ORDNANCE AND EXPLOSIVES DIGITAL GEOPHYSICAL MAPPING GUIDANCE - OPERATIONAL PROCEDURES AND QUALITY CONTROL MANUAL

(DGM QC Guidance)

PREPARED FOR:

U.S. ARMY ENGINEERING AND SUPPORT CENTER, HUNTSVILLE

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PREPARED BY:

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Acknowledgements

The origins of this guidance document started in the spring of 1999. Jeff Gamey of Oak Ridge National Laboratory and I were Government observers for a phase II Field Demonstration for a $50,000,000.00 contract award. Approximately fifty companies competed for this award and final selection was down to four teams. The team that could demonstrate the best ability to detect ordnance and minimize the amount of clutter items selected for excavation would go home with a major prize. As Jeff and I monitored and took notes on the demonstration, we were amazed at the number of mistakes and errors that were being injected into the data from operator error. If this many errors were being made by some of the best companies in the business, think of the learning curve faced by new companies emerging into the OE Geophysical marketplace. That day we decided to record all of the lessons learned we had painstakingly discovered in our career and document them for future Geophysicists. We then started identifying and recording errors we discovered during our Quality Assurance missions for our Military Munition Response Program. This wealth of information became the backbone of this document.

A document of this type and importance is never written by just one person. It is developed by extracting years of experience and knowledge from the best people in the business, and then distilling the information down into a systemized approach with a long list of Lessons Learned. Several people from the Corps of Engineers – Huntsville Center were instrumental in development of this document. Initially, Scott Millhouse and later Roger Young as the OE Innovative Technology Advocate provided the funding needed to support an endeavor of this magnitude. John Sikes and William Veith of the Ordnance and Explosives Center of Expertise were instrumental in focusing the group on the important concepts. Amy Walker, Deb Edwards, Jon Durham, and Dan Plugge of the Geotechnical Branch Geophysical Group were constantly providing data sets that exemplified typical problems encountered from the field data. Andrew Schwartz provided the major drive to completion of the manual by providing countless hours in rewriting sections to insure that the proper emphasis was placed in the appropriate sections.

A partial listing of those personnel who commented on or supplied sections of the document are listed below. We know there are countless others who supplied information, but the information was submitted namelessly under a company's name and we wish to thank them for their efforts and support.

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It is a rare gift indeed to be able to decipher a highly technical document with sections provided by dozens of different sources and generate a single coherent and readable document. Mark Howard of NAEVA Geophysics Inc. has this gift. He is responsible for rewriting this document in its entirety and developing it into the form it is today and we all wish to show him our appreciation for this superhuman effort.

This document was never expected to be a finished product, but as a progress report. It is hoped that years from now, all sections of this report will be improved and rewritten. This work is now left to you, the reader, to improve and advance the science of OE Geophysics for the future.

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DEPARTMENT OF THE ARMY

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Chapter 1: Introduction

This manual outlines procedures, methods and quality control for Digital Geophysical Mapping (DGM) surveys, on the Ordnance and Explosives Program, performed by contractors for the U.S. Army Corps of Engineers Huntsville Center. The primary goal of this manual is to standardize procedures for DGM surveying. While some of the procedures and methodologies described are required, others are preferred. This manual provides details for operating and planning surveys using those instruments that are most commonly used at the time of publication. In many instances, the procedures and methodologies presented herein can be tailored for other less common instrumentation.

Target objectives will affect the type of instruments chosen for a site, as well as the design of the survey. This document describes factors that will influence the target objectives (such as geophysical noise), and offers general guidelines regarding data acquisition, data processing, and other elements of DGM surveys. Numbers for required accuracies, survey design elements, and other aspects of DGM surveying are not specified in this document, because they are project specific.

1.1 Origin of Document

This manual draws on existing Engineering Manuals and Data Item Descriptions (DIDs) for specific processes and guidelines. References are made to these documents for obtaining detailed information on specific topics.

1.2 QC / QA Software

Geosoft Inc., a software and services company based in Toronto, Ontario has developed a suite of QC / QA software for use on Army Corps of Engineer DGM projects. The software provides tools and routines for analyzing various aspects of data quality and flagging data that may be out of specification. It is anticipated that the contractors will use these tools in the same manner as CEHNC in order to identify and address any data that may exhibit out of specification characteristics.

Chapter 2: Planning

The following list for planning geophysical surveys is limited to a brief description of major elements. Many of the planning elements listed below are described in greater detail in the Army Corps of Engineers Engineering Manual EM 1110-1-4009.

2.1 Research Site History

a. Review all previous investigation reports, Archive Search Report (ASR), and any information gathered during site visits. The previous usage of the site and the munitions likely to be present should be defined in this stage of planning.

b. Conduct interviews with military personnel formerly assigned to duty at the site. One goal of the interviews may be to obtain local information and anecdotes regarding munitions and firing areas that are not recorded in the written record.

2.2 Research Site Geology

a. Review surficial geology: obtain geologic maps and literature for the site. Possible sources of information include the United States Geological Survey (USGS), the Natural Resources Conservation Service (NRCS), state geologic and soil conservation agencies, county agencies and theses from universities or colleges in the area.

b. Review bedrock geology: use sources above to obtain information.

c. In some areas a large amount of information may be available concerning surficial and bedrock geology; however most of this information is not relevant to geophysical surveys for buried munitions. If possible, consult with local geophysicists, who will be familiar with local geology and the effects on selected geophysical instruments.

2.3 Preparation of Geophysical Investigation Plan

a. Determine Survey Type: Random, Fixed Pattern, Hybrid, Transects, or Meandering Path. Survey type is dependent on the objectives of the investigation, whether the goal is to conduct Geophysical Sampling, Geophysical Mapping, or Geophysical Interrogation. All are described in Chapter 7 of EM 1110-1-4009. Site conditions such as topography and vegetation may also be considered in the determination of survey type.

b. Determine Geophysical Methods and Procedures proposed for the investigation: Methods and procedures are determined by consideration of all factors described above, as well as type and expected depth of recovery of ordnance. Topography, vegetation, and the presence of physical features that may cause interference must also be considered in the selection of instruments. EM-1110-1-4009 describes instrument characteristics and criteria for selection. Geophysical equipment considered appropriate for the task, and sources for obtaining the equipment, should be listed.

c. Determine required data density (both parallel and transverse to the survey traverse), based on type of investigation: Size and depth of expected ordnance, and method used for detection will dictate minimum requirements for line and station spacing.

d. Define Instrument functionality and response tests: Initial tests, to be performed on the field teams arrival, as well as daily equipment tests will be outlined. Standard tests for EM, magnetics, and the effects of navigational equipment and vehicles are described in detail in Chapter 5 of this manual. Response tests must be designed to evaluate capability to detect representative ordnance expected on site.

e. Define Method of Navigation, means of location and mapping: Describe procedures and equipment to be used in data collection to ensure accurate location of data points. Means of location and mapping points, whether by GPS, ultrasonic or through conventional surveying of grid corners will be defined. Navigational QC is discussed in Chapter 7 of this document.

f. Review Personnel Qualifications: Qualifications are defined in detail in DID OE-025.01, Personnel/Work Standards. For a geophysical investigation, qualifications for the following personnel are relevant:

Project Geophysicist
Site Geophysicist
QC Geophysicist*

Geophysical Staff*
Data Processor*
Unexploded Ordnance (UXO) Personnel
Land Surveyor
Geographical Information System (GIS) Manager

*Qualifications for these personnel are not described in DID OE-025.01. All geophysical field personnel must have an operational knowledge of the tasks they are assigned and must have an understanding of the physical characteristics of the earth that are being measured prior to mobilizing to the site. Depending on the quality control measures established for a given project, site-specific qualifications can be established for field personnel in positions of responsibility in terms of data acquisition and documentation. As an example, the field personnel assigned to man-portable instruments may be required to demonstrate their ability to successfully acquire data over the geophysical prove out area prior to being assigned to field operations. The frequency and criteria for such demonstrations would be established on a project-specific basis.

g. Describe Data Processing and Analysis: Steps or methods used for initial field processing, data analysis, anomaly selection, generation of dig lists, and advanced processing will be documented. Chapter 9 of this manual describes data analysis, processing and dig lists.

h. List survey equipment and services: Prepare list of items needed to perform survey, and services required. List should include sources of supplies and rental sources of equipment that may provide backup instruments in the event of instrument malfunction.

i. Describe Data Storage, Transfer and Archiving: Chapter 8 of this manual describes approved procedures for the storage and transfer of data.

j. Describe Quality Control procedures to be performed: Steps to ensure proper instrument function, accurate mapping and location of anomalies, and repeatability are discussed in Chapter 5 of this manual. It is important that the project team also identify potential failure scenarios that are inherent in each of the processes being proposed for a project. Adequate quality control measures should then be developed and implemented to identify those failures when they occur. For example, it is known that noise is introduced in EM61 data when the instrument bounces over the terrain, and it is generally accepted that the amplitude of the noise is directly proportional to the degree of bouncing as the data is collected. It is also generally accepted that the faster the unit is towed over rough terrain, the more it bounces. Therefore, an adequate quality control measure for monitoring this potential noise source would be to use the GPO data to establish a maximum acceptable survey speed. An additional quality control measure under such a scenario would be to quantify the standard deviation of the background noise in the GPO data and to use that value as a metric against which the site survey data is compared. An analyses of potential failure scenarios should be performed for all methods and processes proposed for a given project, including data acquisition processes, data-processing processes, data positioning processes, anomaly reacquisition processes and anomaly results reviews, and adequate and meaningful quality control measures should be established for each.

k. Describe Procedures for Reacquisition: Methods of reacquisition of anomalies and acquiring feedback from the digging teams are covered in Chapters 10 and 11 of this manual

l. Define Work Schedule- To include sequence of areas (transects, grids, etc.) to be surveyed and site preparation for each area, project completion, schedule of deliverables to client.

2.4 Review of Data Quality Objectives (DQOs)

"The Data Quality Objectives are qualitative and quantitative statements developed to clarify study objectives, define the type of data needed, and specify the tolerable levels of potential decision errors." (EM 1110-1-4009, 1-2). Stakeholders and regulators for the site will be consulted before the objectives are finalized. The DQOs are the basis for defining the objectives of the geophysical investigation and help to define the level of quality that is required of the geophysical data in order to support the decisions that will be made.

The distinction must be made between project DQOs (such as "Acquire data to detect and remove all UXO to a specified depth") and individual quality control measures that will be implemented to document that the geophysical program can support those DQOs. It is expected that quantitative and qualitative metrics will be evaluated for each QC measure that is defined and that pass/fail criteria will be defined on a project specific basis. Appendix G presents two examples of QC metrics and DGM DQOs that have been used successfully on past projects.

2.5 Site Visit

A site visit is highly recommended prior to designing the prove-out, to identify the various physical characteristics of a site and the potential problems that may limit the success of a geophysical investigation. A successful site visit gathers local information that may be crucial to the planning and implementation of a geophysical investigation. The factors below should be evaluated during the site visit:

a. Evaluate topography, density, type and distribution of vegetation. Notation must be made of areas of surface features and potential for interference. Some sources of interference are: overhead power lines (esp. high tension lines), nearby radio transmitters, underground utilities, presence of metallic refuse, former building sites, etc. Determine site modifications necessary such as brush cutting and removal of metallic objects.

b. Evaluate road access to survey areas, condition of roads and trails. Determine whether two wheel drive, four wheel drive, or All Terrain Vehicles are necessary for access. Map useful trails or roads that are not shown on published maps. Look for locked gates or other barriers that may hinder access.

c. Identify private properties that will require right of entry (ROE). Responsible COE District will acquire ROE.

d. Identify any access constraints, such as allowable work hours, special access restrictions.

e. Identify possible areas for Geophysical Prove Out. Factors to be considered are discussed in Chapter 3 of this document.

f. Check for the presence of magnetic soils or rocks through the use of a handheld magnetometer.

g. Availability of on-site facilities and services. This includes:

(1) Electricity: Is electric power accessible, or are generators necessary?

(2) Storage: Are facilities present on site for storage? Are secure containers for storage available locally?

(3) Internet Access: Can the Internet be accessed using national or local Internet service providers? Are phone lines for dial-up access present on site, or high-speed connections?

Chapter 3: Geophysical Prove-Out

Before geophysical surveys for buried munitions can begin on a site, the proposed survey methods and techniques must be tested and evaluated. The results of the Geophysical Prove-Out (GPO) will identify realistic capabilities and limitations of applying geophysics at a particular site and aid in determining proper post-processing procedures for the geophysical data. Additionally, a prove-out demonstration offers the client an opportunity to observe the contractor's methods and evaluate their procedures and compliance with project requirements. A prove-out must be constructed so that it is representative of the project site and the specific buried munition items known or suspected to exist. The GPO should be used to establish site-specific and project-specific data quality metrics that are based upon the data collected during the GPO effort. See Appendix G for examples.

The objectives for the geophysical prove-out listed below are concerned mainly with establishing and maintaining high levels of quality control throughout this phase of the project. Engineering Manual EM-1110-1-4009 provides a detailed list of objectives for a geophysical prove-out. Guidelines regarding the prove-out plan and report may be found in DID OE-005-05A.01. Contractors will consult both of these documents prior to the start of the project to ensure that all objectives for the prove-out will be met. The GPO layout will be included in the Work Plan for CEHNC review and approval. The final design of the GPO is typically a function of the DQOs defined for the project in conjunction with input from the key project team members, including regulatory and stakeholder interests. Additional information regarding the design of the GPO can be found in DID OE-005-05A.01 and EM 1110-1-4009.

3.1 Objectives

a. Each of the geophysical methods commonly used at buried munitions sites has inherent strengths and weaknesses. The geophysical prove-out will provide the contractor and the client a means of evaluating proposed methodologies and selecting the optimum approach (es) for that site. The prove-out also provides a means of evaluating navigational techniques and positional accuracy.

b. In addition to testing data acquisition methods, the contractor may use the prove-out to examine different data evaluation procedures. The field survey will not begin until the contractor has demonstrated compliance with all technical requirements specified in the contract. The contract will include survey objectives and performance criteria to which the contractor will be held accountable.

c. Maximum depth of detection for a geophysical method is largely dependent on the target (nature, composition, depths, orientation, inclination) and the geophysical noise present at that site. The geophysical contractor will use the prove-out area to demonstrate reliable detection depths that can be expected during the survey using a particular instrument.

d. During the survey portion of a project, the contractor will typically process the data on-site, or transfer data to their main office for processing. The data is then examined by a senior staff member or assessed for quality in some other way. Any procedures that will be used during the field survey (including data transfer) will be documented, employed and evaluated for effectiveness during the prove-out.

e. The geophysical prove-out provides an opportunity to evaluate the response of an instrument suspected of malfunctioning during the data collection phase of the project. Should an instrument's performance be called into question, the geophysical contractor will return to the prove-out for evaluation. At a minimum, a portion of the prove-out will be recollected and compared to previous results. Data collection will not be resumed until the instrument has shown appropriate and consistent response, or been repaired or replaced and re-evaluated at the GPO.

f. If, at any time during the survey, a piece of equipment is changed or added the prove-out will be resurveyed. The prove-out will be used to demonstrate and document any changes in response due to the new components as well as to show that the new components are operating properly.

g. It is strongly recommended by CEHNC that the same personnel who will be doing the production geophysical survey work performs the GPO survey to reduce the learning curve and provide project continuity. (See DID OE-005-05A.01)

h. If reacquisition of selected targets is within the scope of the project, the prove-out will be used to demonstrate the contractor's ability to accurately reacquire the positions of discrete target picks. During reacquisition of the prove-out, the contractor will employ the exact methodology that will be used during reacquisition of the survey area. The reacquired targets will then be evaluated to ensure that the contractor has met the positional accuracy criteria specified for that site. See spreadsheet format in Geophysical Dig Sheet and Target History form (in Appendix E).

3.2 Site Selection

a. The prove-out site should have terrain and vegetation conditions that duplicate as closely as possible the conditions that will be encountered in the survey area. If any brush clearing will be done on the site prior to data collection, it should be done to the same degree in the prove-out area.

b. The site(s) selected for the geophysical prove-out should have geophysical noise conditions similar to those expected at the survey site. However, care should be taken not to introduce any additional noise sources. Sources of geophysical noise include magnetic rocks and soils, nearby power lines, and radio transmission towers. A more detailed discussion of geophysical noise can be found in Section 4.2.

c. The prove-out site is usually subject to heavy activity during its construction and the contractor's initial demonstration. The survey team will return to the site periodically through the duration of the project. A location should be selected that will allow easy access for those constructing the prove-out as well as the geophysical surveying team. Access of non-project personnel to the site must be limited. Notification should be made to other potential land users, so the site remains undisturbed. The prove-out site boundaries must be well marked to prevent disturbance. Changes in the prove-out area prior to completion of the project may invalidate direct comparisons of prove-out data.

d. In addition to having easy access, the prove-out should be located in close proximity to the survey area. This will minimize transit time when a return to the prove-out is necessary, and improve the probability that the GPO is located within similar conditions (geology, soils vegetation, terrain, etc.) as the project site.

e. Line direction may affect total field magnetics data if a heading error is introduced into the data. Heading errors are often noted when a survey grid is traversed in two directions, as most grid surveys are done. North – south oriented lines may produce a more pronounced heading error than east – west lines. Heading errors may be instrument and operator specific, and potentially may vary day to day depending on the operator's clothing and footwear. Line direction for magnetics surveys should be planned to coincide with the suspected direction munitions were fired, if possible. By orienting lines parallel to the direction in which munitions were fired, data density will permit better characterization of the source of the anomaly. This is particularly true in the case of man-portable systems, where data density along the survey line is often considerably higher than between survey lines.

f. Two possible prove-out sites should be identified during the initial site visit, prior to the start of the project. If by some circumstance during the project the primary prove-out site becomes unacceptable, the back-up site can be set up, and all operations moved there.

g. For large geophysical investigations, it may be necessary to establish more than one GPO to accurately represent differences in the site conditions in different locales. At large sites it may not be possible to place a GPO that is easily accessed from all parts of the area. Multiple plots, and / or transects / test strips can be used for a GPO. The factors listed above are ranked in importance for site selection, with "a" as the most important and decreasing with b, c, etc.

3.3 Prove-Out Site Preparation

a. Once the prove-out site has been selected, surface clearance of OE and other metallic debris will be performed in the same manner that will be employed in the survey area. Only approved EOD personnel will conduct surface clearance, in accordance with USACE Safety Program.

b. Like the survey areas, sites selected as prove-out areas often contain pre-existing geophysical anomalies that do not represent subsurface OE. Most GPO sites will not have any sub-surface clearance performed, and anomaly avoidance will be used when seeding the site. If the abundance of background anomalies precludes seeding, the GPO will be re-located.

(1) The entire area selected (both the actual plot and the surrounding buffer areas) for the prove-out will be geophysically mapped using the same instrumentation and methods

that will be employed during the actual prove-out and the subsequent survey. This will reveal the presence of any subsurface anomalies prior to the burial of test items.

(2) The prove-out will most often be seeded with test objects without removal of pre-existing anomalies. Data collection will provide an understanding of the OE detection results that can be expected in the actual survey area. Anomaly avoidance procedures will be followed while emplacing the seeded items in the prove-out.

c. Data collection in the prove-out may be accomplished using a local coordinate system. However, final maps should be presented in local state plane coordinate systems or UTM, as requested by the client. The use of state plane coordinates or UTM allows the data to be entered into a GIS and their positions to be permanently recorded. Experience has shown that it may be difficult to reoccupy local coordinates after the conclusion of the project. At a minimum, the four corners of the prove-out and buffer areas shall be recorded in either local and state plane coordinates or UTM.

3.4 Seeding Prove-Out Grid

a. Objects selected for emplacement in the prove-out grid should be representative of the munitions expected at the project site. Research conducted in the planning stages of the investigation, from Archive Search Reports and other sources will identify munitions known or suspected to exist on site. Objects having different mass, shape, and metallurgy will have a different magnetic or electromagnetic response. For this reason, every effort shall be made to bury inert munitions of the types expected at the site. Although it is recognized that responses from munitions will vary depending on the item’s condition and history, the use of inert OE provides a more realistic evaluation than the use of items used to resemble or substitute for ordnance. The use of generic test items having shapes similar to ordnance items (i.e. pipes, scrap metal) generally provides insufficient information to quantify a contractor’s ability to detect actual subsurface OE. This statement is based upon the high variability among the generic test items that have been used and observations from results over GPO grids where both actual inert OE and generic test items were buried. Simulants (inert munitions constructed specifically for demonstration purposes) are good substitutes if actual inert OE items are unavailable, impractical to obtain, or inert items at a given site are in very poor condition (e.g. only partial pieces are available or the items are highly corroded and/or in several pieces). It is recognized that inert OE and OE simulants are not common nor readily available and care must be taken not to derive specific statements about a given system's capabilities in detecting OE based solely on GPO data where only generic test items were buried.

b. Establish and document DQO's for the Prove-Out Grid. The DQO's must cover all aspects of the survey operations, including: planning, data acquisition, processing, interpretation, reacquisition, excavation, post-excavation, and QC. Documentation must be in an easily manipulated format (MS Excel, MS Access, etc.). Consult EM 1110-1-4009, Section 7-10 for a description of the DQO's.

c. The number of items to be placed in the ground must be determined based on the Data Quality Objectives (DQOs) for that project and the budget available for the GPO construction. The GPO seeding program should be designed to test the geophysical system's ability to detect the anticipated items down to their deepest anticipated depths and in positions that would produce the weakest responses on the instruments used. Contractors will not be held liable for technically unachievable goals, as determined during the GPO and the initial phase of fieldwork. A sufficient number of each item should be placed at these depths to demonstrate detection repeatability (e.g. between 3 and 5, or more, "tests" consisting of the same type of item placed at the same orientation and depth), however, the seeding program should not attempt to quantify factors as probability of detection, confidence levels, or false alarm rate, unless required by the project delivery team. In such cases, in order for the statistical results to be valid, the GPO seeding program will require large sample populations for each "test" (usually 40 or more of each item at a given depth and orientation). A statistician, or an individual with expertise in this field, should be consulted for the GPO design and statistical evaluations if parameters such as probability of detection, confidence levels, etc. are to be determined.

d. Whenever possible, seeded items will be buried in orientations that reflect those expected to be encountered in the survey area (usually based on firing direction and distance). If such information is not available, the seeded items should be oriented in such a manner as to produce the minimum response in the measured data. For time domain EM systems, this is typically a horizontal orientation, for frequency domain EM systems, this is typically a vertical orientation, and for magnetometer systems, this is typically at a angle normal to the local magnetic field inclination.

e. Items selected for burial shall be placed at depths equivalent to those expected to be encountered on site. It is also recommended that a few items be buried at greater than expected depths to help in determining maximum depths of detection for that site.

f. When designing the spacing of seeded items within the prove-out, an infinite number of scenarios involving different objects spaced at different intervals can be produced. To assure that an item can be detected at a certain depth, it should be evaluated with the fewest numbers of variables possible. Seeded items should be spaced at least 3 meters apart in order to eliminate overlapping responses and give the contractor the clearest understanding of instrument response at that site. Analyzing the effects of closely spaced objects may be useful if burial pits or areas saturated with buried munitions are being sought.

g. A list will be produced documenting the planned orientation, inclination, depth and location (x, y) for different seeded OE items.

h. Depth estimates based on geophysical data are inherently depths to the center of mass of the object. However, the objective for ordnance surveys is the depth to the top of the object. Both of these values will be recorded in order to make meaningful evaluations of the contractor's depth calculation methodology.

i. The burial of each seeded item should be thoroughly documented. Recorded information will include detailed notes on depth and orientation (azimuth, inclination) as well as sketches of the item's position. Figure 3.1 illustrates the terminology to be used in recording the azimuth and inclination of the buried items. For elongate inert munitions or simulants the x, y, and z coordinates for the nose, tail and center point will be recorded, so that the item's orientation is documented.

j. The contractor will photograph each item prior to its burial, labeled with target identification. Photographs will be taken of the items either in the hole or just prior to planting.

k. A licensed professional surveyor should measure the position of each buried item. Alternatively, with approval from CEHNC, a contractor may use a differential GPS (DGPS) system with sufficient accuracy for positioning. Locations for seeded items in the prove-out should be measured with an accuracy of 0.1 feet. Measurements of test items should include both ends of the item, as well as the center. Inaccurate or imprecise measurements will invalidate any results or conclusions based on the prove-out. Like the prove-out area itself, seeded item locations will be recorded in local and state plane coordinates or UTM. If the GPO requires only a test line(s) instead of a grid, the test items may be located using simple tapeline measurements to an accuracy of 0.1 foot with respect to the control points used to establish the test line(s).

3.5 Seeding Survey Areas

a. It is unlikely that any prove-out area will exactly match the conditions found in the field survey area. Blind seeded items in the survey area will provide an unbiased opportunity to evaluate the contractor's ability to detect subsurface OE under actual survey conditions. Seed items may be emplaced by the Corps of Engineers, or by the prime contractor if a subcontractor is performing the geophysical surveying. The rate of blind seeded items is typically one per five acres surveyed using DGM methods for projects where 250 acres or more will be surveyed; the rate usually increases for smaller projects.

b. Seeded items placed near the boundaries of the survey area will allow evaluation of the completeness of coverage being provided by the contractor. This also evaluates edge effects and the contractor's target selection.

c. Target selection criteria (response threshold) are determined based on data collected in the prove-out. Seeded items in the survey area provide a means of reevaluating the criteria based on actual site conditions.

d. Any items seeded in the survey area must follow the same positional accuracy standards as outlined above for the prove-out (See 3.4k).

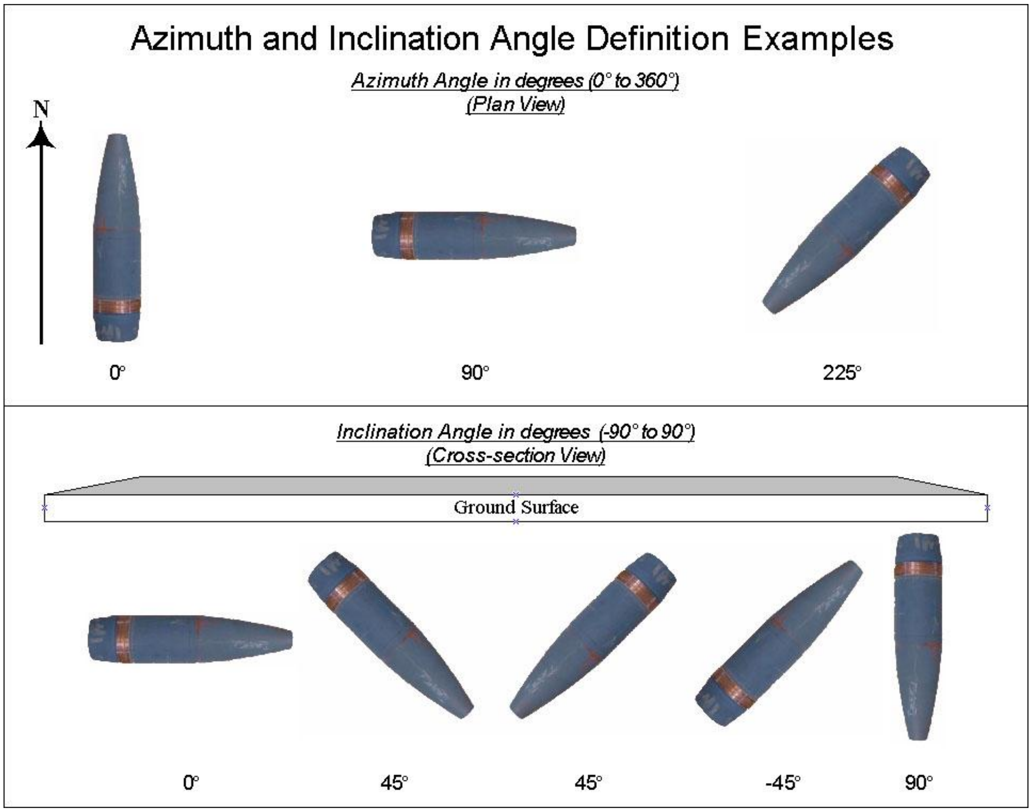


Figure 3-1: Azimuth and Inclination Angle Definition Examples

3.6 Checklist for Prove-Out Location and Design

Project Name: ______________________________

Project Location: ______________________________

CEHNC POC: ______________________________

Reviewer's Name and Title: ______________________________

Date of Review: ______________________________

	Y	N	N/A
Objectives			
a. Have survey objectives been determined, clarified, and documented?	____	____	____
b. Has EM-1110-1-4009 been consulted to ensure that all applicable objectives mentioned therein will be met?	____	____	____
c. Will the prove-out be available during the project for the evaluation of suspected instrument malfunctions?	____	____	____
d. Will the prove-out be available during the project for the evaluation of new equipment and operators?	____	____	____
e. Is the contractor prepared to demonstrate target reacquisition techniques in the prove-out area?	____	____	____
Site Selection			
a. Has the proposed prove-out site been evaluated for the following criteria:			
• Easy access for project personnel?	____	____	____
• Restricted access for non-project personnel?	____	____	____
b. Is the prove-out located in close proximity to the survey area?	____	____	____
c. Does the prove-out have geophysical noise conditions similar to those expected in the survey area?	____	____	____
d. Does the prove-out have terrain and vegetation conditions similar to those of the survey area?	____	____	____
e. Has a backup prove-out site been identified?	____	____	____
Site Preparation			
a. Has surface clearance been performed?	____	____	____
b. Geophysically map entire area prior to burial?	____	____	____

Seeding Prove-Out Grid	Y	N	N/A
a. Have all available sources been consulted to determine appropriate seeded items and orientations?	____	____	____
b. Have DQO's been established and documented?	____	____	____
c. Have appropriate burial depths been determined for the seeded items?	____	____	____
d. Have the DQO's been consulted to determine the number of seeded items?	____	____	____
e. Have the seeded items been spaced a minimum of 3 meters apart?	____	____	____
f. Has a list been made to document the range of burial depths for different OE items?	____	____	____
g. Have the following steps been taken to ensure accurate locations for the seeded items:	____	____	____
• Specify location requirements in x,y,z?	____	____	____
• Measure depth to top and center of mass of each object?	____	____	____
• Measure locations of both ends of non-vertical elongate ordnance?	____	____	____
• Thorough notes taken on each item's burial?	____	____	____
• GPS or a land surveyor employed to record the position of each item?	____	____	____

Seeding Survey Areas	Y	N	N/A
a. Have items been seeded near the boundaries of the survey areas?	____	____	____
b. Has a list been made of number and type of items buried, the range burial depths for different OE items, and percentage of area seeded?	____	____	____
c. Will target threshold be reevaluated based on results of seeded items in the survey areas?	____	____	____
d. Have the positional accuracy standards used during the prove-out been applied to seeded items in the survey areas?	____	____	____

Chapter 4: Amplitude Response and Depth of Detection

4.1 Introduction

Whether a buried munition is detectable is dependent on the size, depth of burial, orientation, inclination, and materials from which it is constructed, geophysical noise present at the site, and the limits of the instrument being used for the survey. Test measurements have been made at numerous sites on inert ordnance items at various depths and orientations. The results of one such study are summarized in the figures of this chapter, illustrating the responses of commonly used instruments to a variety of munitions, at their “best” and “worst” orientations.

For magnetics, it has been shown that the approximately dipolar amplitude response of small target items is inversely proportional to the cube of the distance of separation ($1/r^3$) between the sensor and the anomaly source. Neglecting remanent magnetization, greater induced magnetization is observed when elongate ordnance items are oriented parallel to the earth’s primary inducing field. For electromagnetics, the dipole response varies as $1/r^6$ for the far field, but is slower for the near field. Testing has also revealed that for ferrous items, a vertical orientation generally has a greater EM amplitude response than observed with a horizontal orientation.

The performance goals for geophysical investigations for buried munitions are cited in Data Item Description OE-005-05.01

a. A simplified expression for maximum depth of detection is:

$$\text{Estimated Detection Depth (meters)} = 11 * \text{diameter (mm)} / 1000$$

Equation 4.1

It is however, problematic for a single ‘formula’ to accurately predict site-specific detection depths because detection depth is limited by terrain noise (variable for different areas of each remediation site). Diameter refers to the caliber, or minor axis of typical munitions.

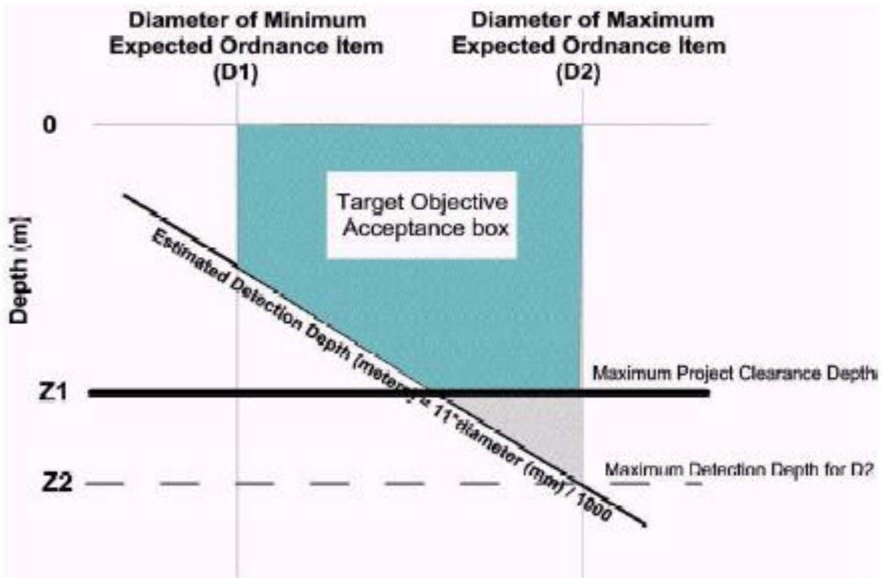
b. 

Figure 4-1: Target Objective Performance Box

c. Figure 4-1 illustrates the Target Objective Performance Box found in DID OE-005-05.01. Contractors will be required to detect and remove all metallic items located within the blue area. If these goals cannot be met at a site, alternative goals will be proposed for consideration. Contractors will not be held liable for technically unachievable goals, as determined during the GPO and the initial phase of fieldwork.

d. The Ordnance Detection and Discrimination Study (ODDS) conducted by USA Environmental, and Parsons Engineering Science for the Corps of Engineers at the former Fort Ord in California, generated excellent examples of static test data using vertical gradient magnetics and EM (time domain and frequency domain). The study was performed in July 2000. Figures 4.2 through 4.4 were compiled using ODDS data, illustrating their findings on maximum depths of detection for 10 different ordnance items, ranging in size from a 22mm sub-caliber M181 projectile, to a 155mm projectile (smoke). It is important to note that all of these were static, free-air measurements recorded using a special non-metallic platform, raised above the ground surface. They are essentially measurements with no terrain noise. Survey data collected from seeded test grids in the ODDS illustrated that dynamic data collected over the ground surface has noise levels that were several multiples of those observed in the free-air tests, and in some instances, the noise levels were orders of magnitude greater.

(1) Maximum depth tested for each OE item was the calculated maximum depth of penetration for soils at Fort Ord. For the EM61 (1m by 1m coils), best and worst orientations were generally with the long axis of the OE item vertical, and horizontal, respectively. The best orientation for elongate items with the GEM-3 was most often horizontal. For the Geometrics 858, the best orientation was ordinarily with the long axis of an OE item parallel to the inclination of the magnetic field, and the worst perpendicular to the magnetic field.

(2) The ODDS static test report listed targets with readings as low as 1.49 mV as detectable for the EM61, and 1.31 mV for the EM61 HH. For the G-858 magnetometer, most readings for the deepest detectable depths were on the order of 1 to 2 nT/f. The GEM-3 used in the static tests was equipped with a 40cm diameter sensing head. Readings as low as 1 (quadrature sum for five frequencies) ppm were recorded for the deepest detectable depth. These numbers may be useful in calculating ideal detection depths, but in a real survey noise levels from a variety of sources will necessitate a higher threshold.

(3) To use the ODDS nomograms to predict whether a target will be detected, superimpose instrument noise and local terrain noise onto the diagrams to estimate possible depth of detection. The instrument noise level for a well maintained and calibrated EM61 is about 1 to 1.5 mV. Therefore, the depth at which any ordnance type reaches this noise level is the ultimate detection depth (ideal conditions, no other noise) for that object. At various locations across a remediation site, the local terrain noise will further reduce the detection depths. It is inappropriate to speak of a 'typical detection depth' for a particular instrument without considering the geophysical noise levels present at the site.

e. Penetration depths for a variety of ordnance types in sand, clay, and loam are given in Table 4.1. When used in conjunction with ODDS nomograms, and a noise threshold is superimposed, the possibility of detecting ordnance at an anticipated depth can be estimated.

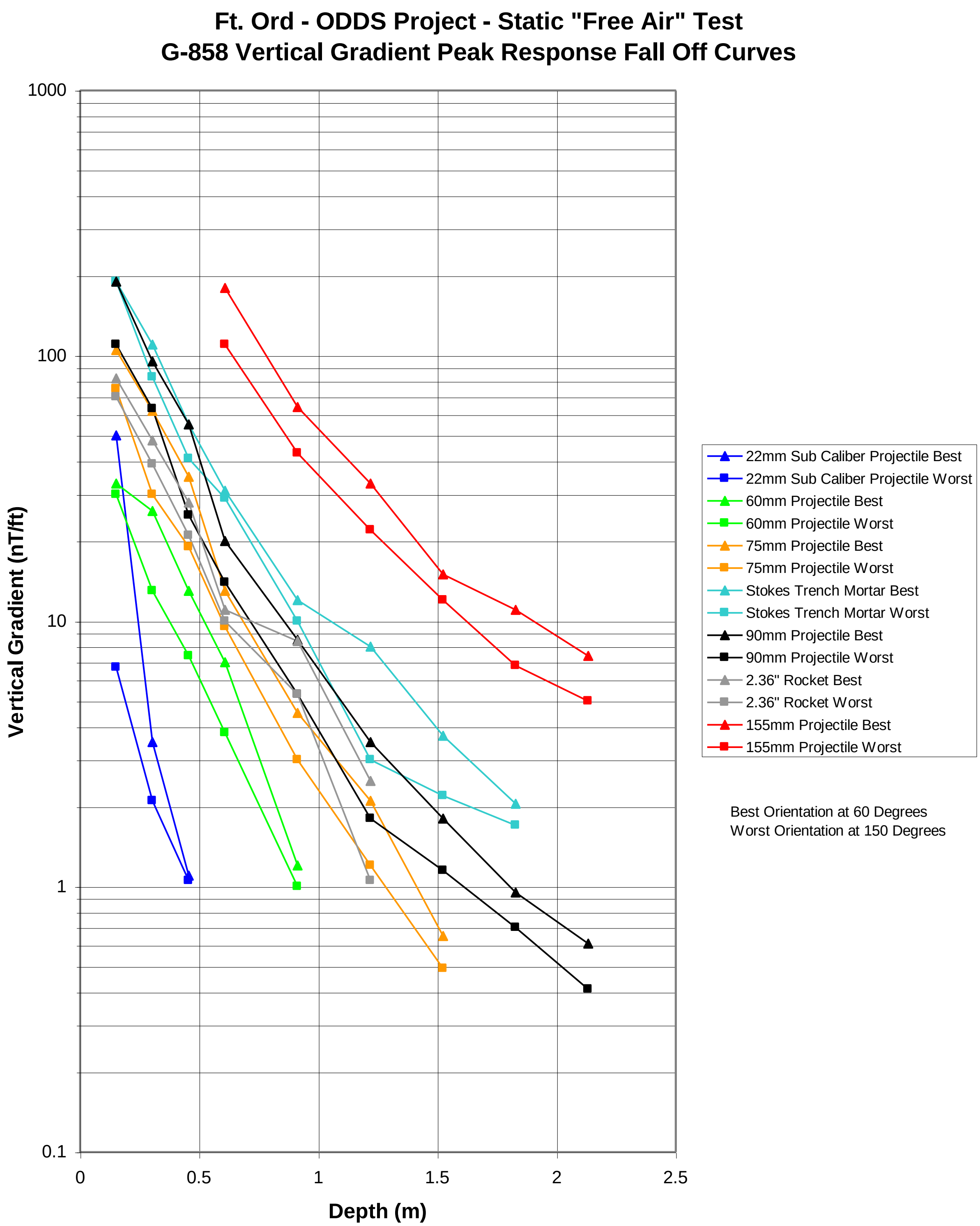


Figure 4-2: G-856 Vertical Gradient Peak Response Fall Off Curves

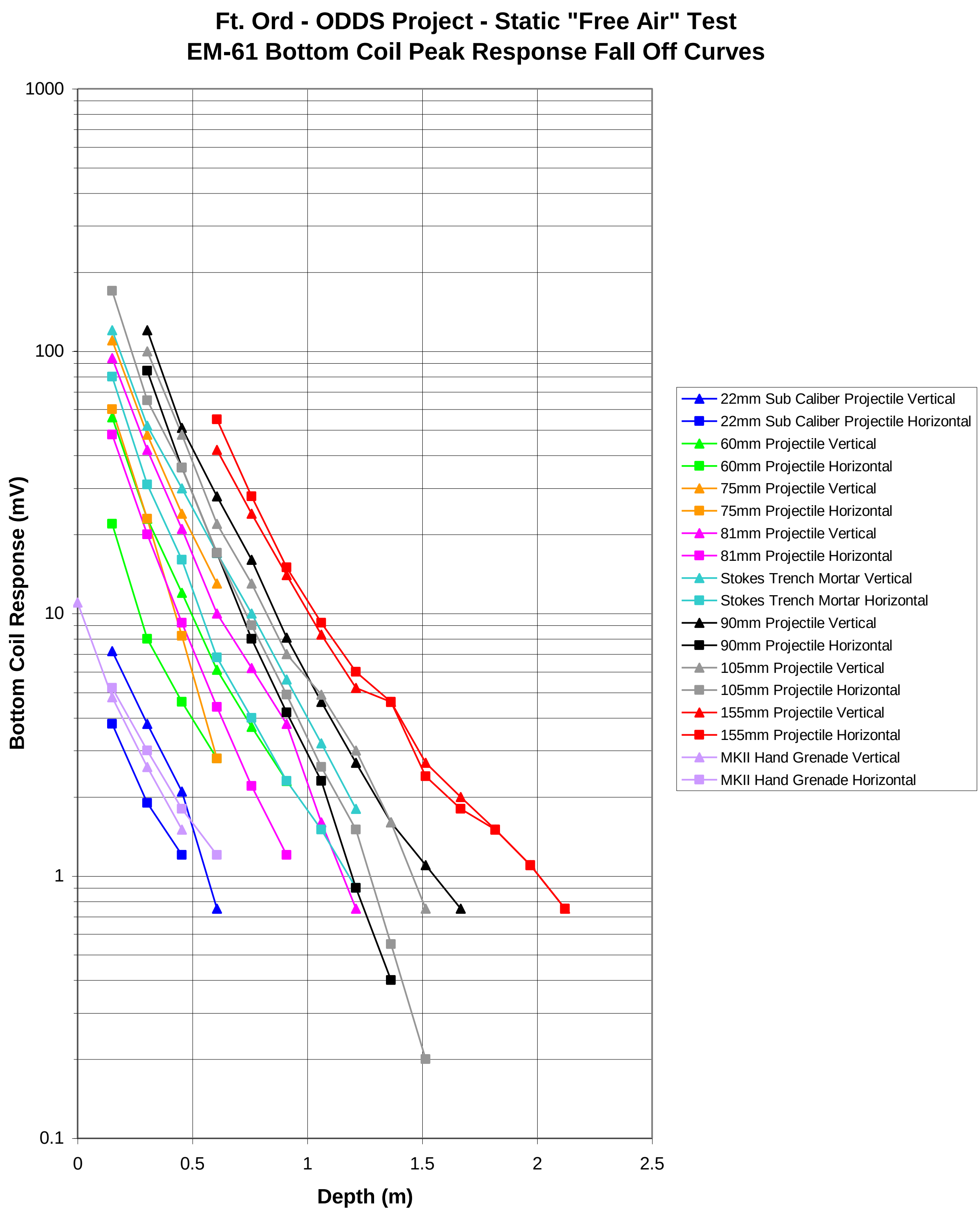


Figure 4-3: EM-61 Bottom Coil Peak Response Fall Off

Source: G. Hunter Ware
Geophysical Associates

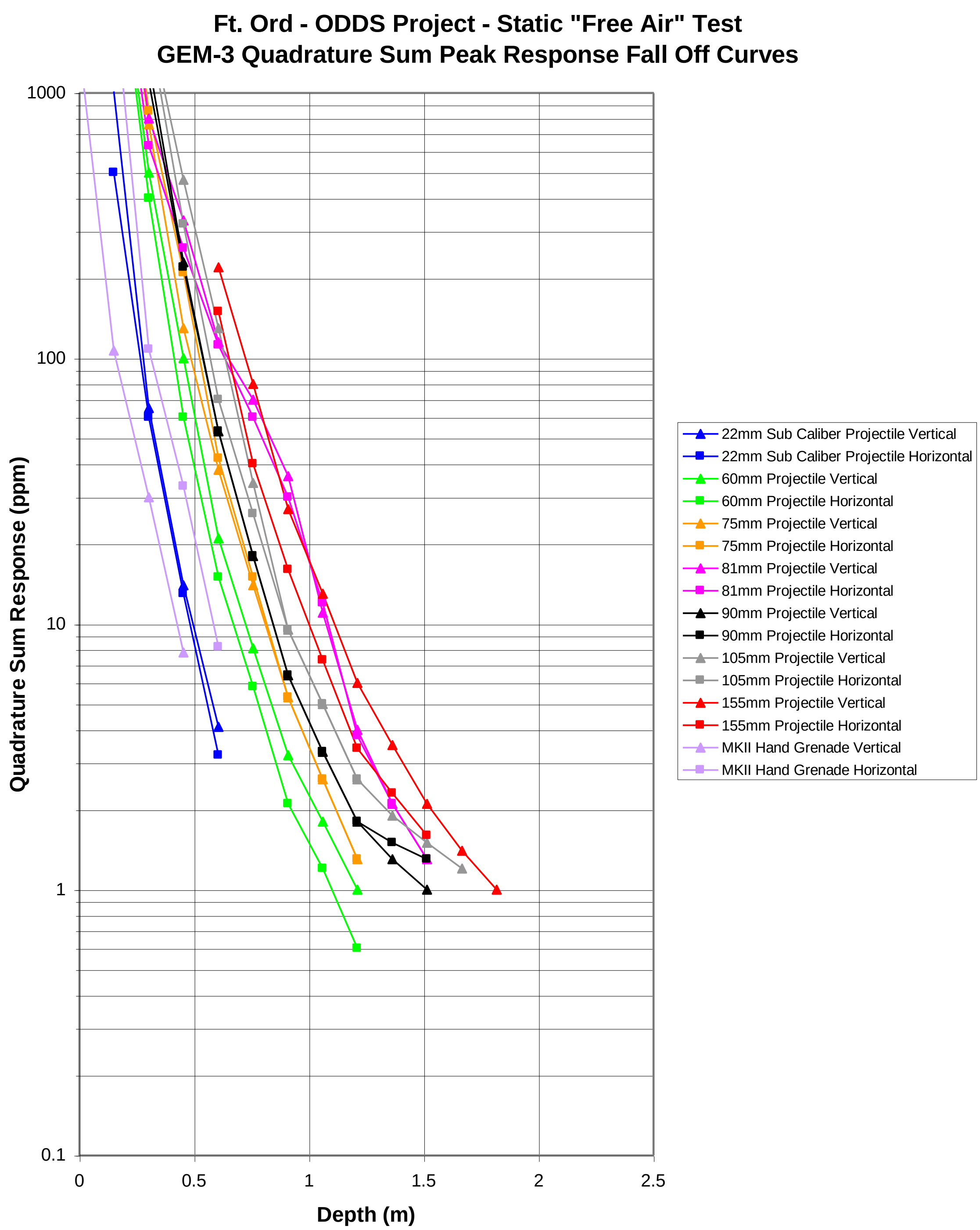


Figure 4-4: GEM-3 Quadrature Sum Peak Response Fall Off Curves

Ordnance Penetration and Detection Table (from EM-1110-1-4009)

Ordnance Item	Depth of Penetration[1, 2] (ft)			Typical Max Detection Depth[4] (ft)	
	Sand	Loam	Clay	Magnetometry	TDEM[5]
14.5 mm Trainer/Spotter, M1813A1	0.2	0.3	0.4	0.3	0.5
20mm, M56A4	2.3	3	4.6	0.4	0.7
22 mm Subcal for 81 mm mortar	1.4	1.9	2.8	0.5	0.8
35 mm Subcal M73	0.5	0.7	1	0.9	1.3
37 mm, M63	3.9	5.2	7.9	1	1.3
40 mm, M822 (AA)	2.3	3	4.5	1.1	1.4
40 mm, M677 (Mk 19)	0.2	0.3	0.4	1.1	1.4
40 mm, M381 (M203/M79)	0.2	0.3	0.4	1.1	1.4
Mk 118 Bomblet	1.9	2.4	3.7	1.5	1.8
Mk 23 3 lb. Practice Bomb	2.7	3.5	5.4	1.7	2
57 mm, M306A1	2.7	3.6	5.5	1.7	2
M9 Rifle Grenade	0.1	0.2	0.2	1.7	2
2.25" Rocket, Mk 4	4	5.2	8	1.7	2
60 mm, M49A1 (charge 4)	1.1	1.5	2.3	1.9	2.2
2.36" Rocket, M6A1	0.4	0.5	0.8	1.9	2.2
66 mm, M72 LAW	0.9	1.2	1.8	2.1	2.4
66 mm TPA, M74	0.7	0.9	1.4	2.1	2.4
BLU-3/B,-27/B,-28/B	2.2	2.9	4.4	2.3	2.5
2.75" Rocket, Practice	8.1	10.7	16.3	2.3	2.5
6 lb. Incendiary Bomb	3.4	4.4	6.7	2.4	2.6
75 mm, M48	4.9	6.4	9.8	2.5	2.7
75 mm, M310	3.9	5.1	7.8	2.5	2.7
81 mm, M43A1 (charge 8)	2.7	3.5	5.4	2.8	2.9
83 mm SMAW Mk 3	2.8	3.6	5.6	2.9	3
84 mm, M136 (AT4)	2.5	3.7	5	2.9	3
3.5" Rocket, M28	0.8	1.1	1.7	3.2	3.2
90 mm, M371A1	2	2.7	4.1	3.2	3.2
25 lb. Frag Bomb[3]	2.1	2.8	4.3	3.2	3.2
AN-M41A1 20 lb. Practice Bomb	5	6.6	10	3.3	3.3
105 mm, M1 (charge 7)	7.7	10.1	15.4	4	3.8
106 mm, M344A1	6.5	8.5	13	4	3.8
4.2" Mortar, M3 (max charge)	4.1	5.4	8.3	4.1	3.9
Dragon Guided Missile	0.9	1.1	1.7	4.3	4
155 mm, M107	14	16.4	28	6.7	5.6
8", M106 (charge 8)	16.4	24.2	36.9	9.7	7.3
M38A2 100 lb. Practice Bomb	8.6	11.3	15.2	9.9	7.4

[1]Penetration depths include the following "worst-case" conditions assumptions: impact velocity is equal to maximum velocity of round; impact is perpendicular to ground surface; munition decelerates subsurface in a straight line; munition does not deform upon impact. Typical penetration depth for any individual item will usually be significantly less.
[2]Maximum depth of penetration assuming a velocity of 500 fps.
[3]All bombs are assumed to have an impact velocity of 1135 feet per second.
[4]Actual detection depth may vary based on field conditions and be either lower or deeper.
[5]Time Domain Electromagnetics
Rev 1-5/11/99

Table 4-1

4.2 Geophysical Noise.

a. The responses of targets may be detected only if they are greater than the background noise level. Geophysical noise (not sensor sensitivity) is therefore the limiting factor in determining thresholds and detection depths. The noise encountered in geophysical surveys is generally of four types:

- Instrument Noise
- Ambient (Disturbance Field) Noise
- Motional or Dynamic Noise (mechanical vibration, etc.)
- Terrain Noise (site-specific, repeatable response of rocks, soils, and metal clutter)

b. Instrument noise is internal and intrinsic to the instrument. It is generally, by design, of much lower amplitude than other sources of background noise.

c. Ambient noise is induced in the sensors by outside fields in its vicinity. It can be caused by nearby utilities, motors, radios, generators, radar, and other electrical or electromagnetic devices. GPS electronics and radios are common sources of ambient noise. An extreme example of this type of noise is illustrated in Figure 4.5 displaying EM61 data collected in the vicinity of high tension power lines.

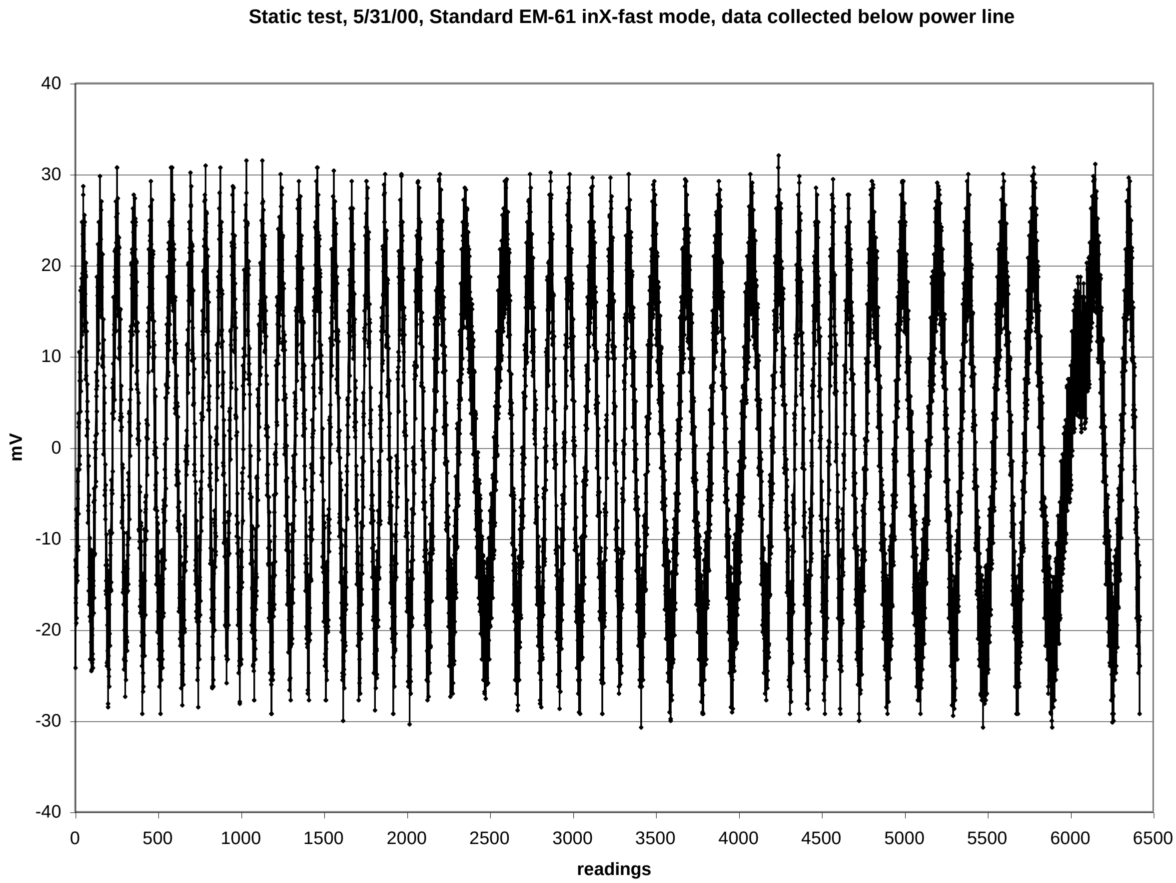


Figure 4-5: Example of Ambient Noise (power lines)

d. Motional noise is caused by mechanical vibration of the instrument and metal on the operator or instrument (wheels, etc.). It can occur anytime the instrument is moving. An example of motional noise is illustrated in Figure 4.6, which shows cesium vapor magnetometer data collected with and without a ballpoint pen in the operator's pants pocket.

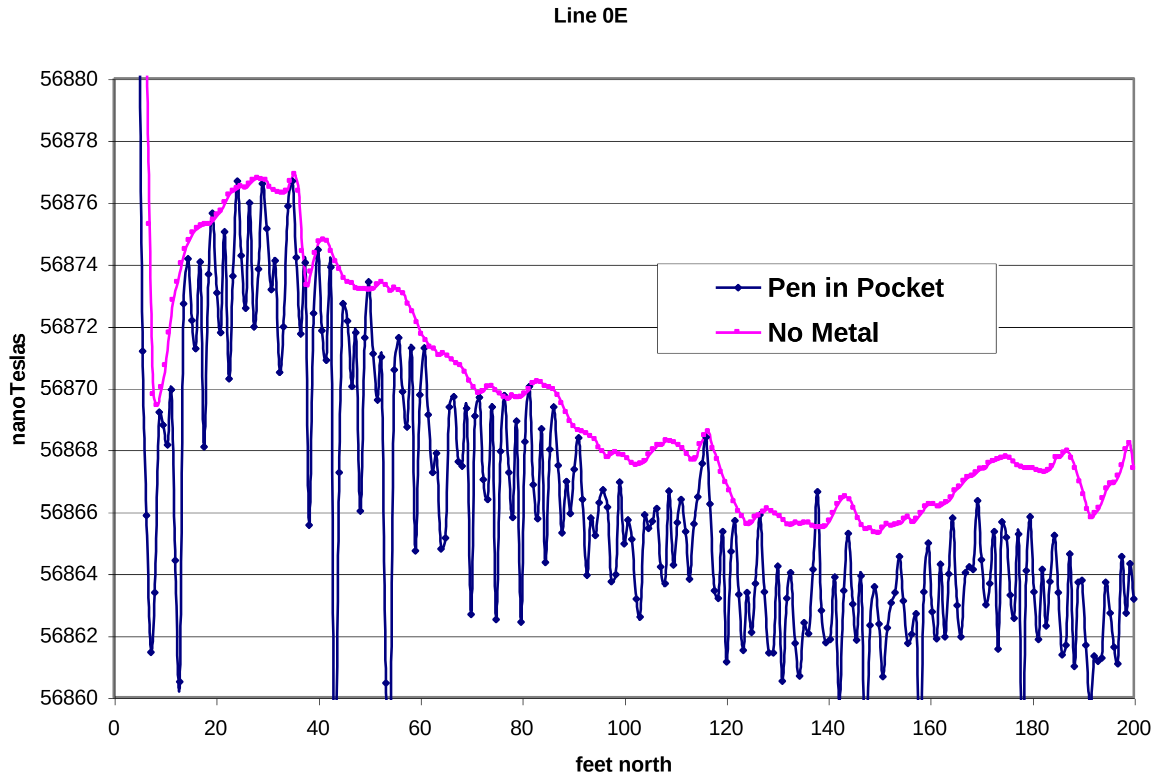


Figure 4-6: Example of Motional Noise

e. Terrain noise is cause by real and repeatable instrument response to magnetic rocks, soils, and metal clutter. The term terrain refers to the sources of response that are actually present in or on the ground. It is usually the largest noise component and often the limiting factor in geophysical detection and interpretation. Examples of terrain noise are shown in Figures 4.7 and 4.8. In Figure 4.7, the northeastern portion of the survey falls in an impact zone with overwhelming terrain noise. Data analysis for discrete target locations in such areas is not possible. Figure 4.8 illustrates geologic terrain noise in magnetics data collected over magnetic bedrock. Interpretation and selection of low amplitude anomalies is difficult under such conditions.

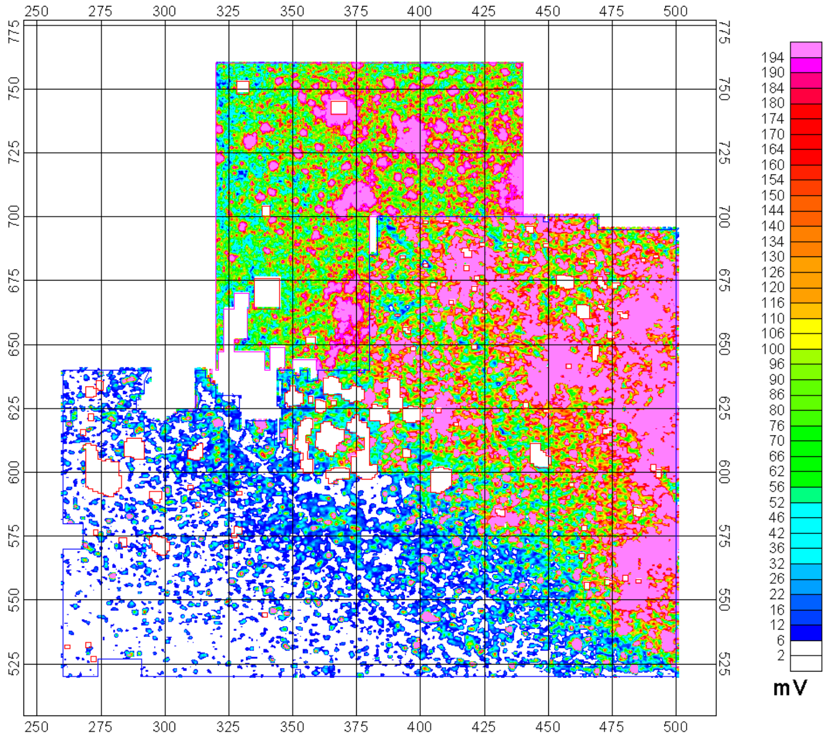


Figure 4-7: Terrain Noise-Impact Area in northeast half of map

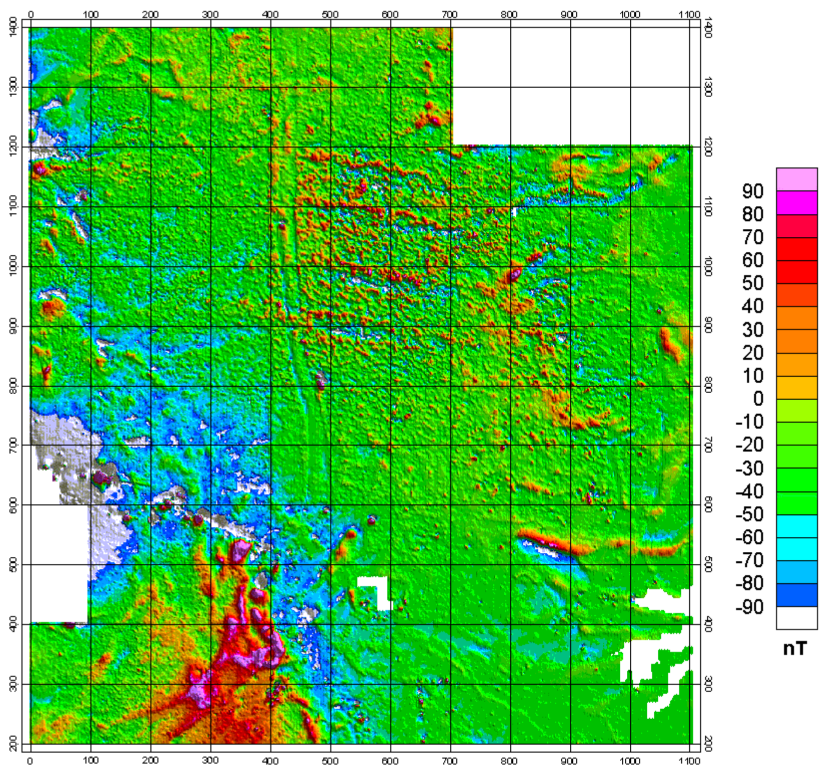


Figure 4-8: Terrain Noise-Magnetic Bedrock in SW portion of map

4.3 Filtering Noise.

a. Short wavelength and long wavelength noise can be suppressed by filtering. Stacking can reduce random noise. Unfortunately, terrain noise is non-random (repeatable) and often contains the same wavelengths as target responses. The size of the EM coil used, or the height of the magnetometer sensor generally range from approximately 0.5m to 1.0m, which is close to the wavelength of targets sought in UXO surveys. Terrain noise of this wavelength cannot be removed by spatial filtering.

b. Static (bench) tests measure the sum of instrument and ambient noise (and also instrument drift). Dynamic tests along an actual survey line are necessary in order to measure motional and terrain noise. Emplacement of one or more calibration objects permits evaluation of amplitude response. A repeated dynamic test survey line also measures positional variation.

c. Noise from a static or dynamic test, or an entire data file, may be quantified as the standard deviation of a histogram of test readings. This is useful for rational data quality evaluation or signal to noise threshold determinations. As an example, setting the threshold to two standard deviations will avoid approximately 95% of the noise. Figure 4.9 is a data frequency distribution diagram showing calculated standard deviation. This histogram shows every reading of a given amplitude collected on a grid. For the raw data, the peak of the histogram falls at approximately 1 mV. The peak lies at 0 mV for the leveled data set. Note the abundance of readings within two standard deviations of 0 mV. Figure 4.10 illustrates the relationship of target threshold versus the number of targets selected for another data set. Selecting targets below the noise threshold may result in very high numbers of targets. This curve is best obtained from leveled data.

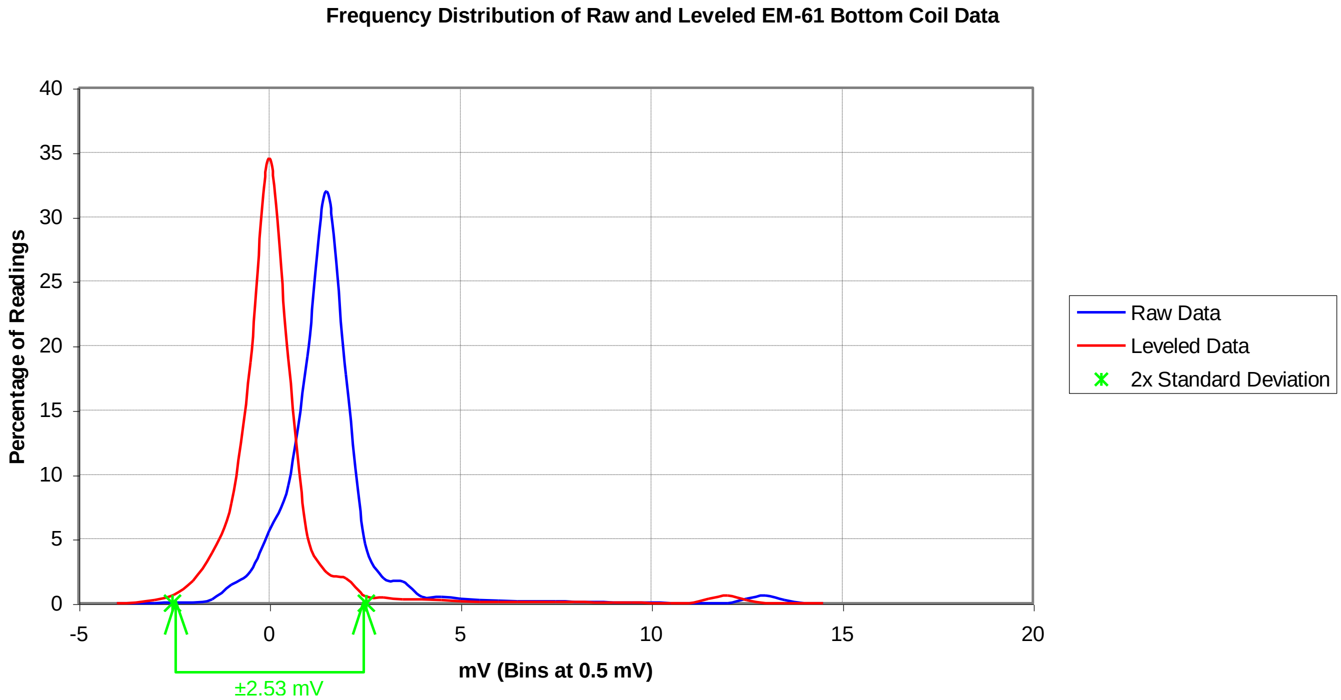


Figure 4-9: Frequency Distribution

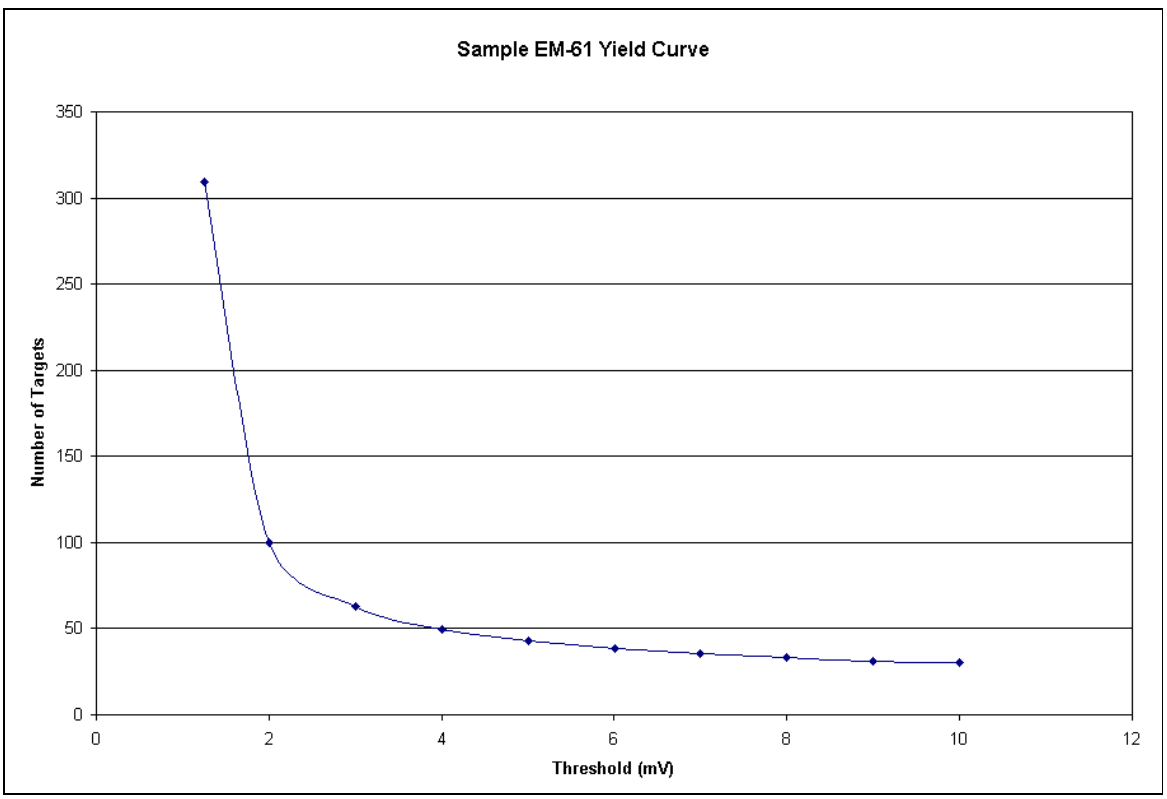


Figure 4-10: Yield Curve derived from leveled data

d. The presence of noise in data reduces the ability to reliably detect low amplitude signal associated with buried munitions. Filtering can improve the appearance and usability of data, however great caution must be exercised, as filtering will likely remove low-amplitude, short wavelength signals associated with buried munitions. Careful application of filters to data can reduce the effects of noise, making true anomalies more apparent in the data. Some effects of applying different filtering techniques to data are shown in Figure 4.11. In this example, the raw unfiltered data exhibits three common forms of noise that may be present in data: (1) high amplitude single point data spikes, (2) low amplitude short wavelength noise and (3) moderate amplitude broad wavelength noise. There are two anomalies of interest centered near 140 and 400 that represent UXO like objects. The example of good filtering uses a short de-spiking filter to remove (1) followed by a short low pass filter to remove (2) and a combination of long demedian and high pass filtering to remove (3) and level the data. The poorly filtered data applies similar filters but with poorly chosen parameters. The de-spiking step was omitted. The length of the high pass and demedian filters is too short and although the broad wavelength features are removed, the anomalies of interest are also removed. High amplitude spikes remain and effective reduction of the chatter is not achieved because the low pass filter length is too short.

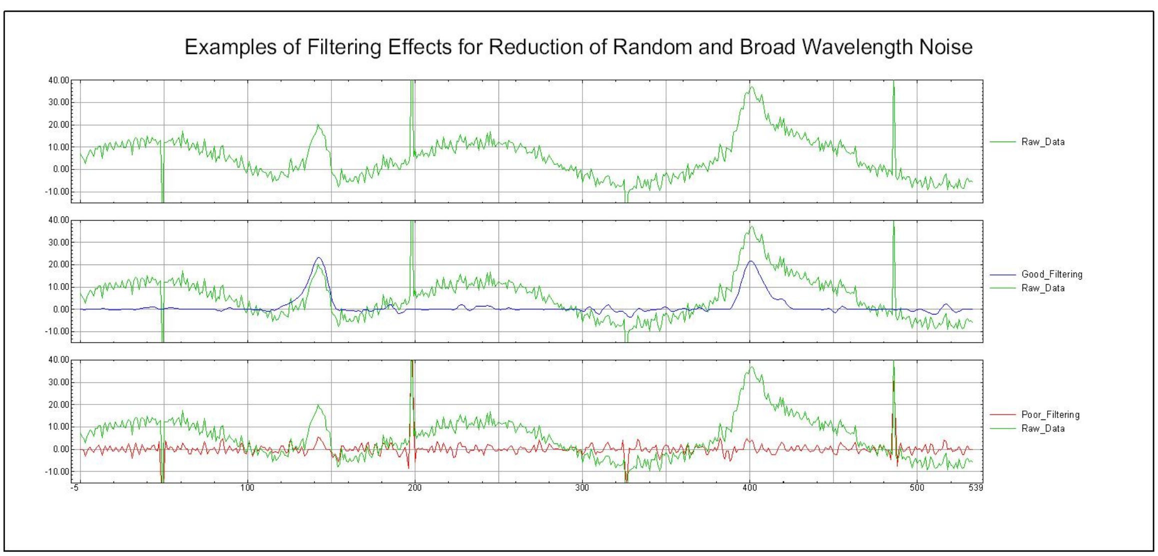


Figure 4-11: Examples of good and poor applications of filters to reduce spikes, random chatter and broad wavelength noise in UXO data.

Chapter 5: Equipment Functionality and QC Tests

Equipment tests and suggested frequency of testing is summarized in Table 5.1. Pass / Fail Criteria are listed in the Instrument Test Checklists included at the end of this chapter. The required frequency of tests may vary by contract.

Test	Frequency of Testing			
	Beginning of Day	Beginning and End of Day	First Day of Project Only	Equipment Change
Personnel Test	X			X
Record Sensor Position	X			X
Cable Shake	X			X
Static (Background)		X		X
Instrument Response		X		X
Azimuthal Test			X	X
Octant Test			X	X
6 Line Test			X	X

Table 5-1

5.1 Out of Box Equipment Tests

Past experience has shown that too often non-functioning equipment arrives at the site, causing delays in surveying. Worse yet, improperly functioning equipment may result in unreliable data, increasing false alarms or missing buried munitions. For these reasons out of box equipment tests are needed to assure instruments are operating correctly. Prior to mobilizing to the field, investigate and document sources for system spare parts, and the time frame in which they are available.

a. Inventory and inspect all components. Equipment manufacturers and most geophysical rental companies provide a packing list showing all included components. Record the serial numbers for all applicable components, and the source of the equipment. This information should be documented on the attached checklist (Checklist for Out of Box Equipment Tests). Check that each item is present, and inspect cables, connectors, harnesses, etc. for signs of wear or damage. Spare cables are essential as the cables are often the most vulnerable part of a system. At least one spare cable should be with each instrument. If necessary, order more cables.

b. Assemble the instrument and power up.

c. With the instrument held in a static position, and collecting data, move cables to test for shorts and broken pin-outs. Shake cable starting on one end and proceeding to the other. An assistant is helpful to observe any changes in instrument response. If shorts are found, mark cable, set aside and replace.

d. Null instrument (EM only). This is a recommended procedure, although it is not required. The EM61 should be nulled prior to conducting the following tests. Older EM61 backpacks are provided with potentiometers for the top and bottom coils, which can be adjusted to null (zero) the instrument. The EM61 MK2 utilizes software to perform nulling, zeroing all channels simultaneously. It is essential the instrument be fully warmed up prior to nulling, and that this procedure is performed in an area free of metal. Warm –up time will vary according to ambient temperature, but should be a minimum of five minutes for warm conditions. Refer to Section 6.4c for additional information on nulling.

e. Conduct Static (Background) and Instrument Response Tests.

(1) Establish an area for these tests that offers convenient access, is free of metal (surface and sub-surface), and is sufficiently far from roads and power lines, transmitters, etc. to avoid these sources of noise. This same point will be used throughout the duration of the project for daily static (background) test and response tests and for nulling instruments. On large sites, multiple test points may be necessary. Clearly mark the location(s) so that the instrument will be located in precisely the same spot each time. Marking the tire locations for the EM61, for example, will satisfy this requirement. To conduct a meaningful static test with a magnetometer, it is important that the sensor remain perfectly stationary during the test. For day-to-day comparisons, the sensor must be in the same location. Small variations in the sensor position can have a large effect on the response. A PVC tube (or any non-ferrous tube) can be driven into the ground, and marked (for directional consistency) for use in magnetics static tests.

(2) Static (background) Test: The primary purpose of performing a static test is to determine whether a particular geophysical instrument is collecting stable readings.

Improper instrument function, the presence of local sources of ambient noise (such as EM transmissions from high-voltage electric lines), and instability in the earth's magnetic field (as during a magnetic storm) are all potential causes of inconsistent, non-repeatable readings. The operator must review the readings to confirm their stability prior to continuing with the geophysical survey. In addition, this test documents the "background" response of the instrument at a specific location, which can then be compared each day to assure a constant value. To pass the Static Test the value of the response must vary less than 20% from test to test.

(a) When the instrument has been powered up sufficiently long to warm the electronics, place the instrument at its normal operating height so that it will remain stationary, and begin data collection. An alternative to waiting for the instrument to warm up is to begin data collection when the instrument is turned on, thus documenting the time required for readings to stabilize. Collect readings for a minimum of three minutes after instrument warm-up. Data collected during static tests should be retained for documentation purposes.

(b) The effects of ambient noise may vary across a project site. Therefore, it may be necessary to perform several static tests across the survey area.

(3) The Instrument Response Test quantifies the response of the instrument to a standard test item. A steel trailer ball is a preferred test item that is easily acquired and transported. A standard 2" diameter trailer ball with integrated shaft should be used as the test item. If a larger test item is used, the response criteria stated below should be adjusted accordingly. Leaving the instrument in the same position as used in the Static Test, place the test item below the sensor, then collect data for a minimum one minute period. The test will document the amplitude of response to the test item and instrument drift. To pass the Instrument Response Test the value of the response must vary less than 20% from test to test. Care must be taken to evaluate significant deviation in the day to day test results as these may be indicative of instrument failure.

f. Equipment not functioning properly will be replaced or repaired as quickly as possible.

5.2 Initial Geophysical Instrument Checks

These tests are normally performed the first day of a geophysical investigation.

a. Six-Line Test: This test is used for all geophysical instruments, and is illustrated in Figure 5.1. Although the test is called the "Six Line Test", it is really six passes (three going one direction, and three going the other) on the same line. The description below is specifically for man-portable systems. Towed array systems may require a different approach to document latency and heading effects.

(1) Use an area that has little background noise and no sources of anomalous responses. A line selected from the site's geophysical prove-out grid is well suited for this task, provided that the prove-out grid is convenient to the survey area.

(2) The test line will be well marked to facilitate data collection over the exact same line each time the test is performed. Background response over the test line is established in Lines 1 and 2.

(3) A standard test item, such as a steel trailer hitch ball will be used for Lines 3 through 6. Heading effects, repeatability of response amplitude, positional accuracy, and latency are evaluated in Lines 3-6.

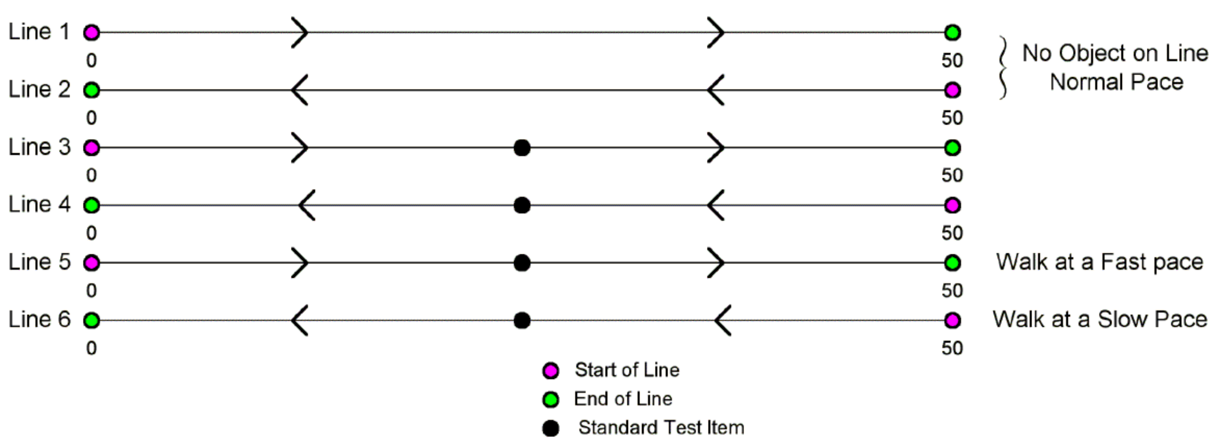


Figure 5-1: Six-Line Test

b. Octant Test or Heading Test: These tests are performed for magnetics only, the Octant test is optimized for survey systems that use digital navigation equipment, the Heading test is optimized for surveys that use conventional navigation techniques (such as line and fiducial positioning).

For the Octant Test, a total of eight lines of magnetic data are collected, passing over the same central point. The arrangement of lines for the test is illustrated in Figure 5.2. The difference in the response over the central point documents heading effects. This is the recommended test for establishing heading correction parameters. Typically, this test is performed once for each system deployment, however, small changes in heading errors from the same deployed system have been observed to occur over shot periods of time. Therefore, in most instances, the actual heading corrections applied to any given set of data will need to be optimized during data processing.

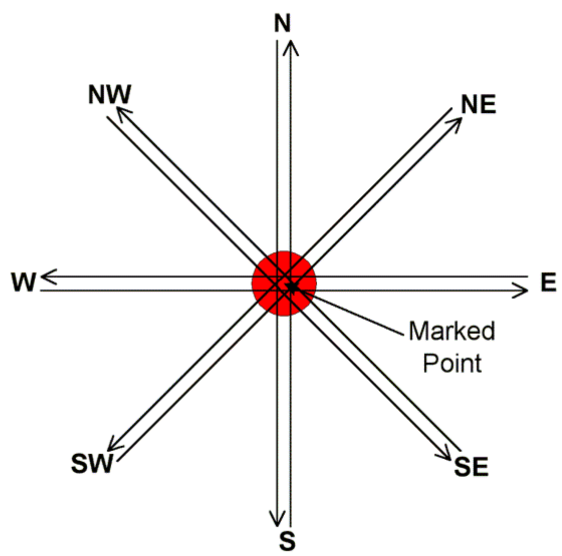


Figure 5-2: Octant Test

For the Heading Test, the operator records the magnetic response at the same location while facing in both directions of travel. For example, in a grid where the direction of travel will be along the grid's Y axis (i.e. north-south in the local grid coordinate system), the operator would locate a magnetically quiet location within or near the grid, and orient the equipment facing north direction and record the measured response. The operator would then turn 180 degrees, place the sensors at the exact same location and record the measured response. This test must be performed for each operator at each deployment, and is usually performed at the beginning of each data collection event. The recorded information would then used to apply dataset-specific heading corrections. Depending on the objectives of the survey, it may not be necessary to apply a correction to compensate for very small heading errors (< 1nT or <0.5nT/ft).

c. Height Optimization: This test is most often applied to magnetics, and for the GEM-3 instrument. It could also be used for an EM61 used in harness or “litter” mode. A line is established with at least one test object along its length. Data are collected with the instrument using a minimum of three different sensor heights. The goal is to optimize the target signal to noise ratio, and maintain adequate sensitivity.

d. Pull-Away Test: This test demonstrates the effects of navigational equipment and/or vehicles used to tow sensors or arrays. With the instrument collecting data in a static (background) test, navigational equipment or vehicles positioned as they would be in the field survey are pulled slowly away from the sensor to gauge any differences in response. This must be performed with the navigational equipment (or vehicle) power off, and also with the equipment powered up. A simple direct current (DC) shift may be observed when the equipment is in normal operating position, compared to values when it is distant, however this is easily removed from the data. If excessive noise is noted, however, steps will be taken to identify the source and correct the problem.

5.3 Daily Instrument Checks

Data collected in these tests must be closely examined each morning, **before** starting the collection of survey data. It is recognized that modifications to the frequency that these tests should be performed may warrant change based upon the project objectives and the quality control needed for a specific task. Any such proposed changes must be made in consultation with the project team.

a. Personnel Test: The instrument operator moves around the stationary, operating instrument to scan for any effects by remaining metal on their person.

b. Measure and record sensor position (s).

c. Cable Shake Test: Prior to collecting data each day, the instrument cables connectors will be tested for shorts as described in the out of box equipment tests. Faulty cables or connectors will be replaced prior to data collection. Tape loose cables to prevent their movement during data acquisition.

d. Null instrument (EM only). This test is recommended, although it is not required. The EM61 should be nulled prior to conducting the following tests. Nulling the instrument simplifies the recording and calculating of quality control functions, such as documenting the instrument's response to a standard object. Nulling does not negate the need to perform fine leveling of the data during post-processing and interpretation. Standard EM61 backpacks are provided with potentiometers for the top and bottom coils, which can be adjusted to null (zero) the instrument. For the EM61 MK2, nulling is achieved through the controlling software. It is essential the instrument be fully warmed up prior to nulling, and that this procedure is performed in an area free of metal. Refer to Section 6.4c for additional information on nulling.

e. Static Test: This test should be performed twice daily in the same location, prior to data collection, and at the end of the day. Data is recorded during a minimum 3-minute duration static test to demonstrate stability of readings. The acceptance criteria for this test are 2.5mV peak-to-peak for EM61 MK1 instruments and the 3rd time gate for EM61 MK2 instruments, and 1nT peak-to-peak for total field magnetometers.

f. Instrument Response Test: Following the static test, a standard test item is placed below the sensor, and readings recorded for at least 1 minute, followed by 1 additional minute of measurements collected with the standard test item removed. Instrument response of equal amplitude from test to test demonstrates that the calibration of the instrument has not changed.

5.4 Data Repeatability

A minimum of one line per grid of repeat data is required for grid surveys. For transect and meandering path surveys, a minimum of 100 feet per linear mile of repeat data is required.

Typically, for convenience, the same personnel collecting the survey data will collect the repeat data immediately following data collection. Repeat data may be collected at a later date and time, however, there is a risk of not knowing that a system's performance metrics are not being met until the repeat data is collected and/or reviewed. For this reason, it is recommended that repeat data be collected and reviewed as soon as practical. A site with a low density of anomalous responses would benefit from a higher percentage of repeat data. When viewed in profile and compared to original data, repeat data provides a means of evaluating the ability of the instrument to respond consistently, and evaluates the positional accuracy of the data. Errors in positional repeatability indicate a problem in the method of navigation or in the ability of the operator to perform an adequate survey. Positional differences (errors) observed in the location of anomalies in repeat data should not exceed one foot. The actual location (on the ground) of the repeated line should be within +/-1 foot of the original survey line. However, in some instances, such as areas with strong horizontal magnetic gradients, the positional tolerance between the repeat line and the original survey line may need to be much tighter in order to reproduce the measured responses.

5.5 Checklist for Out of Box Equipment Tests

Project Name: ______________________________
Project Location: ______________________________
CEHNC POC: ______________________________
Equipment Source: ______________________________
Equipment Serial Numbers: ______________________________
____
Reviewer's Name and Title: ______________________________
Date of Review: ______________________________

	Y	N	N/A
a. Has the equipment been inventoried and inspected for damage or wear?			
b. Are spare parts (cables) included with system?			
c. Has the cable shake test been performed? (Replace any faulty components if necessary)	____	____	____
d. Has the instrument (EM only) been nulled?	____	____	____
e. Has a nearby, noise-free site been selected for static background and static response tests?	____	____	____
f. Have the following instrument function tests been successfully performed:	____	____	____
• Static background test demonstrating <20% deviation in response for at least 3 minutes?	____	____	____
• Instrument response test demonstrating <20% deviation in response from test to test?	____	____	____

5.6 Checklist for Initial Instrument Tests

Project Name: ______________________________
Project Location: ______________________________
CEHNC POC: ______________________________
Equipment Source: ______________________________
Equipment Serial Numbers: ______________________________
____
Reviewer's Name and Title: ______________________________
Date of Review: ______________________________

	Y	N	N/A
a. Was instrument warmed up for a minimum of five minutes prior to operation?			
b. Has the six-line test been utilized to evaluate the following factors:			
• Heading effects?	____	____	____
• Repeatability of the response amplitude?	____	____	____
• Positional accuracy?	____	____	____
• Latency?	____	____	____
c. If magnetics data are to be collected, have the following steps been taken in the performance of the azimuthal test:	____	____	____
• Selected an area free of geophysical noise?	____	____	____
• Fixed sensor head position?	____	____	____
• Marked four cardinal directions on ground?	____	____	____
• Collected data using a variety of sensor head orientations?	____	____	____
d. If magnetics data are to be collected, has the octant test been performed and documented?	____	____	____
e. Has the optimum sensor height for each instrument been determined?	____	____	____
f. Has the pull-away test been performed and successfully demonstrated no influence for navigational or towing equipment?	____	____	____

5.7 Checklist for Daily Instrument Checks

Project Name: ______________________________
Project Location: ______________________________
CEHNC POC: ______________________________
Equipment Source: ______________________________
Equipment Serial Numbers: ______________________________
____
Reviewer's Name and Title: ______________________________
Date of Review: ______________________________

	Y	N	N/A
a. Has the operator been tested for presence of metal?	____	____	____
b. Has the cable shake test been performed? (Replace faulty components if necessary)	____	____	____
c. Has the sensor position been measured and recorded?			
d. Has instrument (EM only) been nulled?	____	____	____
e. Has a static background test been performed and demonstrated <20% deviation in response over at least 3 minutes:			
• Start of day?	____	____	____
• End of day?	____	____	____
f. Has instrument response test been performed and demonstrated <20% deviation in response from test to test:			
• Start of day?	____	____	____
• End of day?	____	____	____
g. Has the operator been thoroughly examined with the geophysical instrument for any sources of response that may not be readily apparent?	____	____	____
h. Has the repeat data been utilized to evaluate the following factors:			
• Repeatability of response amplitude?	____	____	____
• Positional accuracy?	____	____	____

Chapter 6: Data Acquisition

6.1 Safety Requirements

Explosive Ordnance is a safety hazard and may constitute an imminent and substantial endangerment to site personnel and the local populace. An OE Safety Specialist must perform a Hazard Analysis for the area of investigation before a safety program is developed. The following is a list of common elements of safety programs for OE sites. These elements will impact the selection of project personnel for DGM surveys and will affect the production rates and project schedule. Safety considerations will vary depending on the specific contract requirements.

a. A minimum of two people may be required in the field for any work to be conducted.

b. All personnel on site may be required to have current 40 hour OSHA training, and 8 hour refresher training

c. UXO qualified personnel may be required to perform a surface sweep prior to the geophysical team's arrival on site. If necessary, potentially hazardous OE items on the surface will be removed from the area of investigation.

d. Movement by geophysical personnel through areas in which surface clearance has not taken place may require a UXO qualified escort.

e. The contract may specify no intrusive activity (i.e. driving stakes) will be allowed until UXO qualified personnel have checked that the location is safe to insert a stake or other marker.

f. Field personnel may be required to observe exclusion and decontamination zone boundaries.

g. Field teams may be required to have a means of communication available to them at all times.

h. One or more individuals may be required to have a current certification in First Aid and CPR training.

6.2 Survey Design Elements

a. All data acquisition processes have inherent limitations that affect the actual measured or recorded position of geophysical measurements. These limitations often result in the final track plots of a DGM survey displaying coverages that differ from the survey planning. Factors that contribute to this include terrain conditions that preclude the towing of an instrument along perfectly parallel lines, or the presence of obstructions such as trees, fences, etc. As a result, the survey coverage design parameters of across-track and along-track measurement intervals are selected to be smaller than the size of the smallest anomaly anticipated at a site. Line spacing requirements for grid sampling are dependent on the specific geophysical instrument being used, the types of buried munitions expected, and the accuracy needed in detecting the center of the anomaly, which factors in the anomaly reacquisition process. Geophysical investigations for the more common munitions types (mortars, grenades, projectiles, projectile fuses, etc.) that are buried randomly require standardized intervals between lines. The following minimum line spacings have been mandated by CEHNC, and are based upon the limitations of the survey equipment, the need for accurate delineation of the anomaly's center, and the known responses of the more common munitions types listed above. Project specific line spacings shall be established at all buried munitions sites.

	Line Spacing	
Instrument	*English*	*Metric*
EM61 (1m x 1m)	2.5 ft	0.75 m
EM61 MK2 (0.5m x 1.0m, survey broadside)	2.5 ft	0.75 m
EM61 MK2 (0.5m x 1.0m, survey short side)	1.5 ft	0.5 m
EM61 HH	1 ft	0.3 m
Magnetometer	2.5 ft	0.75 m
GEM 3 (60cm sensor head)	1.5 ft	0.5m

For other instruments, alternate line separations may be necessary.

Table 6-1

In cases where munitions with extremely low amplitude responses (i.e. sub-cals) are being investigated, it may be necessary to reduce line spacing to one-half the diameter of the receiving coil in the case of EM, and for magnetics, equal to one-half the expected spatial extent of the anomaly at the deployed sensor elevation above the ground. Such reductions in line separations will have an adverse effect on production rates. When the objective is to find large, deeply penetrating items or burials (caches, pits, and trenches) line spacing can be increased to suit the situation.

b. Adequate data density along the traverse is determined by the same factors as adequate line spacing. However, increasing the data density along survey lines usually does not significantly increase survey time or cost, but it can significantly improve the likelihood of clearly defining an anomaly and its' peak response. The following are maximum along-track measurement intervals for the most common geophysical instruments. When operating in automatic sampling mode, the contractor must determine the appropriate measurement rate and operator speed in order to achieve these intervals.

	Data Density (Along Traverse)	
Instrument	*English*	*Metric*
EM61 (meter wide footprint)	0.66 ft	0.20 m
EM61 (half meter wide footprint)	0.66 ft	0.20 m
EM61 HH	0.33 ft	0.10 m
Magnetometer	0.66 ft	0.20 m

Table 6-2

As with line spacing, if the objective is to find small, shallow items or large, deeply penetrating items or burial features, the along-track measurement intervals may be decreased or increased as required.

c. Meandering Path and Transects: These types of surveys are alternatives to grid sampling that may offer advantages in some investigations. Line spacing for a Meandering Path survey is influenced by vegetation density, as denser areas are avoided. Adequate coverage is achieved when the team acquires the same linear footage as would have been covered with grids. If a meandering path survey is chosen to replace a 100' by 100' grid with 2.5' line spacing, 4100' linear feet of data would be required. Transects use the same criteria to determine adequate coverage, but may use a fixed spacing between lines. When used in this manner transects may be considered as very narrow grids. Data density in both types should meet the requirements listed above. Unlike standard grid sampling, all of the data in Meandering Path and Transect surveys is subject to edge effects. Passing close to or over the edge of an ordnance item reduces the amplitude of the response compared with traveling directly over it. As a result, different thresholds must be considered for selection of anomalies in these types of surveys. Large items are detectable at greater distances from the instrument sensor; therefore a very detailed protocol should be used for anomaly reacquisition, compared with grid sampling. Another important difference versus grid sampling is that the collection of repeat data may require excessive travel-time to the repeat location and can significantly impact production rates.

d. File Naming Conventions: A standardized format for file names will be used throughout the duration of a project, and will be documented. A logical format, incorporating information such as Area, Sector, Grid # is suggested. For standardized tests that will be repeated twice daily, such as Static Background, the file name should include the date, the type of test, and an indication of whether it is AM or PM. An example for this test is 1210SBAM, for a Static Background test collected the morning of December 10. Unfortunately, Polycorders provided with the old standard EM61 limit the number of characters for a file name to 7, so one could drop the last letter: 1210SBA.

6.3 General EM Procedures

Procedures described in this section are applicable to the various EM61 models and other electromagnetic instruments. The information presented here is intended to supplement the operating manuals provided by the instrument manufacturer.

a. Most EM instruments have been designed to keep the operator far enough away from the coils so that small amounts of personal metal will not influence the data. Regardless, pockets should be emptied of coins, knives, etc., and wristwatches removed. Small amounts of metal such as wire-rimmed glasses, earrings, etc. are not detectable by the instrument, and are distant enough in normal use that they cannot cause problems. Use a small, sensitive magnet or a Schonstedt metal detector to sweep the operator for ferrous metal. Steel-toed boots can have a profound impact on data. Steel shanks commonly found in boots are less problematic than steel toes, but should be avoided as the feet may closely approach the coils during data collection. The high sensitivity of the EM61 Hand-Held coils increases the likelihood that metal components in footwear may compromise data quality. Carefully inspect the operator for non-ferrous metal.

Removing metal from the operator is most critical when operating the EM61 in harness mode because the operator is inside the coils.

b. The operating manuals of most geophysical instruments do not include a discussion of a warm-up period prior to collecting data. However, all digital geophysical instruments undergo a short period of calibration drift as the system electronics warm-up. Instruments should be allowed to warm-up a minimum of 5 minutes every time they are turned on. Low ambient temperatures necessitate a longer warm-up period. The geophysical team should carefully examine the readings to ensure that they have stabilized.

(1) Figure 6.1 illustrates drift typically seen in the warm-up period for an EM61. Performing a static test will quantify this warm-up calibration drift and at the same time satisfy the need to document ambient noise at the site. The static test shown in Figure 6.1 exhibits very low background noise. In this example, a standard EM61 was operated in Auto Mode (extra fast), collecting approximately 8 readings / second. The ambient temperature was approximately 70 degrees F. The instrument electronics warmed up and produced stable readings in less than three minutes. The EM61 MK2 has been observed to have a significantly longer warm-up period than earlier models. The instrument should be turned on a minimum of 15 minutes prior to data collection. Careful observation of the displayed response should then be made (using the Null/Monitor screen). When the levels of noise are acceptably low, data collection may begin. During cold weather a longer warm-up time may be required to achieve steady readings.

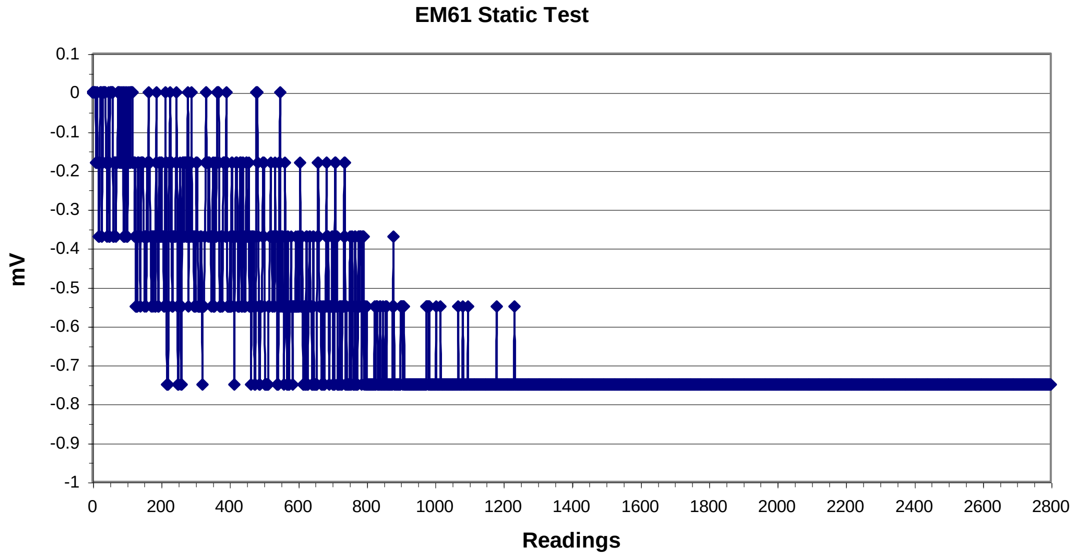


Figure 6-1: EM61 Warm-up in Static Test

c. Loose, dangling cables could potentially cause anomalous responses in EM data. The cable connecting the coils to the backpack, and the GPS cable (if applicable) should be temporarily attached to the handle (with tape, Velcro straps, etc.) in order to eliminate this source of geophysical noise.

d. If GPS is to be used and logged to a separate recorder from that of the EM data, synchronization of the internal clocks is critical for accurate location of data. Once the clocks are synchronized, data collection may begin. See Section 7.3b of this document for more detailed information regarding clock synchronization requirements.

e. After data collection is completed, the contractor will recollect some data in order to demonstrate the consistency of the method. A minimum of one line per grid will be repeated for grid surveying, and at least 100 feet of repeat data is required for meandering path and transect surveying

6.4 Procedures Specific to EM61 Series Instruments

a. The rates of data acquisition for EM61s are limited by the CPU processing speed of the handheld data loggers. A minimum amount of time is required for the system to process and record each reading. If a second reading is triggered before the first is recorded, the data logger (polycorder) will ‘beep’ and the first reading will be dropped. This results in an incomplete data set.

(1) The EM61 MK2 (0.5m x 1.0m coil size) can be used with the Juniper Systems Allegro, or the Juniper Pro 4000 data loggers. The user is offered a choice of auto, wheel or manual mode to collect readings. For auto mode, the maximum data acquisition rate is 15 records/second, with each record consisting of four sampled time gates per station. Wheel mode makes use of an adjustable odometer that can be set to trigger the system at an interval of 10 or 20 cm.

(2) Problems with the Pro 4000 data logger clock have been noted by some users, in which it fails to keep good time. If the clock provides unreliable time, accuracy is degraded when using a time stamp to position the data with GPS. Software available from Geonics (v.1.35) for the EM61 MK2 allows the streaming of GPS data and EM61 data to a single file, eliminating the need to rely on time stamps for positioning. The Pro 4000 may also exhibit an internal malfunction that causes the logging program to crash. When this occurs data logging can only continue after the logger has been reformatted.

(3) Using a Polycorder with the older standard EM61 or EM61 Hand-Held in Wheel or Hip Chain mode, the options of Full, Partial, or No Display are available at the start of each file. Full display permits collection at a rate of 4 per second, Partial display permits 8 per second, and No display allows > 8 readings per second.

(4) Using Auto Mode with the Polycorder, a standard EM61or EM61 Hand-Held in Auto Mode offers the options of User Defined / Fast /Extra Fast data collection rates. The User Defined option is capable of recording up to 4 readings/second. The Fast option records 5 readings/second without GPS and 4 readings/second with a GPS time stamp. The Extra Fast mode collects 8 readings/second without GPS and 7 readings/second with a GPS time stamp.

b. Check battery levels and record in field notebook or grid survey form before and after data collection. EM61 batteries shall be replaced when the voltage falls to 10.5 volts. Figure 6.2 illustrates data collected as the instrument battery drops below proper operating voltage. The apparent linear anomalies in the eastern portion of the figure are solely the result of low battery voltage, which resulted in a string of spurious readings. Unless close attention is paid during data collection, the resulting bad data may not be noticed until the data are processed and plotted.

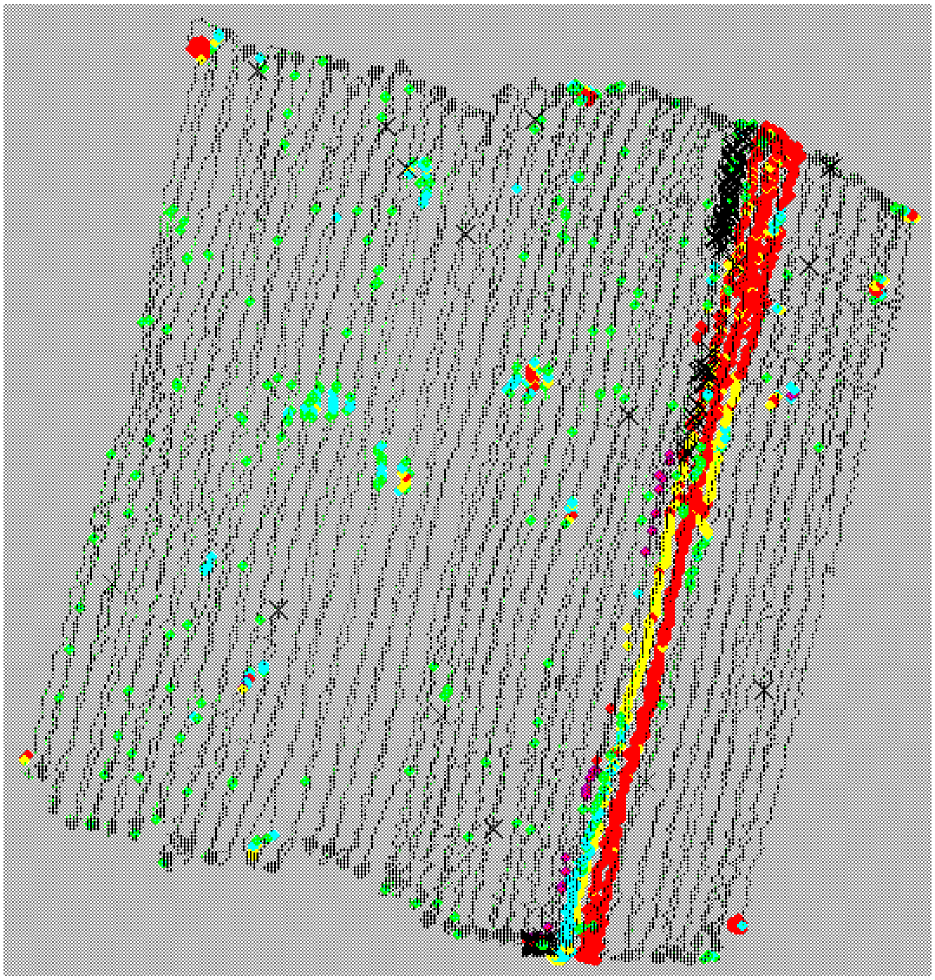


Figure 6-2 Bad data (striping in East) in EM61 data from low battery voltage

c. At the start of every project, the geophysical contractor should establish a nulling station where the top and bottom coils can be leveled. Nulling the instrument simplifies the recording and calculating of quality control functions, such as documenting the instrument's response to a standard object. Nulling does not negate the need to perform fine leveling of the data during post-processing and interpretation. The nulling station must be established in an area free of metal, with no interference from sources of ambient noise. Mark the center of the nulling station with a semi-permanent, non-metallic marker, to ensure consistent placement of the instrument each day. The station should be placed in the same spot as the static test station and will also be occupied at the beginning and end of each workday. The instrument must occupy the same location for each test, pointed in the same direction. Marking the tire locations for an EM61 using a non-metallic marker assures the instrument placement and orientation remains constant. Early model EM61s have no means for nulling.

d. During data acquisition, the operator should pay close attention to sounds emitted by EM61 backpack and the data logger to evaluate instrument function and data quality. Continuous, audible response may be indicative of metal stuck to the instrument (as in the case of barbed wire caught on the coils) or the effect of a low battery, which generates a very distinct audible tone for a period of between 1 to 5 minutes. No audible response over visible metal objects may indicate another sort of instrument malfunction.

e. Older EM61 wheels contain a limited amount of metal that is distributed unevenly within the rim of the wheel. As a result, these wheels cause periodic anomalous responses of several millivolts or more as measured by the bottom coil. With a low enough target selection threshold, the wheel responses may be incorrectly interpreted as being representative of subsurface metal.

(1) Alternatives to using the older hard rubber EM61wheels include substituting either EM61 Handheld wheels or more recent standard EM61 wheels which have solid foam tires. Both types of wheels are free of any metal components and can be easily mounted on the EM61 axles.

(2) In addition to metal components in the wheels themselves, wheel noise can be introduced by nails or metal fragments embedded in the tires. This may also cause periodic anomalous responses as the object rotates past the coils. EM61 wheels will be carefully inspected throughout the data collection process in order to minimize this problem.

(3) Should wheel noise be suspected during the project, the following test should be performed. Invert the EM61 and conduct a static test for one minute followed by collecting one minute of data while slowly spinning each wheel. Any additional

noise present in the portion of the file collected while a wheel was spinning is likely due to the presence of metal somewhere in that wheel.

(4) Filtering of noise introduced by the wheels or objects embedded in the wheels is possible; however filtering may result in missed targets if they happen to fall in the same period as the noise.

6.5 Procedures Specific to GEM-3 Frequency Domain Instruments

a. There are a number of configuration options available for the GEM3 (see users manual) For UXO detection surveys the instrument can be configured to run 5 frequencies simultaneously. The default frequencies are logarithmically spaced from 270 Hz to 24 kHz. A range of 30 Hz to 24 kHz is possible with the instrument.
   Frequency domain calibration requires that the system gain as well as the phase (relationship of inphase to quadrature) are calibrated. Furthermore, the gain calibration must be consistent across the frequency spectrum. The initial gain for any given frequency may be set using a 'q-coil' (supplied by the manufacturer) placed at a prescribed distance from the Tx coil. Phase calibration, and gain alignment between frequencies, may then be effected by using a ferrite rod. This is critical only if the background responses in the survey area are high, and the results rely on a high degree of consistency across our measured bandwidth. The introduction of a ferrite rod should result in no quadrature and an identical negative inphase response for all frequencies. The results of the calibration should be used during processing to confirm and fine-tune the system calibration (see Appendix F).

b. The GEM-3 sensor provides data in parts per million (ppm) of the primary transmitted field. This unit is sensor dependant, thus tests should be performed prior to a survey to ensure that the signal to noise ratio is sufficient to effect target detection. Note that static noise levels are not representative of system noise levels in a dynamic survey.

c. Very small changes in the altitude of the sensor head above ground will result in significant inphase response. It is possible that this response will mask potential target signatures. Because of this, it is important to ensure that the phase calibration is correct (to keep this response from corrupting the quadrature data) and that target selection relies primarily on the quadrature data. A single quadrature channel can be used to select targets; though more reliable results are obtained when combinations (such as quadrature sum) or functions (such as quadrature spread function (Wright et al, 2001)) are used. For further discussion refer to Chapter 9, Section 9.4 c and d. Under some circumstances (e.g. very bumpy terrain), some frequencies may have much higher noise levels, even in the quadrature component. If quadrature channels are being combined, care must be taken to exclude any channel exhibiting increased noise levels.

d. Frequency domain sensors exhibit varying degrees of temporal drift, depending upon frequency and ambient temperature conditions. System warm-up should be extended to 15 minutes and each frequency should be independently drift corrected during post processing.

e. Older GEM-3 models may have limited memory capacity. The use of these on stand-alone dead reckoning type surveys should be avoided.

f. The GEM-3 inphase data are sensitive to magnetic geology. Therefore, over highly magnetic soil, the inphase data are often too sensitive to sensor height (i.e., high motion-induced noise) to be a reliable detection indicator. However, the in-phase spread function can be a very good indicator for discriminating targets (which are selected using the quadrature data) between suspected geologic targets (where little to no in-phase spread would be expected) and suspected buried metallic targets (where an increase in the in-phase spread is expected.) The following hints may be useful to increase the usability of the in-phase data:

Increased Sensor Height: Raise the sensor to a foot or even higher. Do not scrape the ground with the sensing disk in the hope that decreasing the sensor-target distance will increase detection. On the contrary, this degrades the data quality by amplifying the ground effect, which obscures small target anomalies. Note the frequencies below 270Hz may have excessive noise from rapid sensor motion in earth's magnetic field. If that is the case, do not use those frequencies, or exclude those frequencies when processing the data.

6.6 Operating Procedures for Magnetics

a. The magnetometers used in geophysical surveys measure minute variations in the earth's magnetic field. The magnetic field itself goes through changes during the course of a day, which vary from location to location. This effect can be exacerbated by events such as solar flares or geomagnetic storms.

(1) During investigations utilizing magnetics, a base station magnetometer should be used to record diurnal drift for that area. Although data can be filtered by various means to minimize or eliminate diurnal drift, the use of a base station magnetometer is preferable.

(2) Base station data must be collected at a rate of at least 1 reading / minute, as specified in DID OE-005-05.01.

(3) The clocks for the field and base magnetometers must be synchronized before data collection commences. The time stamps in both sets of data allow the field data to be normalized for diurnal drift. Use of a base station will also identify periods of magnetic storms, in which field data should be discarded. Figure 6.2 shows base station readings collected during a typical day and values recorded during a geomagnetic storm.

(4) It is imperative that the site selected for the base station be absolutely free of disturbance while the instrument is collecting. Any unnatural variations in the data will compromise the accuracy of corrected values taken from the field magnetometer. Data should be examined for short-term high amplitude anomalies that could be a result of someone approaching the base station in a vehicle, or otherwise bringing ferrous metal near the sensor. Applying this “correction” to the field data may generate false positives. It is recommended that the base station sensor be placed at least 4 feet above the ground surface to minimize cultural and terrain induced interferences in the base station measurements.

(5) The base station should be proximal to the field area (within 10 miles) and the same location should be used every day magnetics data are collected. In the case of large sites it is permissible to have multiple base station locations based on convenience for the current survey area.

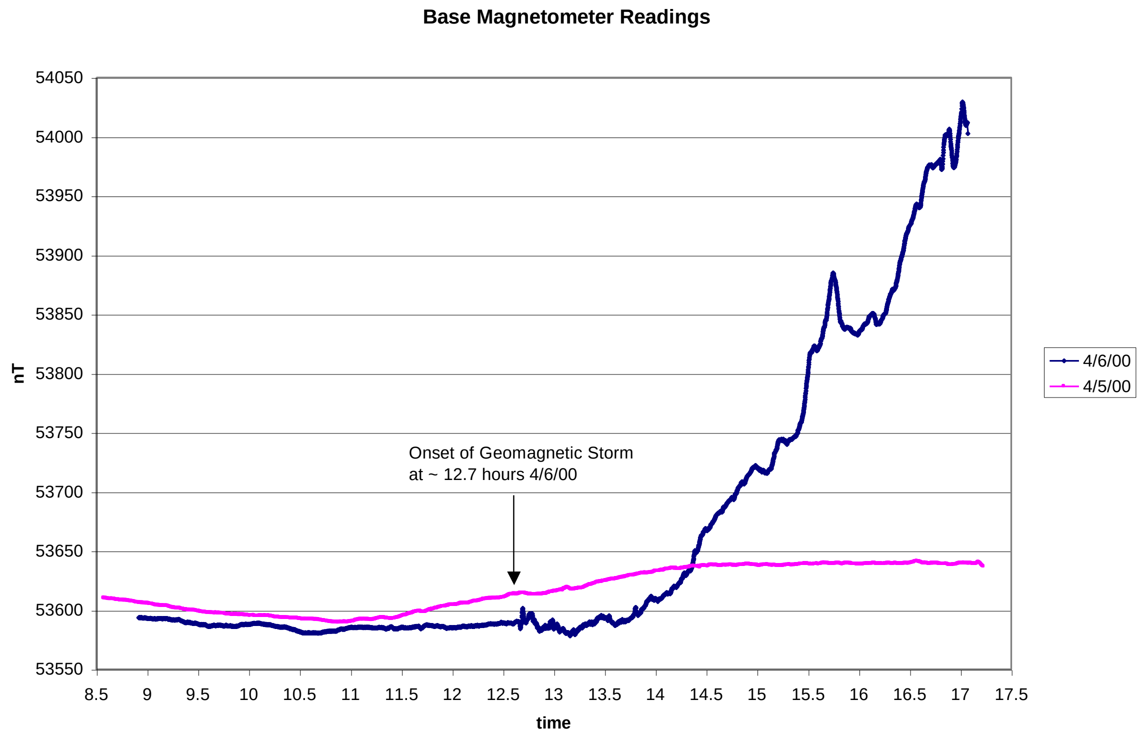


Figure 6-2: Magnetometer Base Station Readings

b. Once the field magnetometer has been assembled, the sensor height will be adjusted and measured to a specified height and recorded. The sensor separation will also be measured and recorded if the magnetometer is being operated in gradient mode.

c. Ensuring a magnetometer operator is free of ferrous metal items prior to surveying is critical. Ferrous metal worn by the operator will introduce noise into the data. Although noise can be filtered in data processing, it is preferable not to introduce noise as noise filtering will often remove responses associated with buried ferrous metal. All sources of metal discussed in Section 6.3a will be removed for magnetics data collection as well. In addition, it is particularly important that footwear be free of ferrous metal since their position relative to the sensor changes continuously. Use a small magnet or a Schonstedt metal detector to test for ferrous metal in boots and all other parts of the operator.

d. In areas with magnetic soils, it is important to keep the magnetometer sensor clean. The sensor should be wiped clean several times / day to remove soil and dust.

e. As with EM instruments, not all manufacturers of magnetometers include a recommended period of warm-up prior to data collection in their manuals. When using any magnetometer, the operator shall monitor readings while maintaining a stationary position until they become consistent. Readings should be monitored for at least 5 minutes, longer as ambient temperature decreases. The Geometrics 858 magnetometer should be warmed-up as directed in the operating manual.

f. With the instrument operating, check battery level and record in field notebook or grid survey form before and after data collection. Replace low-voltage batteries as necessary.

g. Cesium vapor magnetometer sensor heads encounter 'dead zones' when oriented within 10 degrees of parallel or perpendicular to the earth's magnetic field vector. The sensor cannot accurately measure the magnetic field unless it is outside the dead zone (inside the instrument's operating zone). Operating zones vary according to the magnetometer's location within the earth's magnetic field and should be determined prior to beginning an investigation. The instrument's operating manual should include information regarding proper sensor head orientation. Dead zones will be encountered at either end of the operating zone and will be apparent when the instrument displays values that are extreme relative to the local field. The sensor head angle should then be positioned in the middle of the operating zone. Once established, this orientation must be maintained at all times during data collection. The two following methodologies can be used to determine the sensor's operating zones.

(1) Geometrics Inc. provides a computer program (CSAZ.exe) to calculate the best orientation of a cesium vapor sensor at various magnetic field dip angles. The program is available on the Geometrics web page (ftp://geom.geometrics.com/pub/mag/Software), in CSMAGACC.exe. The USGS programs Magpoint, and Geomagix (USGS and Interpex) calculate the field inclination and magnetic declination for a given location. Both programs can be downloaded from the USGS, at http://geomag.usgs.gov/models.html, under the heading "Freeware Programs", listed as Geozip and Geozip2.

(2) The Azimuthal Test can be performed to document the differences in readings based on the sensor's orientations. An illustration of the Azimuthal Test is given in Figure 6.3.

(a) Identify an area free of cultural sources of geophysical noise. When this test is performed near a magnetic gradient, small shifts in the sensor head position will produce large variations in the total field values. It is recommended that an azimuthal test be performed for all proposed magnetometer configurations.

(b) The sensor must be maintained in a fixed position while the operator revolves slowly around it. Placing the sensor head through a hole in the top of a non-magnetic table or into the top of a vertical section of PVC pipe will help to stabilize it.

(c) Mark the four cardinal directions on the ground using pin flags or marking paint. Recording fiducial marks at the moment the operator is facing cardinal directions will aid in determining the heading error for particular survey line directions.

(d) Using a fully warmed-up instrument, begin data collection while facing north, and slowly move in a clockwise circle, pivoting around the table or PVC pipe. Place a marker (fiducial) in the data when reaching each of the cardinal directions. These markers will be used to plot the direction the operator was facing as data points were collected.

(e) Different orientations may need to be evaluated to minimize any observed deviation in amplitude or any magnetic "dead zones" that are encountered.

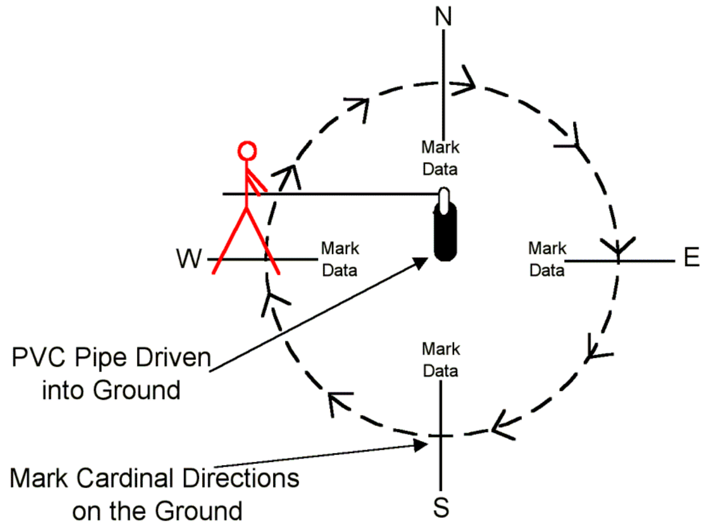


Figure 6-3: Azimuthal Test

f. The amplitude of an item's magnetic response is inversely proportional to the cube of the distance of separation between the magnetometer sensor and the anomaly source. In other words, if sensor height is doubled, the amplitude of the anomaly will be one-eighth of its original value. However, moving the sensor closer to the ground will not always result in improved detection. Surveying with the sensor close to the ground may increase the response to terrain effects (magnetic rocks, soils, and metal clutter). The amplitude of terrain effects may be increased to such a degree that their response significantly degrades the signal to noise ratio of larger, deeper items such as buried munitions. By raising the sensor height, the relative distance between the sensors and near-surface terrain sources is significantly increased while only minimally increasing the relative distance between the sensors and deeper buried objects. The result is a greater decrease in response to items at the surface as compared to those at greater depth. This can, in some instances, allow for easier detection of subsurface sources. An optimum sensor height that will minimize terrain effects while maximizing response to subsurface OE shall be determined during the prove-out and maintained throughout the investigation. If terrain effects are minimal at a site, then the sensors should be deployed as close to ground surface as is practical in order to maximize the signal to noise ratio of detected anomalies.

g. Data collection may begin once the above protocols and data analysis have been met. Whenever possible, data acquisition will continue until such time as the current grid or survey section has been completed.

h. After data collection is completed, the contractor will recollect some data (repeat lines) in order to demonstrate the consistency of the method. A minimum of one line per grid of repeat data will be collected for grid surveying, or 100 feet per linear mile for meandering path and transect surveying.

6.7 Checklist for EM61 Operating Procedures

Project Name: ______________________________
Project Location: ______________________________
CEHNC POC: ______________________________
Reviewer's Name and Title: ______________________________
Date of Review: ______________________________

	Y	N	N/A
a. Has a careful inspection been made to ensure that all metal has been removed from the operator?	____	____	____
b. Has the instrument been warmed-up for 5 minutes?	____	____	____
• Was a static test performed during warm-up to document ambient noise at the site?	____	____	____
c. Were battery levels checked and recorded?	____	____	____
d. Has an appropriate data acquisition rate been selected?	____	____	____
e. Have the EM61 wheels been evaluated for the presence of metal and replaced, if necessary?	____	____	____
f. Have all loose cables been secured?	____	____	____
g. Has the established nulling station been occupied:			
• Start of day?	____	____	____
• End of day?	____	____	____
h. Was the audible response of the instrument monitored during data collection for anything unusual or unexpected?	____	____	____
i. Has adequate repeat data been collected?	____	____	____

6.8 Check list for GEM-3 Operating Procedures

Project Name: ____________________
Project Location: ____________________
CEHNC POC: ____________________
Reviewer's Name and Title: ____________________
Date of Review: ____________________

	Y	N	N/A
a. Has a careful inspection been made to ensure that all metal has been removed from the operator?	____	____	____
b. Has the instrument been warmed-up for 15 minutes?	____	____	____
c. Has the Signal to Noise ratio been evaluated to ensure possibility of target detection?	____	____	____
d. Has an appropriate data acquisition rate been selected?	____	____	____
e. For areas with high background responses, was the instrument calibrated:			
• For system gain?	____	____	____
• Prior to surveying for phase?	____	____	____
• After surveying for phase?	____	____	____
f. Was the sensor head kept at a consistent altitude above the surface of the ground during surveying?	____	____	____
g. Has adequate repeat data been collected?	____	____	____

6.9 Checklist for Magnetics Operating Procedures

Project Name: ______________________________________
Project Location: ______________________________________
CEHNC POC: ______________________________________
Reviewer's Name and Title: ______________________________________
Date of Review: ______________________________________

	Y	N	N/A
a. Has a magnetometer been selected for use as a base station?	____	____	____
• Has a site been selected where the base station will remain undisturbed?	____	____	____
b. Has the sensor height of the field magnetometer been measured, adjusted, and recorded?	____	____	____
• If operating in gradient mode, has the sensor separation been measured and recorded?	____	____	____
c. Has a careful inspection been made to ensure that all metal has been removed from the operator?	____	____	____
d. Has the instrument been warmed up for at least 5 minutes, depending on temperature?	____	____	____
e. Were battery levels checked and recorded?	____	____	____
f. Have the magnetic 'dead zones' been located and appropriate sensor orientations selected?	____	____	____
g. Has adequate repeat data been collected?	____	____	____

Chapter 7: Navigation

7.1 Introduction

Prior to the advent of GPS and other electronic navigation systems, geophysical data were collected and positioned using local coordinate systems. In recent years, GPS in particular has become an increasingly popular tool for geophysical surveys at buried munitions sites. The latest systems are capable of providing, under the right circumstances, positional accuracy measured in centimeters. Despite this, the use of local grids and conventional methods is still preferred in many circumstances, as it provides a high degree of accuracy at low cost, regardless of obstructions such as overhead tree canopy.

7.2 Conventional Navigation

These methods involve placing temporary markers on the ground surface in order to establish data collection lines. In a typical grid layout, the markers allow the operator to traverse the grid using straight, parallel lines and ensure that the entire area has been covered.

a. Grid set-up begins with the establishment of line separation and length in the required units (meters or feet). If squared grid corner stakes are already in place, tape measures can be pulled between them on all sides. Tape measures and/or surveying equipment (transit, compass, etc.) can be used to establish right angles if no grid stakes are present.

b. Fiducial marks (known locations entered into the data during collection) are placed on the ground using temporary markers. Temporary markers commonly used for fiducial locations include measuring tapes, PVC pin flags, marking paint and ropes. The distance between fiducial marks is dictated by site conditions; less visibility due to rolling terrain or dense vegetation will require closer spacing. PVC pin flags left in place provide a useful reference for EOD personnel excavating targets.

Using conventional navigation methods, it is essential that straight-line profiling be maintained. The operator must have easily visible monuments along which to walk. Fiducial ropes with paint marks at every line location will accomplish this. Another commonly used method is to place traffic cones at the start, end and at intervals along each line. The use of cones requires the operator or other team members to move them as data collection proceeds.

7.3 Global Positioning System (GPS)

This method of navigation has increased in popularity in recent years, as the accuracy of the positions has increased. Software for most geophysical systems now includes a means of integrating GPS positions with geophysical data.

a. Standards for Equipment: GPS equipment varies drastically in price and quality, therefore a minimum standard for equipment to be used in Digital Geophysical Mapping (DGM) surveys must be defined. The level of accuracy required for a specific project depends on the goals. For EE/CA surveys, accuracy within a meter may be acceptable, while a more detailed investigation may have more demanding requirements.

(1) Small hand-held units manufactured for recreational use are not acceptable for DGM work. These units typically cost $150 to $400, and while helpful for finding general locations, are not capable of the level of precision necessary for most DGM surveying. When Selective Availability (SA) is not in use by the Department of Defense, these types of GPS units can achieve accuracies of approximately 15 meters. With SA activated, accuracy drops to approximately 100 meters. Wide Area Augmentation System (WAAS) is a system of satellites and ground stations originally developed for aviation, that provide GPS signal corrections. WAAS enabled handheld GPS receivers are reported to have accuracy of <3m.

(2) The use of Differential GPS (DGPS) allows for the correction of errors in positioning from SA and other sources, which include clock errors, atmospheric effects, and signal reflections. Sub- meter accuracy is possible using DGPS, given favorable conditions. Three types of DGPS are in use: 1) utilizing GPS base stations that transmit corrections via radio, commonly known as Real Time Kinematic (RTK), 2) using U.S. Coast Guard or Department of Transportation beacons transmitting corrections, 3) using a satellite based service such as the OmniSTAR system. Post-collection processing of GPS data is also possible using data collected by a nearby base station whose data is made available to the public.

(a) Differential GPS making use of the Carrier Phase permits accuracies within centimeters. Correction of bias factors may be accomplished in real time, using a Real Time Kinematic (RTK) GPS system, or through Post Processing (PP). Both RTK and PP systems utilize a base station, set up on a known point, which then transmits corrections to a roving GPS unit via radio (RTK), or records base station data that is used to apply differential corrections to the recorded roving GPS data (PP).

(b) The United States Coast Guard Navigation Center (NAVCEN) operates the most widely used real-time Differential GPS (DGPS) service, utilizing two control centers and a network of broadcast stations, or "beacons". Real-time differential correction requires a GPS receiver that is tuned to the frequency of the broadcast real-time correction message. When a real-time correction message is present, the receiver will update its position every second allowing the differential correction to be applied to GPS data concurrently with the collection of field data. The correction signals broadcasted over the radio beacon frequencies improve the accuracy and integrity of positions derived from GPS. An effort is underway to expand DGPS coverage through a seven-agency partnership, for the Nationwide Differential GPS (NDGPS) program. The data can be accessed for free and an accuracy of 1-3m is normally possible using the transmitted corrections. Visit the Coast Guard website (http://www.navcen.uscg.gov./dgps/coverage/Default.htm) to view current coverage for the NDGPS system.

(c) Subscription based correction methods, such as the OmniSTAR system, use a network of reference stations to measure atmospheric interference inherent in the GPS system. Reference data is transmitted to global network control centers where it is checked for integrity and reliability. The data is then up-linked to geo-stationary satellites that distribute the data over their respective footprints. Using satellite re-broadcast overcomes the range limitations of ground-based transmissions. Additionally, wide-area solutions, such as those provided by OmniSTAR, correct for errors associated with a single reference station solution. The result is consistently high quality differential corrections available anywhere within the continental United States plus much of Canada and Mexico. With the OmniSTAR system, two levels of service are available: OmniSTAR VBS, and OmniSTAR HP. The VBS service provides sub-meter accuracy, while the HP offers accuracy of <10cm.

(d) Minimum Standards for Data Quality: The number and location of satellites visible to the antenna, and the presence of obstructions influence the level of accuracy for a GPS reading. Depending on the project specific needs, different levels of GPS data quality may be acceptable. Factors that affect GPS data quality are discussed below:

(e) A factor called DOP (dilution of precision) is a measure of the level of precision that can be expected for a particular arrangement of satellites. The DOP is computed from a number of factors, including: HDOP (horizontal), VDOP (vertical), TDOP (time). Together these factors are used to compute the PDOP (position dilution of precision). Lower DOP values indicate better accuracies are being achieved by the DGPS system. Although PDOP is commonly used, HDOP and TDOP may be more applicable to DGM work, in which the x,y coordinates are used to map anomalies. GPS accuracy in the vertical dimension is less than in the horizontal. Most GPS receivers can be programmed to output the calculated DOP values s (HDOP, PDOP, etc.). For DGM surveys, DOP values should be below 6 when using code-only systems and the DOP values should be below 12 when computing code and phase solution. These values are based on information provided by several DGPS vendors, alternative DOP maxima may be acceptable based upon the system's published technical specifications.

(f) Although PDOP (or HDOP) gives some indication of data quality, an important indicator of data quality is the number of satellites used for determining position and the signal to noise ratio (SNR) of each that is being detected by the GPS receiver. It is possible to have a low PDOP and still have significant errors in positioning, especially with few satellites and/or low SNRs from one or more satellites. A minimum of four satellites is needed to determine a 3D position, however accuracy increases with additional satellites. For DGM surveys, a minimum of 4 satellites should be used at all times for GPS data collection.

b. Time Synchronization: If recording geophysical data in a separate device from the GPS data, all measurements in each data file must have an associated time stamp, which is later used to merge the position readings with the geophysical data. This introduces a potential source of error that can be difficult to detect and to correct, and therefore, data collection in this manner is not recommended. Rather, all data from geophysical and navigation instruments should be streamed into a single recording device (typically a field computer), which generates time stamps for all data streams using the same system clock.

(1) When navigation and geophysical data are collected independently, it is crucial that the times be synchronized to permit accurate location of the data. GPS satellites use atomic clocks capable of extremely accurate time keeping. Most code only and code and phase systems use the satellite clock information to continuously correct any drift in the time basis of the land-based receivers. Geophysical instruments use less sophisticated clocks, which may drift in relation to the GPS clocks. Prior to collecting data, the times between all instruments must be synchronized to within 0.25 seconds for surveys performed at normal walking speeds. Tighter synchronizations will be required for surveys performed at greater speeds. When finishing a grid, transect, etc, check the synchronization of the data recorders again, and record any difference noted. If the difference has increased by more than 0.25 seconds (for at total difference of more than 0.5 seconds), the time differences will require correcting. A linear clock drift can usually be assumed.

(2) Vendor software may produce different results for interpolated time depending on the software version, options used, and the operating system. The contractor must document the process used to merge the geophysical data with the GPS data.

c. Quality Control: A point should be established on the site where GPS readings will be collected twice daily (AM and PM), for comparison of the computed position. This point should be located in a convenient area, such as the prove-out grid, or the nulling station. After corrections, the point must be within a certain radius about the actual location depending on the specific equipment used.

d. Planning Software: Software is available from the major manufacturers of GPS equipment for planning surveys ahead of time. The orbits of the satellites, and the time they will pass over a specific area is included in GPS almanacs, which are downloaded from the satellites by the GPS receiver or may be downloaded from the internet. The planning software uses this information to determine the number of satellites and predicted DOP for a given location and date. At certain times of day, the number of satellites visible to the receiver may be inadequate to provide high quality data. Another possibility is that the constellation geometry may be such that a high DOP results. In either case, knowledge of this period ahead of time will prevent the contractor from attempting to collect data with poor precision. Work / Rest periods should be planned to avoid data collection in times of poor satellite geometry or few visible satellites. The entire project team must be aware of implications of planning work around satellite availability. This potentially impacts project scheduling and costs, and should be considered before the project starts.

e. Radio Interference: The quality of data collected with RTK GPS systems can be degraded by radio interference. Interference commonly occurs in urban areas, where radio signals from commercial or government radios use the same frequencies employed by the GPS base station to communicate with the GPS rover receiver. Checking for interference is simplest with GPS base stations with an audio output. By listening to the available frequencies, a quiet one can be selected to broadcast without interference. In many instances, voice transmissions will supercede data transmissions and use of a frequency with heavy radio traffic may cause a loss of signal to the rover receiver, resulting in a drop in positional accuracy. Another potential problem using RTK GPS is the introduction of noise into EM data, when the electronics are placed too close to the coil or EM electronics. Simple “pull-away” tests can isolate the cause of this problem, and the separation increased as necessary to eliminate the noise.

f. Documentation: All operation data from the GPS must be documented, collected and stored.

7.4 Other Positioning Systems

A number of other types of positioning systems have been employed in geophysical surveys, or are currently in development. These other systems include Ultrasonic Positioning, which makes use of an ultrasonic transmitter and a series of stationary receivers to calculate the position of the instrument. Laser Distancing and Robotic Total Stations are other possible navigation systems for positioning data. One method currently under development makes use of time-modulated ultra-wideband (TM-UWB) communications. This system will utilize radios for positioning, with local transmitters on a site. Unlike GPS, the system will be unaffected by dense vegetation and overhead canopy.

a. Regardless of the technology used for positioning, simple QC can be performed by repeated measurements collected at a reference point.

b. Like the test described above for GPS, a reading should be collected in the AM, and again in the PM at one point, which is analyzed for consistency.

c. Each calculated location must fall within a specified distance of the actual coordinate for the test point.

7.5 Data Documentation (METADATA)

All positional data collected using GPS or other methods should have metadata describing the properties and attributes of the data set. A "readme" text (.txt) file should be prepared and submitted documenting the following information:

> Name of Company, Address of Company, Phone Number of Company, name of Operator, E-mail address of Operator, Date Data collected, Model of Navigation Equipment: Serial Numbers of Receivers and Antennas, Base Station(s) used in differential correction, Accuracy of system (according to manufacturer), Software used for data download and differential corrections.
>
> GPS Base station documentation should include the reference location used, full documentation of Coordinate System (WGS 84 or U.S. State Plane), Datum (NAD 83, etc), State Plane Zone if appropriate, units of measure (U.S. survey

feet, meters), and a physical description adequate to relocate the base station location.

Chapter 8: Data Storage and Transfer

8.1 Field Storage and Transfer

a. Instrument data should be dumped from the data logger to a field computer immediately following completion of a survey grid. If the data logger does not have sufficient memory to complete an entire grid, it must be dumped as needed. Immediate dumping lowers the risk of any data being lost as well as allowing the contractor to make initial assessments regarding data quality and methodology.

b. The contractor should create a logical system of directories for storage of raw and edited geophysical data and positional data. The specific design of this system shall be left up to the contractor, but each contractor should adopt one system that can be used on all OE projects.

c. Each day the contractor should perform a backup of all new data files. Appropriate backup media include, but are not limited to, 3.5" diskettes, tape drives, and CD-ROMs.

d. If possible, new data should be transferred electronically to the contractor's corporate office on a daily basis. The transfer may be accomplished via E-mail or using an FTP site. If neither of these options is logistically feasible, data will be shipped to the contractor's office on appropriate media as scheduling permits.

e. The field geophysical team should fill out a Survey Area Report Form each day. The form is included in Appendix D of this manual. Completed report forms should be transferred to the appropriate CEHNC representative at the end of every week.

8.2 Office Storage and Transfer to CEHNC

a. The contractor should provide a centralized location (corporate office) where data from the field can be received, processed, and stored.

b. Processed data should be converted to standard compatible formats for transfer to CEHNC. Submission file formats will be agreed upon prior to the start of the project.

c. As data processing is completed, data should be organized using the contractor's standard directory protocols and transferred to the main data storage system.

d. All data, text, maps, and other accompanying graphics must be submitted digitally via CD-ROM in CEHNC approved formats. Other media may be requested and used at the discretion of CEHNC. A "readme" text file detailing the contents of the transferred data will be included with each submission. Individual data files should include information describing the specifics about the data contained therein. This information is commonly referred to as "header" information, and should include most of the information listed below. The actual header fields that are included in the data files for a given project should be established on a case by case basis.

- Client:
- Data Acquisition by:
- Data Type:
- Project:
- Location:
- Survey Date:
- Instrument Type:
- Sensor Height:
- Height Units:
- Navigation Base Station File:
- Offset between data and navigation reference point:
- Coordinate Projection Datum:
- Coordinate System:
- Coordinate Units:
- Comment:
- Data column names follow:
- (Include a list of names for each column of data)

e. Transfer packets should include raw and edited data files, a log of all survey file names, GPS positioning files, completed geophysical maps, and prioritized target lists. In addition, a data file log / spreadsheet listing acquisition dates, how / which raw were combined to make the processed file, of all delivered data files (with dates sent) should be included.

f. Upon its completion, all data, text, maps, and other accompanying graphics related to the project should be backed up and archived at the contractor's corporate office. The archive period is usually established in the contract between the client and the contractor. Copies of the archive will be sent via an appropriate media to the Huntsville Corps.

8.3 Checklist for Data Storage and Transfer

Project Name: ______________________________

Project Location: ______________________________

CEHNC POC: ______________________________

Reviewer's Name and Title: ______________________________

Date of Review: ______________________________

	Y	N	N/A
a. Has the transfer medium been approved by CEHNC?	____	____	____
b. Are all files in CEHNC approved formats?	____	____	____
c. Have all of the following been included in the transfer packet:			
• "Readme" file detailing contents?	____	____	____
• Log of all survey file names?	____	____	____
• Raw data files?	____	____	____
• Edited data files?	____	____	____
• GPS positioning files (if separate)?	____	____	____
• Completed geophysical maps?	____	____	____
• Prioritized target lists?	____	____	____
• Data File Log / Spreadsheet of Delivered Data Files with Dates Sent?	____	____	____
d. Have the required number of copies, per CEHNC, been included in the transfer packet?	____	____	____

Chapter 9: Data Processing and Analysis

9.1 Introduction

a. This chapter outlines basic data processing procedures for geophysical data collected for buried munitions surveys. Systematic and proven methods are important to maintain consistent quality of data and to allow for an evaluation of data quality. Identifying and reducing the causes of below standard data is simplified by following a basic established method.

b. Qualified personnel for data collection and data processing are the most important factors in producing quality data. Data collection personnel should be trained and familiar with the instruments and their operation. Data processing personnel must have an understanding of the geophysical principles and the nature of the data as well as how the tools operate and are implemented in the field in order to properly evaluate the digital sensor response. A qualified geophysicist must be able to identify and correct for noise factors and be able to distinguish signals above the noise level. Inexperienced personnel may result in a reduction of the quality or incorrect interpretation of data. The main stages of geophysical data processing and analysis for buried munitions are field editing, preprocessing, processing and target selection, advanced processing, quality control, and the preparation of deliverables.

c. Documentation of the processing performed on geophysical data must be submitted to the client at agreed upon intervals. Documentation should include digital logs of the sequence of processing; such as Oasis Montaj log files, Excel spreadsheets, output from processing software, etc.

9.2 Field Editing Data

These steps are performed prior to leaving the site by the field geophysicist or a data processor on site.

a. The software supplied with most geophysical instruments allows the editing of many of the common errors made during data acquisition. A member of the geophysical team, preferably the operator who collected the data, will evaluate the completed file for correctness of line numbers, starting and ending points, and line direction. Fiducial corrections will then be applied to the data. All editing and corrections are then saved using a new file name.

b. Each line's response amplitude should be examined in profile for overall quality. Particular attention must be paid to geophysical noise levels to ensure that they fall within acceptable thresholds. Acceptable noise levels vary from site to site and should be agreed upon based on the GPO and previously collected data.

c. Geophysical sensors will occasionally exhibit dropouts or spikes; extremely high or low values. Magnetometer sensors are especially susceptible to this phenomenon. Anomalous values believed to be drop-outs or spikes should be removed from the data set as they are not representative of responses to subsurface metal. It is recommended that the data points associated with dropouts be completely deleted from the data files. If data is to be interpolated through locations where spikes are removed (e.g. using Geometrics' Magmap 2000 de-spike routine), the project team should establish the maximum allowable interpolation distances. Frequent occurrences, or occurrences over long time intervals, may be indicative of a malfunctioning instrument that should be thoroughly tested and possibly replaced.

d. Metal inadvertently worn by the operator is one of the most common sources of geophysical noise. If unacceptable levels of noise are noted in the data, the possibility of metal on the operator shall immediately be evaluated.

e. Once the data file has been edited and checked for quality, it must be converted to a format that is compatible with the processing software being used for contouring and examination. The most common programs used to contour geophysical data, Golden's Surfer and Geosoft's Oasis Montaj, accept ASCII text files, where the individual data fields are usually delimited by spaces, tabs, or commas. Common convention is for the easting coordinate, or "x", associated with each measurement to be the first value reported in a line of data, followed by the northing coordinate, or "y", then the different values, or channels, of data. Files of these types are commonly referred to as xyz files, with the extensions ".XYZ" or ".DAT." This xyz format is different from geodetic surveying conventions where the northing precedes the easting when reporting coordinates. Since xyz files are usually delimited ASCII text files, they can also be viewed as Microsoft Excel spreadsheets or as common text files in Microsoft Word or Professional Write. If alternate file formats will be required, this should be made known to the contractor prior to the start of the project.

f. In addition to field data, magnetometer surveys will also have base station data that needs to be examined. Base station data should be plotted in profile and evaluated for the presence of drop-outs, spikes, magnetic storms, and any other features that will degrade the quality of the data. Once the data has been deemed acceptable, a diurnal drift correction may be applied to the field magnetometer data. To ensure adequate sampling, a minimum rate of collection of 1 reading per minute is required by CEHNC for base station magnetometers.

g. After the data values have been examined and determined to be of high quality, the positioning of the data must be evaluated. Regardless of whether electronic or conventional navigation methods are used, the process for checking accuracy is essentially the same. The two most common approaches to assessing positioning quality are 1) creating post maps, or track plot maps, showing the geographic position of every point collected, and 2) calculating the speed between successive points. In the first method, the lines and stations should be evenly spaced throughout the track plot map. In the second method, sudden or abrupt changes in the survey speed may indicate errors in either the field acquisition processes or in the post-processing of the positioning data. Problems in data spacing using conventional navigation methods are usually caused by misplaced fiducial marks or end points and can be easily remedied. Less common errors result from inconsistent speeds between fiducial marks or by inverting the survey geometry of a line or group of lines (either in the field when entering acquisition parameters in the data loggers, or during processing when field files are converted to xyz files.) Errors of these types are often more difficult to detect and correct. Data positioning errors found in electronic navigation can be caused by a variety of problems, such as poor time synchronizations, and are often more difficult to fix. Figure 9.1 is an example of poor satellite coverage resulting in badly positioned GPS data.

h. Once the quality of the data positioning is accepted, the survey coverage completeness is assessed. Coverage gaps are assessed in three different categories: 1) coverage gaps that are within a pre-defined limit for the project, 2) coverage gaps that are greater than a pre-defined limit for the project, and 3) coverage gaps due to obstacles or inaccessible areas such as long fence lines, along buildings, under/near trees, etc.

(1) Coverage gaps that are within a pre-defined limit for the project are defined as those areas where the across-track line separation or the long-track measurement intervals exceed the project design parameters but are less than the project's maximum allowable limits for these parameters. For most projects, the total cumulative area where these acceptable gaps are present would be limited to 0.1% of the total area to be surveyed (i.e. 0.1 acre, or approximately 4325 square feet, per 100 acres surveyed), and would specifically exclude large coverage gaps due to inaccessible areas around trees, along fence lines, or other known features. Automated software routines, such as the Footprint Coverage or the Calculate Coverage Area routines available in Geosoft Oasis Montaj, (alternative methods are available through various GIS tools) can be used to quantify the acreage associated with these data gap areas.

(2) Coverage gaps that are greater than the project's pre-defined limits are defined as gaps that the project team has decided will not be acceptable for the intended needs of the DGM survey. The parameters that are used to define these limits are the maximum allowable across track line spacing and the maximum allowable along track measurement interval. Factors that affect these two parameters include survey costs, the likelihood that the smallest target objective may be present where these coverage gaps occur and the level of risk associated with the smallest target objective. The GPO results should be used to help the project team in their decisions. It must be understood by the project team that high costs will be associated in setting small maximum allowable across-track separations and small maximum allowable along-track separations. When evaluating a track plot for coverage gaps of this type, gaps due to obstacles as explained in (3) below are excluded. Coverage gaps that exceed the specified maxima for a project would require returning to those areas to be in-filled.

(3) Coverage gaps due to obstacles or inaccessible areas such as long fence lines, along buildings, under/near trees are usually easily identified in the track plot maps. Gaps such as these are not included in coverage assessments above and may require special processes to arrive at a final disposition to the associated areas. As an example, one such process would be to use a mag and dig operation to clear these types of areas.

i. Fill out Field Editing Checklist (included at end of Chapter 9) to track procedures performed on data set.

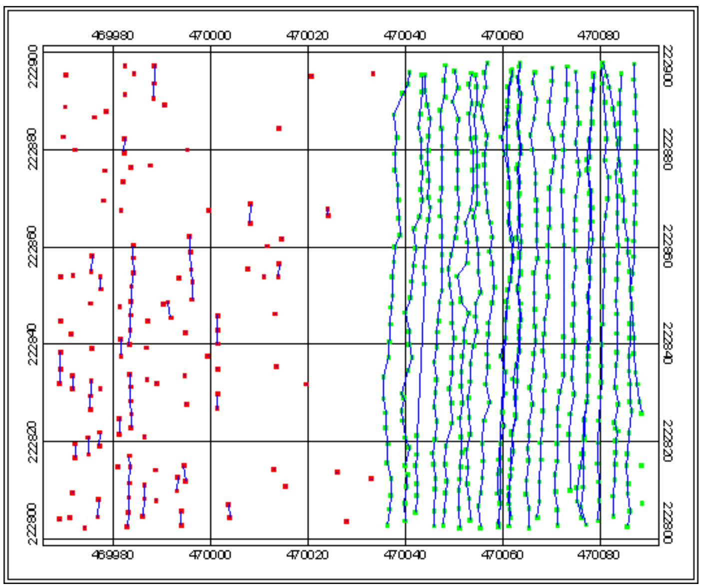


Figure 9-1: GPS points showing drop out. Right side shows accurately positioned GPS data. Left side shows where GPS fix was frequently lost due to tree cover.

9.3 Preprocessing

These corrections are applied to the raw data to improve positioning and remove any other errors introduced by the instrument.

a. Incorporating navigation information. Positioning geophysical data and conversion to required coordinate system. When positioning data are stored in a separate file from sensor data, e.g. GPS, a common marker such as a time stamp is required in both data sets to correctly position the sensor data. This step should also include the interpolation of positions, if required, and any conversion or projection to a specified coordinate system.

b. Removal of Instrument Drift and Leveling of Data. Drift correction is needed when the "no response" value of an instrument changes during the course of the survey. This can be caused by temperature variations and may be minimized by allowing the instrument to warm up for a sufficient amount of time before use. Drift correction, also referred to as “leveling”, may be performed manually by visual inspection of the data or statistically by calculating the standard deviation of the data from all of "no response" values. There are a number of tools available that can be used to correct instrument drift, among them, demedian filters, rolling median and rolling mode filters, linear subtraction (time dependent) and others, that can be effective. However, quality control of the correction process must be maintained as most automated drift correction routines will introduce uncharacteristic signals into the resultant data.

c. Removal of Heading Errors. Heading corrections must be applied to data with a systematic shift based on direction of travel along the survey line (see Figure 9.2). The most common need for heading correction is in magnetics data. Heading errors may also be observed in EM data, possibly as a result of differences in coil height above the ground, terrain effects, and coil geometry. Determining the correction is done using information recorded in the instrument tests performed at the beginning of the survey. Each of the Octant Test, Azimuthal Test, heading test, and 6 line test can provide heading correction information.

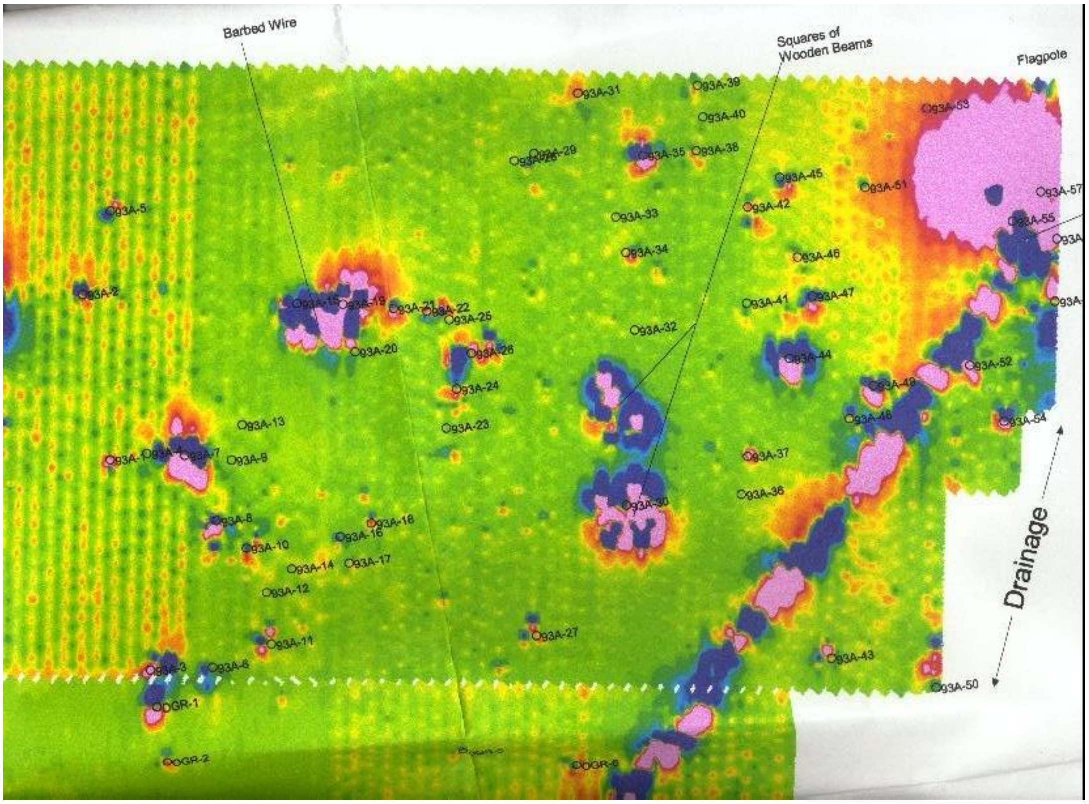


Figure 9-2: Heading error in total field magnetics data (vertical striping)

d. Latency Corrections. Latency or lag effects are visible in gridded data as chevron patterns or wavy edges of anomalies, see Figure 9.3. Latency is caused by a delay in instrument response from the recorded position. Determining the shift can be done by measuring the distance between equivalent points of an anomaly on neighboring lines and dividing this value by two. A negative lag will shift the data forward (for the sensor trailing the logger) and a positive lag shifts the data back (for a sensor leading the logger). The use of a "lag bar" or the 6-line test is recommended to measure latency effects. When a lag bar is used, a steel rod is commonly used for the test, in which the geophysical instrument is traversed over the rod in several passes. A typical latency test consists of three passes over the steel rod, as follows: first pass walking to the north, pass over west end of rod, second pass walking to the south over center of rod, third pass walking to the north, over east end of rod. If no latency effects were observed in the data, the rod will appear as a narrow, linear anomaly. If latency effects are observed, the anomaly will demonstrate a chevron pattern. The required shift can then be measured from the plotted data.

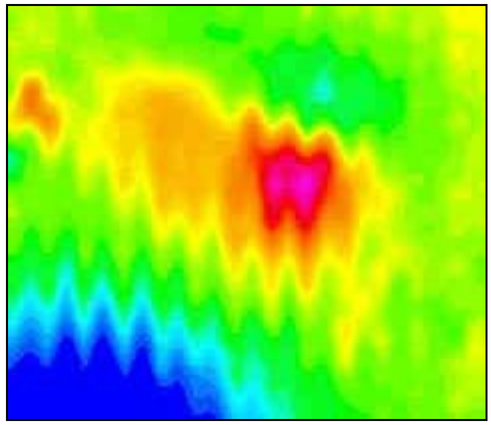


Figure 9-3: Latency in total field magnetics data (vertical striping)

9.4 Processing and Target Selection

This section describes the application of processing routines and filters, analysis of geophysical data and interpretation of gridded or modeled data. When using filters it is important to keep their limitations in mind. Inappropriate usage can result in the removal or corruption of real anomalies, accentuation of noise or ringing, and add errors to the data. An understanding of the effects of filtering is necessary. A good reference is "The Intelligent Application of Filters to Geophysical Data", presented at the UXO Forum in 2002. A processing log should be delivered with the data, describing the filters used. It is also preferred that the filter parameters used be provided, however, if these are not provided, sufficient QC measures will be required to demonstrate that the filtering process did not remove potential target anomalies or otherwise corrupt the data.

a. Gridding and Contouring. Preprocessed data are gridded and contoured to create a smooth interpolated 2D response plot of the area.

(1) Gridding is the process that takes measured values (usually XYZ data) and interpolates data to between known points at grid nodes. Grid nodes are locations where values are not measured and have to be estimated. Many gridding methods exist, and some of the most commonly used methods include Kriging, Minimum Curvature, Bi-directional, and Nearest-Neighbor. Some software programs employ an iterative method when gridding data to achieve a smooth surface that most closely matches the measured data points. Gridding parameters should be selected to best preserve the true nature of the collected data. These parameters include the grid cell size, the initial search radii, blanking distance, tolerance, and the number of iterations.

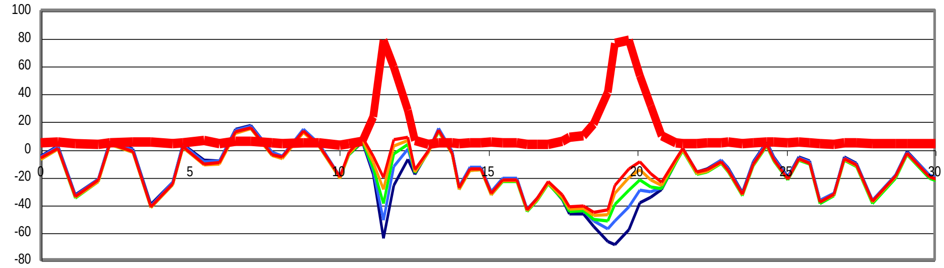
Ideally, the grid cell size would be the sampling interval along data collection lines. A smaller grid cell size will more closely match the collected data, but it will increase the processing time and increase the number of iterations in order to achieve a realistic result. However, with the computer processing speeds and amount of RAM now available, and the relative small areas of data typically processed, choosing a smaller grid cell size will usually only marginally increase the total CPU processing time. A larger grid cell size will result in a map that may have a low resolution and a coarse appearance. Additionally, and more importantly, significant anomalies may be missed or apparent anomalies may not be accurately portrayed. Blanking distances are used to maintain the shape of the grid and should not exceed the maximum sampling interval or instrument footprint . Tolerance is the percent value to which the gridding algorithm must match the measured data points. A smaller tolerance results in a more accurate grid. Similarly, more iterations produce a grid that more accurately matches the data.

(2) Contouring provides a mechanism for summarizing large volumes of data about the spatial variation within the mapped area. As with gridding, certain parameters should be considered when contouring, the most obvious being the contour interval. The contour interval should be such that the lines accurately define the variations within the area of interest. Should the contour interval be too large, detail may be lost in the resulting map. Conversely, a contour interval that is too small will result in a cluttered map that is difficult to read.

b. <u>Calculation of the 3D Analytic Signal for Magnetics Data</u>. The analytic signal is a function that is used to reduce dipole responses to monopole responses in order to facilitate picking anomalies. It is essentially the directional vector of the three magnetic field gradients calculated in the x,y and z directions. This function provides the best solution when both actual total field and vertical gradient data are available, such as when both the top and bottom sensor measurements are recorded from a gradiometer. However, good results can still be achieved when only the total field or the vertical gradient measurements are available. A good reference to the actual analytic signal formula is provided in Geosoft's UX Detect package.

c. GEM-3 Sum of All Quadrature Data: Q-Sum Map. The quadrature data are less sensitive to height variations than the inphase, and thus may provide more reliable detection. The sum of all quadrature data, as a single map, provides excellent detection in magnetic and/or conductive geology. Stacking data reduces random noise and increases the signal to noise. Proper calibration of the instrument is necessary for meaningful results.

d. GEM-3 Sum of All Differences in Quadrature Data. Q-Spread Map: In severely magnetic/conductive geology, the sum of "all absolute differences in quadrature" works well. The multiple-frequency data (inphase or quadrature) tend to "bunch together" over background and "spread out" over a metallic UXO target. On a limited basis, this "sum-of-spreads" approach works equally well with the inphase data. See the graphic example data in Figure 9.4 below, illustrating five-frequency GEM-3 profiles in magnetic geology. Individual frequency profiles are shown in multiple colors, and thick red lines show the sum of all differences as described in the text. The inphase data (top) are sensitive to sensor motion as indicated by noisy raw data, while the quadrature data are relatively immune to the sensor motion. The x-axis is in feet.



Five-frequency inphase profiles and the I-spread profile (thick red line)

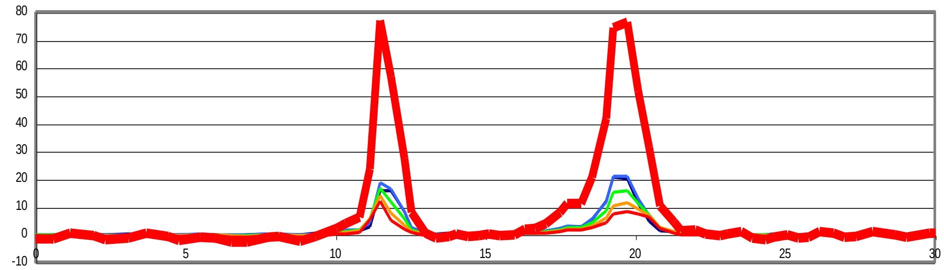


Figure 9-4: Five Frequency quadrature Profiles and the Q-spread Profile

(thick red line is the Q-spread profile)

Source: Geophex, Ltd.

e. Digital Filtering and Enhancement. Data are filtered and enhanced to diminish the effects of noise and enhance the anomalous response and subsequent re-gridding if required. The following list describes some of the more common filters used for geophysical data.

(1) Linear low pass - removes high frequency, short wavelength features from the data. This filter is effective at removing low amplitude high frequency noise and tends to smooth the signal.

(2) Linear high pass - removes low frequency, long wavelength features from the data. The result will be the sharpening of features in the data. For large data sets, a linear high pass filter can be used to remove regional influences, such as geology.

(3) Linear band pass - is a combination of a high and a low pass filter allowing only features with wavelengths between a specified long and short wavelength to remain in the data.

(4) Non-linear - a de-spiking algorithm effective at removing short wavelength features with high amplitudes from the signal. Filter tolerances are set for the width and amplitude of spikes to reject relative to the local background. Once rejected features

are removed they can be replaced by interpolated values based on neighboring readings.

(5) Rolling statistics - calculates the statistics within a moving window along a channel of data. This filter will produce a statistical measure of the data within the moving window and outputs the selected statistical value at the center of the window. This filter can be used as a measure of the variability of the data or as a means to smooth out the appearance of the data.

(6) Difference - useful for identifying noise in data. A difference filter calculates the difference between values in a single channel of data; the fourth difference filter is the most common.

(7) 3x3 Hanning convolution - this smoothing filter tends to reduce low amplitude, high frequency responses within the data. It also improves the appearance of the gridded data by smoothing transitions between contours. The overall effect of the Hanning filter is a reduction in the number of peaks within a grid.

f. Threshold Selection. Generally a single threshold is set for a logical grouping of data, (e.g. per grid, or for all datasets with background values having certain statistical characteristics, etc.) and is based primarily on the level of noise observed in that grouping of data. The results of a prove out performed prior to data collection may be used to gain an understanding of some of the peak responses to expect at a site. However, since few prove out designs provide a complete range of possible target items at their maximum expected depths, nor do they provide a full range of possible responses for each item at a given depth, the GPO data should not be used to establish project-wide threshold values. The selection of the threshold values should be based upon two main factors:

(1) It must be set above the apparent noise level of the data set.

(2) It should be set below the expected response amplitude of buried munition items on the site.

These factors can be contradictory, and in such cases, the noise level should be used to determine the threshold level.

g. Anomaly Selection and Quality Control of Target Picks. A peak-picking algorithm is performed on gridded data to identify anomalies with positive responses above a selected threshold. Any automated target selections must be reviewed by a qualified geophysicist and refined; missed targets should be added and redundant picks removed. If necessary, identify areas or regions that have high ferrous or geologic clutter, as it may not be practical to perform discrete target selection within these regions. It is also possible to examine response characteristics, such as the differences in EM61 MK2 data between successive time gates, to reduce the possibility of selecting anomalies that appear to associated with noise or data spikes. All anomalies must be given identifications that are unique for that project.

h. Prioritization of selected targets. Targets may be prioritized by amplitude (including analytic signal), spatial extent, signal characteristics and other factors.

9.5 Advanced Processing.

Advanced processing involves further steps beyond target selection to prioritize and discriminate selected targets. The items listed below should be regarded as a brief list of the more established advanced processing topics currently being used and developed. There is considerable research being conducted in the buried munitions discrimination field and although some new methods are producing positive results it is not possible to include a complete list of all developmental processing techniques.

a. Mass and Depth Estimates. For magnetic data, crude depth estimates can be made by solving Euler's Homogeneity equation, Equation 9.1.

$$(x - x_0)\frac{\delta T}{\delta x} + (y - y_0)\frac{\delta T}{\delta y} + (z - z_0)\frac{\delta T}{\delta z} = N(B - T)$$

Equation 9.1

Euler's Homogeneity equation. Where (x_0,y_0,z_0) is the position of the magnetic source whose total field (T) is detected at (x,y,z)
B is the regional magnetic field
N is the measure of the fall - off rate of the magnetic field and may be interpreted as the structural index (generally between 2.7 and 3 for ordnance)

Weight estimates from magnetic data are done by looking up mass values based on the analytic signal response and the depth. For EM data, where shallower targets are to be estimated (under 4 feet), depth estimates generally provide better results. The Geonics depth calculations are as follows:

$$\mathbf{d} = -2229.57 + (7288.13 \bullet \mathbf{R}) - (9635.78 \bullet \mathbf{R}^2) + (6458.69 \bullet \mathbf{R}^3) - (2158.63 \bullet \mathbf{R}^4) + (292.118 \bullet \mathbf{R}^5)$$

Equation 9.2

Geonics depth calculation for 1x1 meter coils where
d is in centimeters
R is the ratio $\frac{TopCoil * 1.117}{BottomCoil}$

$$\mathbf{d} = -155.95 + (795.09 \bullet \mathbf{R}) - (1715.82 \bullet \mathbf{R}^2) + (2026.38 \bullet \mathbf{R}^3) - (1413.19 \bullet \mathbf{R}^4) + (582.55 \bullet \mathbf{R}^5)$$

Equation 9.3

Geonics depth calculation for 1x0.5 meter coils where
d is in centimeters
R is the ratio $\frac{TopCoil * 1.117}{BottomCoil}$

b. Analysis of Spatial Anomaly Shape, the Response Tensor or Aspect Ratio. This is used to distinguish between intact ordnance and clutter. Analysis of Spatial Anomaly Shape uses a source model, through which an inverse solution can be determined by adjusting the model parameters to fit the measured anomaly across multiple spatial directions. Analytical expressions for the response field are needed to perform the inversion. This is an extension of inverse modeling to fit models to a profile. The Response Tensor or Aspect Ratio refers to the anomaly shape and a ratio between the width and height of the anomaly. The aspect ratio could be used to determine estimates for physical properties (such as mass) and depth of a source object through inverse modeling.

c. Model Matching. This refers to indirect interpretation of anomalies based on their spatial shape. An atlas or library of theoretical model curves is needed to compare measured data to find a best fit match through trial and error. Because this method usually employs comparative analyses of 2D representations of measured field data to a library of similar 2D data sets, the field data must be of the highest quality and only very minor heading, latency or leveling errors can be tolerated for the comparative analysis to have meaning. Based on the best fit model, an estimate of the basic shape of the source anomaly and other physical characteristics of the object can be determined. The quality of the comparison can be computed to provide a measure of the comparative fit of the model to the idealized curve. This is most commonly used for magnetic data but could also be applied to time or frequency domain electromagnetic data especially with multiple time or frequency gates.

d. Multi-channel Analysis, e.g. Time Decay Curve or Amplitude and Phase Response. Developing systems such as the Geonics EM-63 and Geophex GEM-3 have shown that different ordnance items have unique responses when viewed over multiple time gates or frequencies. Currently algorithms are being developed to discriminate different ordnance using these two instruments.

e. Merging of Multi-sensor Data. For example, magnetic and electromagnetic data collected over the same site will have the advantage of detecting smaller, shallow objects through the EM survey and deeper, larger objects through the magnetic survey. In addition, the combination of these two data sets can provide relatively accurate depth estimates from the EM data as well as size and weight estimates from the magnetic data. By comparing selected EM and magnetic anomalies, classifications such as ferrous/non-ferrous/magnetic rock can be made.

9.6 Data Presentation/Deliverables

The results of the geophysical investigation should be submitted to the Corps as follows.

a. Dig list (in ASCII or Excel format), of selected targets with the target location given in the referenced coordinate system, represented amplitude of response based on selection criteria, and any comments or details regarding target properties. Refer to example (Target History Form) in Appendix E.

b. The following notes and instructions provide directions for creating geophysical maps for O/E projects. The “Blocks” listed below correspond to the areas identified in Figure 9.5. Maps will include all the following basic map features in addition to any other necessary site information.

(1) General

(a) Map scales should be even multiples of the base units presented in the map. Example: for scales based on one inch being equal to X number of feet, the scale should be an even multiple of 12, e.g. 1:120 (or one inch = 120 inches = 10 feet)

(b) Map sizes should be designed to fit standard printer or plotter sizes. Preferred paper sizes for small maps are letter (8.5”x11”) and tabloid (11”x17”). For larger maps, the preferred sizes are C1 (24”x36”) or smaller.

(2) Block 1: Title Block

(a) Use this area to provide Figure number, the map Title and sub-title (e.g. instrument and type/component) and the location of the information being presented (e.g. site/area name and property/grid ID).

(b) The fonts used here should be large.

(3) Block 2: Map Display Area

(a) Grid ticks or grid lines should be visible and labeled, though these can be in small fonts to allow for as large an area as possible being reserved for the display of information

(b) The use of surrounds/frames is not required, and may be omitted to maximize the area reserved for the display of information.

(c) All symbols associated with anomalies and known cultural features should be identified. Abbreviated ID’s may be used, though an explanation of the abbreviating method should be included in the legend notes (e.g. anomaly ID S1G1-001, anomaly #1 from grid 1 of sector 1, could be abbreviated to simply the number 1 on the map)

(4) Block 3: Legend

(a) The legend should include all objects/symbols shown on the map.

(b) The following symbol conventions are preferred:

- Open, unfilled circles for locations of anomalies picked from the data
- Polygons with dashed lines for bounding areas with multiple/overlapping anomalies (e.g. used to identify area of a suspected burial pit)
- "X" symbol for locations of known surface features
- All other symbols should conform to either the Civil or Surveying and Mapping sections of the Tri-Service Spatial Data Standard

(c) Color scale bars should use a color scheme that clearly differentiates between anomalies and background readings. Background values should be plotted in white or gray, so as not to distract the viewer. A classic "cold to hot" color scale should be used, with negative values plotted in blue and high positive values plotted in red. The range of values should be "Fixed", so that the same color scale is utilized across the site. The region of major interest is almost always near the detection / background limit, not the maximum or minimum values of the data set. A standard color scale for Geosoft's Oasis Montaj and Golden's Surfer mapping packages are available upon request from CEHNC.

(d) Clearly label the scale as the "Map Scale".

(5) Block 4: Project Area Index Map

(a) Use this area to show direction arrows, including true north, magnetic north, and grid north

(b) Subject to client approval, the Index Map area may be omitted to provide more area for Area 3 (the Legend) and/or Area 2 (the Map Display Area).

(c) Clearly label the scale as the "Index Map Scale"

(6) Block 5: Project Information Block

(a) Use this area to include pertinent project information. The minimum requirements are to have boxes for the following information:

- Client
- Project
- Contractor
- Map creator
- Map approver
- Date map was created
- Map file name
- Scale

(b) The map file name should include the full path and file extension.

(c) The scale should match that shown in the legend.

(7) Block 6: Logos

(a) Include one of the USACE Castle logos in the lower right corner of the page.

(b) The words U.S. Army Engineering & Support Center, Huntsville should be visible below the castle logo.

(8) For submittals the contractor should provide maps in editable form (if available, e.g. Geosoft .map or Surfer .plt formats) and map images in a common image format, such as a geo-referenced TIF file, for viewing without the software used to produce the maps.

Site maps showing the location of the data and relevant cultural features in addition to the basic map features. Often cultural features can cause a response in the geophysical data. Fixed location features are also useful for relocating grids established with a local coordinate system. If digital submission is requested, files must be in a format compatible with GIS (ArcView) software.

Additional site information to support mapping should be provided if available.

(1) Details of several methods of positioning using site information can be used. If a local grid system is used, culture maps created in the field during data acquisition noting the location of cultural features with reference to the local grid coordinates must be included.

(2) Additional GPS data to identify points or features of interest. If GPS is used to shoot in points and/or boundaries of cultural features this can be presented with gridded RTK GPS geophysical data.

(3) Georeferenced aerial photographs of the site can be presented or superimposed with geophysical data when positioned with GPS or surveyed corners. Broad scale surface features can sometimes be matched with geophysical anomalies, combining two highly informative visual representations of the site.

(4) Known cultural features with anomalous responses in the geophysical data should be marked out on the maps and noted within the accompanying report text.

(5) Presentation of digital elevation models.

(6) Additional geologic information or geophysical data collected using other methods. This information is useful for broad scale interpretation of data collected at buried munitions sites. Geologic background responses may be visible in the geophysical data and are more easily identified with additional site information.

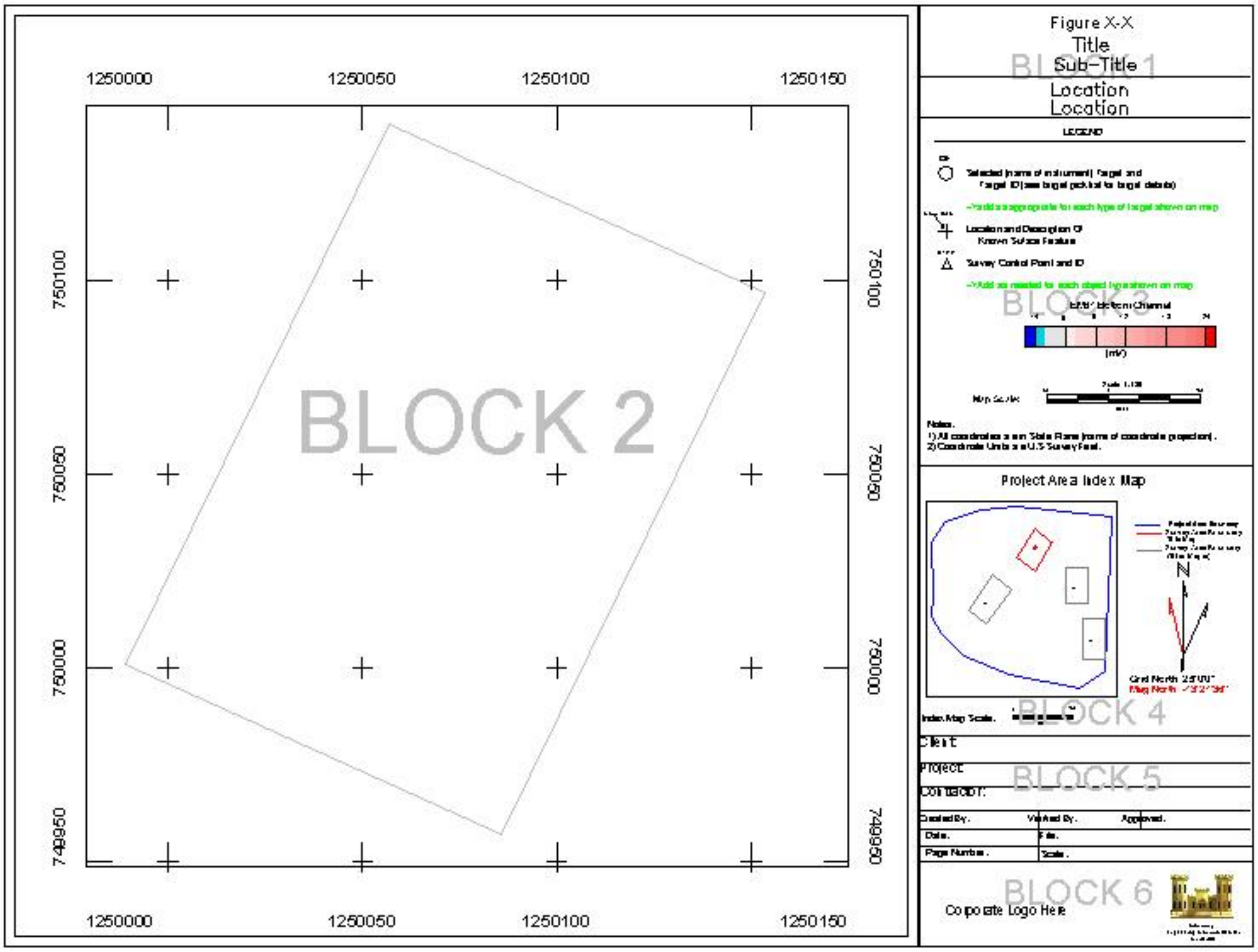


Figure 9-5: Example Map Showing features to be included in Geophysical Maps

9.7 Checklist for Field Editing

Project Name: ______________________

Project Location: ______________________

CEHNC POC: ______________________

Reviewer's Name and Title: ______________________

Date of Review: ______________________

	Y	N	N/A
a. Have the following items been evaluated for correctness and edited if necessary:			
• Line numbers?	____	____	____
• Start and end points?	____	____	____
• Line direction?	____	____	____
• Fiducial locations?	____	____	____
b. Has the data been examined in profile and evaluated for geophysical noise?	____	____	____
c. Has the data been examined for the presence of drop-outs and spikes?	____	____	____
d. Has the presence of metal on the operator been eliminated as a possible source of geophysical noise?	____	____	____
e. Has the edited data been converted to the appropriate .xyz format?	____	____	____
f. If using magnetics, have the following steps been taken:			
• Examined base station data for any problems?	____	____	____
• Performed diurnal correction to field magnetometer data?	____	____	____
g. Has the positional data been evaluated for accuracy and completeness?	____	____	____

9.8 Checklist for Data Processing

		FILENAMES:	
Site:	______________________	Raw:	______________________
Location:	______________________	Edited:	______________________
Contractor:	______________________	Processed:	______________________
Sector:	______________________	Contour Map:	______________________
Grid:	______________________	Target List:	______________________
Processor(s):	______________________	Target Map:	______________________

	Y	N	N/A
Preprocessing			
a. Coordinate Conversion Projected Coordinate System ______________________	____	____	____
h. Removal of Drift and Leveling	____	____	____
i. Removal of Heading	____	____	____
j. Latency and Offset	____	____	____
Processing			
a. Initial Gridding	____	____	____
k. Calculation of 3D Analytic Signal	____	____	____
l. Digital Filtering and Enhancement ❑ Filter 1: ______________________ ❑ Filter 2: ______________________ ❑ Filter 3: ______________________ ❑ Filter 4: ______________________ ❑ ❑	____	____	____
m. Threshold Selection Threshold value ______________________	____	____	____
n. Anomaly Selection Number of targets ______________________	____	____	____

Chapter 10: Anomaly Location and Marking

10.1 Introduction

a. Accurate reacquisition and marking of targets selected for excavation is critical to the success of a geophysical survey. The objective of target reacquisition is to mark on the ground the location of each target, with adequate precision to minimize the size of the excavation and time required to remove the target. The two primary elements of reacquisition are: locating and marking the interpreted x,y target locations from the dig list, and adjusting marked locations to improve their precision.

b. It is imperative that the DGM contractor responsible for the original data acquisition maintains the responsibility chain by performing all aspects of target reacquisition. The best results can only be obtained by those who are most familiar with the survey procedures and navigational methods utilized during data collection. A responsible field geophysicist should be present during reacquisition activities, or be involved with training of the personnel. In the best case the same personnel originally acquiring the data perform the reacquisition. The following are procedures for target reacquisition with discussions on methodologies and techniques.

10.2 Marking Interpreted Target Locations

The first step in successfully reacquiring targets for excavation is to survey and mark the locations as interpreted from the geophysical survey data. The contractor shall utilize the same navigational methods and techniques as were used during the original investigation. Resurveying the x,y target locations in this manner is vital to accurate reacquisition. For example, due to terrain characteristics, problems are often encountered when interchanging Global Positioning System (GPS) and traditional tape measure surveying methods. Target locations should be marked in the field using non-metallic pin flags. Each flag should be labeled with a target identification number so that the status of each anomaly can be tracked and documented through reacquisition, excavation, and final QC procedures.

10.3 Challenges in Re-locating Targets

a. After marking target locations interpreted from original survey data, the opportunity exists to improve upon those locations through further, detailed geophysical investigation. Using the same type of geophysical instrumentation to acquire the actual peak of an anomaly, the interpreted location can be refined. There are several reasons why this is advantageous:

(1) To compare the reacquired target amplitude to the original amplitude, the same type of instrument must be used. By comparing amplitudes the team can verify that the correct target has indeed been reacquired. Lower amplitude anomalies (below the selected threshold) may exist in close proximity to the target.

(2) Different instruments have different depth detection capabilities, and in some cases different capabilities for types of metal that can be detected. Aluminum targets identified by an electromagnetic instrument will not be detected by a magnetometer.

(3) Assuming the instrument(s) used for the original survey were selected with response (or lack of) to site-specific noise in mind, using the same instrumentation will avoid complications from noise elements during reacquisition.

b. The location of an anomaly's peak response, whether using magnetic or electromagnetic methods is not always directly over the target.

(1) Magnetics: Cesium vapor (CV) magnetometers commonly used for digital geophysical mapping of buried munitions sites can be setup to collect either vertical gradient or total field measurements. In the case of total field magnetics, the peak response is rarely observed when the sensor is directly over the target item. Since total field measurements are direct measurements of the primary field, the total field response of a dipolar anomaly (most OE items are dipolar) will be highest to the south and lowest to the north. A simplified example using a dipolar model is illustrated in Figure 10.1. The location of the target is most often between the anomaly peak and trough, as illustrated. For vertical gradient magnetics, the location of the target may fall under the peak response, depending on the inclination of the Earth's field, the orientation and configuration of the target, and remanent

magnetization. The peak response may be offset from the target location, depending on the factors listed above, but will be relatively close to the target in any case. For both total field and vertical gradient magnetics data, processing using pole reducing filters or analytic signal must be used to correctly place the peak response over the target location. The popular Schonstedt flux-gate magnetometers operate as gradiometers. Since these handheld devices are not restricted to being operated vertically, the level of response is dependant on instrument orientation. If operated in a vertical orientation, they act as true vertical gradiometers.

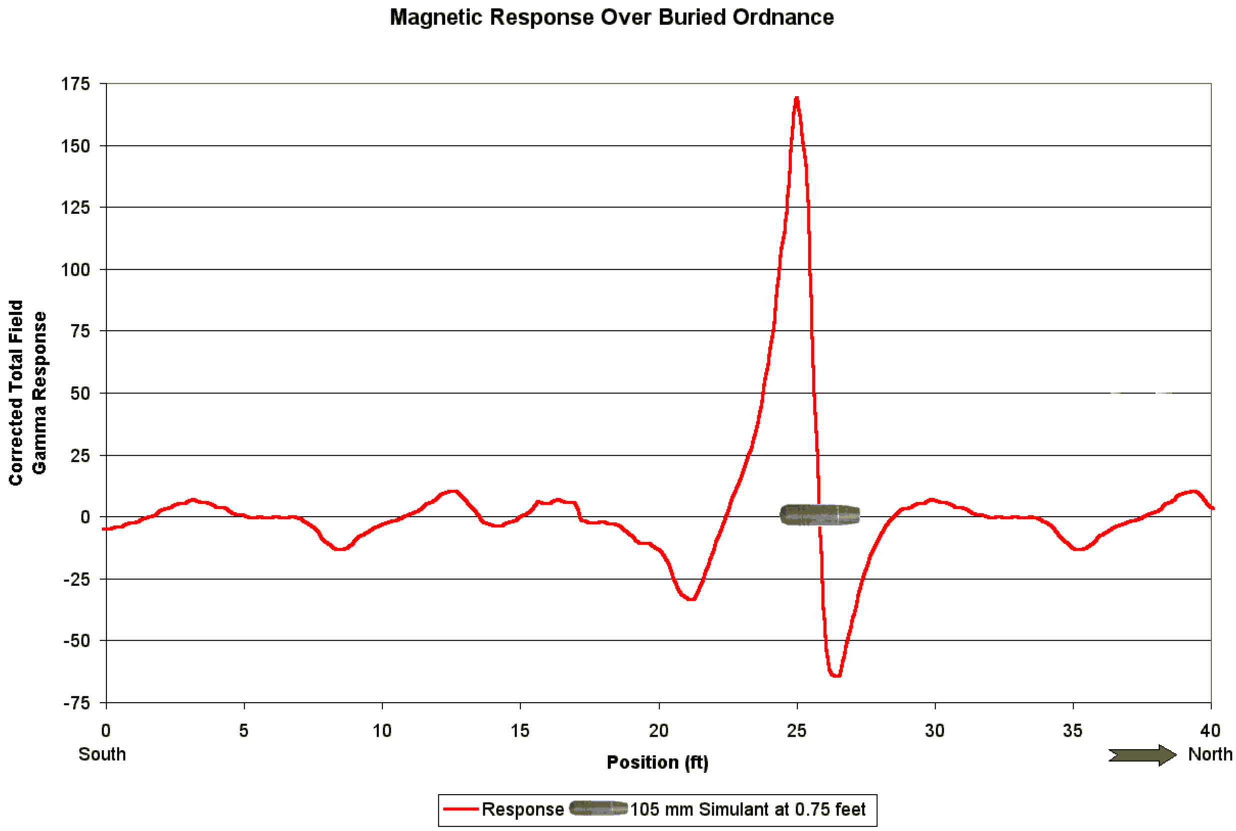


Figure 10-1 Location of OE item in relation to magnetics peak signal

(2) EM: Responses are not always highest directly above the target item. Like the distorted primary fields measured by magnetic methods, the dimensions of secondary fields measured by EM instruments are rarely uniform. As a result, the peak responses are often located adjacent to the target's position. An additional complication of relatively large coil EM instruments, such as the EM61, is that peak responses may occur when the target item is located beneath an edge of the coil,

rather than the center of the coil. This effect is frequently observed when the target is relatively small in size and shallow. A profile over such a target produces a double-peak response as the front and back coil edges pass in close proximity to the shallow target.

(3) For reacquisition purposes, the peak response obtained by an EM instrument, and the peak response for vertical gradient magnetics is considered to be the best real-time measurable location of the target. Reacquisition using a magnetometer to measure total field is problematic. Post processing of total field survey data involves calculating the analytic signal for each data point, the results of which produce anomalously high readings at the inflection point (directly over the target). With current commercial software, reacquisition is a real-time procedure without the advantage of post processing. To reacquire targets using total field requires locating both the highest and lowest responses and selecting a point between as the target location. Undoubtedly, survey areas containing a dense distribution of anomalies are too complicated to decipher using total field. In such cases it is recommended that an alternate geophysical method such as vertical gradient be used, although it would compromise the ability to compare amplitude responses throughout the survey, reacquisition, and post-excavation QC procedures.

10.4 Adjustment of Target Locations

a. The accuracy of locations interpreted from geophysical survey data is a function of survey line spacing, accuracy of the data positioning methodology, depth of burial, the skill level of the operator who collected the data, and the application of proper editing and processing. After marking x,y target locations as discussed above, each target can then be further investigated in order to improve upon the accuracy of the interpreted locations.

b. Adjustment of a target location begins at the resurveyed marker with a copy of the geophysical contour map in hand and the appropriate geophysical instrumentation operating in automatic, or search mode. Assuming the original data are accurately located, the actual target location will typically be found at a distance of less than one-half the survey line spacing from the interpreted location. Survey data collected under difficult terrain or vegetation conditions, for example, may have a greater degree of positional error.

c. An efficient and systematic technique for locating each target location is as follows:

(1) Locating Anomaly. The operator investigates the footprint of the contoured anomaly for the presence of anomalies. If multiple anomalies are present within a specified distance of the target marker, each one must be investigated independently.

(2) Locating peak response/Verification of target

(a) Once an anomaly has been detected, the operator begins a series of short traverses while monitoring the amplitude of response. Line length can be determined by referencing the geophysical contour map for the diameter of the anomaly footprint. At the point of highest response along that profile, the operator turns 90 degrees and performs a second traverse. When the location of highest response along the second traverse is identified, a third traverse may be surveyed over the new “high”, perpendicular to the last. The operator continues this process of tracking the peak until the location of highest response cannot be improved.

(b) Once the target location has been identified, it is necessary to verify that it is the correct target. This is accomplished by comparing the amplitude of peak response of each target to the maximum amplitude that was recorded during the initial survey. If the reacquired peak amplitude is equal to or greater (to within 150% of the original signal), it can be assumed that the correct target has been identified. If the reacquired peak response is less than that of the original survey, then the investigation must continue in search of the correct target. In order for amplitudes to be compared, it is important that the geophysical operator has followed appropriate instrument nulling procedures. Once the target has been verified and its location has been identified, the pin flag should be relocated to that position. It may be beneficial to confirm that the flagged location generates a response using a Schonstedt (or other instrument used by the excavation team) in order to confirm that the excavation team will be able to reproduce a signal during their effort. If a signal is found to be generated with the Schonstedt, this will help ensure the true source of the targeted anomaly is removed. If no signal is detected, the excavation team may need to be instructed to dig within a predetermined radius of the flagged location or use alternate instrumentation.

(c) Multiple peaks: After reacquiring the target, the immediate surrounding area should be investigated in order to determine if any additional anomalies are present. As a result of the inherent limits to the amount of data collected using typical line spacings for a survey, multiple anomalies may be identified during reacquisition within an area in which only one target was identified from the original survey data. Any additional anomaly peaks identified that meet the threshold for target selection (specific for each project) should be marked with pin flags for excavation and assigned a target number.

10.5 Documenting Target History

Documentation of the history and status of all targets selected for excavation is required. The dig sheets include target identification, x,y coordinates, and amplitude from the original survey data. The reacquired (and adjusted) x,y coordinates and peak amplitude response must also be documented. Finally, documentation continues through post excavation quality control procedures to include the final post-excavation amplitude response and any associated comments or explanations. The EOD contractor performing the excavations is responsible for documenting dig results including: the identity of metallic items found during excavation, depths, orientations, and mass. The dig sheet in Appendix E is provided to document target histories. The accuracies for reporting information on recovered items on the dig sheet should be determined on a project specific basis.

Chapter 11: Quality Control of Target Excavation and Feedback

11.1 Introduction

Quality control procedures applied during the excavation of targets provide closure on the status of each potential buried munitions target identified by DGM. Using digital geophysical instrumentation to assess the status of anomalies during the excavation process is a quantitative method of determining whether performance objectives are met.

11.2 Contractor / Instrumentation Consistency

a. The geophysical contractor responsible for the original data collection and reacquisition should perform the QC of target excavation if possible. In addition, it is preferred that personnel should also remain consistent throughout all phases of the project. Aspects of the post excavation QC process may be left to the discretion of the site geophysicist.

b. Chapter 10 contains a thorough discussion on the appropriate instrumentation for the reacquisition process, including post-excavation QC, as well as recognition of target anomalies. In short, the same geophysical instrumentation utilized for the actual reacquisition is preferred for post-excavation QC to allow comparison of anomaly response amplitudes before and after excavation to determine to what extent each anomaly has been reduced.

11.3 Clearance Criteria

Site specific clearance criteria must be established to determine when performance objectives have been met. For a variety of reasons, the QC results of each target excavation will not always be absolute. Complete target removal does not always result in an amplitude response equal to background, or zero. The geophysicist performing the QC of target excavations will require these criteria to determine when the removal effort has been adequate and there no longer exists a potential for the presence of buried munitions. The contractor shall record and report on all discrepancies between final reacquired mapped locations of anomalies as shown on the dig sheet, and actual locations of the excavated anomalies. The contractor shall also report on any anomalies that could not be reacquired. Examples of clearance criteria are as follows:

(1) The target location has been excavated to the required clearance depth.

(2) The target item has been exposed and identified as non-munition, but is impractical to remove.

(3) Final amplitude of the anomaly is below the threshold value for target selection.

11.4 Challenges in Performing Post Excavation Quality Control

a. Proper sensor elevation must be maintained during the post excavation QC in order to acquire accurate readings. The instrument operator must be conscious of the level of the ground surface as it was prior to disturbance. Consideration will be made for wheeled instruments so they remain level and are not hindered by the presence of spoils piles.

b. Recognition of background response demands that instruments used for QC are properly warmed up and nulled, as discussed in Section 6.4c. Target amplitudes that remain above background levels following excavation may necessitate further excavation or may be due to influence from nearby cultural objects or adjacent targets that cannot be removed. Anomalies comprised of multiple sources may require several excavation attempts before the amplitude is reduced sufficiently.

c. In areas of saturated response, only the most significant targets may be identifiable from the original survey data and selected for excavation. The less significant secondary anomalies will become evident following the first round of excavation. The possibility exists for the response from munition items to be overshadowed by that of larger sources, resulting in an incomplete removal effort. Proper post excavation QC includes the investigation of the entire footprint area of each anomaly selected for removal to identify the presence of secondary anomalies. The geophysical operator must refer to the geophysical contour map while performing QC for information on the lateral extent of target anomalies.

d. In some cases target density may give a saturated response for all geophysical tools. In these “Special Case Areas” no individual targets can be discerned. A scraper or backhoe may be brought in to remove the sources of saturated response, then an EM or magnetics survey is performed as a final check.

11.5 Coordination Between Geophysical and UXO Teams

a. The process of excavation followed by geophysical QC may be conducted multiple times on a single target before the anomaly is removed entirely. The transfer of information between geophysical and UXO teams is necessary to provide a coordinated effort towards the efficient removal of targets. Ideally, a UXO Technician III will be present as the geophysical team performs QC checks on each excavation. In the event an anomaly has not been fully eliminated, the two groups can exchange information on the dig results and the peak location of the remaining anomaly.

b. It is important that the QC failure criteria are documented in both the job contract and work plans, so that all is clear before the project is bid and progresses.

11.6 Feedback Procedures

Developing and improving digital geophysical mapping techniques and interpretation procedures for the detection of buried munitions is an on-going process that benefits from the results of actual site investigations. The results of excavations shall be recorded on the Target History Form (see Appendix E) by the responsible UXO team. Excavations that produce OE items will also include information regarding depth, orientation, inclination, and condition of the item. Please refer to the guide for measuring orientation azimuth and inclination in Section 3.5. The completed Target History Form will be made available to the geophysical contractor to promote improvements in all aspects of geophysical surveying.

Appendices

Appendix A: References

United States Army Corps of Engineers. *Data Item Description*: *Geophysical Investigation Plan* (OE-005-05.01). Washington: Government Printing Office. Oct 1, 2002.

United States Army Corps of Engineers. *Data Item Description*: *Geophysical Prove-out (GPO) Plan and Report* (OE-005-05A.01). Washington: Government Printing Office. Oct 1, 2002.

United States Army Corps of Engineers. *Data Item Description*: *Location Surveys and Mapping Plan* (OE-005-07.01). Washington: Government Printing Office. Oct 1, 2002.

United States Army Corps of Engineers. *Ordnance and Explosives Response* (EM 1110-1-4009). Washington: Government Printing Office. June 23, 2000.

Elizabeth Baranyi, M.Sc. and Lorraine Godwin, Geosoft Inc., Toronto, ON, Canada; David Wright, AETC Inc., Raleigh, NC, USA. *The Intelligent Application of Filters to Geophysical Data*, UXO Forum 2002, Orlando, Florida

An Index of DID's pertaining to Ordnance and Explosives can be found at http://www.hnd.usace.army.mil/oew/dids.asp

Current ER, EP, and ER and DoD Directives can be found at http://www.hnd.usace.army.mil/oew/erepems.asp

Appendix B: Geophysical Equipment Sources and Useful Website Addresses

Manufacturers and Rental/Service Companies

Geometrics: Manufacturer of geophysical equipment. Provides sales and rentals of equipment.

www.geometrics.com

Geonics, Ltd.: Manufacturer of geophysical instruments. Provides sales and rentals of equipment.

www.geonics.com

Geophex: Manufacturer of geophysical instruments. Provides sales and rentals of equipment.

www.geophex.com

Scintrex, Limited: Manufacturer of geophysical instruments. Provides sales and rentals of equipment.

www.scintrexltd.com

GISCO: Provides sales, service, and rental of geophysical equipment.

www.giscogeo.com

Exploration Instruments, LLC: Geophysical equipment rentals.

www.expins.com

KD Jones Instrument Corporation: Provides sales and rentals of geophysical instruments.

www.kdjonesinstruments.com

SAGA Geophysics, Inc.: Geophysical instrument rental company.

www.sagageo.com

TerraPlus: New and used geophysical equipment supplier for rent or purchase.

www.terraplus.ca

Data Processing and Presentation Software

Geosoft, Inc.: Software that enables productive use of spatial data in exploration, UXO detection and environmental investigations.

www.geosoft.com

Scientific Software Group: Providing advanced contour, graphing, and digitizing software, including Surfer.

www.ssg-surfer.com

ESRI: Providing GIS and mapping software, including ArcMap, ArcGIS, and ArcView.

www.esri.com

AutoCAD: Providing data design software.

www.autodesk.com

GPS

Ashtech Inc.: Manufacturers of GPS receivers.

www.ashtech.com

Garmin International: Designs, produces, and markets GPS receivers.

www.garmin.com

Magellan Systems Corporation: Manufacturers of GPS receivers.

www.magellangps.com

OmniSTAR Inc.: Providers of wide-area differential GPS service in North America.

www.omnistar.com

Trimble Navigation Ltd.: Manufacturers of GPS receivers.

www.trimble.com

Miscellaneous

Tripod Data Systems: Develops hardware and software for mobile computing applications.

www.tdsway.com

TerraServer: Provides high resolution USGS aerial photographs and USGS topographic maps.

www.terraserver-usa.com

Ordnance Detection and Discrimination Study (ODDS) Static Test Data: Geophysical Static Tests data from the July 2000 study conducted by USA Environmental and Parsons Engineering Science for the Corps of Engineers.

http://www.fortordcleanup.com/adminrec/ar_pdfs/AR-OE-0291A-D/

U.S. Government Websites

USGS – United States Geologic Survey

www.usgs.gov

NOAA – National Ocean and Atmospheric Administration

www.noaa.gov

US Army Corp of Engineers – Huntsville Center

www.hnd.usace.army.mil

NRCS – Natural Resources Conservation Service

www.nrcs.usda.gov

USDA – United States Department of Agriculture

www.usda.gov

EPA – Environmental Protection Agency

www.epa.gov

DOE –Department of Energy

www.energy.gov

Appendix C: INDEX OF ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
CV	Cesium Vapor
CEHNC	Corps of Engineers Huntsville Center
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DIDs	Data Item Description
DOP	Dilution of Position
DQOs	Data Quality Objectives
EM	Electromagnetic
EM	Engineering Manual
EOD	Explosive Ordnance Disposal
FTP	File Transfer Protocol
GIS	Geographic Information System
GPO	Geophysical Prove Out
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
HH	Handheld
MV	Millivolt
NRCS	National Resource Conservation Service
nT	Nanotesla
ODDS	Ordnance Detection and Discrimination Study
OE	Ordnance and Explosives
PDOP	Positional Dilution of Precision
POC	Point of Contact
QA	Quality Assurance
QC	Quality Control
RTK	Real Time Kinematic
SA	Selective Availability
TDOP	Time Dilution of Precision
TM-UWB	Time Modulated Ultra Wideband
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
VDOP	Vertical Dilution of Precision

Appendix D: Survey Area Report Form

Survey Area Report Form

Appendix E: Geophysical Dig Sheet and Target History

Geophysical Dig
Sheet and Target Hist

Appendix F: GEM 3 Calibration

GEM 3 Calibration

Appendix G: Data Quality Objective Examples

DQO Examples