CHAPTER 8
GEOPHYSICAL INVESTIGATION

8-1. Introduction.

a. The purpose of this chapter is to provide the reader an in-depth understanding of how geophysics is used to detect metals, and Munitions and Explosives of Concern (MEC). We first introduce the reader to various systems used to collect and position geophysical data. We then explain in general terms the capabilities and limitations of geophysical and positioning systems. Next, we explain the various elements involved in planning and then executing geophysical investigations. Chapter 9 explains the different aspects of quality control and quality assurance of geophysical systems and presents various approaches for demonstrating and documenting quality control of geophysical systems.

b. In this chapter we use the term *geophysical system* to define the entire "package" of tools and procedures used for a given project, or used to meet a specific project goal. The term *geophysical system* therefore can be thought of as the collection of tools and procedures that are finally selected for use from the array of technologies and deployment options available.

8-2. Geophysical Systems.

a. Geophysical systems are comprised of geophysical tools, positioning and navigation tools, deployment platforms and data management and interpretation techniques. Instrument operators are also considered components of the geophysical system when their tasks are essential to the system's performance. Geophysical systems are broken down into the six fully integrated components, as follows. If any of these components are lacking, the overall geophysical system may not be able to locate MEC effectively. It is important to carefully plan and integrate all aspects of each component into the geophysical investigation and not to start field work prematurely.

(1) Experienced Personnel. Personnel experienced with the theoretical and practical aspects of detecting relatively small MEC and selecting likely MEC anomalies from multiple non-MEC anomalies that are also likely to be present. The selection and utilization of geophysical equipment is complex and requires qualified, experienced individuals. A qualified geophysicist will manage all geophysical investigations for MEC. A "qualified geophysicist" is a person with a degree in geophysics, engineering geophysics, or closely related field and who has a minimum of five years of directly related MEC geophysical experience.

(2) Site Preparation. Site preparation for geophysical investigations at MRAs includes making the ground surface safe for personnel to perform their tasks and removing vegetation and obstacles to meet equipment use needs.

(3) Geophysical Systems Instrumentation. Geophysical instrumentation and related detection capabilities and limitations are discussed in sub chapters below.

(4) Deployment Platforms. Geophysical platforms are discussed in the sub chapter below.

(5) Analysis Procedures. Procedures for accurately documenting the geophysical data collected, steps used in analyzing the geophysical data, and different options available for interpreting the data.

(6) Anomaly resolution procedures. These procedures define how the PDT will verify each anomaly selected for intrusive excavation is completely resolved. The term anomaly resolution is used to describe all tasks and actions to be taken in verifying or confirming the dig results fully explain the source of the anomaly.

8-3. Geophysical Tools.

a. Detection and location of MEC primarily depends on the ability of geophysical instruments to distinguish the physical characteristics of MEC from those of the surrounding environment. The best currently available detection systems all detect the metallic content of the MEC, not the explosive filler. There are several instruments currently under development to detect the explosive materials; however, they are in the conceptual design and testing phase, and have not yet been proven as reliable technologies for detecting buried MEC in the field. In this chapter, we focus on the various geophysical detection systems currently available and widely used to detect MEC. We briefly describe some of the lesser used systems, and explain why their use is limited to specific missions within the MEC detection arena. This chapter does not address explosives "sniffers" or other technologies formulated around detecting the explosive components of MEC.

b. These various geophysical technologies are packaged in many ways. For simplicity, geophysical detectors are grouped into two main families of detectors based on how their data is interpreted. Analog geophysical tools are defined in this document as instruments that produce an audible output, a meter deflection, and/or numeric output, which are interpreted in real-time by the instrument operator. Digital geophysical mapping tools are defined in this document as instruments that digitally record geophysical measurements and where the recorded data can be geo-referenced to where each measurement occurred. This family of tools can either be interpreted in real-time, near real-time, or any later time after data collection work is complete.

(1) Analog Geophysical Tools. This family of detectors includes all hand-held metal detectors and coin detectors, and hand-held ferrous locators. This family also includes those digital tools that can be operated as analog tools as defined above.

(a) Analog Geophysical Surveys ("Mag & Flag" or "Mag & Dig"). This methodology is the approach used primarily by active EOD personnel to locate buried ordnance. Hand-held metal detectors, usually magnetometers, are used to screen an area. Whenever the instrument detects an anomaly, the operator places a small flag in the ground. Advantages of analog geophysical surveys include:

- Ability of geophysical operator to use real-time field observations.
- Provides a precise anomaly location.
- Provides a real-time indication of anomaly location.
- Anomalies can be excavated immediately following the survey.
- Can be operated with fewer vegetation and topographic constraints.

(b) Analog geophysical surveys are particularly effective in areas where vegetation and terrain limit the use of larger digital systems. Also, analog approaches will be considered for use when there is insufficient difference between MEC at the MRA and other metallic fragments and debris at the project property such that digital mapping is ineffective. Challenges for analog surveys include:

- Quality is dependent on operator training and demonstrated performance. Quality is also affected by human factors such as attentiveness/distraction factors and hearing ability,
- Defining rigorous QC measures that are capable of assessing the consistency of the operator's effectiveness for the duration of the survey.
- Higher percentage of small, non-MEC items typically detected during mag & flag surveys. This results in a higher number of intrusive investigations vs. digital geophysical surveys.
- Inability to evaluate electronic data further.
- No permanent electronic record.
- Hand-held magnetometers are less sensitive to small amplitude anomalies and anomalies with low horizontal gradients than their digital counterparts.
- Hand-held magnetometers are limited to detecting ferrous items only.

- Hand-held electromagnetic induction metal detectors' depth of detection capabilities are related to the size of the coils (typically small) and transmitter power (typically low) which cause hand-held systems to typically have a shallower maximum depth of detection.

(2) Digital Geophysical Tools. This family of detectors includes all geophysical tools capable of recording and geo-referencing geophysical measurements and includes all land borne, airborne and marine detectors.

(a) Digital Geophysical Surveys. Most magnetic and electromagnetic instruments have the capability to output a digital signal to a data logger that can be co-registered with positional information to develop a two-dimensional map of the characteristic that the instrument is measuring. Digital geophysical surveys are able to capitalize on the use of sensors with higher sensitivity, application of noise reduction techniques, and advanced data-analysis techniques. Advantages of digital geophysical surveys include:

- Uniform process for data collection and analysis.
- Geo-referenced location of data and anomalies.
- Removes operator subjectivity (to place or not to place a flag).
- Ability to further evaluate electronic data.
- Permanent electronic record.
- Ability to define rigorous QC measures that are capable of detecting all/most possible failure modes for the geophysical survey.

(b) Challenges for performing digital geophysical mapping include:

- Decreased effectiveness in high clutter areas.
- Vegetation and topographic constraints.
- Defining anomaly selection criteria that meet the project team's needs in terms of identifying all MEC while not selecting large numbers of non-MEC anomalies.

(3) Specific Types of Geophysical Instruments. Geophysical equipment can also be divided into two broad classes of instruments: passive and active. Passive instruments measure existing magnetic fields and the fluctuations within those fields. Passive instruments commonly used to detect MEC include all types of magnetometers. Active instruments

typically transmit an electromagnetic field and measure responses from the ground in the immediately vicinity of the detector. The active instruments most commonly used for MEC detection include electromagnetic induction metal detectors.

(a) Magnetometers. Magnetometers were one of the first tools used for locating buried munitions. Most military munitions contain iron (ferromagnetic metal). When these types of MEC are in the presence of the earth's magnetic field, a disturbance in the field is generated which magnetometers can detect. Some magnetometers use two magnetic sensors (called gradiometers) configured to measure the difference over a fixed distance of the magnetic field, rather than the absolute magnetic field. This configuration allows the gradiometer to perform with greater tolerance to cultural interference and improves detectability of some small MEC items. Since magnetometers respond to ferromagnetic metals, they will not be used to try to detect MEC that does not have a significant ferromagnetic metallic content. In addition, magnetometers are sensitive to many iron-bearing minerals and "hot-rocks" which sometimes cause a high "false-positive" count. Currently, two types of magnetometers are most often used to detect buried munitions.

- Fluxgate Magnetometers. Fluxgate magnetometers are inexpensive, reliable, rugged, and have low energy consumption. Fluxgate magnetometers have long been a standard of Explosive Ordnance Disposal (EOD) units as a quick, inexpensive field reconnaissance tool.

- Optically Pumped Magnetometers. Optically pumped magnetometers (common commercial types include the cesium-vapor and potassium-vapor magnetometers) utilize digital technology and are more expensive to purchase than fluxgate instruments. However, their high sensitivity, speed of operation, and high quality digital signal output make them a good choice for situations where digital data or digital post-processing is required. These magnetometers are often used in conjunction with proton precession magnetometers that provide information on the time varying changes in the Earth's magnetic field (diurnal variations) so that these changes can be removed from the magnetic field data. Proton precession magnetometers are less costly than optically pumped magnetometers and have less sensitivity and slower measurement rates but are suited for recording the relatively slow diurnal variations.

(b) Electromagnetic Induction Metal Detectors. Electromagnetic induction metal detectors work by either rapidly turning the current on and off or a sinusoidally varying current within a coil on the instrument. This varying current generates a changing primary magnetic field into the ground and induces electrical eddy currents in any nearby metallic objects. These currents then produce a secondary magnetic field that is measured by the instrument. They differ from magnetometers in that they are not limited to detecting ferrous items and can detect any conductive metal. In addition, electromagnetic induction metal detectors are usually less

affected by geologic sources than are magnetometers. There are numerous types of electromagnetic induction metal detectors available. However, two types are most commonly used in the search for MEC: time domain electromagnetic detectors (TDEMI) and frequency domain electromagnetic detectors (FDEMI).

- Time Domain Electromagnetics. TDEMI instruments work by pulsing an electrical signal in the transmitter coils which produces a primary magnetic field that induces an eddy current in the ground. The transmitting coil is turned off and the secondary magnetic field produced from the resulting eddy current decay is then measured at predefined times. The eddy current decays much more slowly in conductive targets (such as metallic items) than in resistive materials (most soils). Such instruments provide a capability to locate all types of metallic military munitions. Because the signal from the buried metallic objects is recorded during a time when the signal from the instrument is off and the signal from the geology is attenuated, TDEMI instruments are one of the more reliable methods of detecting buried metallic items.

- Frequency Domain Electromagnetics (FDEMI). FDEMI instruments work by transmitting a sinusoidally varying electro-magnetic signal at one or more frequencies through a transmitter coil. A separate receiver coil measures a signal that is a function of the primary signal and the induced currents in the subsurface. Depending on the size of the instrument and the frequencies generated, the system can detect metallic objects at varying depths and sizes. Because the signal from the buried metallic objects are recorded during a time when the primary signal is still on, these instruments measure the induced currents in the subsurface metallic objects differently than the TDEMI instruments. FDEMI instruments measure differences in the phase and amplitude between the received signal and the transmitted signal. The presence of subsurface metallic items will result in changes in the measured parameters. The depth at which FDEMI instruments can detect metallic objects is dependent on antenna loop size and transmitter power. However, if careful measurements are made at multiple frequencies, this information can often provide diagnostic information on the type of buried metallic objects as well as the size of the object. Most commercial coin detectors are FDEMI instruments.

Table 8-1. Geophysical Detection Technologies (as of January 2007)

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Flux-Gate Magnetometers	**Medium:** Have been used as the primary detector in traditional Mag-and-flag and mag-and-dig operations. High industry familiarization. Detects ferrous objects only	**High:** Light and compact. Can be used in any traversable terrain. Widely available from a variety of sources	**Lower** than average on most terrain	Schonstedt 52-CX Schonstedt 72-CX Foerster FEREX 4.032 Ebinger MAGNEX 120 LW Vallon EL 1302D1 or 1303D Chicago Steel Tape (magna-trak 102)	Analog output not usually co-registered with positional data
Optically Pumped Magnetometers	**High:** Standard detector for digital magnetic data collection for MEC detection. High industry familiarization. Detects ferrous objects only	**Medium to High:** Relatively light and compact and can easily be used in open areas. Can be used in most traversable terrain. Widely available from a variety of sources. Processing and interpretation requires trained specialists. Discrimination	**Average** in typical terrain. Much below average when arrays of multiple detectors are used	Geometrics G-858 Geometrics G-822 Scintrex Smart Mag Gem Systems GSMP-40	Digital signal should be co-registered with positional data for best results.

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
		possibilities are limited to magnetic susceptibility/magnetic moment estimates and depth estimates. Detection capabilities are negatively influenced by iron-bearing soils.			
Cryogenic Magnetometers	**High:** Research instrument that has promise for improving detection depth. Low industry familiarization. Detects ferrous objects only.	**Low:** Research instrument currently undergoing testing and modifications and only useful in open, level terrain. Minimal availability, still requires validation testing before being implemented on MEC field surveys.	**Much Higher** than average. Very low availability.		Limited Commercially Available
TDEMI Metal Detectors	**High:** Standard detector for EM. High industry familiarization. Detects both ferrous and non-ferrous metallic objects.	**Medium to High:** Typically utilizes one meter wide by 0.5 meter or one meter for transmitter and receiver coils, but alternate sizes are available. Can be used in most traversable terrain. Most commonly used instrument is widely available. Processing and interpretation are relatively straight forward. Discrimination possibilities exist for multi-	**Average** in typical terrain. Below average when arrays of multiple detectors are used	Geonics EM61 Geonics EM 61-hh Geonics EM61-MK2 Geonics EM63 G-tek/GAP TM5-EMU Vallon VMH3 Schiebel AN PSS-12	Digital signal should be co-registered with positional data for best results. Detection depths are highly dependent on coil size(number of turns and wire resistance are important), and

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
		channel systems			transmitter power.
Frequency-Domain Electromagnetic Induction Metal Detectors	**Low-Medium:** These systems have not been the primary detector in any highly-ranked MEC detection systems. However, experience demonstrates capability of detecting small items and potential for improved discrimination information with multi-frequency digital units. Not good for detecting deeply buried, single items. High industry familiarization. Detects both ferrous and non-ferrous metallic objects.	**High:** Hand-held detectors are light and compact. Can be used in any traversable terrain. Widely available from a variety of sources. Discrimination possibilities exist among some multi-channel systems.	**Lower** than average cost in typical terrain, with the exception of the Geophex GEM3 which is Average.	White's All Metals Detector Fisher 1266X Garrett Geophex GEM3 Foerster Minex Minelabs Explorer II	Analog output not usually co-registered with positional data Digital output should be co-registered with positional data.
Sub Audio Magnetics	**Medium:** Detects both ferrous and non-ferrous metallic objects. Capable tool for detection of deep MEC. Detects deepest MEC. Low industry familiarization	**Low:** High data processing requirements. Available from one source. High power requirements. Longer than average setup times.	**Higher** than average. Very low availability.	GAP Geophysics PTY - SAM	Not Commercially Available

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Magnetometer-Electromagnetic Detection Dual Sensor Systems	**Higher:** Detects both ferrous and non-ferrous metallic objects. Medium industry familiarization. Higher potential for discrimination.	**Medium:** High data processing requirements. Available from few sources.	**Higher** than average. Lower costs using a towed array platform.	ERDC EM61HH & G-822 SAIC STOLS / VSEMS (vehicular) SAIC MSEMS (man-portable)	Not Commercially Available Available still under development
Marine Side-Scan Sonar	**Low:** Visualizes shapes of both metallic and non-metallic objects. Only detects items on surface of water body floor. Medium Low industry familiarization	**Medium:** Requires boat, trained operator, experienced field drivercrew, low vegetatiocalm water may be needed n Vegetation can hinder acoustic signal propagation	**Average** for marine investigations	Klein 5500, EdgeTech DF-1000, Triton Elics Sonar Suite, GeoAcoustics, Fishers SSS-100K/600K, Marine Sonic Technologies,	Few have applied these technologies to the UXO problem.
Airborne Multi- or Hyper- spectral Imagery and Infrared Sensors	**Low to Medium:** Detects both metallic and non-metallic objects. Only detects largest MEC. Requires line of sight. Low industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with	**Medium:** Requires aircraft and an experienced pilot. Substantial data processing and management requirements. Available from few sources.	**Low-Medium per acre** when surveying large areas (>500 acres). Aircraft and maintenance costs. Processing		Active area of growth for application to the UXO problem.

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
	other airborne technologies		costs.		
Airborne Synthetic Aperture Radar	**Low:** Detects large surface metallic objects. Requires line of sight. Medium industry familiarization	**Low:** Requires a specialized aircraft and an experienced pilot. Unique and substantial data processing and management requirements. Available from very few sources.	**Higher** than average due to aircraft operation and maintenance costs and data processing and validation costs.		Few have applied these technologies to the UXO problem.
Airborne LIDAR	**Low to High:** Detects both metallic and non-metallic large surface objects. High industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with other airborne technologies.	**Medium:** Requires aircraft and an experienced pilot. Substantial data processing and management requirements. Available from increasing number of sources.	**Low-Medium per acre** when surveying large areas (>500 acres). aircraft and maintenance costs. Processing costs.		Active area of growth for application to the UXO problem.

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Ground Penetrating Radar	**Low:** Many mine detection systems use ground penetrating radar as one detector, however, has very low never successful success rates as a stand-alone MEC detection system. Detects both metallic and non-metallic objects. Susceptible to variable environmental/geological conditions. Medium industry familiarization.	**Low:** Large, bulky, Requires trained operator and is slow to operate. Difficult to use in any but the easiest terrain. Widely available from a variety of sources.	**Higher** than average. Systems are slow. and Required survey coverage is expensive	GSSI, SIR2, SIR3, SIR8, SIR10 Software and Sensors and Software RAMAC	Data output is usually viewed in either transects, not maps

Note: Data positioning is a significant factor that can substantially affect the success of any geophysical technology. The effectiveness and implementability of data positioning technologies must also be considered when evaluating a geophysical technology.

8-4. Positioning and Navigation Techniques.

a. The precision, and often the accuracy, of measured geophysical data positions are critical components of the geophysics products. Because the ultimate goal of magnetometer and EM surveys is to reproduce the actual potential field that exists over a given site, the success of the surveys relies heavily on how well the geophysical system can accurately and precisely locate where each measurement was actually taken.

b. We define *precision* as how well a positioning system can register where one measurement was taken with respect to all other neighboring measurements that were taken (see figure below). We define *accuracy* as how well a positioning system can register where measurements were taken with respect to a geographic coordinate system. This term is used to define how close reported coordinates are to the actual, physical locations on the earth where the measurements were taken. In most cases, the terms precision and accuracy need not be differentiated, and only the term accuracy need be used. However, there could be some cases, for example during site characterizations, where the accuracy of a group of measurements is not critical to a project's objectives, but where their precision is.

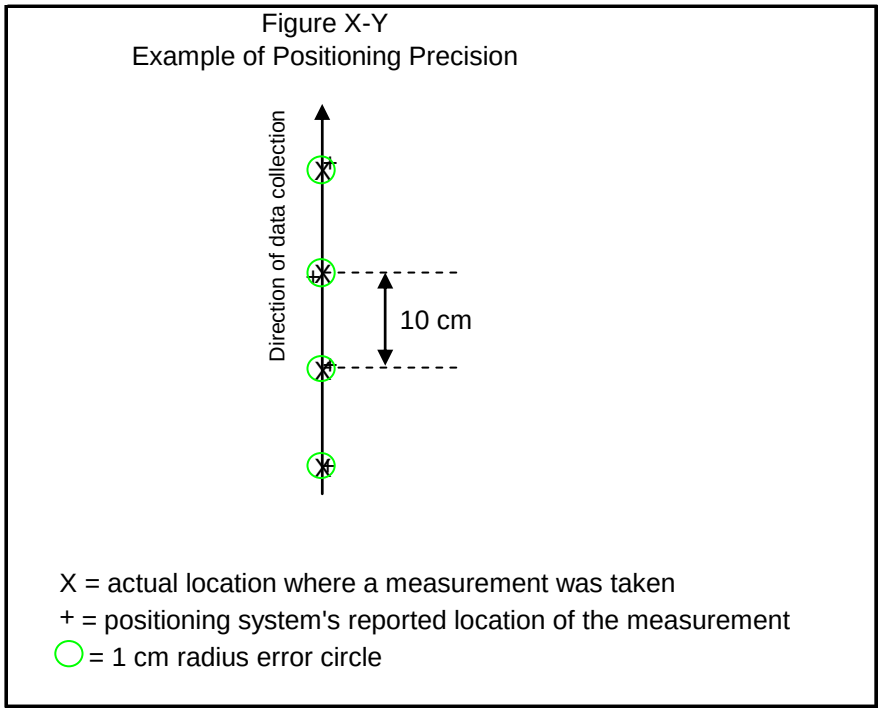

Figure 8.1: Example of Positioning Precision

c. There are three levels of accuracy needed for Geophysics to support the MMRP program:

(1) Screening level to determine areas of interest as implemented by airborne sensors or characterization efforts by ground based sensors by corridors, transects or meandering pathways. Typical accuracies will be sub-meter to tens of meters.

(2) Area mapping as performed by man portable and towed arrays. Typical accuracies will be sub-meter to several decimeters.

(3) Interrogation where highly accurate dense data is acquired to interrogate and then by post processing the accurate layered data, discriminate a previously located target anomaly. Typical accuracies will be centimeter to sub-decimeter.

d. The remainder of this sub-chapter describes various positioning options for geophysical surveys.

(1) Line and Fiducial. Line and fiducial (also referred to as line and station, conventional positioning, or straight-line profiling) positioning is the simplest form of geophysical data positioning, and has been in use for the longest period of time. The premise of line and fiducial positioning is that the geophysical instruments are operated in straight lines between fixed, known locations. Often, a rectangular coordinate system is used to define a local Cartesian coordinate system over a given area. These areas are usually called grids, and each grid is uniquely identified. The normal convention is to assign Cartesian coordinates of zero east (or zero "x") and zero north (or zero "y") to the southwesternmost corner of a grid. Grid dimensions can be tens of meters to several hundred meters on a side. The geophysical measurement positions in the grid are calculated by collecting data in a straight line from one known location in the grid to another known location in the grid. Most often, fiberglass measuring tapes are stretched along either the southern and northern edges of the grid, or along the western and eastern edges of the grid, from one grid corner to the next. In this manner, the distance gradations on the fiberglass tapes provide the known locations along the grid boundaries, and the geophysical operator can traverse the grid from one known point to another with relative ease. As the operator traverses the grid to collect data, the geophysical instrumentation is setup to either collect data at regular intervals in time (time-based triggering), or at regular intervals in distance by use of an odometer trigger (distance-based triggering). Note that these are triggering mechanisms <u>only</u>, and are used to cause the instruments to take and record a measurement. Common time-based triggering intervals are 0.1 sec (10Hz measurement rate) and common distance triggering intervals are 20cm. The data logging system is configured to capture the starting location, the direction of travel, the measurement triggering parameters and any other instrument-specific information that is needed to calculate positions of individual geophysical measurements that are recorded. Since the distance traveled along each survey line is known, all measurements recorded along a linear

segment can be equally spaced between the known points between which the data were collected. Often, intermediate known points, or fiducial marker lines, will also be established within a grid by stretching additional fiberglass measuring tapes parallel to, and at equal intervals between, the fiberglass tapes placed along the grid's boundary. These intermediate markers are used by the operators to help maintain straight survey lines and to allow them to make "fiducial marks" at known points within the data stream. Data that is "marked" with a fiducial mark (often a special character appearing in a marker column within the data stream) signifies the sensor was at a known location at the time that measurement was made. Figure 8-2 illustrates a grid setup over a 50m by 50m area. In this example, there is one intermediate fiducial line setup between the southern and northern grid boundaries, and data is to be collected along parallel, north and south oriented lines. The arrows along the lines indicate the planned direction of travel along each line.

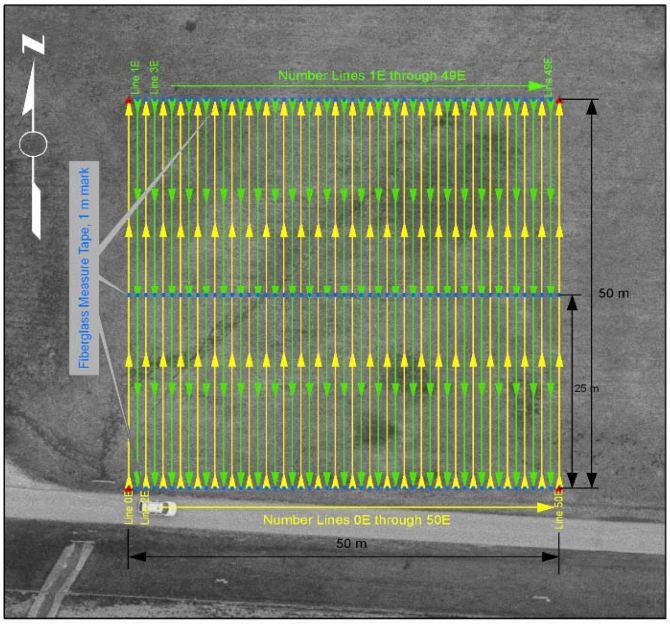

Figure 8-2: Line and Fiducial Grid Setup

(a) Referring to the figure above, data is collected in the following manner:

- The operator aligns the equipment along the line to be traversed and enters line specific coordinate and triggering information into the data logger.

- The operator places the sensor directly over the marker along the grid boundary and begins collecting data along the line immediately as he/she begins moving. Or, the operator places the sensor outside of the area to be surveyed and begins moving along the line to be traversed. As the sensor crosses over the grid boundary, the operator immediately begins data collection.

- The operator maintains a straight line traverse along the line to be surveyed, and uses a toggle switch or other momentary switch to enter fiducial marks when the sensor moves directly over a fiducial line. If a time-based triggering system is being used, the operator must maintain a constant pace between all known locations (i.e. between the start of line location and the first fiducial mark, the first and next fiducial mark, etc., and the last fiducial mark and the end of line location. If distance-based triggering is being used, then the operator need not maintain a constant pace, but he/she must maintain forward travel at all times.

- When the sensor passes over the boundary that defines the end of the line, the operator immediately ceases collecting data.

(b) Figure 8-3 illustrates a typical data stream of EM61-MK2 data collected using distance-based triggering. This figure is provided to help the reader understand how data is collected, and what the collected data looks like when the line and fiducial method is used. In this example, the line number (e.g. Line 0) corresponds to the Easting, or x coordinate, along which data were collected. Data were collected in north-south directions.

(2) DGPS & RTK DGPS. 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. 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 characterization surveys, accuracy within 10 meters may be acceptable, while a more detailed investigation may have more demanding requirements.

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/Example Data Set
/Intrument: EM61-MK2
/Coordinate System: Local, units: feet
/Column Names follow:
/NORTH,EAST,STD-4-1,STD-4-2,STD-4-3,STD-4-4,TIME
LINE  0.00
      0.00       0.00      67.97      25.89      -1.21      -3.10  15:27:41.180
      0.66       0.00      70.69      32.47       6.74      -3.33  15:27:41.871
      1.32       0.00      78.41      38.75      12.41      -1.14  15:27:42.283
      1.98       0.00      94.97      49.79      17.93       1.66  15:27:42.642
        .          .         .          .          .          .     .
        .          .         .          .          .          .     .
        .          .         .          .          .          .     .
    162.96       0.00       4.14     -17.45     -23.32     -17.38  15:28:32.924
    163.65       0.00       5.87     -17.90     -24.07     -16.55  15:28:33.800
    164.32       0.00       6.47     -16.02     -22.79     -16.63  15:28:34.599
    165.00       0.00       7.90     -14.14     -20.99     -16.93  15:28:36.578
LINE  2.50
    165.00       2.50       8.02     -16.41     -23.82     -16.33  15:29:31.769
    164.32       2.50      12.85     -12.55     -21.40     -16.33  15:29:32.192
    163.64       2.50      18.75      -8.39     -19.58     -15.65  15:29:32.446
    162.97       2.50      23.44      -5.29     -18.30     -14.82  15:29:32.698
        .          .         .          .          .          .     .
        .          .         .          .          .          .     .
        .          .         .          .          .          .     .
      3.31       2.50     218.64     136.74      72.50      28.05  15:30:26.182
      2.65       2.50     187.37     114.18      61.60      21.81  15:30:26.434
      1.98       2.50     153.83      89.67      47.39      14.82  15:30:26.741
      1.33       2.50     126.84      69.96      33.55       9.33  15:30:27.033
      0.66       2.50     100.36      53.34      22.72       4.29  15:30:27.338
      0.00       2.50      80.51      38.52      12.41      -0.98  15:30:27.658
LINE  5.00
      0.00       5.00      18.51       6.75      -1.21      -0.91  15:32:04.485
      0.67       5.00      60.17      25.42       0.61      -4.10  15:32:04.964
      1.33       5.00      77.43      36.44       9.79      -1.97  15:32:05.389
      2.00       5.00      95.45      51.41      20.27       1.14  15:32:05.800
        .          .         .          .          .          .     .
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Figure 8-3: EM61-MK2 data stream

(a) Small hand-held units manufactured for recreational use are not acceptable for most 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. One exception to this is that these units can normally provide the needed accuracy for performing initial characterization work. When Selective Availability (SA) is not in use by the Department of Defense, these types of GPS units can achieve accuracies of approximately 10 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 3-5m.

(b) 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.

- Differential GPS makes use of the Carrier Phase that allows accuracies within 1-20 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). DGPS is the most accurate and common form of GPS surveying performed for MEC detection.

- 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 apply the differential correction to GPS data concurrently with the collection of field data. 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 1-10m 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.

- 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 improved accuracy but its capabilities have not been evaluated for the MMRP.

(c) 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:

- 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 (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.

- 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.

(d) 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.

- 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.

(3) Robotic Total Station, example is the Leica 1200. A Robotic Total Station (RTS) operates under a different concept than the other positioning systems. The RTS essentially is an automated laser survey station that derives its position from traditional survey methodology by determining the station coordinate position and orientation based upon reference to two existing known points establishing a baseline. The RTS tracks a prism attached to the geophysical sensor and computes the location. See figure 8-4. The robotic portion maintains track on the moving prism and records relative position and elevation in reference to the survey baseline. Dynamic positions may be recorded at several times a second.

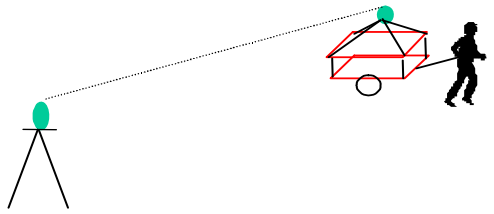

Figure 8-4: RTS Single point position tracking

(a) The technology must have constant line-of-sight from the single point RTS station to the roving prism. Position gaps must be interpolated with loss of line-of-sight. With the use of the appropriate firmware and operation procedures the RTS can maintain lock in moderate wooded areas by predicting the location of the sensor and then reacquiring it following the obstructions. The technology can provide sub-centimeter accuracy for static positioning in open areas. This precision gets diluted by interpolations for areas with loss of line-of-sight such as obstructions caused by tree trunks and branches. For visibility, the prism is generally on an extended pole above the geophysical sensor. Error can be introduced by sloped terrain where the sensor lean provides a variable offset in relation to the actual sensor location. A position accuracy of .07- .27 meters has been consistently demonstrated in field trials.

(4) Laser Fan Systems, example is the ArcSecond UXO *Constellation***.** This system uses the precision of laser measurements in a different way than the RTS. Rather than taking a range and angle measurement to the rover from the RTS instrument as referenced from an established baseline, the Laser Transmitter System takes angular measurements in reference to multiple laser transmitters or beacons. A scale factor is applied during setup by the system hardware, by reference to a known distance or by known points to establish distances and known points which are referenced to establish the coordinate reference. These angles are solved to the rover's geometric location and scales applied for coordinate positional output. Three dimensional position and in some configurations also attitude and orientation, are determined at up to 40 Hz. Generally four transmitters are set up around the perimeter of the work area. See Figure 8-5.

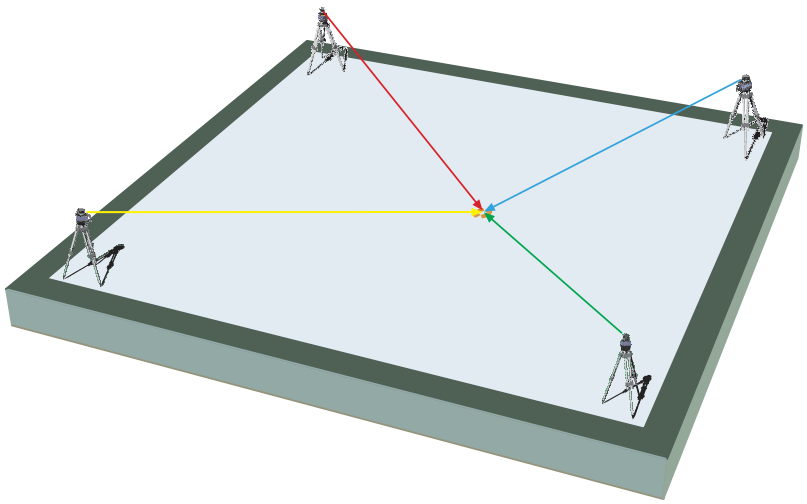

Figure 8-5: Laser Transmitter typical layout

(a) Since this system is laser based it requires line-of-sight for the rover but it is more accurate than the RTS in open and obstructed areas because of the high positional sampling rate and the redundancy of measurements from multiple transmitter locations. Like the RTS, three dimensional positions must be interpolated for times when the rover does not have visibility by two transmitters. Unlike the RTS, the rover is not affected by instrument lean. The system projects the position to the desired spatial instrument reference point. Some configurations also capture attitude and orientation to permit advanced geophysical sensor modeling which provides local high 3D accuracy for anomaly interrogation. A disadvantage is the additional hardware for the multiple transmitters and a maximum range with the external transmitter strobes of 100 m. A position accuracy of .01- .18 meters has been consistently demonstrated in field trials (average .01m interrogations, .04m area navigation & .11m as picked from the geophysics).

(5) Radio Frequency (RF), example is the ENSCO Ranger. The RF system exploits a unique direct sequence spread spectrum measuring system to provide precision geolocation and simultaneous data communications. Multiple base-station radios are used to measure their distance to one or more mobile radios. These multiple distance measurements can then be used to compute the coordinates of the mobile radios. Repeated, sequential distance measurements and coordinate computation enables tracking the mobile radio's path. This navigation system is directly integrated with a data logger and geophysical instrumentation. See Figure 8-6.

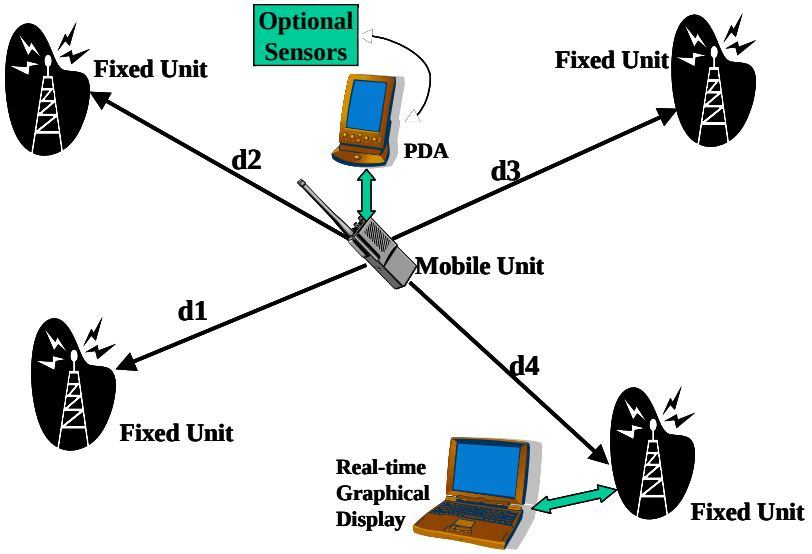

Figure 8-6: RF positioning system

(a) The RF system communications architecture is based on direct sequence spread spectrum (DSSS) in the 2.4 GHz Industrial, Scientific, and Medical (ISM) band. This allows the system to operate as unlicensed transmitters under FCC rules with a 1-watt transmit power. Core circuitry takes advantage of widely available and inexpensive components commonly used in 802.11b wireless network products. The key element of the system is the ability to accurately measure distance. Methods for using a DSSS radio for semi-precise time-of-flight measurement are well understood for coarse measurement. This system differs in that a fine measurement is made to estimate more precisely the time-of-arrival (and hence the distance traveled) of a signal. It is this fine measurement that provides the sub-meter accuracy.

(b) An improvement to this system is having the radio navigation system augmented with an inertial navigation system (INS). The INS systems use the *Ranger* (specific ENSCO instrument?) position as a starting point and the INS to acquire a high accuracy relative position

for 3D instrument tracking. A position accuracy of .17-.57 meters, similar to dynamic DGPS, was demonstrated for *Range*r. The INS enhancement for the interrogation areas has demonstrated a relative position accuracy of .03-.05 meters.

(6) Acoustic. Example system is the Ultrasonic Ranging and Data System (USRADS). This navigation system utilizes ultrasonic techniques to determine the location of a geophysical instrument each second. It consists of three basic elements: a Data Pack, up to 15 Stationary Receivers (SRs) and a Master Receiver. The Data Pack is mounted on the geophysical sensor back pack with the ultrasonic transducer mounted approximately 1 meter above the sensor. The Data Pack fires the transducer and by monitoring the time-of-flight the location of the geophysical sensor can be determined. The SRs are placed throughout the survey area with about 9 required per acre. A minimum of two are required to be on known points. The system software automatically determines the locations of the SRs by utilizing the time-of-flight information between all SRs. Finally, the Master Receiver and laptop computer acts as the master timer between the components, as the data processor and as the data collector. The computer computes the sensor position location and displays the survey data. Position accuracy of 0.15 m is expected with proper SRs distributed at up to a 150' spacing.

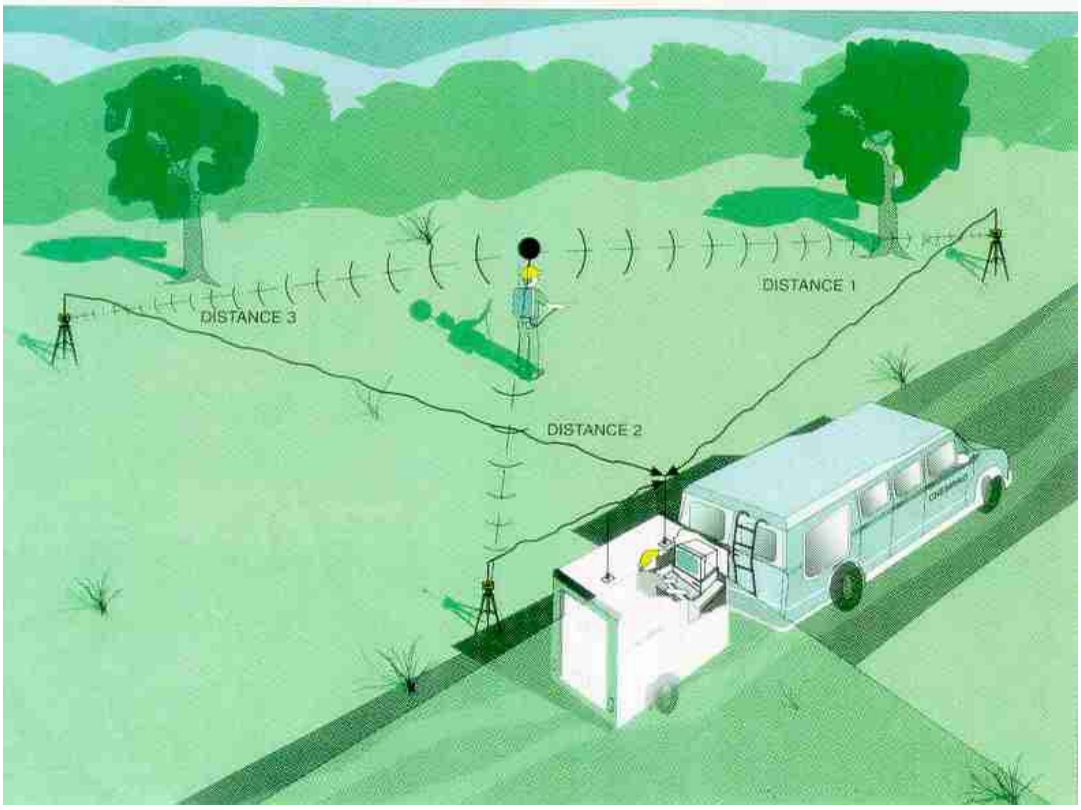

Figure 8-6: Acoustic

(7) Other Geophysical Systems Positioning Components Some geophysical systems incorporate additional equipment to improve positioning accuracies. These include digital tilt meters to record roll and pitch of sensor platforms and digital or gyro compasses to record platform bearing.

8-5. Geophysical System Deployment Platforms. Geophysical instruments can be deployed using various platforms in order to collect data in the most efficient manner over a particular project property.

a. Man-Portable Systems. Many geophysical instruments can be deployed using individuals to carry or pull the equipment across the survey area.

Figure 8-7

b. Multiple Instrument Arrays. In cases where a particular geophysical instrument provides good detection results and the terrain permitting, several sensors can be joined in an array that is pulled behind a vehicle to achieve greater data density and greater production rates than possible with a single sensor system. However, due to access and mobility limitations, such arrays are generally limited to large, open areas with relatively flat terrain.

Figure 8-8

c. Airborne Systems. Recent developments in sensor technology, computers, and navigation techniques have led to the effective use of airborne techniques for geophysical surveys at MRAs. Successful airborne techniques have included magnetic, electromagnetic, and Light Detection and Ranging (LIDAR) surveys. Potential airborne techniques include infrared, hyperspectral imaging and synthetic aperture radar but require further validation testing using both helicopter and fixed-wing platforms. Airborne surveys have the potential to achieve greater data density and production rates than possible with ground-based systems. However, due to access and site-specific requirements, airborne surveys are generally limited to large open areas and relatively large MEC targets, because the increased distance from the targets to the sensor reduces the ability to detect smaller objects. At project properties where large areas exist that allow the platform to fly close to the ground (i.e. grasslands or agricultural areas), airborne systems can provide a method for footprint analysis to identify the high MEC density areas or the location of large items.

Figure 8-9

d. Underwater Systems. Recent developments in sensor technology, computers, and navigation techniques have also led to the effective use of geophysical surveying for UXO in shallow marine environments. The surveys have included magnetic, electromagnetic and side scan sonar methods.

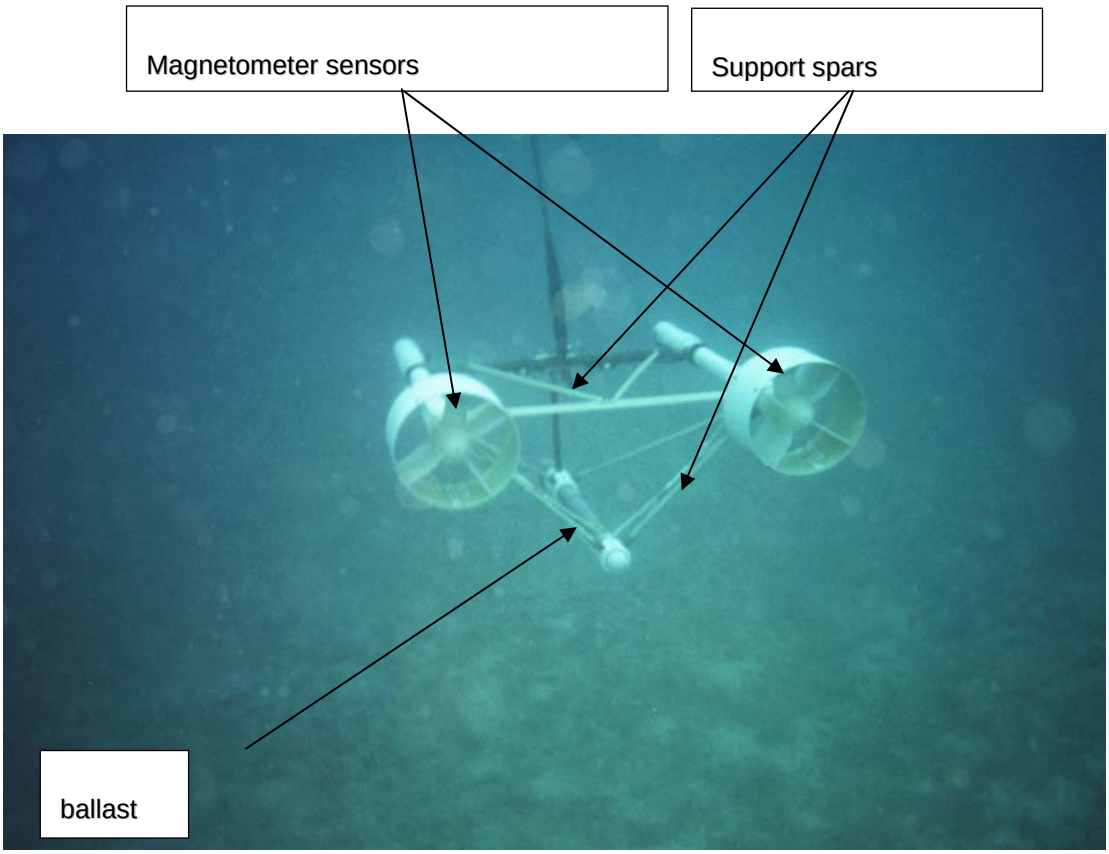

Figure 8-10

8-6. Anomaly Selection Criteria and Anomaly Prioritization. Geophysical systems produce data that offer several advantages in how a PDT can design criteria for detecting anomalies and analyzing the characteristics of those anomalies to decide whether or not they should be placed on dig lists. Using their characteristics as the basis, anomalies can further be categorized between "more likely to be associated with MEC" and "less likely to be associated with MEC". In some cases, it is possible to categorize an anomaly as "Not likely to be MEC". Depending on how an anomaly is categorized, a decision can be made as to whether or not the PDT should proceed and excavate that anomaly. These types of decisions are normally described in detail in anomaly prioritization plans, also referred to as "prioritizing anomalies", "anomaly prioritization" or "anomaly ranking". We use the term anomaly prioritization in this sub-section. It should be noted that the concept of anomaly prioritization is often captured within the framework of how anomalies are detected and selected onto dig lists, and an anomaly prioritization plan may not needed. We first discuss how anomalies are detected and selected

for intrusive investigation, we then discuss how anomaly prioritization methods are developed and used.

a. Anomaly Characteristics. A geophysical anomaly is defined as geophysical measurement(s) that are distinguishable from nearby background measurements. Quantifiable anomaly characteristics are limited to digital geophysical mapping systems and some analog systems that provide a digital readout of the instrument's measurements. Quantifiable characteristics are identified below. All other systems offer only the ability to use qualitative characteristics to detect and select anomalies. We use the terms "anomaly detection" and "anomaly selection" independently, though in some systems, and in particular analog systems, these two actions occur simultaneously. Anomaly detection is used in reference to how above-background measurements (anomalies) are identified. The term anomaly selection is used in reference to how above-background measurements are selected onto dig lists or otherwise selected for intrusive investigation (such as in mag and dig operations.)

(1) Detecting and selecting anomalies with analog systems. Analog systems used in audio mode or by monitoring meter deflections only offer the ability to discern relative size and relative signal strength. An experienced operator can sometimes use these characteristics to estimate source depth and source size, but such estimates are subjective in nature. Often the option for selecting or rejecting anomalies detected with these devices is limited to rejecting only those anomalies with very small spatial extent (small size) and high signal strength characteristics. Such anomalies are expected to be associated with small near-surface metallic sources because the strength is high (if the small piece of metal were deep, the strength would be much less) and the spatial extend is small (if the source were a large piece of metal, the spatial extent would be large). If small MEC are a target objective, this approach would not be valid. Due to their inherent limitations, analog systems do not offer any additional options for differentiating MEC from non-MEC anomaly sources based on anomaly characteristics. All claims made by Contractors or field personnel regarding their ability to discriminate MEC-like anomalies from non-MEC anomalies should be demonstrated on the GPO and accepted by the project's Government geophysicist.

(2) Detecting anomalies from DGM data. Digital mapping systems offer the ability to quantify the following anomaly characteristics:

(a) Anomaly peak response for all channels of data recorded

(b) Spatial extent (area) of above-background measurements

(c) Estimated target depth

(d) Estimated signal to noise ratio based on all above-background measurements (also referred to as the anomaly power SNR)

(e) Estimated magnetic moment (for magnetometer systems)

(f) Estimated time-constant and related decay-curve characteristics (for TDEMI systems)

(g) Estimated conductivity and susceptibility (FDEMI)

(h) Estimated shape parameters

(i) Estimated location of the item's center

(j) Estimated weight

(k) Estimated remanence (for magnetometer systems)

(l) One or more of these characteristics are used to distinguish whether the characteristic values for one measurement or a group of two or more contiguous measurements are distinguishable from other surrounding measurements. This process is often automated using tools such as the automatic anomaly picking tool available in Geosoft's UXDetect.

(3) Selecting DGM anomalies onto dig lists. The most common approach to select anomalies is referred to as "threshold picking". Often these approaches are applied in a simple manner and base anomaly selections from a single channel of data, and are performed using the automated tools described above. This approach is not recommended unless supported by project needs. Recommended approaches will use either more sophisticated methods to detect and select anomalies, or a phased approach to first detect above-background measurements and then quantify one or more anomaly characteristics to select anomalies onto dig lists based on multiple criteria. In all cases, the methodology for detecting and selecting anomalies should be completely documented and reviewed by Government geophysicists for compliance with PDT needs and project objectives. Listed below are common issues to consider when developing methods for selecting DGM anomalies onto dig lists.

(a) Factor for measurement variability. Many selection criteria are initially based on GPO data, which can not capture all possible burial scenarios. It is also known that there is a high degree of variability in responses from different MEC of the same model when buried in the same orientation and at the same depth. Therefore, anomaly selection criteria may require a degree of conservatism be included in their definitions.

(b) Factor for variability in how data may be collected. Many selection criteria are based on GPO data collected under conditions that will differ from those encountered on-site. It is critical that the manner in which anomaly characteristics are defined factor for slight variations in data quality such as: changes in instrument height, changes in survey speeds, variations in coverage densities, variations in background levels, and changes in filtering/leveling parameters that are used. The goal is to demonstrate the field data is of the same quality, and

was collected and processed using the same parameters as the data used to define the anomaly selection criteria. Normally, the quality control plan will include tests to confirm these parameters in field datasets do not vary significantly from those of the datasets used to define the anomaly selection criteria.

(c) Identify critical characteristics or combinations of characteristics that will require placing an anomaly on a dig list. For example, estimated shape parameter or estimated time constant (for TDEMI systems) alone will normally not be critical characteristics, whereas the combination of peak response value and spatial extent would be a critical combination for selecting anomalies onto dig lists.

b. Defining and Using Anomaly Prioritization Methods. One of the greatest challenges on many MEC projects is differentiating anomalies associated with MEC from those not associated with MEC, in particular small pieces of fragments from functioned ordnance. One of the tools available to the PDT in this regard is the use of anomaly prioritization methods. Anomaly prioritization methods are developed in response to the need to minimize project costs and minimize schedule impacts and disruptions to local stakeholders and area residents. Anomaly prioritization plans will make use of one or more of the following prioritization tools:

(1) Anomaly characteristics,

(2) Statistical information,

(3) Anomaly dig results,

(4) Previous investigation data, and

(5) Historical information

(6) These tools are used to provide justifications and explanations for not excavating all anomalies that may meet one or more non-critical characteristic criteria (see example in last bullet item above for definition and explanation of critical characteristic criteria). Basically, when anomaly selection criteria are defined, certain assumptions are attached to those criteria because it is not technically feasible to unambiguously define each MEC anomaly characteristic for each scenario (item condition, item depth and orientation, local clutter, geology variations, etc.) on an individual project site. The solution is to define selection criteria that are conservative enough to reliably select MEC anomalies onto dig lists. Most solutions also include selecting small to medium quantities, typically between 5% to 20%, of these anomalies that otherwise would not be selected onto dig lists as a measure of continuous checking the assumptions used in developing the anomaly selection criteria. Some example prioritization plans are presented below.

(7) **Example 1:** Excavation project, target MEC is 60mm and larger. Characterization data indicate MEC is located from the surface to 0.3m depth. DGM system is demonstrated to reliably detect all target MEC to a depth of 0.7m, and some MEC in certain orientations are detected to a depth of 1.2m. Criteria for anomaly characteristics are defined for peak response value for an aggregate of all channels of data, anomaly SNR, and anomaly spatial size. The table below provides an example summary of how anomaly characteristic criteria can be defined. The anomaly prioritization plan is outlined below:

(a) All anomalies meeting all selection criteria will be placed on dig lists

(b) All anomalies meeting both the SNR and size criteria will be placed on dig lists

(c) For anomalies located around target locations, 20% of those not meeting the above criteria but which have characteristics in the range of target objectives at 1.2m depth will be selected onto dig lists. Only those anomalies meeting all three criteria will be selected. If MEC are found in this group of anomalies, the remaining 80% will be evaluated against the new criteria.

(d) For anomalies located outside target locations, 15% of those not meeting the above criteria but which have characteristics in the range of target objectives at 1.2m depth will be selected onto dig lists. Only those anomalies meeting all three criteria will be selected. If no MEC are found in this group of anomalies after a statistically representative number have been investigated, the percentage of these investigated anomalies will be adjusted down with PDT concurrence. If MEC are found, the selection criteria will be adjusted using the characteristics of the MEC anomalies found. The percentage investigated may also be adjusted up with PDT concurrence.

Table 8.2: Example GPO Results and Anomaly Selection Criteria (Prioritization Example #1)

Burial Conditions	Anomlay Characteristics	Minimum values measured above background	Maximum values measured above background
Target objectives at 0.7m	Peak response (sum of all channels)	17mV	155mV
	SNR	32	420
	Size	1.5 m^2	1.9 m^2
Target objectives at 1.2m	Peak response (sum of all channels)	7mV	55mV
	SNR	4	175
	Size	.9 m^2	1.3 m^2
Target objectives at 0.3m	Peak response (sum of all channels)	750mV	2200mV
	SNR	1600	4750
	Size	2.1 m^2	2.7 m^2
Small clutter items, various depths	Peak response (sum of all channels)	8mV	88mV
	SNR	2.5	210
	Size	.7 m^2	1.65 m^2
Anomaly Selection Criteria (based on 75% of values from target objectives buried at 0.7m)	Peak response (sum of all channels)	19mV	
	SNR	24	
	Size	1.1 m^2	

(8) **Example 2:** Characterization project, target MEC is 40mm projectile and larger, to a size of 155mm. Expected MEC depths are not known. DGM system is demonstrated to reliably detect all target MEC to a depth of 0.3m, and some MEC in certain orientations are detected to a depth of 1.5m. Criteria for anomaly characteristics are defined for peak response values for two channels of data. The figure below illustrates the logic in assigning anomaly priorities based on the two channels of data, whether all channels were above background or not, and whether one or both channels were in the range of values detected in the GPO. The anomaly prioritization plan that was utilized is outlined below:

(a) Place all rank 1a anomalies on dig lists

(b) Place 50% of rank 1b anomalies on dig lists

(c) Place 15% of rank 2 anomalies on dig lists

(d) Place 10% of rank 3 anomalies on dig lists

(e) If a rank 2 or rank 3 anomaly produces MEC, revise criteria in concurrence with PDT.

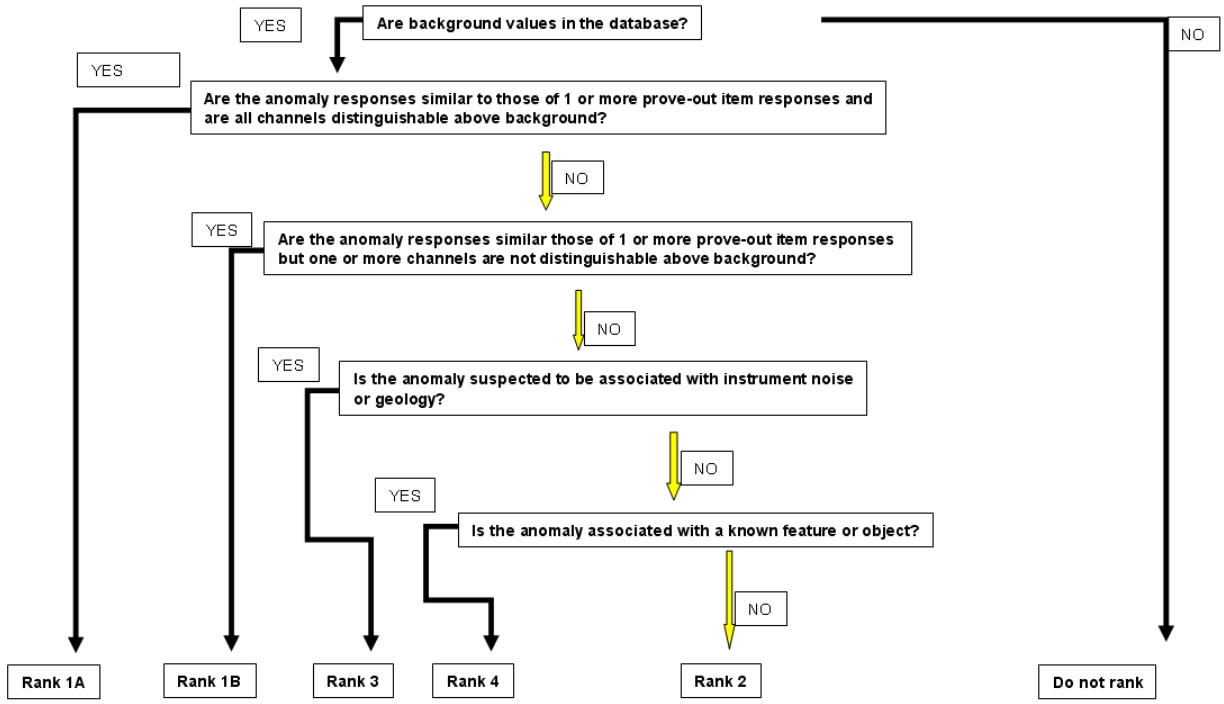

Figure 8-11: Prioritization Example #2

8-7. Anomaly Resolution. The term anomaly resolution is used in reference to all activities related to reacquiring previously detected anomalies and/or excavating anomalies to the point they are unambiguously explained. There are two key aspects to anomaly resolution, anomaly reacquisition and anomaly excavation, which also include reporting dig results.

a. Anomaly Reacquisition. Anomaly reacquisition is a critical element of DGM systems because this task must physically match anomalies on dig lists with their sources. This is achieved by using a method to navigate to the selected location, reproducing a signal at that location and placing a plastic pin flag and/or painting the ground surface above the reacquired source. The challenge is in matching selected anomalies with their true sources because those sources are often buried or otherwise obscured from view. In cases where an anomaly being sought has no other nearby anomalies or other sources of interference, and the anomaly has a high SNR, this task can be fairly straight forward and have little likelihood of reacquiring the wrong source. In other circumstances, reacquiring the originally interpreted anomaly will be difficult and reacquisition procedures will need to be explained in great detail. The following are critical factors to consider in planning and performing anomaly reacquisition procedures. All procedures should be demonstrated in the GPO, including simulated failure scenarios.

(1) **What is the accuracy of the reported dig list coordinates and what is the accuracy of the navigation system used to reacquire those points? What is the allowable distance between reacquired location and interpreted location?** Often the sum of errors in the DGM positioning will be between 0.5m to 1.5m and the accuracy of navigation tools used to reacquire anomalies will typically be between 2cm and 30cm. The accuracy of the interpreted coordinates can be even greater when closely detected anomalies are aggregated together. Therefore, search radii for locating the true anomaly source must factor the sum of all potential positioning and reporting errors in interpreted anomaly locations.

(2) **If the reacquisition team will be able to reproduce the originally interpreted response, what are the tolerances for the reproduced response?** Anomalies detected in dynamic DGM surveys will often have detected amplitudes that are less than those observed during reacquisition. Further, if weaker signals are present in proximity to a selected anomaly location, criteria must be established to either flag all nearby anomalies regardless of reacquired amplitude, or reacquire all anomalies meeting project-specific criteria, typically peak amplitude. Criteria must also be established for minimum and maximum allowed signal strength of reacquired anomalies, any location where a source cannot be located within those criteria should be labeled as an ambiguous reacquisition result.

(3) **If the reacquisition team will not be able to reproduce the originally interpreted response, what measures are used to provide confidence the correct anomaly is actually reacquired? What will constitute an ambiguous reacquisition result and what procedures are in place to resolve such results?** Reacquisition procedures that use geophysical systems not having the same detection capabilities as those used to collect the original data must have

very specific procedures in place to prevent the wrong anomaly from being reacquired. Typical criteria to include in such procedures are: limits on how far a suspect source location can be placed from the originally interpreted location, requiring all detectable anomalies within the total error radius be flagged for excavation, that all dig results must be reviewed by the interpreting geophysicist or other designated geophysical personnel, that a percentage of all anomalies will be verified using the original geophysical system during post-excavation verification, and including the requirement to return to all ambiguous reacquisition results.

b. Excavation and Reporting. Anomaly excavation routines are covered under the intrusive operations section(s) of the work plan. This topic is included herein as it pertains to the meeting project objectives of unambiguously resolving geophysical anomalies. The disposition and final location details of each anomaly are normally recorded on the final dig sheets, which should be submitted to all PDT members in accordance with project needs and/or SOW/PWS requirements. The reported dig results should be reviewed by the interpreting geophysicist or other designated geophysical personnel, and those personnel must have authority to require additional reacquisition and/or excavation activities be performed for any and all anomalies having characteristics that are not unambiguously explained by the reported dig results. These reviews can include automated searches to compare reported findings with predetermined threshold criteria. For example, the dig team can be required to report an anomaly source as large (greater than 5 pounds or greater than 18 inches in length), medium (between 1 and 5 pounds or between 6 to 18 inches in length), or small (less than 1 pound or less than 6 inches in length). Automated routines can then be developed to compare those reported results to preset anomaly criteria of large (SNR greater than 500), medium (SNR between 50 and 500) or small (SNR less than 50). Tests where a match is not made between reported finding and anomaly characteristics would be flagged for further review by project geophysicists. Any combination of anomaly characteristics can be developed into any number of tests to compare dig results with various anomaly characteristics. Tools are available in Geosofts UXProcess for simplifying these tests. Relational databases are also good tools for automating these tests. Excavation reporting should be demonstrated during the GPO including simulated failure scenarios.

8-8. Special Considerations for Planning Geophysical Investigations.

a. Survey Coverage Considerations. Survey coverage issues will arise when competing project objectives are defined within the framework of the project's DQOs. As an example, survey coverage issues will arise in situations where a project objective to not disrupt protected or endangered species is stated, but complying with that objective restricts vegetation clearance and therefore limits or precludes geophysical mapping. Other situations will arise where accessibility is hindered by terrain conditions, cultural interferences, or other natural or manmade impediments. Another common conflict arises in resources required to meet some stated objectives, such as wanting *all* detected anomalies investigated during a characterization

project. Often the resources required and costs associated with such an objective will be very high, but the "value-added" to the characterization outcome would be minimal in doing so.

(1) Sometimes compromises can be reached, such as using less sensitive detectors that require less vegetation removal and therefore minimize impact to native or listed species, or using anomaly selection schemes that provide representative samples of each different anomaly type. Sometimes no compromise can be reached and either the areas in question will be left unmapped or the requisite steps will be taken to make all areas accessible to the mapping and response technologies.

(2) Issues impacting survey coverage should be identified as early as possible during planning phases. If none are immediately identified during planning, but the potential exists for such issues to arise, it may be beneficial for the project team to plan for such cases and include any such plans in the geophysical work plan. In the event compromise strategies are used, it is critical that all project team members completely understand the benefits and limitations of the compromise strategy in terms of what MEC will likely be detected, and what MEC may go undetected. The characterization and excavation needs listed in Geophysical Investigation Strategies can help in identifying and resolving survey coverage issues during project planning.

b. Managing False Positives, No Contacts, "Hot Rock" Contacts and Geology Contacts. Many geophysical instruments detect anomalies associated with geology and cultural features such as power lines. When such anomalies are repeatable they are usually associated with geologic sources, also referred to as "hot rocks". When the sources are not repeatable, or are detected with highly varying signal strengths they are usually associated with cultural features such as power lines, or vehicles passing by. In many cases, small MEC near the surface or large MEC buried deep can have anomaly characteristics similar to anomalies that could be associated with local geology. In other instances, MEC responses will almost never have responses similar to local geology, such as when power lines are present over or near a project site. Such anomalies can usually be interpreted as cultural interference, however, on occasion, these may manifest themselves in geophysical data with characteristics similar to MEC.

(1) For any project where the field teams may encounter any of these situations, the contractor should develop, and submit for Government concurrence, a plan for accepting and/or rejecting the reported findings for anomalies that have characteristics of geology/cultural features and MEC. Normally, such plans will be confined to managing low-amplitude and/or small spatial extent anomalies reported as false positives, no contacts or geology (hot rock). These types of anomalies are more prone to have response characteristics that could be associated with either a metallic source or some other noise source. This plan should define specific metrics for accepting or rejecting anomalies in this category, and the plan should identify quantity thresholds that will trigger a re-evaluation of the project methodologies to address increased, or unexpected high quantities of false positives and/or no contacts.

8-9. Geophysical System Capabilities and MEC Detection Capabilities. In this sub-section, we describe how MEC detection rates and detection depths are evaluated on a project-specific basis.

a. MEC "detectability" is dependant upon numerous factors, but the general rule is, the larger the MEC, the deeper it can be detected. Many factors must be considered when evaluating whether a given geophysical system or technique can detect a given MEC item at a specified burial depth. Factors that are specific to MEC items that affect how deep they can be detected include their length, diameter, surface area, volume, weight, and their 3D orientation with respect to the geophysical sensor when the sensor is passed over them. Factors of the geophysical systems that are relevant to the detection depths of MEC include, for EMI detectors, the physical size of the instrument's transmitter and receiver coils, the operating power of the transmitter coil, the sensitivity of the receiver(s), the measurement/sampling densities, the speed of the survey platform, the distance of the coils above the ground, and the geologic conditions and environmental conditions at the site. For magnetic detectors, the relevant factors are the sensitivity of the magnetometer, the measurement/sampling densities, the distance of the sensor(s) above the ground, and the geologic conditions and environmental conditions at the site. Lastly, a factor common to all geophysical surveys, both analog and digital, is how the criteria for anomaly selections are established. Often a trade-off must be made between the total number of anomalies that can be selected for excavation and the number of low-amplitude anomalies that can be selected which may be associated with smaller, deep-buried MEC if they occur on the project site. Often, the GPO is used to estimate how deep MEC can be detected under the site-specific geologic and environmental conditions.

b. For performance based contracts, the factors described above must be evaluated and, in most instances, written into the project execution plan and/or project quality management plan as part of the project's geophysics performance metrics.

c. When the types of MEC at a site are unknown, or are only suspected, and the PDT needs to establish initial minimum detection capability requirements, the generalized formula below can be used as a screening tool during geophysical system selections. However, it must be noted that this formula does not account for MEC item composition, weight or length, nor does it account for the item's burial orientation (i.e. pointing down, laying flat, etc.) or adverse geological or environmental conditions (i.e. ultra-mafic geology or MEC detection in urban environments.) This formula is based, in part, upon evaluations performed at JPG and at other locations, and only provides an initial estimate of how deeply MEC can be expected to be detected, provided the assumptions stipulated with the formula are valid.

Table 8-3: Simplified Expression for Estimating MEC Detection Depths Using Geophysical Techniques

Estimated Detection Depth (meters) = 11*diameter (mm)/1000
Assumptions: Item length is at least two times its diameter Item is not constructed of thin-walled metal Item is in a "worst-case" orientation with respect to the sensor (e.g. for EMI instruments, the item's long axis is co-planar with the system's coils) **Definitions:** Depth = actual depth to top of buried MEC, in meters. Diameter = diameter of minor axis of MEC, in millimeters. Length = length of major axis of MEC.

d. Actual detection capabilities encountered at the site will be different than those estimated by the formula above; any item not buried in a worst-case orientation should be detected at depths greater than those estimated by this formula. Also, items having lengths that are less than twice their diameter, or items manufactured with thin-walled metals, will only be reliably detected at depths that are shallower than those estimated by this formula. Conversely, items that are very long compared to their diameter, such as most rockets, or thick-walled items, such as some projectiles, will be reliably detected at depths that are greater than those estimated by this formula.

e. Penetration Depth Considerations. The maximum possible depth of MEC is an important consideration in the selection of an appropriate detection system. If MEC is intentionally buried, factors affecting burial depth may include type of soil, mechanical vs. hand-excavation, depth of water table, etc. If the munition was fired or dropped, then the depth of penetration can be estimated by considering soil type, munition type and weight, and impact velocity. There are many cases where MEC can penetrate deeper than geophysical systems can currently reliably detect. At such locations, it is possible that undetected MEC remains deeper than it can be detected. The topic of ordnance penetration is still under discussion in the MMRP community. For up-to-date information on this topic contact the MM CX. Figure 8-12 shows the depth of recovery for thousands of MEC items. The curve indicates that while the maximum depth of penetration of MEC will resemble the depth predicted in the penetration

analysis, the actual depth of penetration for most items is much lower. In fact, Figure 8-12 shows that most items were located less than two feet deep.

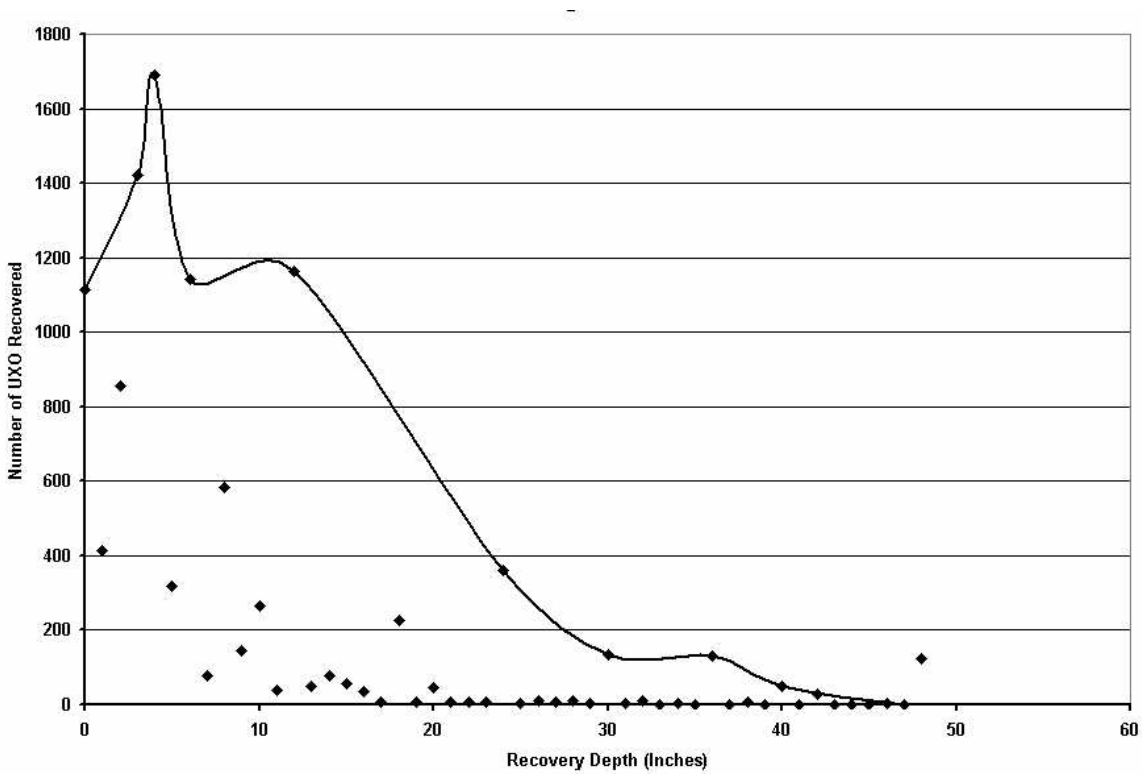

Figure 8-12: Actual Depth of Recovery of Fired UXO

Reference: UXO Recovery Database, NDCEE, 2003. Unexploded Ordnance (UXO) Task 307.

8-10. Digital Data Format and Storage and Coordinate Reporting.

There are two types of data typically generated during MEC investigations: geophysical mapping data and geographic information systems (GIS) data. Though geophysical data can be considered as geographic information, it is often not practical to treat all geophysical mapping data as GIS data. Specifically, the databases used to store and interpret geophysical measurements are designed to work with specialized geophysical processing and interpretation software and often are not easily reformatted to meet GIS storage and reporting standards, and rarely does the need arise to do so. However, geophysical maps and anomaly databases produced as the result of geophysical data interpretations are often key components to the project GIS, and these will often be produced according to the guidelines defined for the project GIS.

For project specific requirements, refer to the DID and/or PWS/SOW.

8-11. Geophysical Prove Out Planning. The following paragraphs describe the PDT's responsibilities during the geophysical system selection process or geophysical prove-out. The GPO can be a complex and time-consuming effort, the PDT must collaborate to confine the scope of the GPO to basic project needs.

a. GPO Purpose. There can be many purposes to a geophysical prove-out, as follows. It is necessary to state the prove-out objectives and to describe how these objectives will be met in the GPO Work Plan.

(1) Determine if a particular geophysical system will work at a particular site. There are geologic, terrain and other differences that can cause proven geophysical systems to not work at particular project properties.

(2) Determine the optimum geophysical system configuration and SOPs for a particular project property. All geophysical systems have inherent strengths and weaknesses. Very seldom will one instrument or system have the best absolute detection rate, the lowest false alarm rate, the highest production rate, and the lowest cost. Test plots provide information used to select an optimum geophysical system(s).

(3) Prove detection depth capabilities. This objective is not recommended, but is provided here in the event the PDT has no information on a particular MEC item that is uncommon in current MRS projects. The reason this is not recommended is that a large population of data from national test sites and other GPO sites are available, and the cost for such a test are generally prohibitive. A more reasonable objective would be to demonstrate that the system is meeting typical detection performance capabilities for a given target of interest, and/or that the project objectives, as stated by the PDT in the PWS/SOW, are technically feasible.

(4) Prove detection depths at which the probability of detection should be approximately one hundred percent for MEC items of a given size or grouping. This objective is not recommended, but is provided here in the event insufficient information on a particular MEC item is available to estimate depths at which probability of detection should be approximately one hundred percent. A more reasonable objective would be to demonstrate the system is meeting typical detection performance capabilities for a given target of interest. Normally, a buried MEC item must produce a geophysical anomaly with relatively high signal to noise ratios in order to be detected with high certainty. However, all magnetic and electromagnetic detection technologies measure potential fields whose magnitudes (or "strengths") are inversely proportional to the distance cubed (or more) between the sensor and the buried item. See Section 8.3 for more information on geophysical detection capabilities.

(5) Assure contractor compliance with the contract. Test plots provide a safe area for the geophysical investigation team to develop site-specific field and evaluation procedures necessary to demonstrate compliance with project requirements.

(6) Evaluate the PDT's data collection, data transfer method(s), and data transfer rates.

(7) Establish site-specific geophysical data needs and site-specific data quality measures and protocols for all work tasks involving geophysics and all work tasks that use geophysical data. The GPO provides the PDT the opportunity to describe how they define "good data." Elements that affect data usability will often focus on coverage, measurement densities (along-track and across-track measurement intervals), and accuracies or precisions of reported measurement locations. These elements often assume instrument function checks were successful. For example, based on GPO results, a response action designed to detect 81mm mortars in an open field may require 100% coverage of the site, that sensor line spacing be 0.8 meters (typical) and not exceed 1m, that along-track measurement intervals be 25cm (typical) and not exceed 80cm, and that positioning accuracy be 20cm (typical) and not exceed 30cm.

(8) Establish site-specific anomaly characteristics for selection criteria.

(9) Demonstrate anomaly resolution procedures to assure contractor SOPs will achieve both project requirements and quality control and quality assurance requirements. Many anomaly resolution procedures use geophysical systems with different detection capabilities, and the Contractor must demonstrate their SOPs account for such differences. See Section 8.2.5 for more information on the topic of anomaly resolution. GPO sites located outside of project boundaries are best suited to demonstrate all anomaly resolution procedures.

b. Factors in GPO Site Selection.. Selection of the GPO site(s) will be based upon the technical and site-specific considerations developed and finalized during the TPP process and/or PDT meetings. Factors to be considered include:

(1) Similarity of terrain, vegetation, and geologic conditions to actual field conditions.

(2) Proximity to the project property.

(3) Isolation from overhead power lines, radio transmitters, underground utilities, etc.

(4) Convenient access.

(5) Likelihood that area will remain undisturbed during period of use.

(6) Rights-of-Entry.

(7) Possibility of pre-existing buried MEC.

(8) Need to excavate known and/or unknown anomalies

c. Factors in GPO design.

(1) Pre-Seeding (Background) Geophysical Mapping. After a location has been selected and the surface prepared, a pre-seeding geophysical survey will be performed in order to determine and document base-line geophysical conditions at the location.

(2) Size and Configuration. Each plot is unique, but for project properties where a significant amount of geophysical mapping is anticipated, then a test plot of one-quarter acre to one acre in size and with 20 to 50 separate buried items, would be typical. For project properties with limited geophysical mapping, much smaller and less complex plots will be considered. Test plots need not be square; they can be any convenient shape. For projects where transect data collection is expected, the GPO should be configured to test this methodology, including turning points. It may be necessary to prepare more than one prove-out grid, mini-grid, or test strip if site conditions vary significantly.

(3) Survey Accuracy. The basic need is to determine the centroid of each item to high enough precision to test positioning accuracy. Survey accuracy of the test plot corners and of all items buried in the test plot will typically be to the nearest 3 cm as referenced to the control point(s) or reference point(s) used. Additional information may be required, such as position of nose and tail if advanced processing or discrimination is planned.

(4) Layout. Test plots will have items or areas designated as “known” items or areas. The geophysical mapping team will be provided all pertinent information about the known items or areas so they can optimize their equipment and procedures. Government PDT members can use items placed at locations unknown to the Contractor to independently evaluate Contractor procedures and claims.

(5) Seeded Items. A listing of probable military munitions to be seeded in the grid will be developed by the PDT. After the list is developed, sources of inert items will be determined. Any inert munitions used as seed items should be painted blue and tagged with a non-biodegradable label identifying the items as inert and providing a contract reference, a point of contact address, phone number, and a target identifier. It is preferable that inert ordnance or similar items be utilized in the GPO grid. However, due to the difficulty in locating and transporting such items it will often be necessary to manufacture surrogate items of approximately the same composition, size and shape for use in the test plot. If such surrogate items are used, it is necessary to demonstrate that each item is reproducing the geophysical characteristics of the actual munition(s) of interest, based on in-grid comparisons or references to signature libraries. In many cases, multiple types of military munitions have been utilized at an area and it will not be feasible to duplicate all of them. In such cases the geophysicist(s) and

UXO technician(s) will work together to determine when different types of military munitions may be consolidated into one class, or group, for GPO purposes.

(6) Depths and Orientation. The seed items will be buried at various depths and orientations. There is seldom a reason to bury the seed items excessively shallow or deep. Rather, the seed items will be buried at depths to demonstrate that the project objectives, as stated by the PDT in the PWS/SOW are technically feasible. The orientation of the item will also affect the instrument's ability to detect that item. In general, duplicate items will be buried in an East-West orientation, a North-South orientation, and an up-down orientation, at each depth studied. The number of seeded items will be sufficient to provide a representative sampling of probable munitions (type, orientation, condition, and depth). Generally, the number of seeded items placed in the GPO will not be sufficient to prove a probability of detection (Pd) of the geophysical survey instruments for all items at each of the various depths. The number of items needed to demonstrate the Pd of the geophysical systems for all MEC at all expected depths and orientations would be far too numerous, and the construction of the GPO far too expensive. The number, orientation, and depths of the seed items used in the GPO will be sufficient to characterize the capabilities and limitations of the proposed geophysical systems and to evaluate the ability of the proposed geophysical equipment to locate each type of MEC at the anticipated depths and orientations. After the seed items are buried, care will be taken to blend excavation locations back to natural conditions.

(7) In-Field Seed Item Depth Testing. In some circumstances, it may be beneficial to perform open-hole tests over seeded items before they are interred, the purpose being to confirm they are indeed detectable. For instance, if seed item response at some predetermined SNR is identified as a project need, open-hole tests are effective for confirming any particular deep buried items are at least detectable at those SNRs prior to interment. Signal to noise ratios are not expected to increase as a result of interment; rather, they are likely to remain the same or decrease. Other useful information is recording maximum response of seed items placed on the ground surface. For such tests, the seed items are placed along the ground surface and data collected over them when placed at both their "best" and "worst" orientations. For example, these orientations would be horizontal and vertical for horizontal-loop TDEMI detectors.

(8) Cultural Interference. Some field locations will have significant cultural interference. In such cases, consideration will be given to duplicating that interference in the test plot. Sources of this cultural interference could include proximity to buildings and power lines and/or cultural debris (metallic trash items).

(9) Munitions Debris Interference. At most impact areas there are many times more pieces of munitions debris (frag) than there are MEC. This frag often results in a serious degradation in the capability of the geophysical systems to detect MEC. In such cases, consideration will be given to duplicating the effects of frag in the test plot, either through the

use of artificially placed frag, or by the actual establishment of the test plot in an area containing frag.

(10) Data Collection Variables. It is important to collect and analyze test plot data using the same equipment, personnel and procedures that are planned for field use. Multiple geophysical surveys using each proposed geophysical instrument will be performed. When collecting data for a prove-out, the following elements are subject to modification and evaluation. It will not be necessary to evaluate every factor at every location. However, sufficient data should be collected to analyze changes in anomaly responses as functions of typical variability expected for each element as a result of differing site conditions. The PDT will determine the elements to be evaluated for a particular project:

(a) Instrument Height. The height of the detection portion of the instrument can be modified. Generally speaking, the closer the detector is to the MEC, the more pronounced the instrument response will be. When the intended target is small items, it may be beneficial to move the detector closer to the ground. On the other hand, if the intended target is large, it might be beneficial to raise the detector in order to minimize the influence of small items.

(b) Instrument Orientation and Direction of Travel. Instrument orientation and direction of travel can have a pronounced effect, particularly with magnetometry. A magnetometer can measure different values over a single location, depending on direction of travel and orientation. When precise surveys are being performed it is necessary to add a "heading correction" to each data point in order to account for this variation.

(c) Measurement Interval. Instrument readings will be collected at intervals sufficient to meet project objectives, depending on the type of instrument used. Typically, measurement interval range between 0.1m and 0.5 m. In most cases the highest available data collection frequency should be used. There is rarely a reason to use a lower frequency given current data storage capabilities and computer processing speeds.

(d) Lane or Line Width. Lane width is usually specified for mag and flag type surveys and refers to the distance between operators. Line width is typically specified for digital surveys and refers to the distance between the lines along which the geophysical data is being collected. The widths may be modified depending on the size and/or orientation of the intended MEC. For large items such as 500 lb bombs or 5-inch rockets, a lane or line width of 5.0 feet may be acceptable. For small items or items with anticipated vertical orientations, lane widths of 3 feet or line widths of only one 1.0 foot may be necessary.

8-12. Data Analysis and Interpretation. The ability to analyze and interpret the geophysical data collected at the prove-out grid will be demonstrated by the PDT using the methods of its choice. The digital data collected at the prove-out grid from each geophysical instrument will be post-processed and analyzed. The results of mag and flag performed using different process

variables, such as variable lane widths or instrument settings, will be assessed individually. A final listing of selected target anomalies will be prepared and provided to the PDT for comparison with seeded item locations.

a. Many software packages can be used to evaluate geophysical data. Often the geophysical equipment manufacturers provide specialized software for specific systems. This software is primarily used to transfer the data from the instrument to the computer and perform corrections to the data. Corrections such as navigation adjustments and rotation and translation of coordinate systems are necessary before analyzing the data. The corrected data is then transferred into a software package designed to facilitate contouring, mapping and selection of anomalous data potentially representing MEC.

b. Field editing of the data will include removal of data spikes, correcting for fiducial marks, and exporting ASCII data files.

c. Initial processing (sometimes referred to as "pre-processing") of the geophysical data will include incorporation of navigation and positional information, instrument drift and leveling, heading error corrections, and latency corrections.

d. Additional processing of the geophysical data may include digital filtering and enhancement techniques, development of threshold and anomaly selection criteria, and anomaly prioritization.

e. All processing needs to be well documented so that results can be checked and procedures verified.

f. Anomaly Selection Variables. Different anomaly characteristics can be used to discriminate anomalies more likely to be associated with MEC from those less likely to be associated with MEC. As part of the GPO, all available anomaly characteristics should be evaluated to determine how different combinations of characteristics and different criteria for each may be used to reduce the level of digging required for a given project. Many anomaly characteristics can be calculated automatically, and these include: peak anomaly response, signal to noise ratio of the anomaly power (based on all above-background measurements), spatial area of contiguous above-background measurements, and model fit parameters. Other characteristics exist that are system-dependent.

g. Data Evaluation. The geophysical data will be evaluated and scored so that the different geophysical approaches can be compared and ranked. Scoring criteria will include, as a minimum, the following: detection rate; false alarm rate; production rate; cost per unit area; equipment durability and safety. No single geophysical system is likely to achieve maximum scores in all evaluated areas. Therefore, the evaluation team will determine which approach is likely to be the most efficient for the project property and project objectives.

h. Selection of Detection Systems. The PDT, based upon the results of the GPO, and, if appropriate, experiences at other project properties having similar geophysical conditions, will select one or more systems for use. Factors influencing the selection may include detection rates, false positive rates, production rates, required operating protocols/SOPs, equipment durability, and safety. The GPO report will contain all supporting information required by the PDT to support their selection decisions.

8-13. Geophysical Work Plans.

a. The Geophysical Investigation Plan, a component of the Work Plan, will be submitted to the PM and MM DC. The MM DC will route the plan to the appropriate technical staff for review, comment and approval. Once approved by the DC and CO, the Geophysical Investigation Plan represents the standard to which all geophysical activities are compared to assure compliance during the project.

b. Prior to initiating field activities, a Geophysical Investigation Plan will be prepared. This plan, which is a subsection of the Work Plan, is prepared to describe the project requirements for all activities related to geophysical operations and those tasks that rely on geophysical data and interpretations. The Geophysical Investigation Plan will include, either by inclusion or by reference (usually to the GPO), justification for using the proposed geophysical system(s) and related methodologies. The plan will also explain how the proposed methods and procedures will be tailored to anticipated site conditions, technical requirements, applicable safety and security regulations, and strategies. The Geophysical Investigation Plan will include procedures for a geophysical instrument prove-out, if one is required and was not previously completed.

c. For project specific requirements, refer to the DID and/or PWS/SOW.