US Army Corps of Engineers

ARMY Environmental Quality Technology Program

EQT

Final Report

U.S. Army Environmental Quality Technology

Project BA4 IIE, Task 5a, Demonstrate Marine Magnetometer Systems

and

Project BA4 IIE, Task 5b Demonstrate State Of The Art In Underwater Positioning Systems

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1. Introduction

The U.S. Army Engineering and Support Center, Huntsville (USAESCH), demonstrated the current state of the art in marine magnetometer systems and underwater positioning systems for the purpose of detecting ferrous munition items. This work was funded through, and performed in support of, the U.S. Army Environmental Quality Technology Project BA4 IIE, Task 5a (demonstrate marine magnetometer systems) and Task 5b (demonstrate state of the art in underwater positioning systems.) Work performed by the USAESCH is explained in the EQT Marine Positioning Demonstration Plan (BA4 IIE Tasks 5a and 5b), prepared by the USAESCH in April 2005 (USAESCH 2005). The objectives of that plan are listed below:

1. Demonstrate current positioning capabilities for fixed and towed marine magnetometer platforms. Positioning capabilities of fixed platforms have already been demonstrated using the HNC shallow marine magnetometer system.
2. Assess the positioning limitations of a deployed system in regards to current and wave action.
3. Assess any interference the positioning system introduces in marine magnetometers and identify limitations and challenges to accurately positioning marine geophysical data without introducing signal interferences. This is not a primary objective. The thrust of this demonstration plan is to assess current positioning systems. It is assumed that if a positioning system is found to have useable applications in the UXO industry, that it could be re-engineered to work within the limitations of the geophysical equipment.
4. Optional: identify limitations and challenges to setting-up a waterborne GPO

1.1 Demonstration Tasks

The objectives listed above were achieved by following the steps outlined in the demonstration plan. These steps are listed below:

1. Identify underwater positioning systems that may be capable of providing high accuracy positioning of marine magnetometers. (High accuracy is defined as +/- 20 cm to 30 cm, similar to current land-based RTK DGPS capabilities.)
2. Acquire training in the use of the systems that are identified as having the potential to meet project needs.
3. Assess the effects of the positioning system on the geophysical sensor data. This assessment will likely be initiated concurrently to Step 1, but additional tests may be identified as tasks 1 and 2 are performed.
4. Evaluate best achievable positioning accuracies for a given system. This step will provide all the data needed to assess Objective #1. This step will also identify indications of problems that could be assessed for Objective #3.
5. Introduce wave action and current and evaluate the positioning accuracies that are achieved.

Steps 1 through 4 were performed to completion. Step 5 was only partially performed by simulating wave action on one of the tested systems. Collecting data on how wave

conditions affect the data from the towed sensor platform was difficult since we did not encounter high wave conditions during the survey period. Funding constraints precluded further testing in high current conditions.

Supplemental data is available from a marine geophysical demonstration performed in open waters in Puerto Rico by the USAESCH in June of 2005. That data is used in this report to help demonstrate the current capabilities of marine magnetometers. Supplemental data for demonstrating marine magnetometer capabilities is also available from two previous shallow water surveys performed by the USAESCH in August of 2003.

1.2 Schedule of Activities

All activities performed by USAESCH personnel in support of this EQT project were carried out between April and September 2005. Greater details on the schedule of events and activities is presented below

U.S. Army Environmental Quality Technology Project BA4 IIE, Task 5a & Task 5b							
Schedule							
		2005					
		April	May	June	July	August	September
Assess feasibility of ORE Trackpoing II Plus and DesertStar Aquamap positioning systems							
Obtain instruction in using the ORE Trackpoint II Plus							
Acquire Marine magnetometer from ERDC-Vicksburg							
Perform demonstrations of capabilities using ORE Trackpoint II Plus as well as Fixed Array magnetometer systesms							
Obtain instruction in using the Desert Star Aquamap positioning system							
Reduce data and analyse capabilities of the various systems tested							
Prepare project report							

1.3 Report Contents

This report presents findings and assessments for both Tasks 5a and 5b of the EQT BA4 IIE project. Section two of this report describes the technologies identified and demonstrated. Section three addresses the current capabilities of marine magnetometers applied to detecting underwater MEC. Section four describes the different underwater positioning systems evaluated during this project. Section five presents our conclusions.

2. Description of Technologies

The technologies used during this project are commonly available marine geophysical and underwater positioning systems. The primary marine geophysical equipment used was the Geometrics G881 dual sensor horizontal magnetic gradiometer. Data from a second magnetometer system, a Geometrics G858 man-portable system deployed from a watertight submersible array, was also used in this report to demonstrate alternative positioning and sensor deployment options. Three types of positioning technologies were evaluated during this project: ultra-short baseline acoustic positioning system (USBL), long baseline acoustic positioning system (LBL), and a conventional real time kinematic differential positioning system (RTK DGPS) mounted on a fixed array. The RTK DGPS is an independent system used in conjunction with two different software algorithms that are evaluated in this report: the Geometrics Inc. Interpolator algorithm, which is available with the Geometrics Inc. MagLogNT data acquisition software; and the freeware data-merging algorithm available in MagMap2000, available from Geometrics, Inc. The table below summarizes the datasets used to evaluate marine magnetometer capabilities.

Table 2-1
Datasets Used To Evaluate Marine Magnetometer Capabilities

Positioning System	Geophysical System	Location of Evaluation	Evaluation Date
RTK DGPS	Geometrics G858 Fixed Array	APG Main Pond, MD	August 2003
RTK DGPS & MagLogNT Interpolator	Geometrics G881 Dual Sensor Fixed Array	APG Shallow Water Demonstration Pond, MD	July 2005
RTK DGPS & MagLogNT Interpolator	Geometrics G881 Dual Sensor Towed Array	APG Shallow Water Demonstration Pond, MD	July 2005
RTK DGPS & MagLogNT Interpolator	Geometrics G881 Dual Sensor Towed Array	Culebra, PR	June 2005

Table 2-2 summarizes the datasets used to evaluate underwater positioning system capabilities.

Table 2-2
Datasets Used To Evaluate Underwater Positioning System Capabilities

Positioning System	Geophysical System	Location of Evaluation	Evaluation Date
RTK DGPS & MagLogNT Interpolator	Geometrics G881 Dual Sensor Fixed Array	APG Shallow Water Demonstration Pond, MD	July 2005
RTK DGPS & MagLogNT Interpolator	Geometrics G881 Dual Sensor Towed Array	APG Shallow Water Demonstration Pond	July 2005
RTK DGPS & MagLogNT Interpolator under simulated wave conditions	Geometrics G881 Dual Sensor Towed Array	APG Shallow Water Demonstration Pond, MD	July 2005
RTK DGPS & USBL	Geometrics G881 Dual Sensor Towed Array	APG Shallow Water Demonstration Pond, MD	July 2005
RTK DGPS & USBL under simulated wave conditions	Geometrics G881 Dual Sensor Towed Array	APG Shallow Water Demonstration Pond, MD	July 2005
LBL	Geometrics G881 Dual Sensor Towed Array	San Luis Reservoir, CA	August 2005

Short baseline acoustic positioning technologies were not evaluated because a system could not be identified within the timeframe of this project.

2.1 Geometrics G881 Dual Sensor Horizontal Magnetic Gradiometer

The Geometrics G881 dual sensor horizontal magnetic gradiometer is an array of one standard G881 magnetometer and one standard G880 magnetometer. Figure 2-1 shows the components of the array. The G881 and G880 magnetometers are identical in all respects except the G881 has an integrated depth sensor that is used to measure the depth of the array. Specifications on the G880 and G881 are available on the world wide web at the following URL:
http://www.geometrics.com/Downloads/MagDnForm/MagDown/magdown.html

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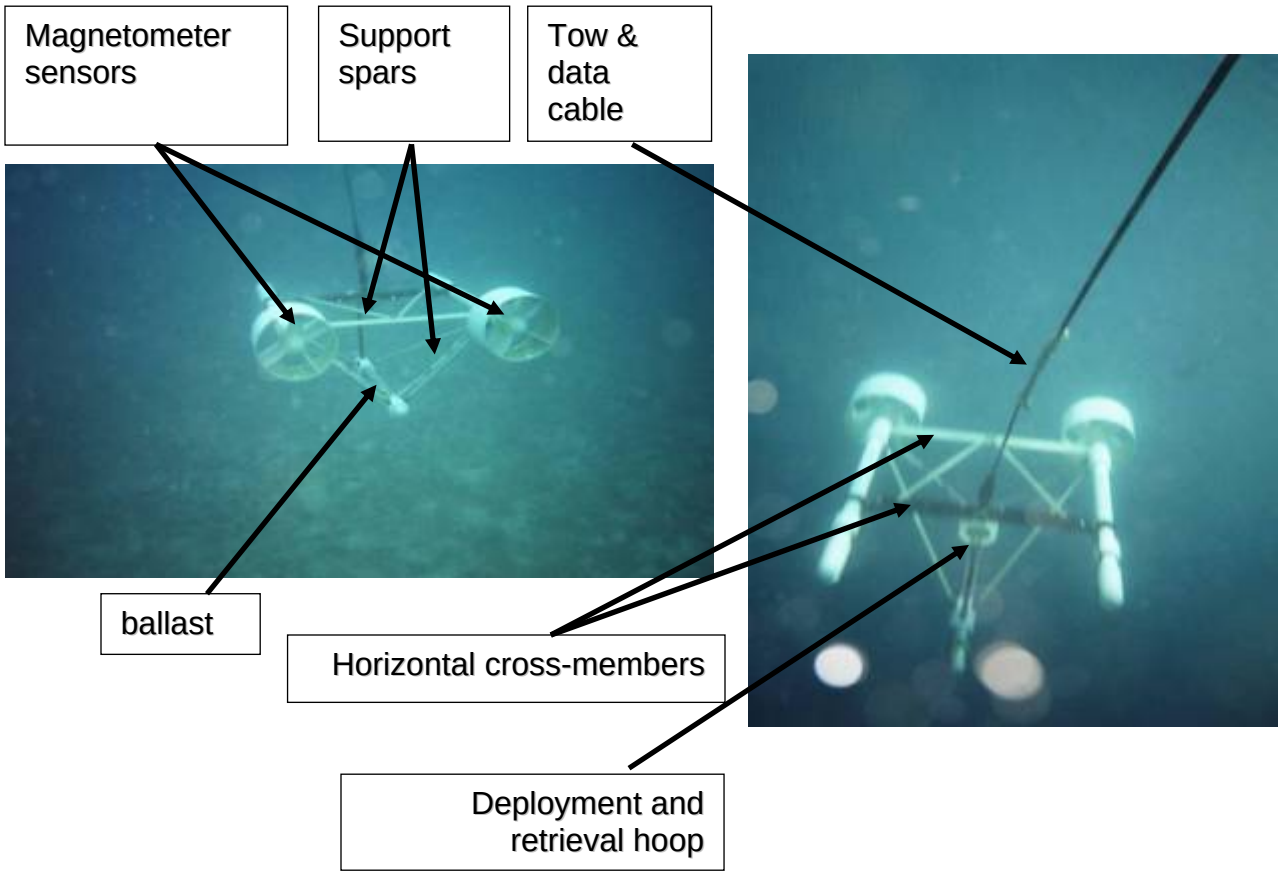

Figure 2-1, Geometrics G881 dual sensor horizontal magnetic gradiometer

The system used during this project was designed to be deployed at depths greater than those encountered during our evaluations. The manufacturer states that deployment depths of approximately 40 meters can be achieved although this statement was not independently verified during this evaluation. When deployed in water shallower than about 4 meters, the array was suspended below a small inflatable raft and towed behind the vessel in order to eliminate any potential heading or other on-board noise sources from the tow vessel. The raft was towed between 14 and 18 meters behind the tow vessel. When operating in water greater than 4m deep, towing directly from the stern of the tow vessel usually resulted in the array being sufficiently behind the vessel to eliminate heading and interferences from on-board noise sources.

The dual sensor array used during this project exhibited very low system noise levels, on the order of ±0.02 nT. This very low noise level allows for very high signal to noise ratios for MEC items that produce signals as low as 1 to 1.5 nT at the sensors. During this project, the sensors were also maintained at constant depths with only +/-5cm typical variance due to slightly different survey speeds. The combination of these benefits are the datasets have very little interference from outside sources, such as the tow vessel, power

sources, system electronics, etc., and the data is collected at essentially the same geoid elevation. These benefits simplify interpreting and selecting anomalies, and are likely to simplify and provide better modeling results for discrimination routines.

The horizontal array used during this project was found to be minimally affected by wave heights of between 20 and 80cm. It is assumed that single sensor systems not having horizontal components in their design, such as those seen in Figure 2-1, would be less likely to maintain a constant depth under those wave height conditions.

One limitation of the horizontal array is the ballast weight is located roughly 50cm below the sensors. Since the array is "flown" at a constant depth, sensor depth is usually set to be at least 1.5m above the shallowest area being surveyed to minimize the likelihood of contacting the bottom. This translates to the ballast assembly being at least 1 meter above the bottom at all times. In areas having highly varying bottom topographies, the safety margin would likely be increased to either 1.5m or 2m, resulting in sensor heights of 2m or 2.5m above the shallowest point.

2.2 Watertight Submersible Fixed Array using Conventional Positioning Systems

The USAESCH constructed a watertight magnetometer array to demonstrate that fixed array systems could be used for shallow marine surveys for MEC. The array was first used in 2003 at Osborne Pond, Camp Edwards, Massachusetts, and in the main spoils pond at the Aberdeen Proving Grounds, Aberdeen Maryland. For details on the design and capabilities of this watertight submersible fixed array magnetometer system, refer to reports *Geophysical Mapping of Main Pond, Old Bombing Range And Chelsea Pond,* dated October 2003 (UEASECH 2003), and *Marine Geophysical Mapping of Osborne Pond, Camp Edwards,* dated September 2003 (UEASECH 2003). Additional details on the design and performance of this fixed array system can be found in *Magnetometer System for Detecting MEC in Very Shallow Marine Environments***,** proceedings of the UXO/Countermine Forum 2004 (Schwartz 2004). Figure 2-2 illustrates the construction and components of a submersible fixed-array system.

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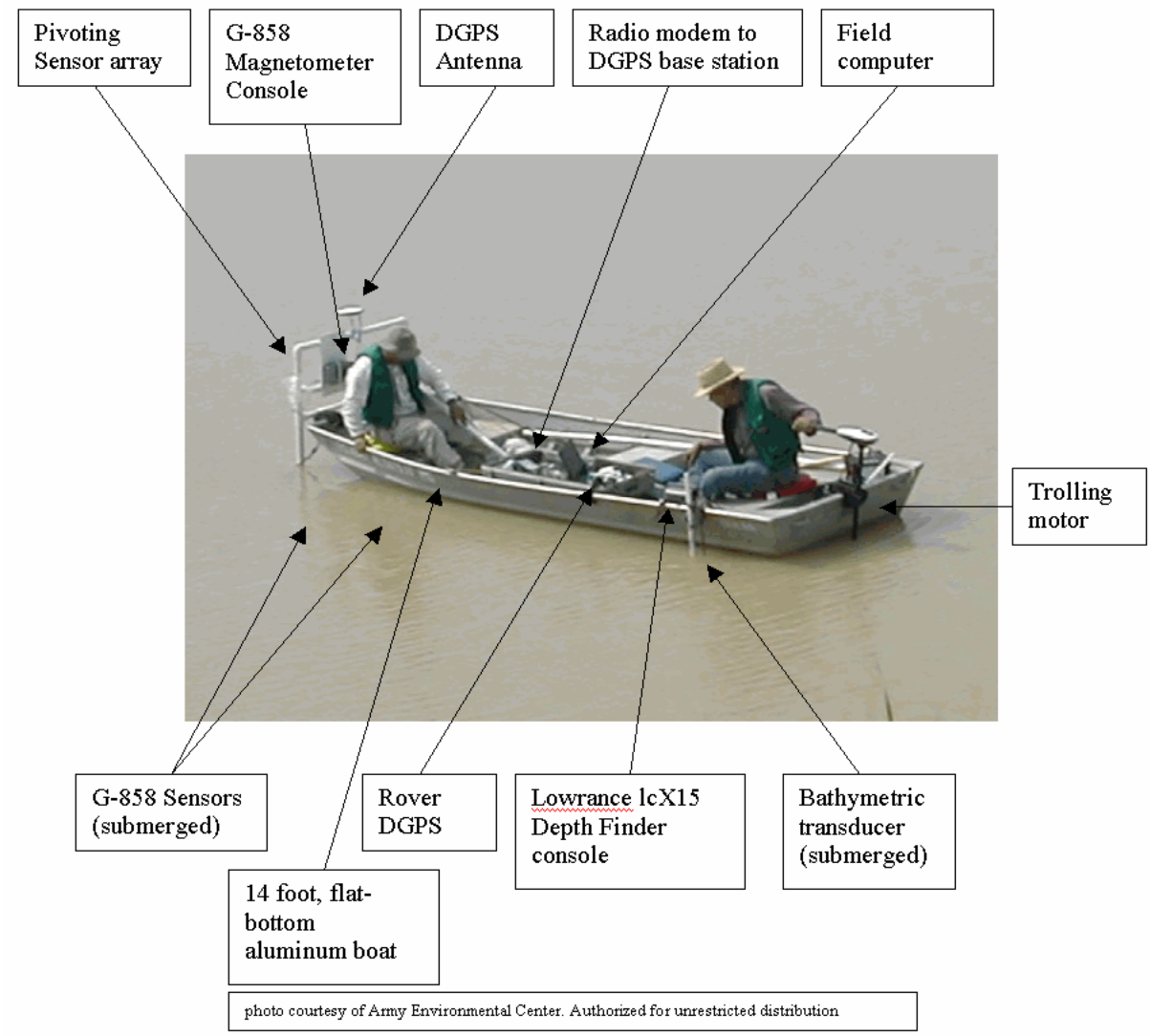

Figure 2-2. Submersible fixed-array equipped with a dual-sensor G858 magnetometer

The benefits of fixed array deployments are the systems can be designed to have very low noise and the sensors are easily maintained at a constant depth. The watertight submersible fixed array used by USAESCH exhibited low system noise levels, on the order of ±0.15 nT. Since all fixed arrays normally maintain the sensors at constant depths with negligible variations, it can be assumed the data is collected at the same geoid elevation. An additional benefit of fixed arrays is they can use any conventional positioning system commonly available because the geometry of the array is fixed. Most fixed arrays use one or more RTK DGPS antenna to calculate the position of the array. Robotic total stations or other advanced laser positioning systems could also be used. The USAESCH system uses a two-centimeter RTK DGPS system and MagMap2000 freeware from Geometrics, Inc (discussed below) to produce datasets with position accuracies of 20cm or less.

Limitations of fixed arrays include the need to design deployment systems that minimize heading effects from the survey vessel and positioning equipment, the need to position

the array beyond the influence of external noise sources on the survey vessel (power supplies, vessel propulsion systems, etc.) and the difficulty of deploying the arrays in deep water. Heading effects can be substantial from most survey vessels not fabricated entirely of fiberglass or aluminum, and the vessel's propulsion system and on-board power systems will produce magnetic interference, which can extend from 3 meters to beyond 6 meters from the source. Components of the array that contain iron or other sources of magnetic fields will induce heading errors, which must be corrected during post-processing of the data. The design and shape of the array's components will produce hydrodynamic drag, which reduces survey speeds and could reduce position accuracies through bending or bowing of the array.

To provide comparisons between towed magnetometer data and fixed array magnetometer data for this project, the G881 horizontal array was attached to the base of a fixed array and operated over the same area as the towed deployments. This was performed to collect fixed-array data without needing to put non-watertight G858 sensors at risk of being damaged.

2.3 Ultra Short Baseline Acoustic Positioning Systems

Ultra short baseline acoustic positioning (USBL) systems are designed to provide positions of submersible vehicles or platforms. USBL technologies are designed around an array of very closely spaced hydrophones that calculate both range and bearing to an acoustic transponder mounted on the submerged platform (commonly referred to as the "target"). Additional positioning equipment, such as DGPS, gyro compass and a high precision vertical reference unit (VRU) can be used to calculate geographic positions of the submerged target. The gyro compass provides data on the vessel's bearing, (the direction the vessel is pointed with respect to geographic north) and the VRU provides roll and pitch data. All of these variables must be known to solve the geometry equations to calculate the geographic position of the target.

The ORE Trackpoint II Plus, manufactured by ORE Offshore, Inc. was evaluated for this project. The ORE Tackpoint II Plus system has three small hydrophone elements mounted in a watertight housing approximately three inches in diameter. A deck unit houses the electronics, user interface and power distribution for the hydrophone components. Figure 2-3 shows the components of the system. There are two basic operating principles used to calculate the target's range and bearing; range to the target is calculated from the two-way travel time of acoustic signals transmitted between the Trackpoint II Plus array and a transponder mounted on the target. Bearing is calculated by measuring the difference in arrival time of the target's acoustic signal at each of the three hydrophone elements. When computing the relative position of the target with respect to the Trackpoint II Plus hydrophone, the system must also know the depth of the target, which can be transmitted by the target's transponder if equipped with a pressure sensor, or the depth can be entered manually. To calculate accurate geographic positions, the system must also know the position of the vessel, the vessel's bearing, and the roll and pitch of the vessel. For the latter, a low-resolution vertical reference unit supplied with the Trackpoint II Plus will suffice in calm sea states. On open water, the manufacturer recommends using a high resolution VRU. The ORE Trackpoint II Plus has

a published horizontal accuracy of 0.5m and target position repeatability better than 0.25% RMS of the slant range. During our evaluations, we found the horizontal accuracy to be equivalent to the manufacturer's published value, but estimate the target repeatability to have been slightly worse due to operating in a shallow, confined pond. Proper training in the operation of the system is required to achieve these accuracies. Additional product specifications can be found at the following URL: http://www.ore.com/navigationDataSheets/Trackpoint.pdf

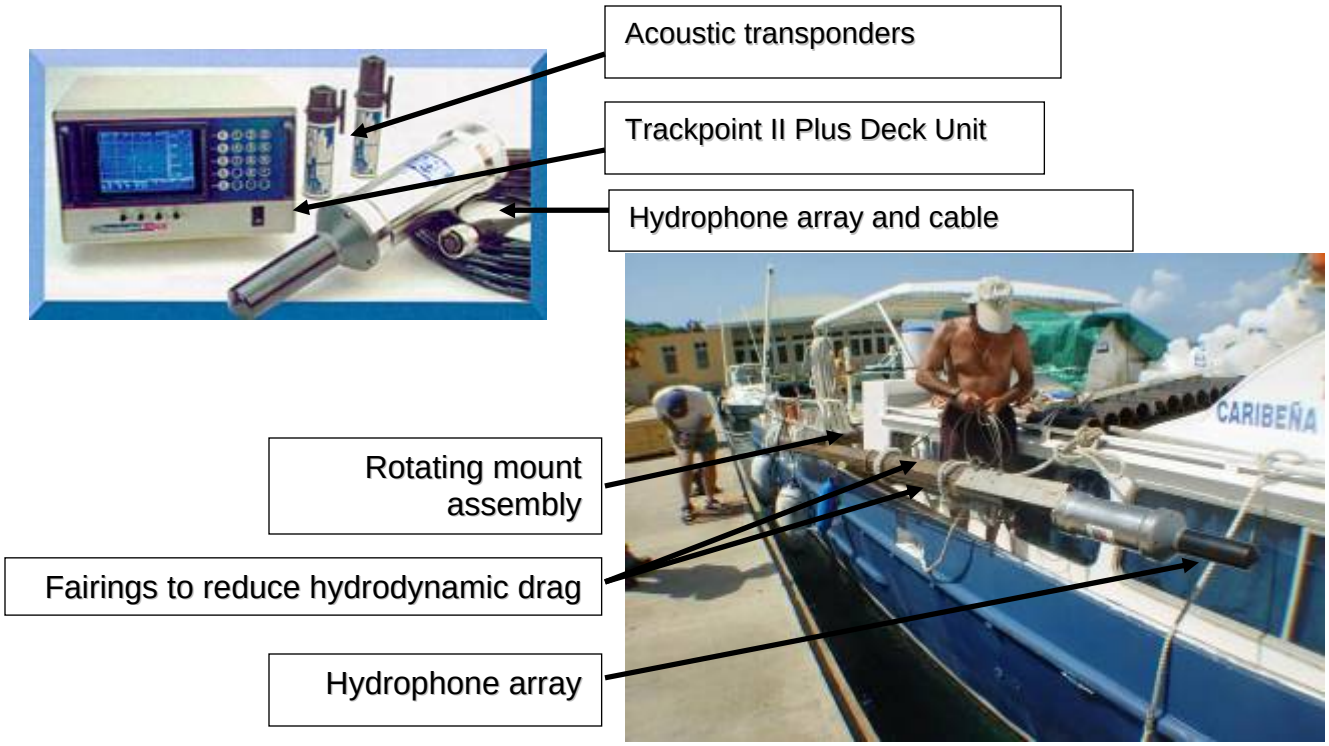

Figure 2-3, components of the ORE Trackpoint II Plus system.

The benefit of USBL systems is they are "autonomous" in the sense that all the required positioning equipment is located on the survey vessel (with the exception of the RTK DGPS base station if land-based differential corrections are used). Data acquisition can be continuous and production is limited only to survey speed limitations and availability of differential GPS corrections. The acoustic transponder mounted to the front of the array may have contributed to heading error. The heading error of the array with the transponder attached is in the range of ±1nT. The heading error is easily removed from the data using heading correction software.

The limitations of USBL systems include: the hydrophone must be mounted rigidly to the vessel, the hydrophone must be mounted at least 1m from the vessel's hull, it's location with respect to the roll and pitch center of the vessel must be known, the speed of sound in the water must be known, and the gyro compass must be surveyed onto the vessel (to correct for misalignment of the gyro compass with respect to the centerline of the vessel).

In addition, non-homogeneous velocity profiles through the water column will degrade the range calculations. However, for operating in shallow water conditions likely to occur at underwater MEC sites in lakes, rivers, estuaries and calm open-ocean areas, all but the non-homogeneous velocity profile can be addressed. Water velocities can usually be assumed constant in the depth range of 1m to 20m in non-brackish waters. Lastly, the system is complex, particularly when deployed with DGPS, a gyro compass and an external, high precision VRU. Training on the system's theory of operation, installation, calibration and use is required. Training for the ORE Trackpoint II Plus is available from the manufacturer.

2.4 Long Baseline Acoustic Positioning Systems

Long baseline acoustic positioning (LBL) systems are designed to provide positions of submersible vehicles or platforms. Long baseline technologies operate on the same principles as land-based micro-wave and radio-frequency positioning systems. Transponders placed on the sea floor are used to triangulate relative positions of a transceiver mounted on the target. If the geographic locations of the stationary transponders are known, LBL systems can also calculate geographic locations of the target's transceiver.

The AquaMap LBL system manufactured by Desert Star Systems, LLC, was evaluated for this project. The AquaMap system consists of a transceiver that is mounted on the target, four stationary transponders that are suspended above the water bottom, and the AquapMap software. The software will run from any commonly available computer and can be configured to transmit target positions over RS232 communication ports. The system is not designed to record geophysical data from external systems. Figure 2-4 shows a screen-snapshot of the AquaMap software while in use, and Figure 2-5 illustrates the components of the AquaMap system. The system has a published accuracy of 0.15m under well-controlled setups, with setup times of between 10 and 20 minutes. During our evaluations, we found the horizontal accuracy to be equivalent to the manufacturer's published value, and the on-water setup time for a moderately controlled-setup was less than 30 minutes for our first deployment of the system. The time to install the transponder onto the magnetometer array and test for interference was less than one hour. The system is simple to deploy and operate, and adequate training can be achieved in one day. Training is available from the manufacturer. Additional product specifications can be found at the following URL:
http://www.desertstar.com/newsite/positioning/diver/aquamap2.html.

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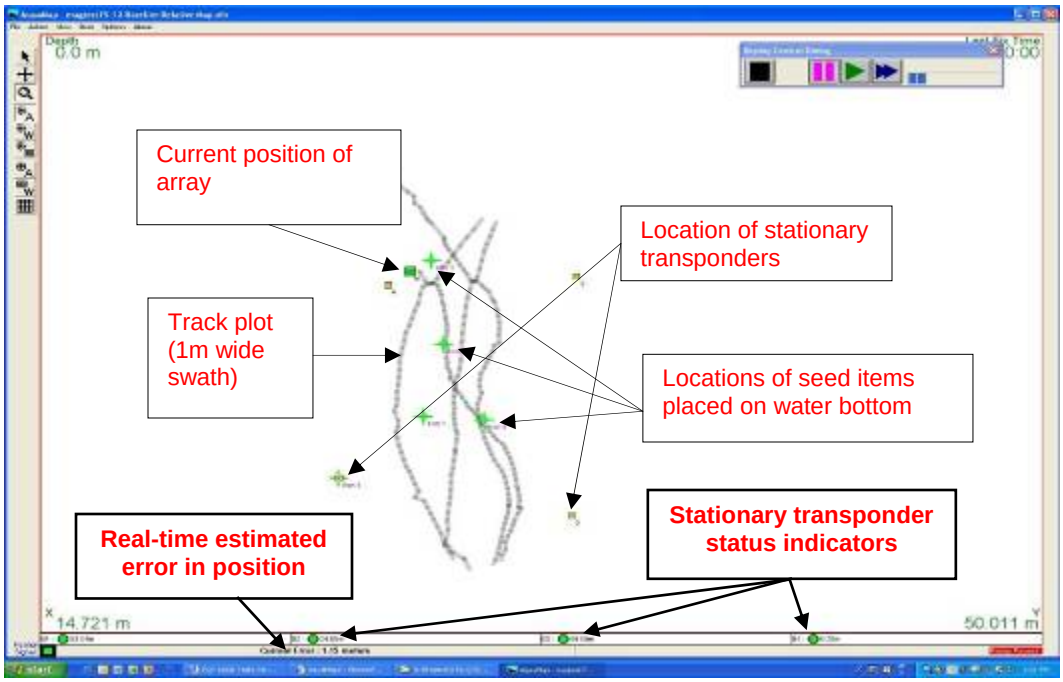

Figure 2-4, screen shot of AquaMap software in play-back mode. Real-time survey is identical

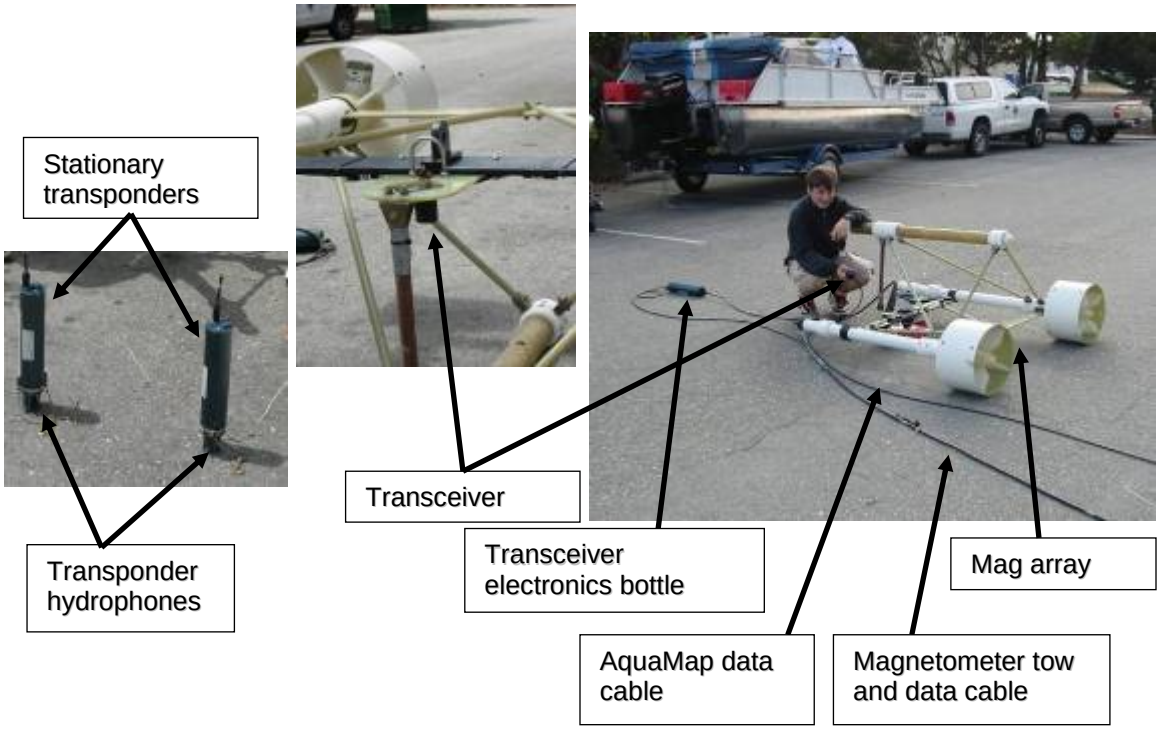

Figure 2-5, hardware components of the AquaMap system

The benefits of LBL positioning systems are they can provide accurate positions of submerged targets with minimal hardware requirements and simple setup procedures. The system evaluated during this project has an auto-configuration routine that quickly calculates the location of the stationary transponders, which permits data to be collected in a local coordinate system within minutes of placing the last transponder. In addition, the LBL system we tested does not require any additional real-time inputs to operate, including DGPS positions. The LBL acoustic transponder mounted to the front of array was not detected by the magnetometer sensors.

The primary limitation of LBL positioning systems is the geographic locations of stationary transponders must be known if geographic locations of the target are required. If all work can be performed within a local coordinate system then this limitation is insignificant. Additional limitations include: the stationary transponders must remain motionless to achieve high accuracy position solutions, some system designs may limit the distance between stationary transponders to less than approximately 250 meters in order to maintain high position accuracies and position update-rates of between .5 to .125 Hz (once every two to eight seconds).

2.5 Geometrics, Inc. Interpolator Algorithm

The Geometrics, Inc, interpolator algorithm is packaged with the data acquisition software MagLogNT. The interpolator algorithm is a computer model that estimates the location of a towed, submerged target with respect to the positioning antenna mounted on the survey vessel. The algorithm uses information about the location of the tow-point, the location of the vessel's positioning antenna with respect to the tow point, the amount of cable outlay (commonly referred to as "cable layback" or simply "layback"), and the target depth to estimate the target's position. Figure 2-6 illustrates the set-up windows that are part of the interpolator routine. Figure 2-7 shows a screen snap-shot of MagLogNT with the estimated position of the target shown behind the tow vessel. Additional information can be found in the MagLogNT manual at: http://www.geometrics.com/Downloads/MagDnForm/MagDown/magdown.html

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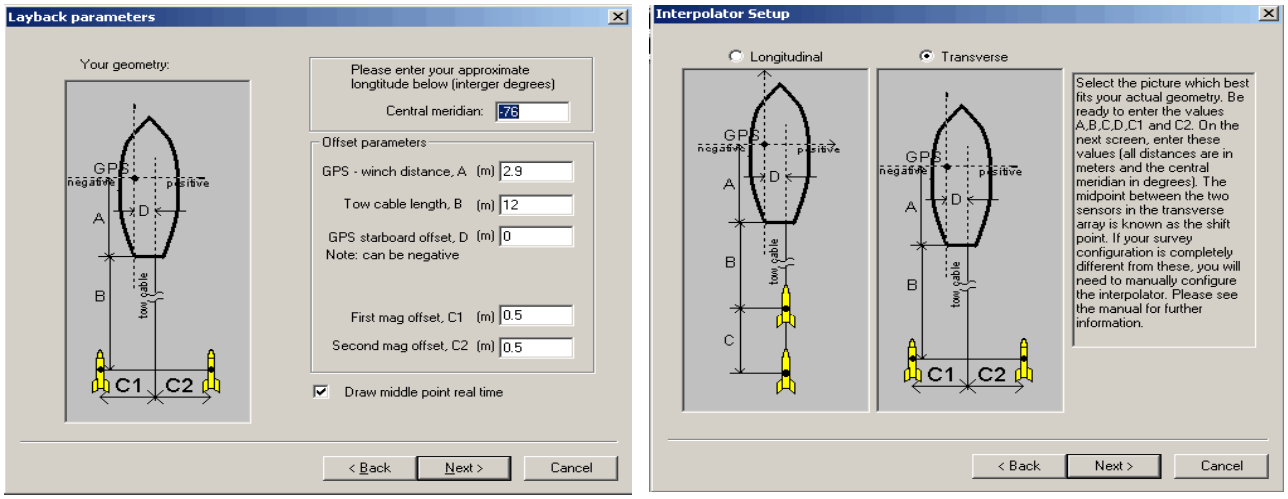

Inputs for Setup Geometry **Inputs for Array Configuration**

Figure 2-6, example of interpolator setup parameters

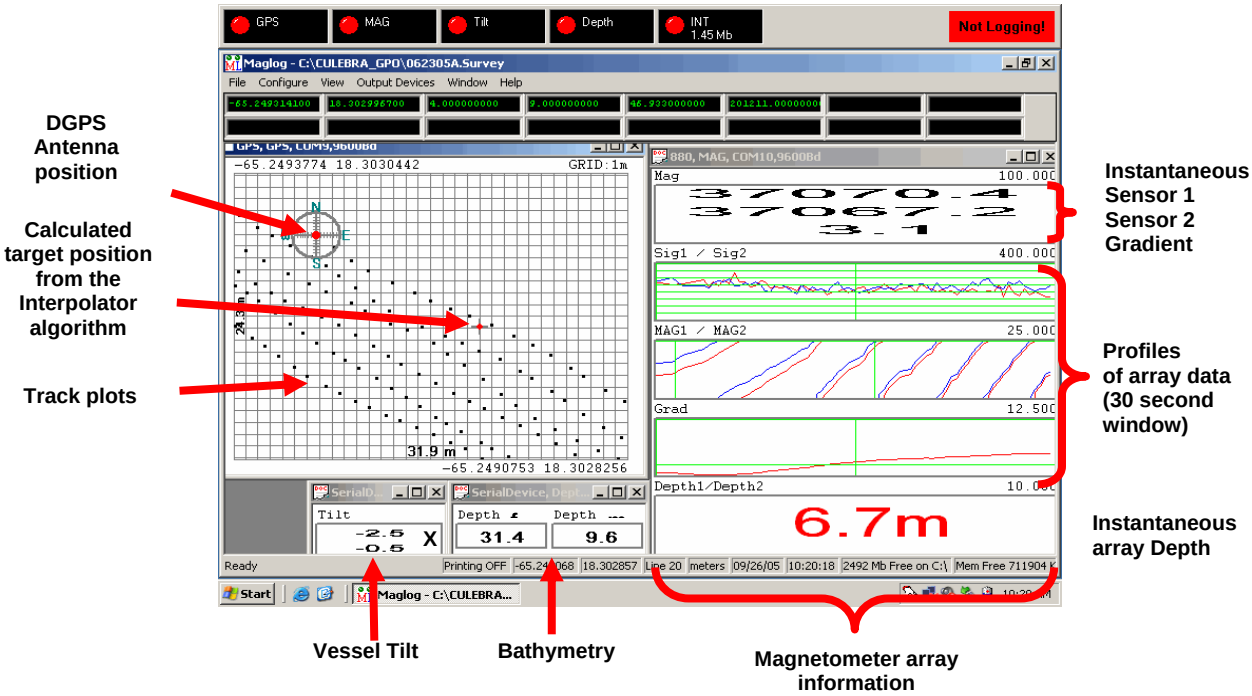

Figure 2-7, screen snap-shot of MagLogNT during data acquisition.

Similar to USBL systems, the primary benefit of the interpolator algorithm is that it is autonomous in the sense that all of the required positioning equipment is located on the survey vessel (with the exception of the RTK DGPS base station if land-based differential corrections are used). Data acquisition can be continuous and production is limited only to survey speed limitations and availability of differential GPS corrections. All that is required is a NMEA GGA positioning string input from any positioning system. The algorithm will also accept bearing data from a digital gyro compass, and one was used when collecting the fixed array dataset. The algorithm also produced good solutions in simulated wave conditions and real wave conditions to heights of approximately 0.8m (ref. Feasibility Study of Geophysical Methods for Offshore Military Munitions Response Surveys in the Vicinity of Culebra Island, Puerto Rico). The MagLogNT software does allow background maps to be loaded in the positioning window display, and does facilitate survey planning by allowing the user to draw pre-planned survey lines on the base map. Additionally, the MagLogNT software was able to simultaneously manage data received from up to six communications ports during our evaluations.

The limitations of the interpolator algorithm are straight-line data acquisition are needed in order to maintain high accuracies in the calculated positions. Minor corrections to maintain course are handled well by the routine, but data positioned during change-of-line turns were not reproducible. The MagLogNT routine does not support track-indicator functions (it cannot be used to track individual lines nor does it provide steering corrections to track a specific survey line.)

2.6 Geometrics, Inc. MagMap2000 Data Merging Algorithm

Geometrics, Inc. provides MagMap2000 as freeware to facilitate downloading, processing, viewing and exporting magnetometer data collected using Geometrics magnetometers. The MagMap2000 freeware is commonly used in the MEC community to download, view, process and merge G858 magnetometer data with positioning data, either in the form of line and fiducial positioning or DGPS positioning. The DGPS merging routine is very well suited to merging magnetometer and positioning data collected from fixed arrays, either land based or waterborne. The routine is simple to implement and provides good results. This freeware allows limited editing of positioning data (sudden jumps in position, referred to as data “spikes”, can be deleted) and it provides a smoothing routine that automatically eliminates “chatter” and minor positioning data spikes. There are numerous other functions used on a routine basis in the MEC industry, and more information can be found in the MagMap2000 manual at: http://www.geometrics.com/Downloads/MagDnForm/MagDown/magdown.html.

The benefits for merging geophysical and positioning data from this freeware include: ease of use, limited editing of positioning data (deleting spikes in position solutions), and it provides a smoothing function for position solutions.

Limitations of this freeware are that it is designed to work only with data collected using Geometrics products and the positioning algorithm only allows for two-dimensional inputs of the sensor to positioning antenna offsets. The positioning routine cannot correct

for varying elevation geometries, such as those encountered when using towed submerged platforms.

3. Marine Magnetometer Capabilities

This section illustrates current capabilities in marine magnetometer technologies applied to detect MEC. The information in this section is taken from evaluations performed at the Aberdeen Test Center's Shallow Water Demonstration Pond, Aberdeen Proving Ground, Aberdeen Maryland, and a marine geophysical demonstration performed in shallow waters around the island of Culebra, Puerto Rico.

Though the "success" of any marine geophysical survey searching for MEC is highly dependent on the quality of positioning solutions, this section only discusses the capabilities of marine magnetometer systems to detect ferrous objects that may be MEC. These discussions assume that data positioning needs can be met for the intended use of the magnetometer data, and that the underlying quality of the positioning is qualitatively good. Qualitatively good positioning for this evaluation is defined as magnetic dipoles are distinct and well shaped across multiple survey lines and magnetic signatures are reproducible. The topic of positioning capabilities and limitations is discussed in Section 4 of this report. All data presented in this section is positioned using the MagLogNT Interpolator algorithm.

3.1 Aberdeen Test Center Shallow Water Demonstration Pond Data

Magnetometer data collected at the Aberdeen Test Center Shallow Water Demonstration Pond is presented in Figures 3-1 through 3-3. These figures present total field magnetometer data from a single sensor of the dual-sensor array. The decision to present only single sensor data is based on availability of funds. This decision does not impact the evaluations or conclusions of this project. All data is corrected for diurnal variations, heading and latency errors.

Figure 3-1 presents magnetometer data collected using a fixed-array. The sensors were flown at a depth of 0.8m ±0.02m with sensor heights ranging from 1.6m (shallow areas) to 2.9m (deep areas) above the bottom over the area surveyed. This dataset was chosen as the basis of comparison for all other datasets collected at this site because it has the least possible errors in positioning. There are 302 anomalies associated with magnetic dipoles and monopoles in this dataset. As shown in the figure, the magnetic field is reproduced very well with minimal distortions attributable to common sources of errors such as precision errors, heading errors, latency errors, depth variations or diurnal variations. One oddity worth noting about this dataset is the heading tests indicated no heading effects associated with the fixed array data. We use the Octant test, following standard USAESCH quality control protocols, to collect data on heading errors. However, after plotting the survey data an eight nanoTesla heading error was noted, and subsequently removed. It is not known why this heading effect was not produced in the heading test data. The heading effect is presumably attributed to ferrous components on the survey vessel, though this is not confirmed.

Figures 3-2 and 3-3 present the magnetometer data collected using the towed array with sensors deployed at depths of 1.3m ±0.05m (typical) and 1.8m ±0.05m (typical), respectively. The sensor height for the 1.3m depth dataset ranged from 1.1m to 2.4m above bottom and 0.5m to 1.9m for the 1.8m depth dataset. There are 276 anomalies associated with magnetic dipoles and monopoles in the 1.3m depth dataset and 210 in the 1.8m depth dataset. As shown in both figures, the magnetic fields are reproduced very well with minimal distortions attributable to common sources of errors such as positioning, heading, latency, depth variations or diurnal variations. The anomalies in these datasets are typically reproduced within 1 meter of those observed in Figure 3-1. The signal to noise ratios are greater in these datasets compared to those in Figure 3-1 due to the sensor being closer to the anomaly sources.

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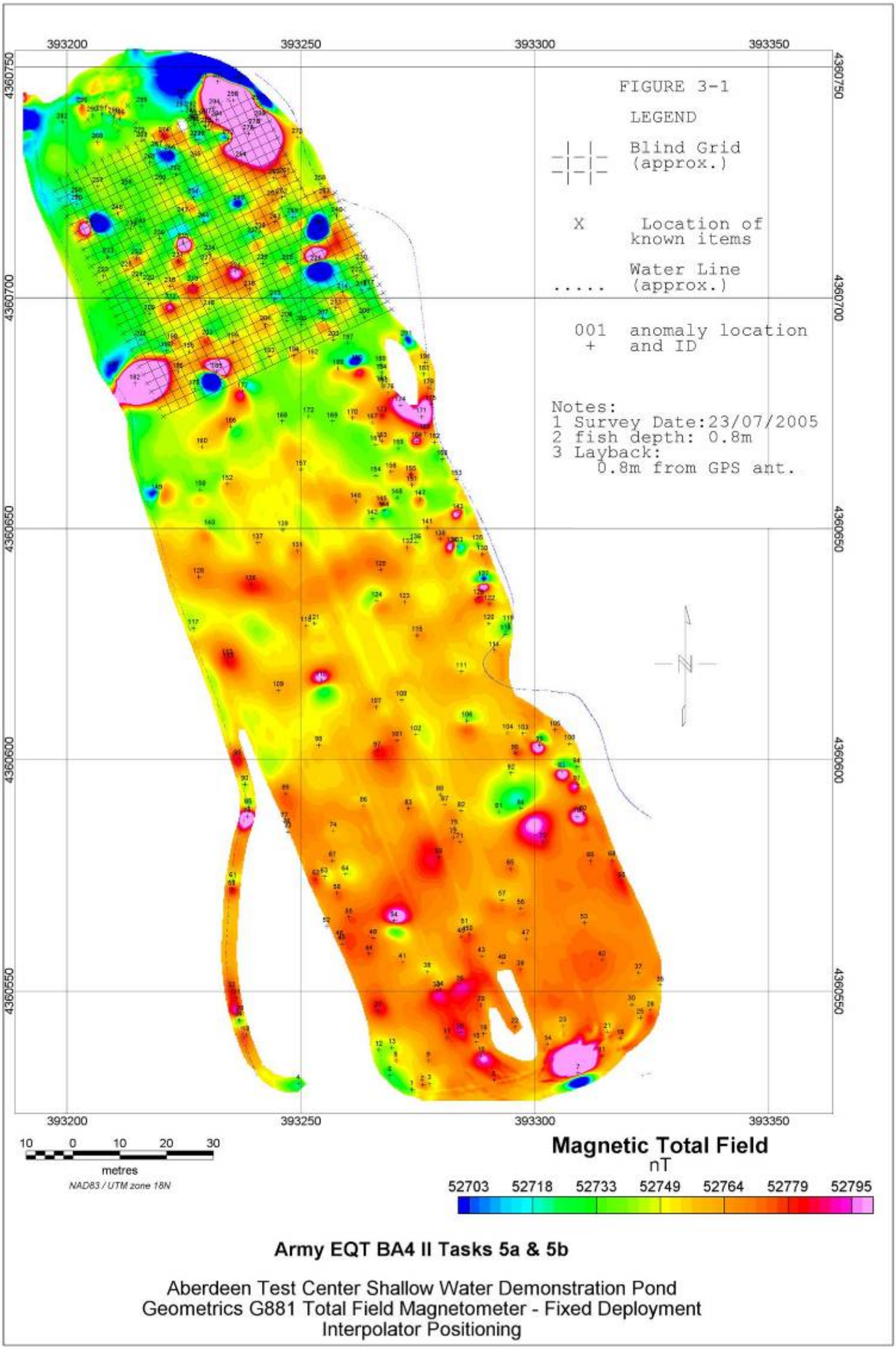
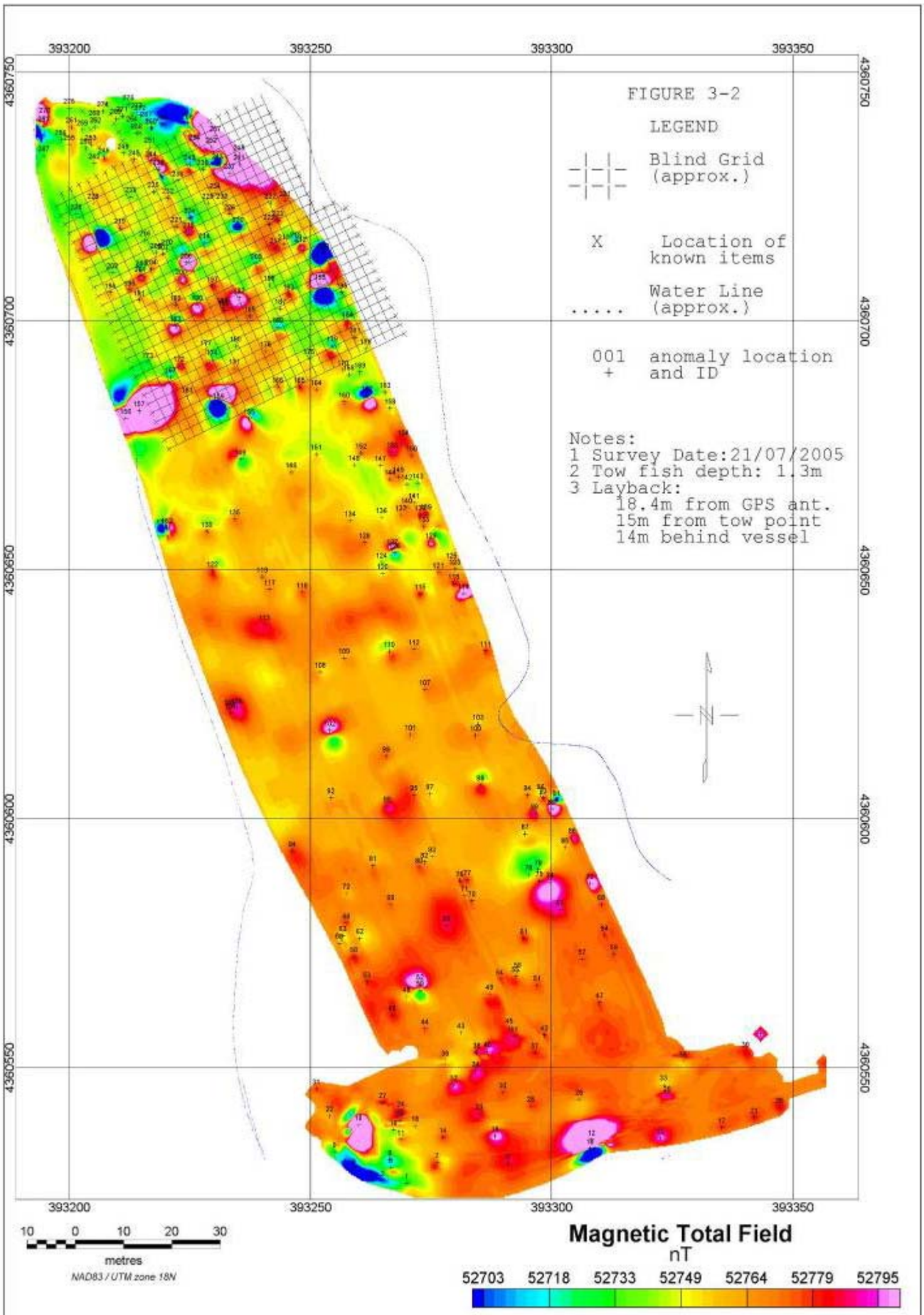
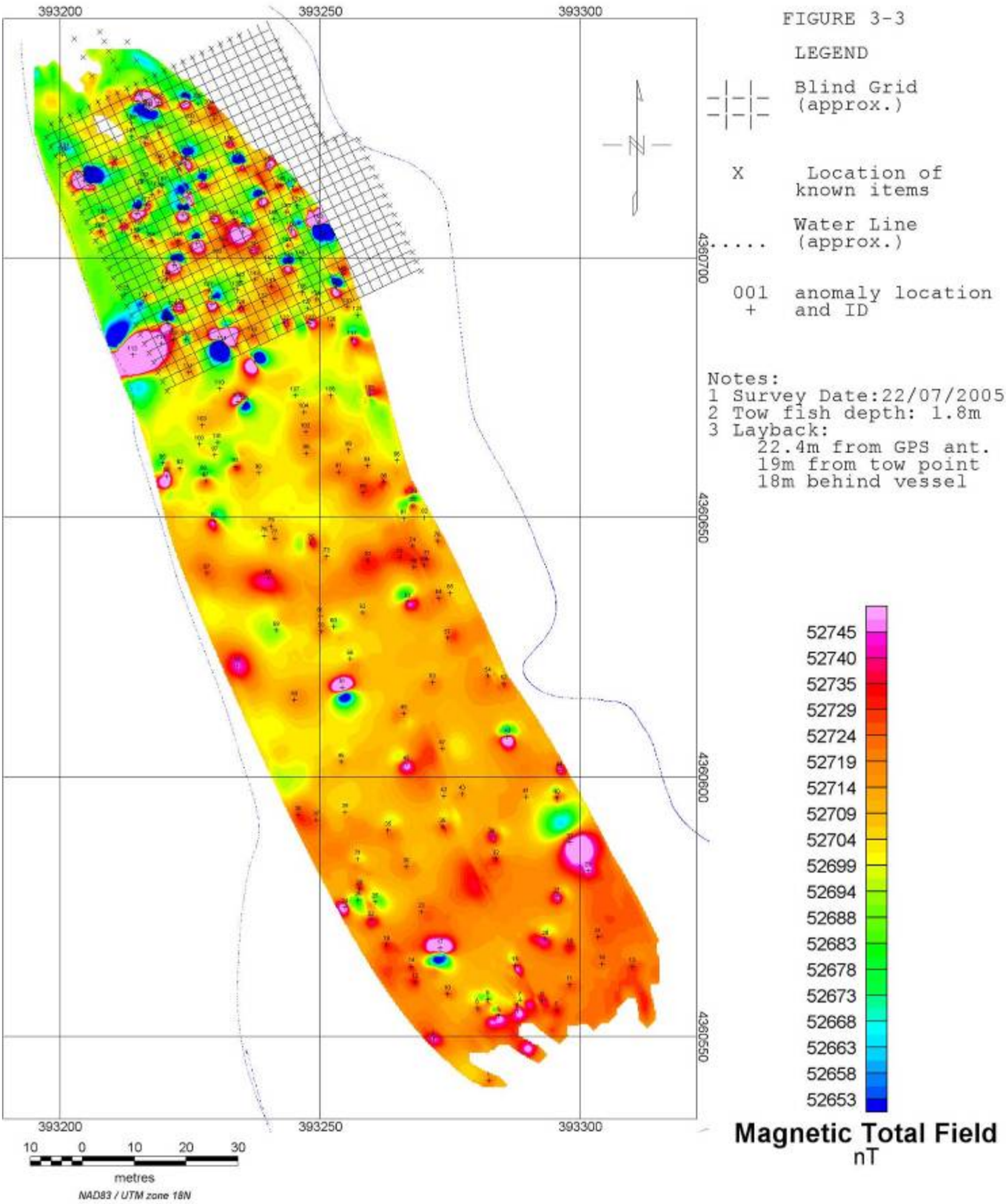


FIGURE 3-1
LEGEND
Blind Grid (approx.)
X Location of known items
Water Line (approx.)
001 + anomaly location and ID
Notes:
1 Survey Date:23/07/2005
2 fish depth: 0.8m
3 Layback:
0.8m from GPS ant.
393200
393250
393300
393350
4360750
4360700
4360650
4360600
4360550
10 0 10 20 30
metres
NAD83 / UTM zone 18N
Magnetic Total Field
nT
52703 52718 52733 52749 52764 52779 52795
Army EQT BA4 II Tasks 5a & 5b
Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Fixed Deployment
Interpolator Positioning



Army EQT BA4 II Tasks 5a & 5b

Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Shallow Deployment
Interpolator Positioning



Army EQT BA4 II Tasks 5a & 5b

Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Deep Deployment
Interpolator Positioning

One interesting observation worth noting is the automated anomaly selection routine used to interpret these datasets tended to select anomalies over both the peaks and troughs of individual dipoles. The automated selection routine uses the analytic signal, which is calculated from the total magnetic field. In some instances, the interpreting geophysicist used professional judgment to move some anomalies closer to the estimated center of their respective dipole. This task was not performed on all anomalies as this effort was not needed for the purposes of this report. It is not known why the analytic signal routine did not select anomaly locations centered on the dipoles. The automated anomaly selection routine was used to quickly locate anomalies in order to facilitate comparing one dataset to another.

3.2 Culebra Marine Geophysics Demonstration Data

The data presented in this sub-section was collected during a marine geophysics demonstration performed by the USAESCH in June 2005 in support of the Culebra, Puerto Rico, Formerly Utilized Defense Site Military Munitions Response Project. The data presented herein was collected in open water sea-trials. Simulated 4-inch, 6-inch and 8-inch projectiles were used during the demonstration. The purpose of the sea-trials was to demonstrate capabilities for characterizing the marine environment for the presence of MEC. The Culebra data was collected using the Geometrics dual-sensor horizontal gradiometer, towed along lines spaced two meters apart. Both sensors were processed so that the final dataset has a 1m nominal line spacing.

Figure 3-4 shows three datasets collected over one of the demonstration areas. The right-most panel shows the background total-field map of the area before seeding. The center panel is produced from data collected at a height of approximately 1.5 meters above the sea floor, the left-most from data collected at 3 meters above the sea floor. Note the significant decrease in signal to noise ratio in the data collected at 3 m compared to that at 1.5 m. Figure 3-4 illustrates that magnetometers with operating characteristics similar to those of the G880/881 can be used to heights of 3 m above the source when simply detecting pieces of ferrous metal similar in size to 4-inch projectiles or larger. However, to detect and differentiate one ordnance item from other nearby items, the sensor(s) needs to be flown no more than about 1.5 m above the sea-floor. The area where these datasets were collected has between 2 to 3 meters of sand overlying a hard acoustic reflector. The reflector is interpreted to be rhyolite basalt associated with cliff outcrops visible along the sea shore approximately 400 meters east of the test area.

Additional data collected during this effort demonstrates that none of the simulated steel items were detected at a distance of 6m below the sensors. Other tests performed on-island show that proximity to the rhyolite bedrock significantly degrades the signal to noise ratio for all test items used during the demonstration.

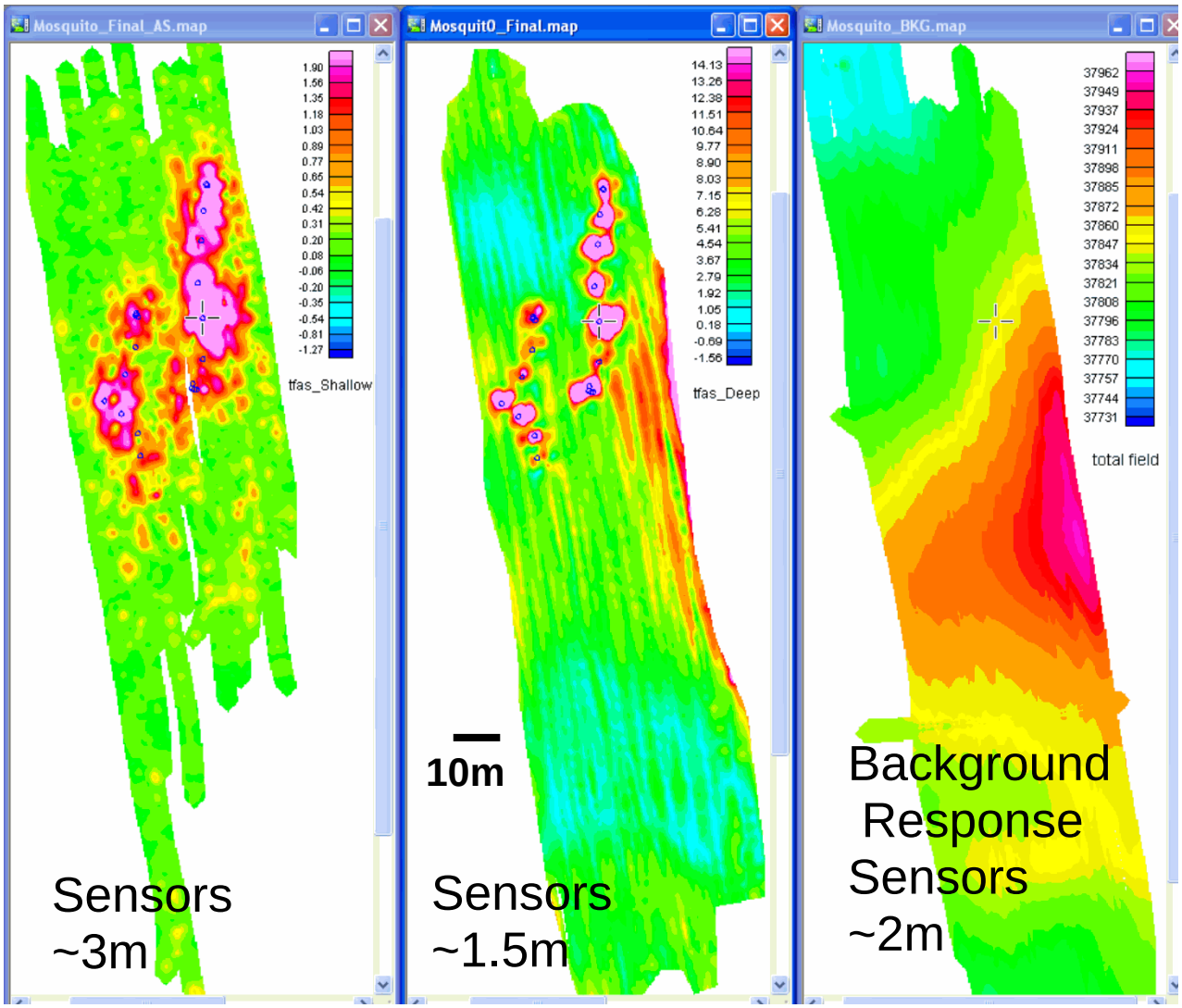


Figure 3-4, results of magnetometer interpretations performed for the Culebra, PR, marine geophysics demonstration. The background response is the measured total field. The two post-seeding datasets show the analytic signal calculated from total field data. The indicated sensor distances are heights above ocean-floor bottom.

3.3 Vessel Propulsion System Interferences

The information presented in this section is based on observations of data collected while operating four different vessel propulsion systems; a single four-stroke 70hp outboard motor, twin 70hp two-stroke outboard motors, a single 6hp two-stroke outboard motor and a single 50-pound thrust electric trolling motor. Table 3-1 presents our observations of interference to magnetometers from these propulsion systems.

Table 3-1
Vessel Propulsion Interference

Propulsion System	**Distance between sensors and propulsion system**	**Interference**	**Remarks**
70hp, four-stroke outboard motor	Between 5m and 17m	None observed	May have contributed to heading effect observed in fixed-array data when sensor was 5m from motor (see sub-section 3.1)
Twin 70hp, two-stroke outboard motors	Between 4 and 8 meters	None observed under normal operation. Engine start sequence did significantly interfere with sensor data	May have contributed to minor heading effects (in the range of +/- 2nT), but is not suspected. Heading effects were easily corrected (reference Feasibility Study for Geophysical Methods for Offshore Munitions Response Surveys-Culebra, PR.)
6hp two-stroke outboard motor	Between 3 and 4 meters	Significant interference observed	Interference was variable and had significant high-frequency content. The interference could not be filtered from the data. Interference likely due to electrical system (see Appendix A)
50-pound thrust electric motor	Between 3.5 and 4 meters	DC offsets observed when changing speeds. Offset value appeared to vary with battery power level	DC offsets in the range of 4 to 12 nT, moderate effort to remove effect from data. Can be easily corrected by maintaining constant throttle setting and using simple heading corrections to remove offset (reference Marine Magnetometer Survey, Main Pond, Aberdeen Proving Ground and Marine Geophysical Mapping of Osborne Pond, Camp Edwards, also see Appendix A)

4. Marine Positioning Capabilities

In this section we evaluate three current positioning systems that can be used to position marine geophysics data. Two are acoustic positioning systems, the ORE Trackpoint II Plus and AquaMap, and one is a computer algorithm, MagLogNT Interpolator. The MagMap2000 positioning algorithm is not evaluated herein because its capabilities have been demonstrated on numerous MEC projects. The MagMap2000 and MagLogNT Interpolator algorithms produce identical results when used to position datasets collected from fixed-arrays.

For the purposes of this report, we assess the positioning systems by how well they reproduce dipole signatures (distinct and well shaped across multiple survey lines) and how well magnetic signatures are reproduced on overlapping survey lines.

We use two terms in this report to define the characteristics of positioning systems, precision and accuracy. We define positioning *precision* as how well a positioning system can register where one measurement was taken with respect to all other neighboring measurements. As an example, if for a particular survey, measurements are taken precisely every 10 cm along a line and the positioning system reports positions for each measurement within 1 cm of where the measurements actually occurred, then we can state that the precision of the reported positions is ±1 cm and the distance between any two measurements is within ±2cm of the actual distance. Figure 4-1 illustrates this example. Precision is critical to reproducing anomaly signatures that can be associated with MEC. Some precision errors are inherent to the positioning system and most cannot be corrected during post processing. Two typical sources of precision errors that can be corrected during post processing are latency and "spikes" in positioning solutions.

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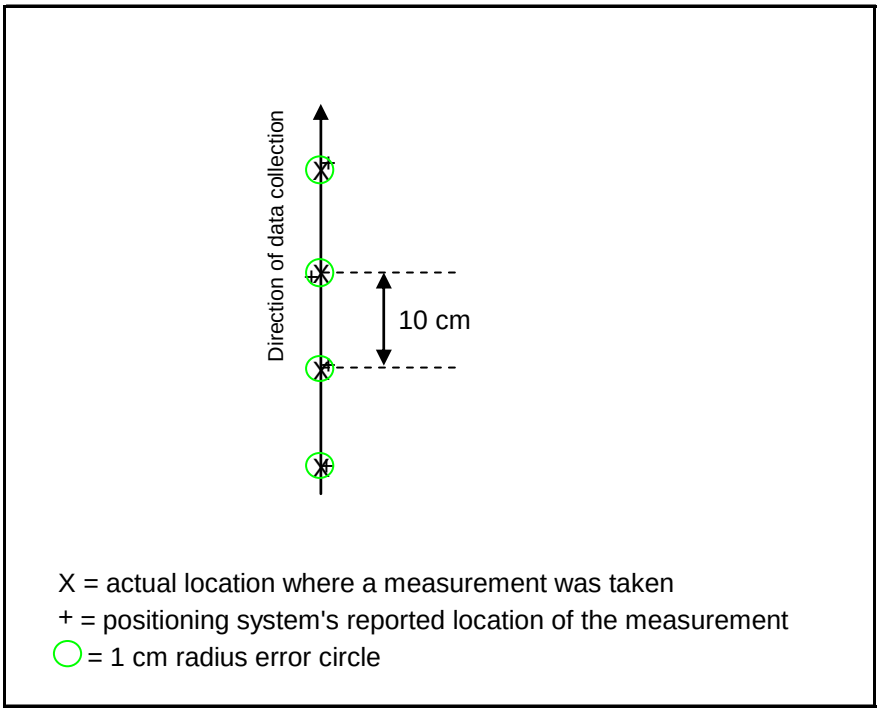


Figure 4-1. Example of how positioning precision is defined.

We define position *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 actual, physical locations on the earth where measurements were taken. Accuracy is critical in being able to return to a specific location where an anomaly is detected and locate its source at that location. Accuracy errors can often be "fixed" as they normally require simple translations to correct (shifting the entire dataset in either a due east or west and/or north or south direction.) If the precision looks good and accuracy errors are suspected, these will normally occur from having used an incorrect sensor offset value either during survey setup or during post processing, or from having an error in the coordinate used, or entered, at the RTK DGPS base station. These errors are easy to identify and correct if one or more known points are detected in the data and can be positively correlated to specific anomalies. In most cases, the terms precision and accuracy need not be differentiated, and the term accuracy can be used to capture all needed information to describe the quality of positioning data.

Figures 4-2 through 4-8 in this section show total field magnetometer data collected from a single sensor of the dual-sensor array. The decision to present only single sensor data is based on availability of funds. This decision does not impact the evaluations or conclusions of this project. All data is corrected for diurnal variations, heading and latency errors. All positioning examples except one are produced from data collected in the Aberdeen Test Center's Shallow Water Demonstration Pond. The one example not from this site presents data collected using the AquaMap positioning system in the San Luis Reservoir in California. For all but the dataset collected in California, we use the fixed array dataset as the basis to

compare position accuracies from all other datasets. This datasets exhibits very good precisions and very clean data with little to no external noise interference. Potential positioning errors are limited to offset values used between the GPS antenna and magnetometer sensor during post-processing. These have been verified and no error is suspected. For convenience, Figures 4-2 through 4-7 have been placed at the end of this section.

Accuracy and precision estimates presented in the following subsections are the result of detailed reviews of various anomaly signatures and locations, and other fine details of the measured magnetic fields. See Figures 4-9 and 4-10 for examples of how anomaly signatures and locations were compared in order to estimate positioning precision and accuracy. For convenience, Figures 4-9 and 4-10 have been placed at the end of this section.

4.1 MagLogNT Positioning System

Figure 4-2 shows the fixed array magnetometer data. This is the same data shown in Figure 3-1. The sensors were flown at a depth of 0.8m ±0.02m with sensor heights ranging from 1.6m (shallow areas) to 2.9m (deep areas) above the bottom over the area surveyed. The precision of this data is estimated to be ±5cm typical. In some areas the reproduced magnetic signatures show precision errors that approach ±10cm, in others there are no perceived errors. The accuracy of this dataset is believed to be very high based upon the fact that about half of the anomalies in the Blind Grid are centered between 0cm and 20cm over Blind Grid burial locations (see Figure 4-9 for an example where the anomaly and Blind Grid location are coincident). Some anomalies in the Blind Grid are located up to 50cm from a Blind Grid Location. The possible causes for such discrepancies are 1) the item shifted during burial, 2) the item moved during settlement as the pond was filled with water, 3) the item was moved as a result of being dragged by our equipment, 4) interference between closely spaced items, or 5) positioning inaccuracies. Since many of the anomalies do fall very close to Blind Grid locations and since there are no differences in any of the data collection parameters for the fixed array dataset, we do not believe positioning inaccuracies in excess of 20cm exist in the data. The dynamic accuracy of the RTK DGPS system used during this project is estimated to be 20cm based on accuracy tests performed with the same model system at other MEC sites (reference Quality Assurance Made Easy Working with Quantified, Site-Specific QC Metrics, proceedings of the UXO/Countermine Forum, 2004).

Figure 4-3 presents the deep deployment magnetometer dataset positioned using the MagLogNT Interpolator. This is the same figure shown in Figure 3-3, and is reproduced here to illustrate the capabilities of the MagLogNT Interpolator routine. The array was towed 19 meters behind the tow-point and was 22.4 meters behind the DGPS antenna. It was towed at a depth of 1.8m. This figure shows dipoles that are reproduced very well. We estimate the precision of this dataset to be ±5cm typical. In some areas the reproduced magnetic signatures show precision errors of ±10cm, in others there are no perceived errors. Comparing the dipole centers between the fixed array dataset and the deep deployment towed array dataset, the accuracy of the latter is estimated at 25cm (typical) when straight line profiling is achieved. In some areas along straight-line profiles the reproduced magnetic signatures show accuracy differences of approximately 50cm, others show no perceived

accuracy errors. In turn-around areas, the accuracy of reproduced anomaly signatures degrades to 3m or more.

Collecting data on how wave conditions affect the data from the towed sensor platform was difficult since we did not encounter high wave conditions during the survey period. Figure 4-4 presents the magnetometer data collected under simulated wave conditions and positioned using the MagLogNT interpolator routine. Since the positioning systems were hard mounted to the boat, the crew simulated wave conditions on the positioning systems by rocking the tow vessel from side to side during the course of the survey. The roll angles recorded during the survey were between ±7 degrees. The DGPS antenna was 1.25 meters starboard of the roll-pitch center of the vessel at a height of 2.7 meters, and swung through an arc approximately 0.8m in length with a period of approximately two seconds. To facilitate comparison of positioning solutions, the anomaly locations shown in this figure are those from the fixed array dataset positioned with the interpolator algorithm, which are shown in Figure 4-2. Figure 4-4 shows fairly well reproduced dipoles. We estimate the precision of this dataset to be ±15cm typical. In some areas the reproduced magnetic signatures show precision errors of approximately ±25cm, in others there are no perceived errors. Comparing dipole centers between the fixed array dataset and the towed array dataset collected under simulated wave conditions, we estimate the accuracy of the latter to be 35cm (typical) when straight line profiling is achieved. In some areas the reproduced magnetic signatures show accuracy errors of 70cm, in others there are no perceived accuracy errors.

4.2 ORE TrackPoint II Plus Positioning System

Figures 4-5 presents the deep deployment magnetometer dataset positioned using the ORE Trackpoint II Plus. This is the same magnetometer data used to produce Figure 4-3, except it is positioned using the ORE Trackpoint II Plus. The array was towed 19 meters behind the tow-point and was 22.4 meters behind the DGPS antenna, at a depth of 1.8m. To facilitate comparing the ORE positioning solutions to the interpolator positioning solutions for the same magnetometer data, the anomaly locations in this figure are those from the interpolator positioned data shown in Figure 4-3. Figure 4-5 shows fairly well reproduced dipoles. We estimate the precision of this dataset to be ±35cm typical. In some areas the reproduced magnetic signatures show precision errors of approximately ±60cm, in some areas the precision is as low as ±15cm. Comparing the dipole centers between the fixed array dataset and the data positioned using the ORE Trackpoint II Plus, the accuracy of the latter is estimated to be 25cm (typical) when straight line profiling is achieved. In some areas along straight-line profiles the reproduced magnetic signatures show accuracy errors of approximately 50cm, others show no perceived accuracy errors. In turn-around areas in open water, the accuracy of anomaly locations degrades to approximately 2.5m. In turnaround areas near shore, our data shows that precision and accuracy errors increase significantly, to the point of not being able to interpret dipole signatures. See the track plots near the northern and southern boundaries of the area surveyed in Figure 4-5 for examples; the submerged platform always follows a gentle arc behind the vessel while turning, it never changes direction abruptly as these track plots suggest. This increase in positioning errors is attributed

to multi-path acoustic returns detected at the hydrophone, which result from acoustic signals reflecting between multiple acoustic reflectors (the water-air interface, the water-water bottom interface and the water-survey vessel interface.)

Figure 4-6 presents the magnetometer data collected under simulated wave conditions and positioned using the ORE TrackPoint II Plus. To facilitate comparing positioning solutions, the anomaly locations shown on this figure are those of the fixed array dataset positioned with the interpolator algorithm, which are the same anomaly locations shown in Figures 4-2 and 4-4. Figure 4-6 shows the larger dipole anomalies to be marginally well reproduced, while the smaller anomalies are poorly reproduced. We estimate the precision of this dataset to be ±50cm typical. In some areas the reproduced magnetic signatures show precision errors of ±80cm or more, in others the errors were approximately ±20cm. Comparing dipole centers between the fixed array dataset and the dataset collected under simulated wave conditions and positioned using the ORE Trackpoint II Plus, the accuracy of the latter is estimated to be 60cm (typical). In some areas the reproduced magnetic signatures showed accuracy errors of 1m, in others, the accuracy errors were as low as 20cm. Some anomalies could not be reproduced due to precision errors.

4.3 AquaMap Positioning System

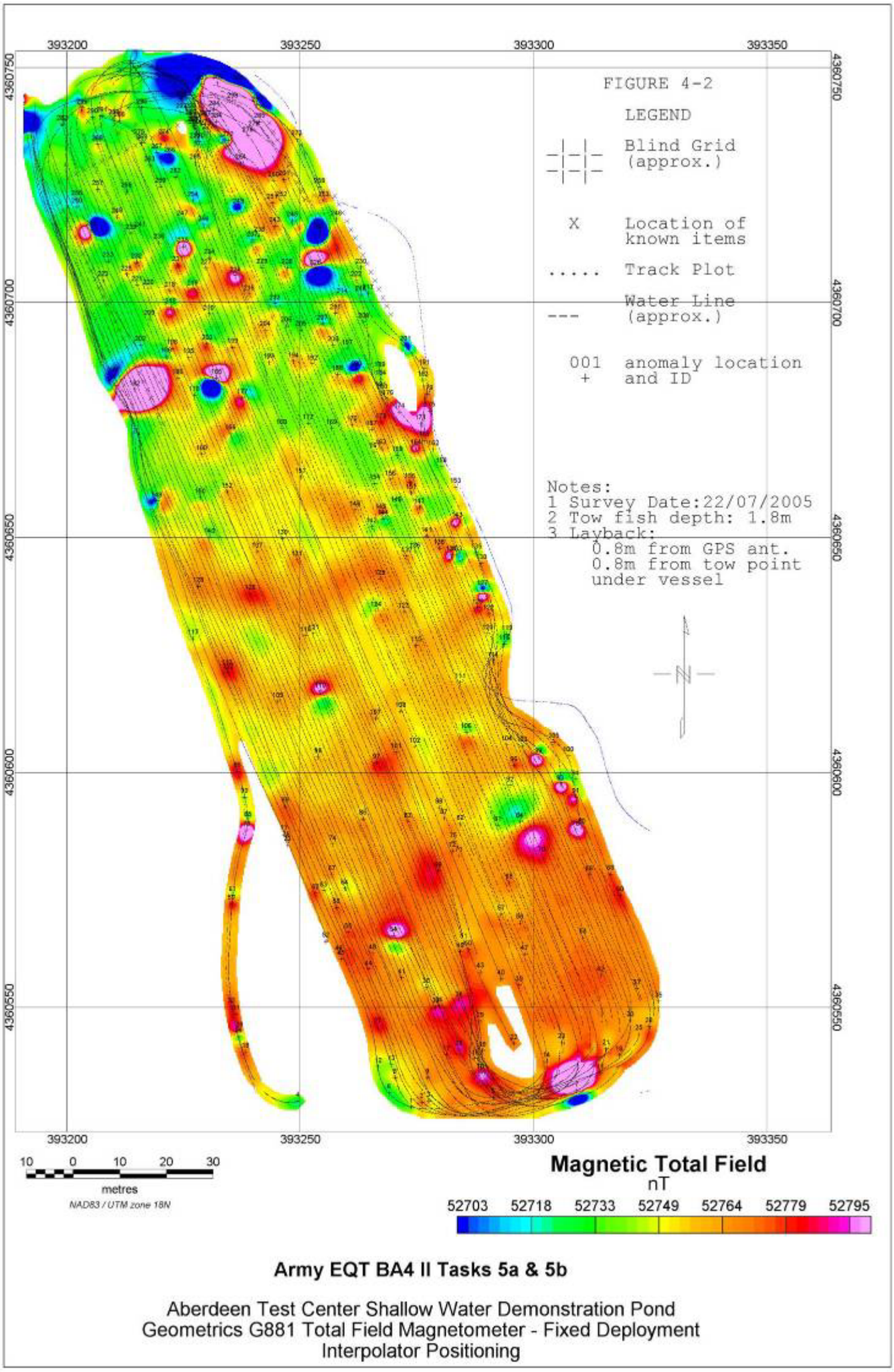
Figure 4-7 presents magnetometer data collected using the Aquamap positioning system. This dataset was collected over a small evaluation area where four 2-inch diameter by 12-inch long pieces of pipe were placed on the water bottom. The locations of the pipes were surveyed using the AquaMap system, and are believed to be accurate to within 0.8m, which accounts for inaccuracies in the positioning system and inaccuracies in getting the transponder over the pipes. The precision of this data is estimated to be ±10cm typical. The accuracy is difficult to determine since the accuracy in the pipe locations is fairly large (≈.8m), however, we presume the accuracy is in the range of 15cm to 50cm based upon the reproducibility of anomalies over the recorded pipe locations. It is possible the accuracies are closer to the 15cm value but we have insufficient data to conclusively support that finding.

4.4 Summary of Positioning Precisions and Accuracies

Table 4-1 summarizes the positioning precision and accuracy estimates presented in the preceding sub-sections.

Table 4-1
Summary of Estimated Precisions and Estimated Accuracies For Marine Positioning Systems

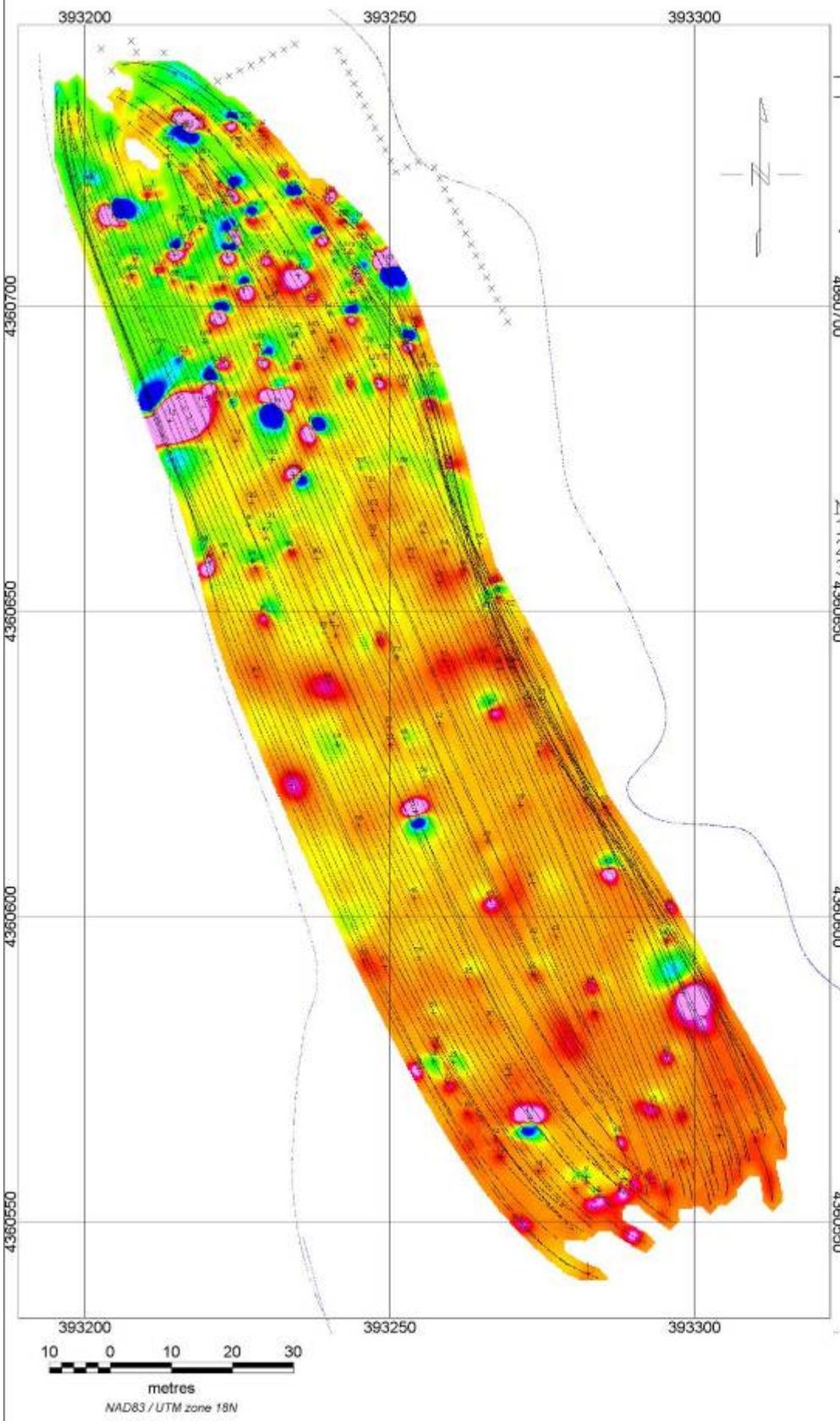
Positioning System	Deployment Conditions	Estimated Precision	Estimated Accuracy
MagLogNT Interpolator or MagMap2000	Fixed array, no waves	Typical:2cm to 5cm	Typical:10cm to 20cm
		Range :0cm to 10cm	Not determined
MagLogNT Interpolator	Towed array, no waves	Typical:5cm	Typical:25cm
		Range :0cm to 10cm	Range :0cm to 50cm
MagLogNT Interpolator	Towed array, simulated waves	Typical:15cm	Typical:35cm
		Range :0cm to 25cm	Range :0cm to 70cm
ORE Trackpoint II Plus	Towed array, no waves	Typical:35cm	Typical:25cm
		Range :15cm to 60cm	Range :0cm to 50cm
ORE Trackpoint II Plus	Towed array, simulated waves	Typical:50cm	Typical:60cm
		Range :20cm to 80cm	Range :20cm to 1m
AquaMap	Towed array, no waves	Typical:10cm	Typical:15cm to 50cm
		Range : not determined	Range : not determined



Army EQT BA4 II Tasks 5a & 5b

Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Fixed Deployment
Interpolator Positioning

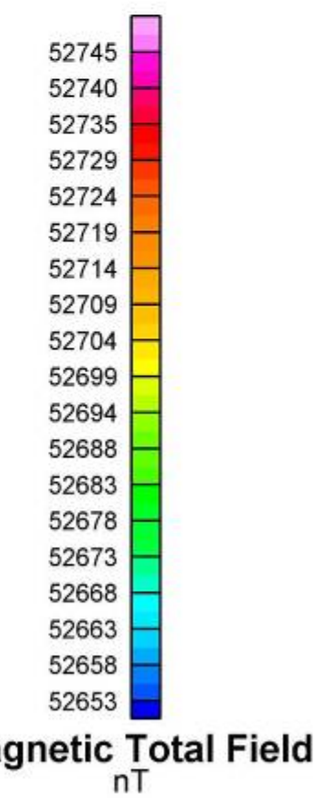
FIGURE 4-3



LEGEND

_|_|_	Blind Grid (approx.)
X	Location of known items
.....	Track Plot
---	Water Line (approx.)
001 +	anomaly location and ID

Notes:
1 Survey Date:22/07/2005
2 Tow fish depth: 1.8m
3 Layback:
22.4m from GPS ant.
19m from tow point
18m behind vessel



Army EQT BA4 II Tasks 5a & 5b

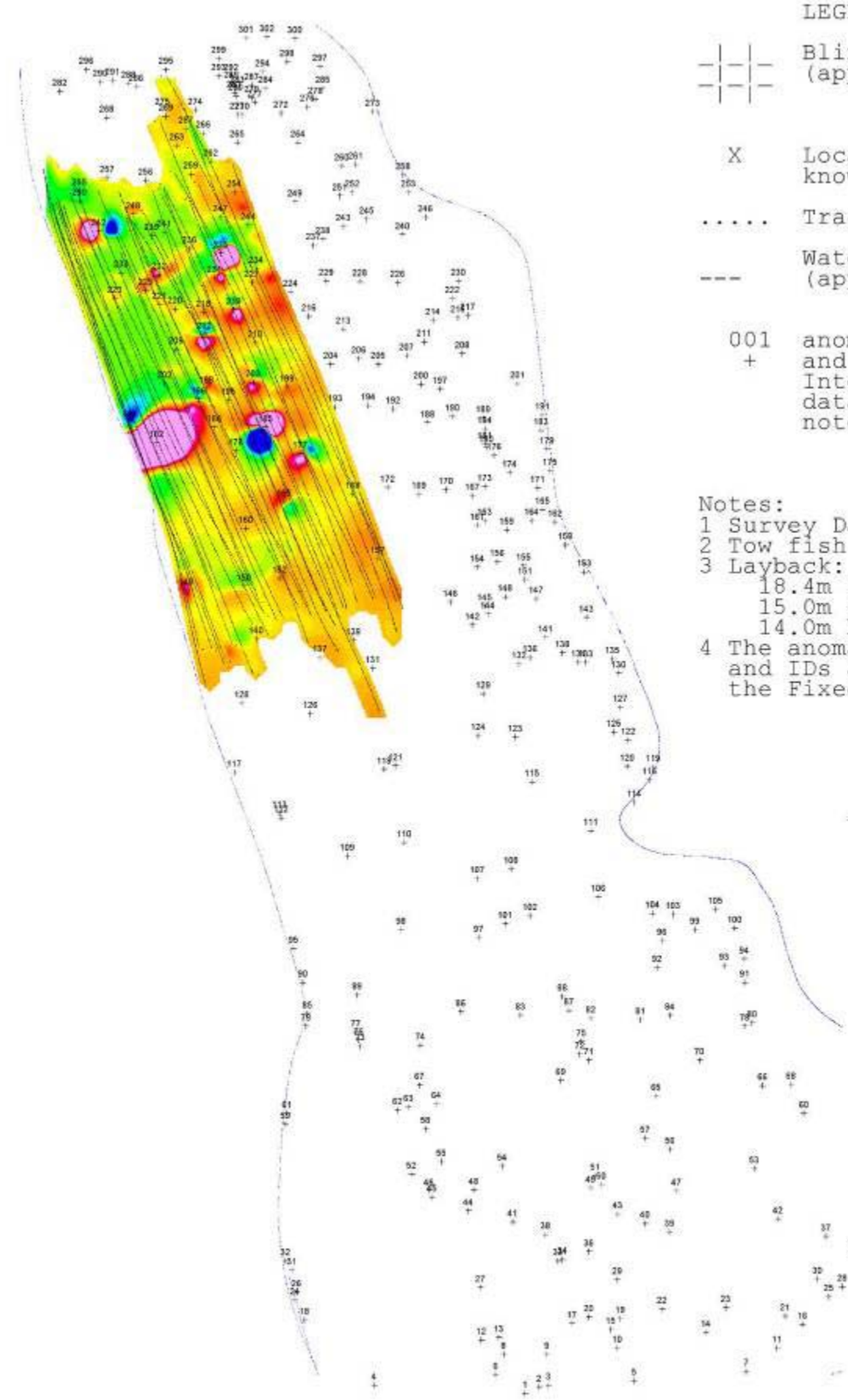
Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Deep Deployment
Interpolator Positioning

FIGURE 4-4

LEGEND

-|-|- -|-|-	Blind Grid (approx.)
X	Location of known items
.....	Track Plot
---	Water Line (approx.)
001 +	anomaly location and ID from Interpolator dataset (see note 4)

Notes:
1 Survey Date:22/07/2005
2 Tow fish depth: 1.3m
3 Layback:
18.4m from GPS ant.
15.0m from tow point
14.0m behind vessel
4 The anomaly locations and IDs are those from the Fixed Array dataset



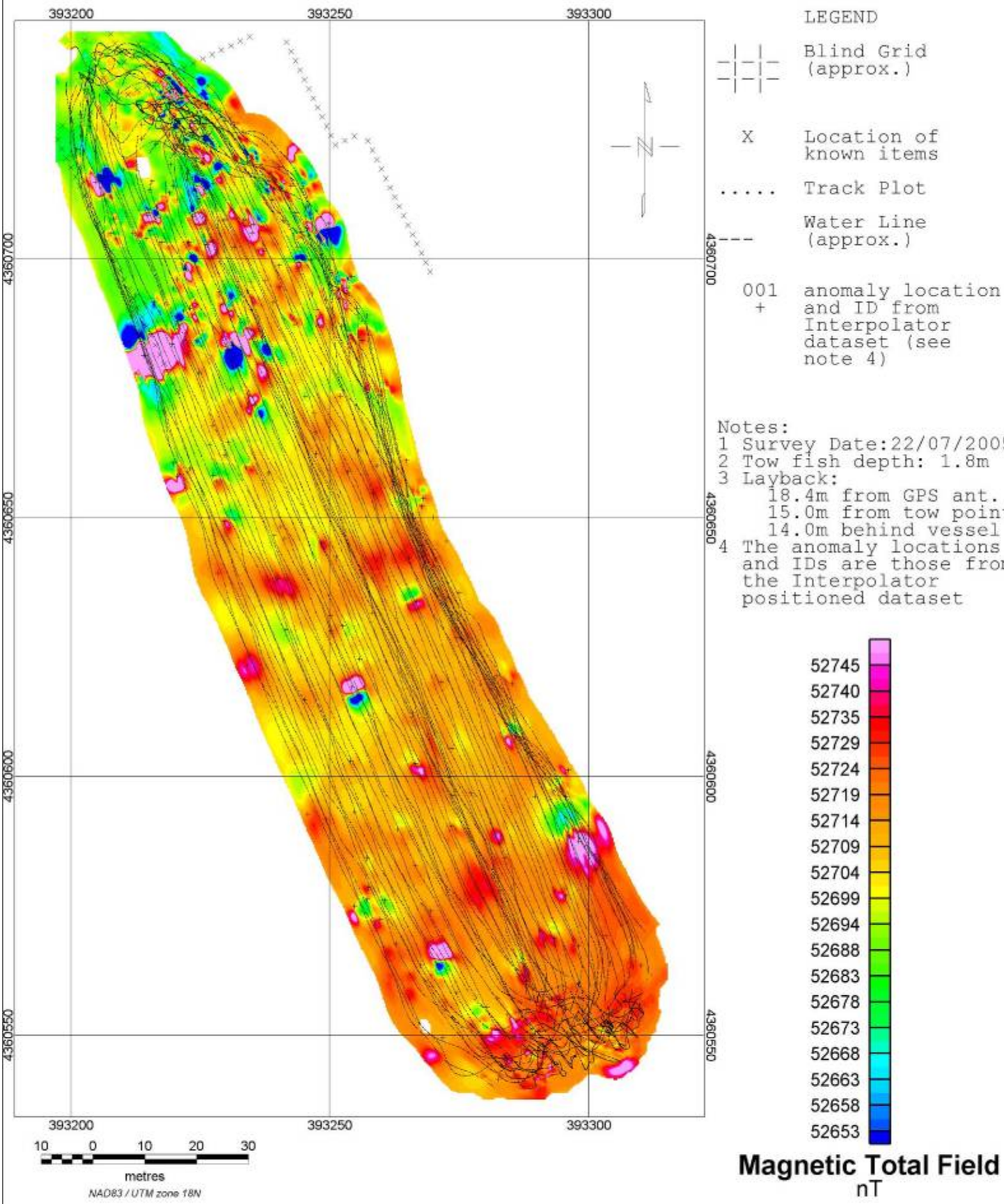
10 0 10 20 30
metres
NAD83 / UTM zone 18N

Magnetic Total Field
nT
52703 52718 52733 52749 52764 52779 52795

Army EQT BA4 II Tasks 5a & 5b

Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Rocking Deployment
Interpolator Positioning

FIGURE 4-5

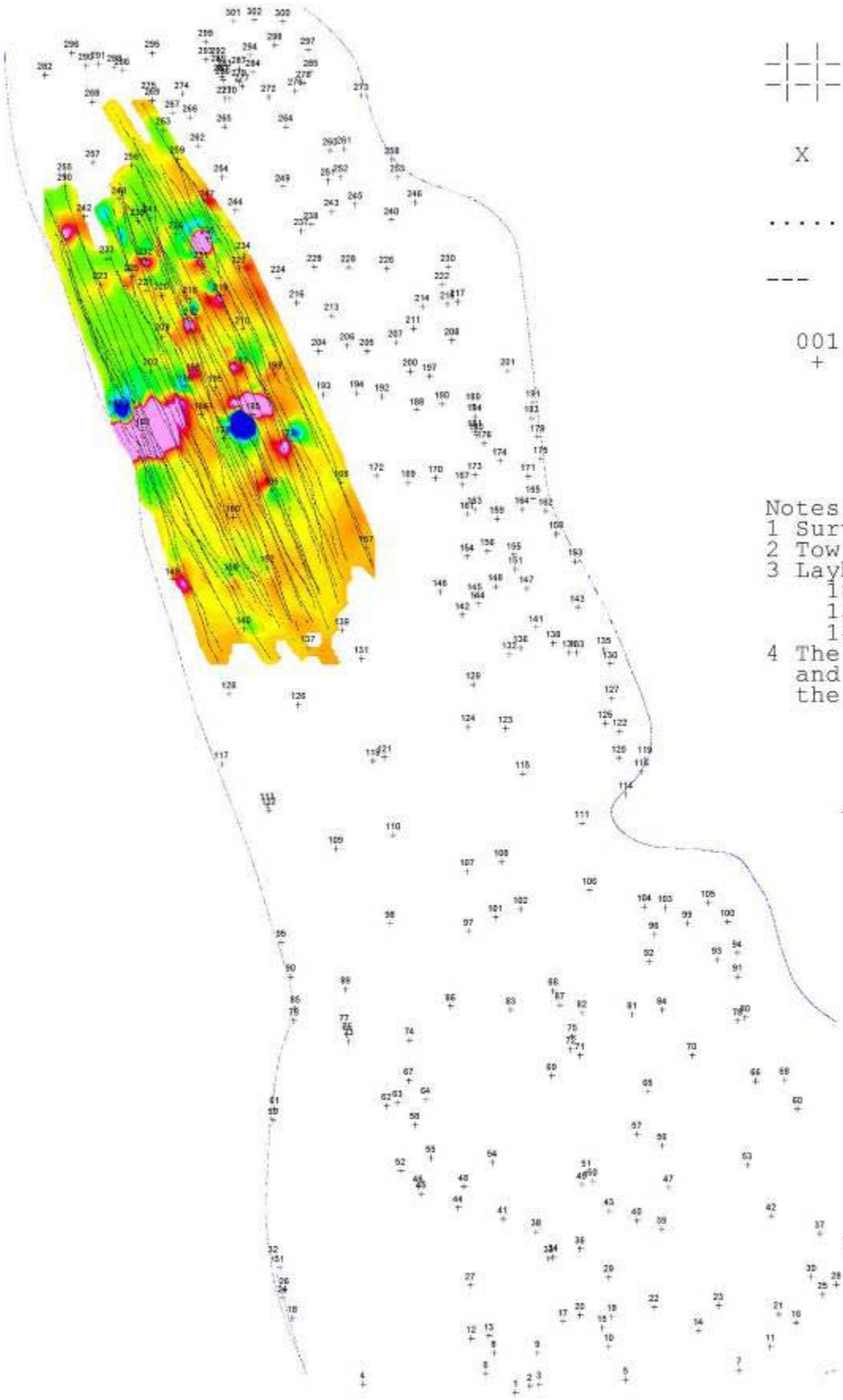


Army EQT BA4 II Tasks 5a & 5b

Aberdeen Test Center Shallow Water Demonstration Pond

Geometrics G881 Total Field Magnetometer - Deep Deployment
ORE TrackPoint II Plus Positioning

FIGURE 4-6



LEGEND

_|_|_ -|-|- -|-|-	Blind Grid (approx.)
X	Location of known items
.....	Track Plot
---	Water Line (approx.)
001 +	anomaly location and ID from Interpolator dataset (see note 4)

Notes:
1 Survey Date:22/07/2005
2 Tow fish depth: 1.3m
3 Layback:
18.4m from GPS ant.
15.0m from tow point
14.0m behind vessel
4 The anomaly locations and IDs are those from the Fixed Array dataset

N

10 0 10 20 30
metres
NAD83 / UTM zone 18N

Magnetic Total Field
nT
52703 52718 52733 52749 52764 52779 52795

Army EQT BA4 II Tasks 5a & 5b

Aberdeen Test Center Shallow Water Demonstration Pond
Geometrics G881 Total Field Magnetometer - Rocking Deployment
ORE Trackpoint II Plus Positioning

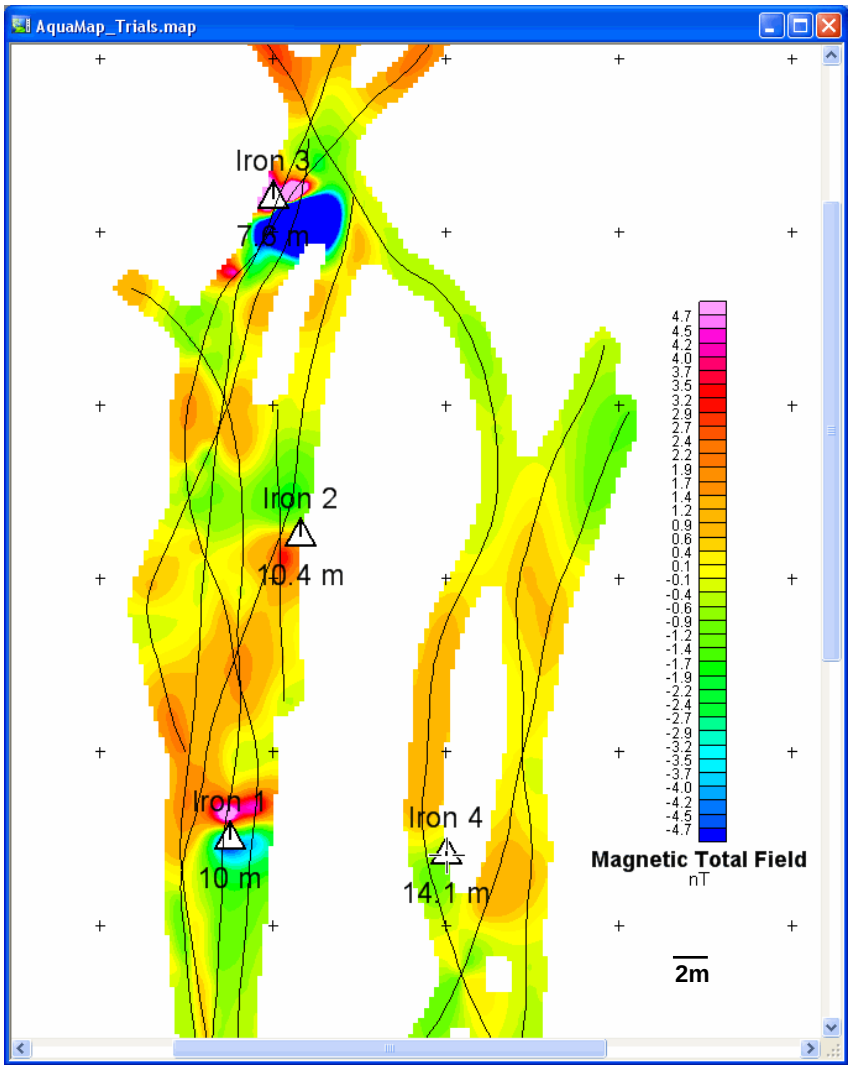
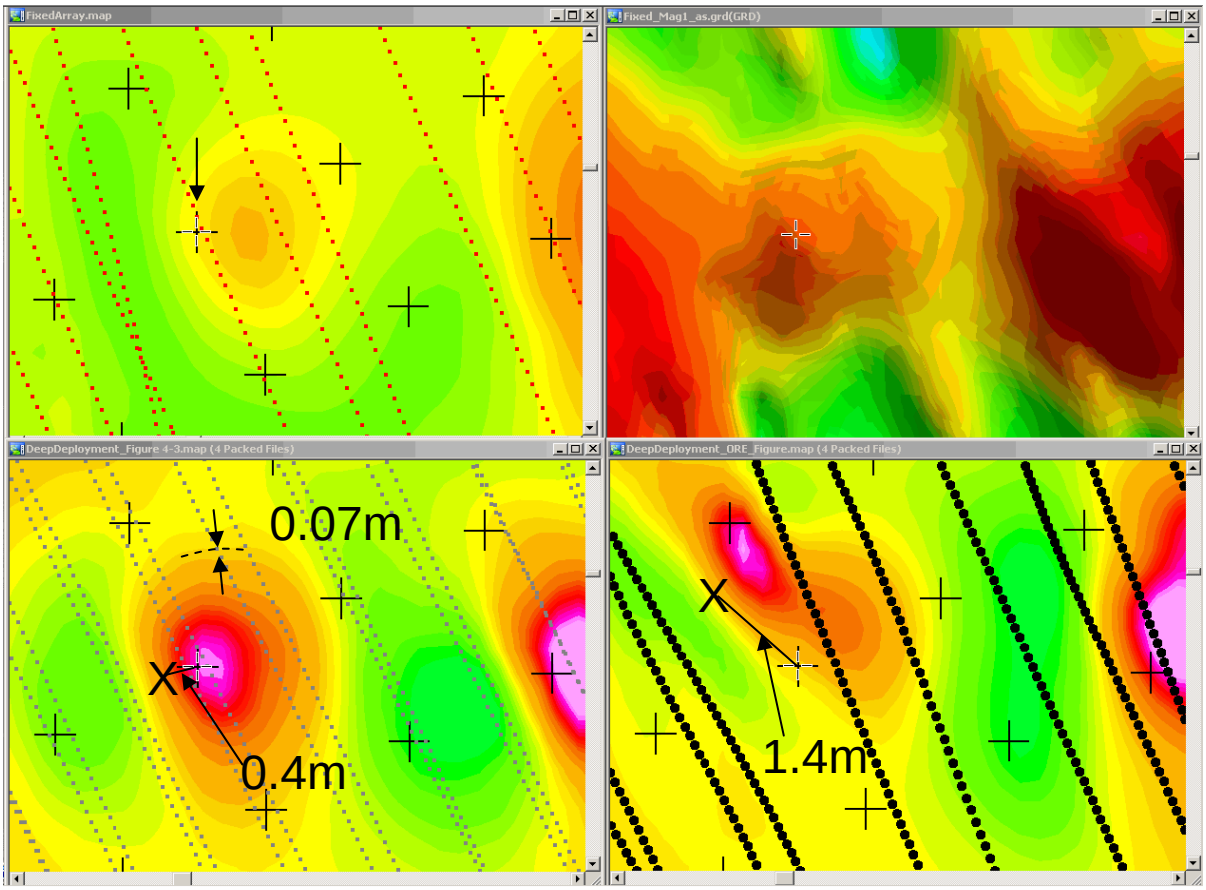


Figure 4-7. Example of AquaMap positioned magnetometer data. Sensor depth maintained between 6.8m and 7.4m

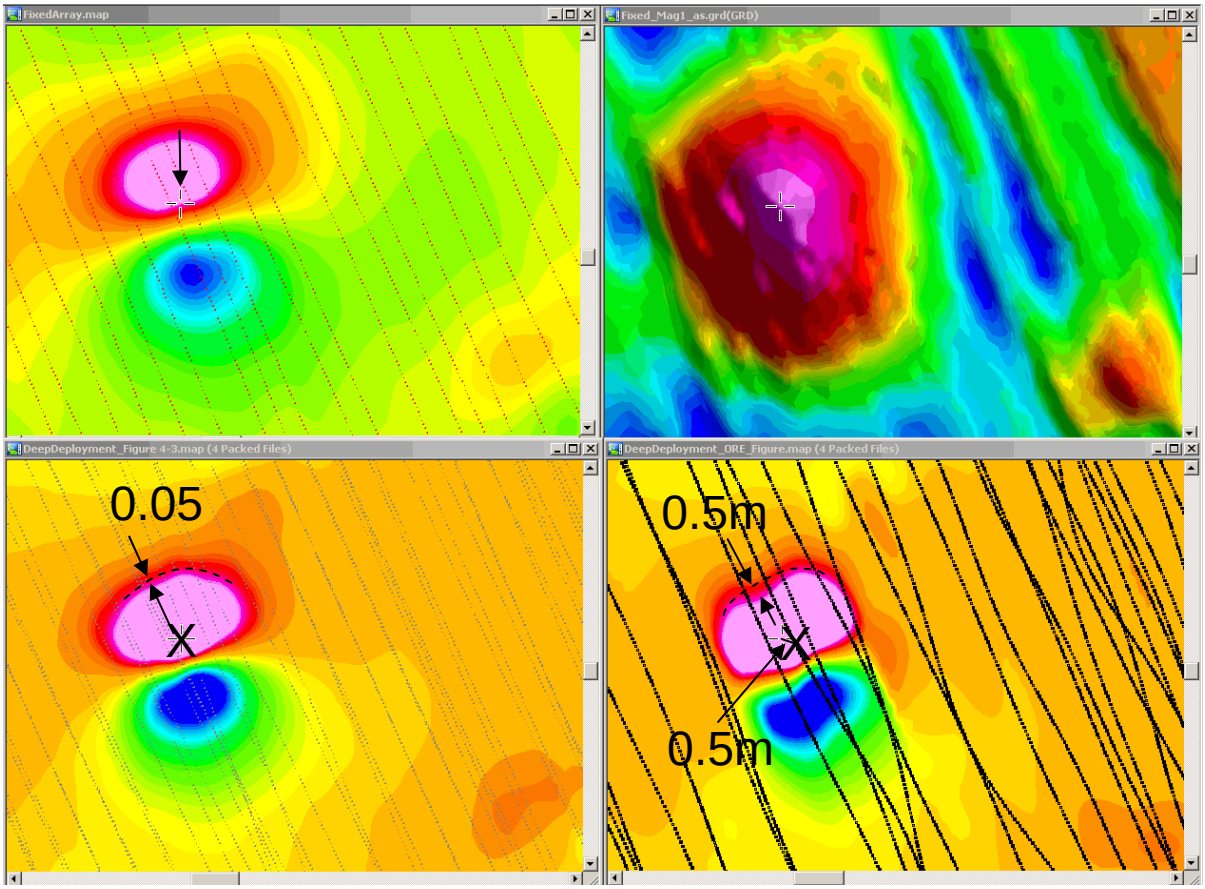
Panel A Panel B



Panel C Panel D

Figure 4-9. Example of how qualitative estimates of positioning precision and accuracy were derived over anomaly (denoted by arrow in Panel A) located at blind grid coordinate 4,360,687.28N, 393,243.2E. Other blind grid centers are denoted by the "+" symbols. Panel A shows the fixed array total field map and Panel B shows the corresponding analytic signal map. This dataset shows the anomaly located directly over the center of the grid cell. Panel C shows the deep-towed dataset positioned with the MagLogNT interpolator and Panel D the same dataset positioned with the ORE Trackpoint II Plus USBL. The "x" symbols denote the interpreted anomaly locations from these datasets. Notice in Panel C the minor deflection of 0.07m in the northern portion of reproduced magnetic anomaly. This minor deflection is attributed to precision error. Other less pronounced precision errors are evident in this panel. The accuracy errors are too great in Panel D to allow meaningful estimates of precision. No noticeable precision errors are evident in Panel A. The small dots in Panels A, C and D represent the positioning solutions for each dataset.

Panel A Panel B



Panel C Panel D

Figure 4-10. Example of how qualitative estimates of positioning precision and accuracy were derived over anomaly (denoted by arrow in Panel A) located in open shallow water area at 4,360,617.3N, 393,254.3E. Panel A shows the fixed array total field map and Panel B shows the corresponding analytic signal map. The white "+" symbol denotes interpreted anomaly location from the fixed array dataset. Panel C shows the deep-towed dataset positioned with the MagLogNT interpolator. The "x" symbols denote the interpreted anomaly locations from these two datasets (The "x" and the "+" in Panel C are about 0.02m apart). Notice in Panel C the minor deflection of 0.05m in the northern portion of reproduced magnetic anomaly. This minor deflection is attributed to precision error. Other less pronounced precision errors are evident in this panel. Notice in Panel D the deflection of 0.5m in the northern portion of reproduced magnetic anomaly. This deflection is attributed to precision error. Other less pronounced precision errors are evident in this panel. No noticeable precision errors are evident in Panel A. The small dots in Panels A, B and C represent the measurement locations for each dataset.

5. Conclusions

The current state of the art in marine magnetometer surveying for ferrous MEC is demonstrated in this report. This report also presents four options available to position marine geophysical data: the ORE Offshore Trackpoint II Plus acoustic positioning system, the Desert Star AquaMap acoustic positioning system, the Geometrics, Inc. MagLogNT Interpolator algorithm, and the Geometrics, Inc. MagMap2000 algorithm.

Marine magnetometers with operating characteristics similar to the Geometrics G880/881/882 units are very sensitive to small changes in the measured magnetic field. Areas having little geologic interference can have total field anomalies as small as 1.5 to 2 nT and signal to noise ratios of 10:1 or more. The primary benefits of marine magnetometer surveying is the ability to maintain the sensor(s) at essentially the same geoid height and the sensor deployment platform can be designed to have little to no interference on the magnetometer measurements. Towing individual sensors or sensor arrays allows data to be collected at great distances from potential noise or interference sources on the survey vessel. In some cases, where a fixed array is attached directly to the survey vessel and interference is observed in the measurements, the combination of data acquisition protocols and post-processing techniques can often reduce or eliminate the noise and interference effects. The greatest challenge to marine magnetometer surveying is accurate and precise positioning of the measured data.

Positioning options for marine geophysical data range from the simple: the fixed array platform mounted to the survey vessel, to the complex: ultra-short baseline acoustic positioning of towed submerged platforms. There is no one system that is better than all others for all sensor deployment platforms. When properly deployed and operated within their design constraints, all of the positioning systems we evaluated can provide positioning solutions with adequate quality to accurately position the detector readings so that the data can be interpreted to detect and locate underwater ferrous MEC.

The easiest deployment method is the fixed array attached to the survey vessel. This deployment method is limited to geophysical sensors that are not significantly affected by the survey vessel or equipment on the vessel. Positioning these arrays is simple and straight forward using commonly available software. Arrays that can be towed either on or beneath the water surface can be accurately positioned using currently available computer algorithms designed specifically for this purpose. Using algorithms to calculate measurement positions will be limited to straight-line profiling, and for submerged platforms the sensor depth is needed to provide accurate solutions. Use of the algorithms is generally simple and straight forward. If towing a platform directly behind the tow-point is not possible due to site constraints (such as a cross-current), and other constraints preclude using a fixed array, the geophysical sensors will need to be positioned using an acoustic positioning system. Ultra-short baseline and long baseline acoustic positioning systems can provide positioning solutions meeting the precision and accuracy needs to accurately position the detector readings to allow interpretation of the geophysical data to detect and locate ferrous targets which could be MEC. Long baseline system can be relatively simple to deploy and operate.

However, the area these types of systems can cover in a single setup will generally be limited to between 1 hectare (2.5 acres) to 6.25 hectares (15.4 acres), and are dependent on system design. Ultra-short baseline systems are complex and require specialized training and equipment. Our evaluations suggest this type of positioning system is best suited in rivers and other areas where cross-current will shift the towed platform left or right of the survey vessel's path. Short baseline acoustic positioning technologies were not evaluated because a system could not be identified during the time span of this project.

Of the positioning systems evaluated, all but two require straight line profiling to successfully position geophysical measurements with sufficient accuracy to relocate detected anomalies. Fixed arrays and platforms positioned with long baseline acoustic technologies do not require straight line profiling to provide accurate positioning solutions. However, straight line profiling simplifies heading corrections (for magnetometer platforms) and maximizes production. Straight line profiling is recommended for all marine geophysical surveys to detect ferrous MEC. If the purpose of the survey is solely to detect anomalies for the purpose of characterizing potential MEC presence, any of the systems evaluated herein will provide useable positioning solutions without straight line profiling.

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Appendix A
Propulsion Systems Static Tests

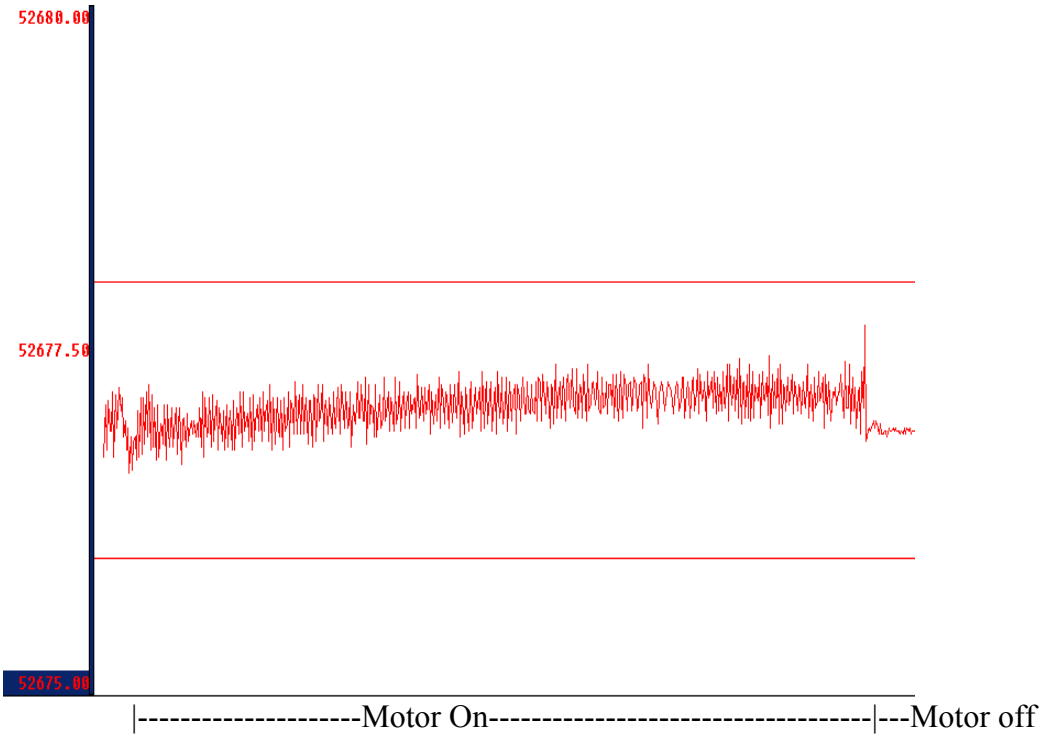

Figure A-1, Static test with 6HP outboard motor. Distance between motor and sensor is approximately 16 feet. The abrupt change towards the end of the line is where the outboard motor was turned off. Note the significant interference to the measured response.

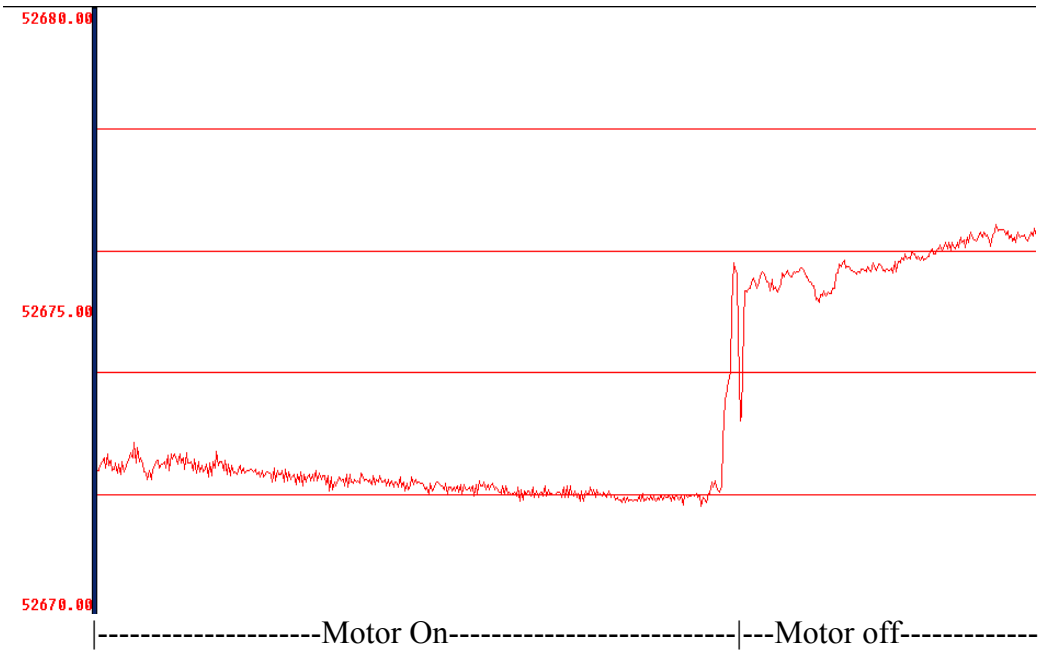

Figure A-1, Static test with 50-pound thrust trolling motor with the Motor running at full throttle. Distance between motor and sensor is approximately 11 feet. The abrupt change towards the end of the line is where the motor was turned off. Note the lack of significant interference when the motor is operating. The only effect is a DC shift in the measured response.