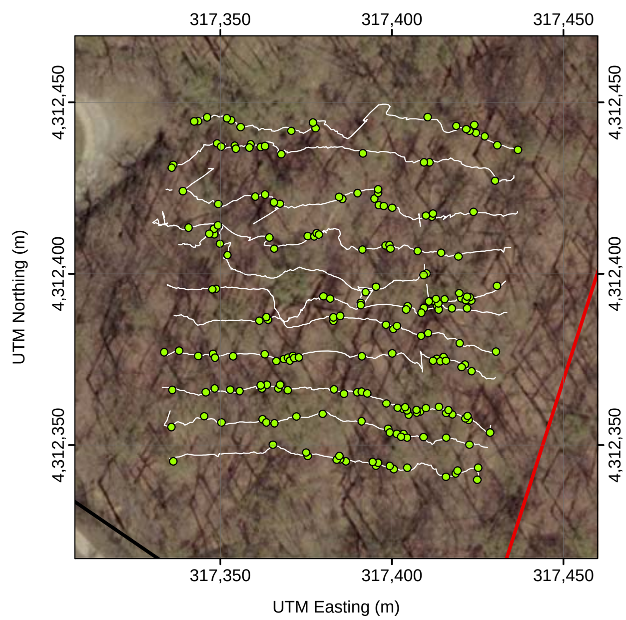

Figure D-24. Subset of anomalies from Figure D-23 with maximum Peak Extraction function values between 100 and 250.

4.3 Conclusions from the Data

It is evident from the magnetic anomaly map in Figure D-21 that the anomaly density throughout this site is substantially higher than the background value assumed in the transect planning process. This likely indicates that the cultural background at this urban site is higher than we have observed at the isolated bombing targets we have previously surveyed. We are not, however, able to use the data collected here to eliminate the unlikely possibility that the target of interest covers the entire site surveyed.

The moving window analysis function in VSP described above was used to develop a histogram of the number of cells with a specified anomaly density which is shown in Figure D-25. The densities plotted were calculated using a 75 m window. If a target were present, one would expect an inflection point in the plot where the cells with densities above background (corresponding to the target) rise above the falling background distribution. There is no obvious break in Figure D-25 between background density and potential target density although one might hypothesize a subtle inflection around 1,700–1,800 anomalies per acre with a background of 1,300 per acre (compare to the value of 10 assumed during transect planning).

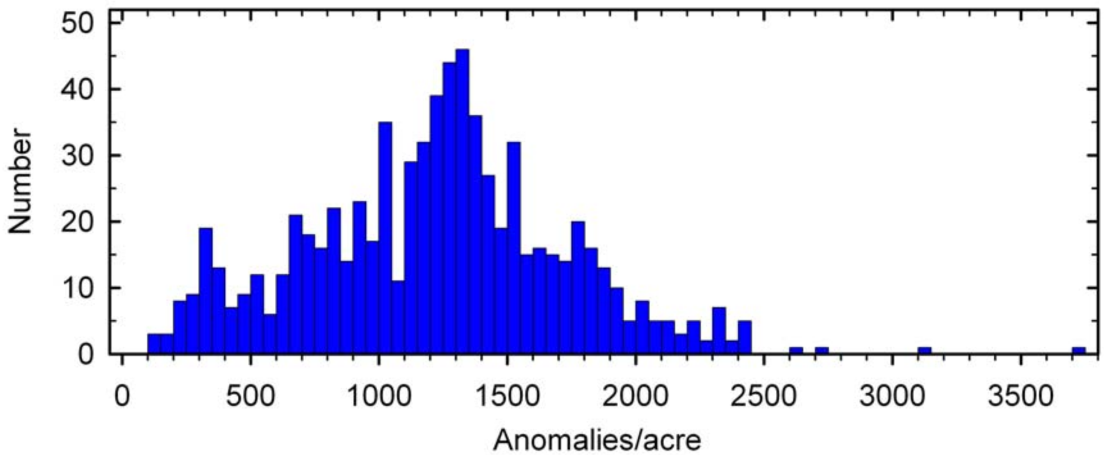

Figure D-25. Histogram of anomaly density over the site calculated using a 75 m window in VSP.

The analysis module of VSP was run to search for areas of the site with an anomaly density of 1,800 per acre. The areas marked as exceeding this critical density are highlighted in Figure D-26. With the exception of one small area in the interior of the site, all the areas marked in Figure D-26 are on the periphery of the site and likely result from an old fence (north and east sides) or the magnetically active rocks lining the road and stream (south and west sides).

A revised probability of detection curve calculated using the measured site background density and three transect spacings is shown in Figure D-27. From these results, we can conclude that there is an 80% probability that we would detect a 45 m radius target area with an anomaly density of 250 anomalies per acre above a background of 1,300 anomalies per acre. Of course, it is straightforward to translate the results of this survey to such hypothetical quantitative examples. However, because little is known about the potential target size and density, it is difficult to draw firm conclusions about the presence of a real target area. We do see from Figure D-27 that doubling the number of transects (22.5 m spacing) would not add significantly to our confidence that no target is present at this site but halving the number (90 m spacing) would have significantly reduced our ability to draw conclusions from these data.

From the discussion above, we can draw several conclusions about this site:

- one should not expect to detect a lightly-used target (100 to 200 anomalies per acre) on a site with background anomaly density similar to that shown in Figure D-25,
- from the data measured during this demonstration, we can conclude with 80% confidence that there is no 45-m radius target with a density of 250 anomalies per acre or greater on this site although, as discussed above, the applicability of this to a real target is difficult to judge, and
- it is unlikely that there is a significant disposal site in the area searched for AOI 2 (although there is a concentration of small anomalies near the reported position of the AOI).

The conclusion above regarding a 45 m radius target does not imply that there are not individual items on the site. From the site walkover, we know that muntions fragments exist in the study area. However, the transect method is designed to traverse and detect localized areas of anomaly density above background. Since the transects only cover a small fraction of the total site, it is possible to have a number of items distributed throughout the site that are missed by the transect survey. Although we have not been able to identify an area of concentrated munitions use on this site, we have acquired high-quality geophysical data over the site which will be valuable for planning future stages of the characterization of this site. These data have been transmitted to the site team.

Figure D-26. Areas marked by the analysis module of VSP as exceeding a critical anomaly density of 1,800 anomalies per acre.

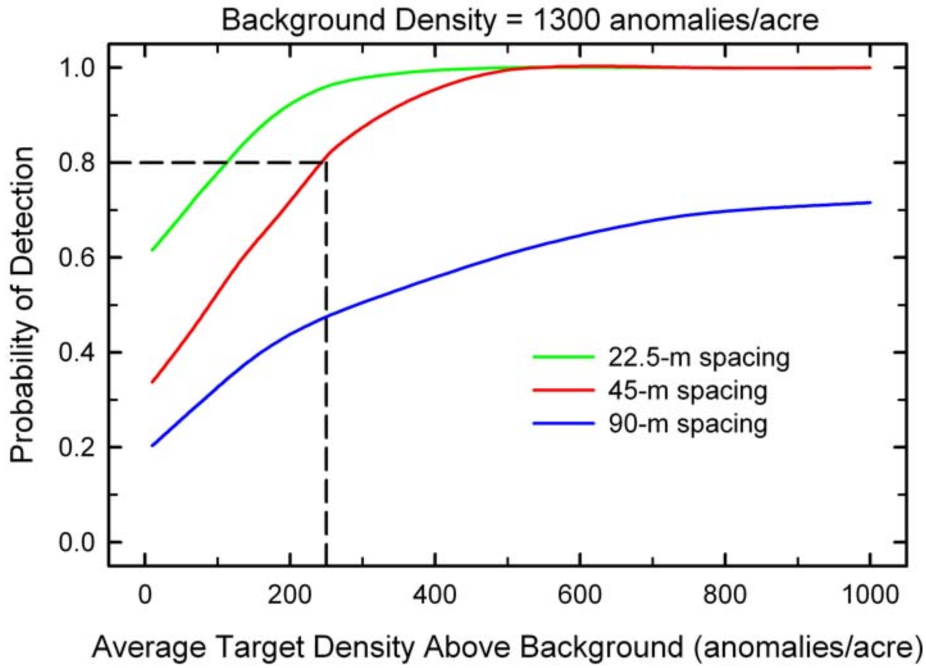

Figure D-27. Probability of detecting a 45-m radius circular target area as a function of anomaly density above a background of 1,300 anomalies per acre.

5.0 IMPLEMENTATION ISSUES

5.1 Regulatory and End-user Issues

The ESTCP Program Office has established a Wide Area Assessment Pilot Program Advisory Group to facilitate interactions with the regulatory community and potential end-users of this technology. Members of the Advisory Group include representatives of the US EPA, State regulators, Corps of Engineers officials, and representatives from the services. ESTCP staff have worked with the Advisory Group to define goals for the Pilot Program and develop Project Quality Objectives.

This demonstration site represented a number of unique challenges for the WAA technology. Results from this demonstration will be of great interest to the members of the Advisory Group and will play an important role in determining the acceptability of the use of these methods to the regulatory community.

5.2 Stakeholder Issues

There are a large number of identified stakeholders for this demonstration site. Although the specific demonstration site is entirely Federal property, it is part of the larger Spring Valley FUDS. The Corps of Engineers has established a site working group with representatives of national and District of Columbia, regulators, project contractors, Corps representatives, and local elected officials. Personnel from the ESTCP Program Office briefed this group on our initial plans on 3 October 2006 and returned to this group with our results in late February 2007. There is an established Restoration Advisory Board for this site. Corps of Engineers personnel have briefed the RAB on our proposed demonstration and the results of this demonstration will be communicated to the RAB

6.0 REFERENCES

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