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Technology Demonstration Report (TDR)

for

Underwater Survey Equipment

in support of

Explosive Remnants of War (ERW)

Technical Survey Operations

Revision 1.0

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Prepared by:

Orca Maritime Inc.

Prepared for:

Geneva International Centre for Humanitarian Demining

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1 Introduction

1.1 Background

Throughout the world, explosive remnants of war (ERW) remain an international problem. The survey of contaminated areas and clearance of land-based ERW have been addressed through established programs and procedures to mitigate the risks of these hazards. But as communities, nations, and industries move into the maritime environment, underwater ERW is coming to the forefront as a threat to operations in the construction, energy, mining, fishing, and tourism industries. ERW from amphibious battles, historic ordnance dumpsites, sunken ships and aircraft laden with ordnance, naval mining, littoral "live fire" training areas, and other war-related operations that occurred inland and near coastal waters, pose a hazard to socio-economic development.

With regard to underwater ERW survey and clearance, very little has been done to establish efficient and cost effective methods of identifying and mapping ERW concentration areas. Current methods are often relatively low-tech, slow, inaccurate, and expensive. Like land-based survey and clearance operations, underwater site management is crucial to safe and expeditious clean up efforts. Accurate mapping is the foundation on which a robust plan is built. By establishing an underwater geographic information system (UGIS), remediation progress and hazard removal are monitored and managed through a systematic approach. The UGIS displays both detected ERW and other information that is important to the project, such as project boundaries, sensitive environmental areas, depth changes, etc. The UGIS for this demonstration is compatible with, and could potentially be an "underwater" extension of GICHD's Information Management System for Mine Action (IMSMA). It essentially uses ArcGIS to plan and evaluate progress of the underwater ERW project. Through periodic remapping during the course of a clean-up operation, teams can ensure that hazardous items are removed while simultaneously monitoring the environmental impact of operations, enabling them to take the necessary precautions to minimize potential damage to sensitive underwater ecosystems.

1.2 Demonstration Objectives

The technology demonstration held from 23 March 2015 through 10 April 2015 assessed the potential of new technologies and evaluated the performance and characteristics of commercial-off-the-shelf (COTS) equipment and software. The results of this demonstration are intended for use by National Mine Action Authorities (NMAA), operators and donors to initiate the concept of identifying equipment options for underwater ERW projects and to inform procurement decision makers of some of the new technologies available for use in this field. The need to evaluate underwater Search, Classify and Map (S/C/M) technology for ERW remediation is crucial to ultimately establishing universal standards for underwater data collection, analysis, storage, and underwater site management. The equipment and software evaluated during the technology demonstration was not intended to be the "only" solution, or cover the spectrum of potential alternatives. The equipment was selected as one potential "set" of equipment and software to employ for ERW technical surveys, based on the experience of Orca Maritime in underwater EOD/underwater mapping operations and discussions with the GICHD sponsor of the technology demonstration.

The demonstration was conducted in order to provide an independent assessment of the suitability and effectiveness of underwater sensor equipment for use in the global ERW survey and clearance operations in the "in-shore" (0-5m depth) and "near-shore" (5-50m depth) zones.

Specifically, the following sensors were demonstrated and their detection capabilities were evaluated against representative (inert) underwater ERW samples:

- High frequency side scan sonar, combined with interferometric bathymetry from autonomous unmanned vehicles (AUVs);

- Total field magnetometer towed by an AUV;
- Multi-senor gradiometer magnetometer towed by a surface vessel;
- Diver underwater navigation system. This system was not used for initial detection, or "area survey" of the area. Rather, it was used to reacquire previously detected targets, to gather more detailed identification information; and
- High frequency scanning sonar and video camera from remotely operated vehicles (ROV). As with the diver navigation system, the ROV-mounted sensors were not used for target identification, not initial area survey.

Demonstration objectives included:

- Evaluation of represented sensor technologies and verification of their functionality, applicability, and utility within the operational parameters of the test environment.
- Introduction of remotely operated vehicle (ROV) technology to investigate and record with video footage suspected ERW at locations "handed off" from detection sensors.
- Testing a diver-held sonar and navigation system used to investigate suspected ERW at locations "handed off" from detection sensors.
- Evaluation of the utility of integrated detection sensor data, investigation information (video, diver sonar recordings) and other geospatially referenced information (overhead imagery, nautical charts, etc.) in an underwater geographic information system (UGIS) for use in underwater ERW remediation site management, QA/QC, and record keeping.

To achieve these objectives, the demonstration accomplished the following:

- Conducted open water testing verifying the functionality of all system components and capabilities in a simulated operational environment.
- The processing of all data from the represented sensors, rendering all data layers and/or icons in a comprehensive UGIS for display on a standard personal computer.

Deviations from the originally proposed plan for the technology demonstration:

- The smaller of the two ROVs, the SeaBotix LBV200, was not demonstrated in this technology demonstration. The utility of the LBV200 was reconsidered after using the larger vLBV300, which is the minimum size ROV for meaningful work for ERW technical surveys. Although there are some cases where the LBV200 could be used, they are the exception. Low thrust capability, the lack of a scanning sonar and navigation system (on the model available for this demonstration), and the underwater visibility conditions present in both fields of the demonstration were considered prohibitive for this ROV.
- The towed side scan sonar was not employed for this demonstration. In addition to the fact that a simple towed side scan sonar is not considered new technology, the demonstration team quickly recognized that the decisive sensor to conduct search, classify, map (S/C/M) missions as part of a technical survey for underwater ERW is the magnetometer. In many cases during this demonstration, the side scan component of multiple data sets collected by the AUVs did not indicate any target when, in fact, the magnetometer recorded valid indications of the ERW simulators. Since the AUV surveys were conducted first, the vessel-towed side scan sonar, lacking a magnetometer counterpart or ability to tow the magnetometer "in tandem", was not considered relevant by itself in this mission area.

1.3 Authority

The demonstration was authorized and sponsored by the Geneva International Center for Humanitarian Demining.

2 Equipment Demonstrated

The original Demonstration Plan included the operation of an airborne unmanned vehicle (AUV) – mounted magnetometer from Broadband Discovery Systems. Due to unforeseen circumstances, the BDS system was not able to participate in the demonstration during the scheduled dates.

2.1 Autonomous Underwater Vehicle (AUV)

The Ocean Server Technology IVER3 580 AUV platform carries a variety of underwater sensor technology. With a standard length of 150cm to 215cm and a weight of less than 38.5kg, the IVER3 580 provides a very portable capability for use in small boats or from shore. The AUV used for this demonstration was equipped with a Klein 3500 combination side scan and interferometric bathymetry sonar, an extended range Doppler Velocity Log for 80+ meter bottom lock and Doppler Velocity Log, and magnetometer when towing the Marine Magnetics Explorer "mag tail" sensor. It carried an underwater acoustic modem, Iridium transceiver, WiFi and GPS for its communication, navigation, and tracking requirements. This vehicle also had an increased working depth limit of 200m. Mission endurance is advertised to be 8-14 hours at a speed of 2.5 knots (configuration dependent). Actual mission endurance during this demonstration was observed to be 6-7 hours without the towed magnetometer. Mission duration decreased further when towing the magnetometer.

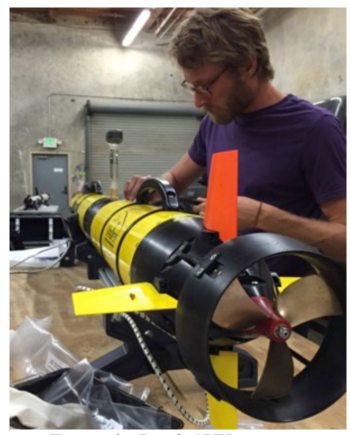

Figure 1. Iver3 AUV operator conducting pre-mission checks.

2.2 AUV-Towed Total Field Magnetometer

Figure 2. Marine Magnetics Explorer magnetometer towed behind the Iver3 AUV.

The Marine Magnetics Explorer Total Field Magnetometer. This AUV-towed magnetometer is lightweight (3.8 kg in air / 1.2kg in water) with low power consumption (2W), making it highly suitable for AUV-towed operations. The Explorer delivered high-resolution data at 0.02nT RMS/rt-Hz with an absolute accuracy of 0.1nT. Its sensors are omnidirectional and therefore unaffected by the earth's magnetic field. In other words, there were no "dead zones" in the data. The sensor requires no realignment or recalibration. The Explorer has a range of 18,000nT to 120,000nT, a gradient range of over 10,000nT/m, and a sampling range of 4Hz to 0.1Hz.

2.3 Vessel-Towed Multi-Sensor Gradiometer

The Marine Magnetics SeaQuest Multi-Sensor Gradiometer. This device consists of a three-sensor biaxial platform that measures transverse horizontal gradient over a baseline of 1.5 m, and vertical gradient over a baseline of 0.5 m. Real-time longitudinal gradient measurement is accomplished by comparing successive total-field measurements to each other using their relative GPS positions along the survey track, or by adding a fourth sensor to the platform tail if higher precision is required. SeaQuest provides a base noise spectral density of 0.01 nT-RMS/rt-Hz per sensor. This translates to roughly 0.009 nT/m noise in horizontal gradient, and 0.028 nT/m noise in vertical gradient. Relating noise levels to actual detectable changes requires a defined threshold signal-to-noise ratio (SNR) used to identify anomalies. If a SNR of 10 is used to define minimum detection levels, SeaQuest's practical magnetic gradient detection levels are 0.1 nT/m in the horizontal and about 0.25 nT/m in the vertical.

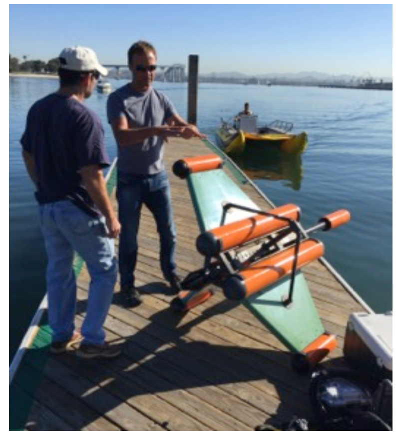

Figure 3. SeaQuest operator conducting pre-mission checks.

2.4 Remotely Operated Vehicle (ROV)

Figure 4. ROV operator placing vLBV300 into the water

The SeaBotix vLBV300 Remotely Operated Vehicle. This ROV provides an innovative approach to a small yet highly capable inspection-class ROV system. The vLBV300 is 18kg in air. Off the shelf, it comes with an average video camera, a three-prong grabber arm and guillotine cutter arm. For this technology demonstration, the ROV was also outfitted with a Tritech SeaPrince scanning sonar, a GoPro Hero 3+ camera for HD photo/video capability, and the Tritech MicronNav USBL navigation system. The vectored thruster configuration of the ROV provides control in all horizontal directions and operates in mild to moderate conditions found in the offshore environment. The vLBV300 has bollard thrust with 18.1-22.5 kgf forward. Thruster vector angle is variable from equal horizontal to forward optimized. Dual vertical thrusters provide vertical control and roll stabilization. It has four video channels including HD, 4 high-speed data channels and three high-speed ethernet channels. The vLBV300 uses the low drag, all copper tether. The 8.9mm diameter tether has 100 kgf working load and can be attached to the rear or top of the vLBV300 depending on conditions. The ROV is controlled through the Integrated Control Console (ICC), which provides the operator with hand controls and a real-time view of the ROV's camera, scanning sonar and navigation display. Transporting the vLBV300 is relatively simple with the shipping and operational "foot print" of the ROV and its ancillary equipment being comparatively small when regarding the systems capability.

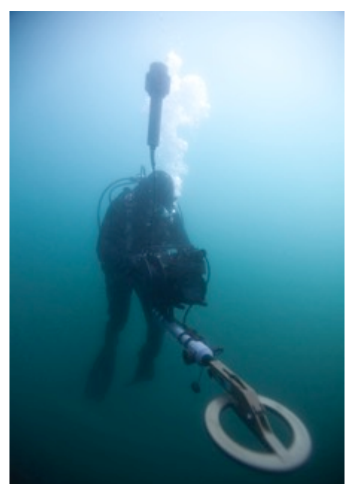

Figure 5. Scuba diver with Shark Marine Underwater Navigation System with metal detector attachment.

2.5 Diver Operated Underwater Navigation System

The Shark Marine Navigator, Diver Held Sonar Imaging and Navigation System. This small, portable system provides an advanced capability where diver navigation and situational awareness are critical in reducing search times while increasing the effectiveness of the search and the safety of the diver. The Navigator system used in this technology demonstration was equipped with a number of options used at different times, including a dual frequency forward-looking multi-beam sonar, a Doppler Navigation System (DNS) for submerged positioning, a GPS for starting position, a video/still camera, a ProMag Overhauser magnetometer, and an Ebinger 725K metal detector. The Navigator's DiveLog software is used for mission planning. Its intuitive operation is designed to simplify the planning, and execution of search operations. DiveLog supports large area searches with side scan sonar, magnetometer, gradiometer, and metal detector for buried targets such as guns and ordnance, as well as scanning sonar, radiation detectors, bathymetric multi-beam sonar, and cameras.

3 Software

3.1 CleanSweep

CleanSweep from Oceanic Imaging Consultants (OIC) is a Hydrographic Data Processing Software. It can import data from all major sonar systems, remove water column, process navigation and attitude, correct beam patterns, enhance imagery, mosaic the data, and export the final image to other GIS and mapping packages.

3.2 UXO Marine

The UXO Marine extension from GeoSoft is a magnetometer post-processing software. Geosoft's UXO Marine provides comprehensive processing and visualization of magnetic data for location and analysis of underwater cables, pipelines, and unexploded ordnance (UXO).

3.3 ArcGIS

ArcGIS from ESRI is the worldwide software standard for GIS analysis and mapping. ArcGIS can be used for:

- creating and using maps;
- compiling geographic data;
- analyzing mapped information;
- sharing geographic information; and
- and managing geographic information in a database.

The system provides an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the Web. The demonstration team for this event did not have experience in the use of the Information Management System for Mine Action (IMSMA), and thus did not use IMSMA to store and track the data as though it were an ERW project. However, there are many similarities between the GIS-based IMSMA and the UGIS generated from this demonstration. Further discussions with GICHD will are anticipated to address the potential for extending the IMSMA model to include underwater-specific ERW mapping, storage and management tools.

4 Demonstration Procedure

4.1 Demonstration Location

The technology demonstration was conducted in San Diego, California, USA. The map in Figure 6 shows the two fields, one inside San Diego Bay (in-shore field), and one west of the San Diego coast (near-shore field).

Figure 6. Technology Demonstration areas

4.2 Demonstration Environmental Conditions

Condition	In-shore Field	Near-shore Field
Water Depth	4 m	18 m
Bottom Type	Mud / Silt	Sand
Bottom Slope	Flat	Flat
Underwater Visibility	1 – 6 m	0 – 0.5 m
Surface Conditions	1 – 2 m seas, 0 – 15 knot winds	0 – 0.5 m seas, 0 – 15 knot winds

Table 1. Demonstration conditions in the two areas selected for the technology demonstration.

4.3 Description of Demonstration

The technology demonstration provided an independent assessment of the suitability and effectiveness of underwater sensor equipment and software for use in ERW technical surveys in the "in-shore" (0-5m depth) and "near-shore" (5-50m depth) zones. Specifically, Orca Maritime, an underwater services company, demonstrated new technologies in advanced underwater sensor systems and software that can be used in technical survey operations in support of ERW technical surveys. Within the scope of the demonstration, Orca Maritime introduced the use of autonomous underwater vehicle (AUV), remotely operated vehicle (ROV) technology, towed magnetometer technology and diver-held navigation and sonar technology.

Each of the two 200m x 100m areas in Figure 7 was seeded with simulated ERW targets. Nine targets were laid in the near-shore field, and eleven targets were laid in the in-shore field. The targets were made from steel pipe sections, and filled with concrete. There were four different diameter sizes selected to represent different sizes of ERW: 2-inch, 4-inch, 6-inch and 8-inch. Each empty steel pipe section was weighed with the eyebolt prior to filling each with concrete to determine a relative difference in metallic content, relating to different magnetic signatures to the different detection sensors. Concrete was used as a filler to emulate explosives, a common practice in manufacturing inert, but realistic ordnance shapes for military training. Figure 7 below shows photos of the four different size targets used.

Figure 7. Simulated ERW targets, from left to right: 8-inch, 6-inch, 4-inch, 2-inch diameter steel black pipe filled with low alkali Type II/V cement.

The 20 shapes were laid randomly in the in-shore and near-shore fields. Positions were recorded but not revealed to the detection sensor data analysis team.

Although each piece of equipment/technology was evaluated individually, the demonstration was conducted in two phases, to represent a proposed approach to combining these technologies in a technical survey effort in support of ERW remediation. The two phases were:

Phase I - Search, Classify, Map (S/C/M). This is the process of conducting a wide area search to detect and "classify" objects as potential ERW through analyzing the data collected by the search equipment/technology. Normally, underwater detection sensors pass at a low altitude above the seabed in order to be effective, especially for smaller targets. Prior to employing these detection sensors in areas where bathymetry information is sparse or outdated, a "high pass" survey with a bathymetry sensor is strongly recommended to prevent damage to a detection sensor from impacting protrusions from the bottom, such as coral heads, large rocks or uncharted wrecks. The objective of the high pass is to detect any such obstructions so that the tracks planned with the detection sensors can avoid them. The bathymetry data set is processed and imported into the project UGIS as a layer, which serves as a baseline for the technical survey. In areas where bathymetry is well documented, a high pass is not necessary.

Different sensors may be used to conduct the initial search missions. The two most common sensors for searching for ERW are magnetometers and side scan sonars. The data sets from these two sensors are normally collected in parallel tracks, either with an AUV or a vessel-towed sensor. When the sensor has completed a mission, the data set is analyzed with software to determine the presence of any ERW targets, referred to as contacts of interest (COI). This process is called post-mission analysis (PMA). The result of the PMA is a list of COIs that must be further investigated. Each COI is individually numbered and characterized by an image (magnetic anomaly and/or sonar image, or "snippet") and a geodetic position, normally in latitude/longitude. The list of COIs is then used in the second phase of the technical survey: Reacquire and Identify (R/I), explained below. After all of the data sets from all of the search sensors are analyzed, each data set is consolidated into a mosaic of the individual tracks and stored as a map layer in the project UGIS. Additional layers may include all the COIs from the different S/C/M sensors.

Phase II – Reacquire and Identify (R/I). The R/I phase is the process of validating the COI list. This is done either with an ROV or with divers. The advantages of each method are described later in the report. Essentially, a higher fidelity sensor is used to reacquire each COI by returning to its recorded position and inspecting it with a camera, a high resolution imaging sonar, human eyes, etc. COIs that are confirmed as actual ERW, or that cannot be ruled out (some targets have heavy sea growth or advanced corrosion/deterioration) remain on the COI list. COIs that are confirmed non-ERW are removed from the COI list and identified as such. It is important to maintain a record of the non-ERW COIs as well, both for historical purposes, and to avoid follow-on S/C/M or R/I efforts from wasting time on non-ERW objects that have already been ruled out (but not removed). The UGIS is updated with a description of each COI, characterizing it as ERW or non-ERW, and adding any further information that was collected during R/I.

In the end, all detection sensor data, investigation information (video, diver sonar recordings) and other geospatially referenced information (overhead imagery, nautical charts, etc.) is imported into the UGIS program. The UGIS acts as a central repository for all data related to the ERW remediation site, allowing for data storage, historical analysis, progress tracking, quality analysis and control, and various other applicable data fusion requirements associated with remediation work.

5 Demonstration Results

5.1 Autonomous Underwater Vehicle with Side Scan Sonar and Interfero-metric Bathymetry Sonar (Iver3-580, OceanServer Technology, Inc.)

A. <u>Ability of equipment to fulfill it's function in the required operating environment.</u> The use of portable AUVs demonstrated navigationally accurate wide area search capability where geodetically aligned, or "co-registered" data sets are critical. To demonstrate the "high pass" option recommended as a precursor to employing detection sensors closer to the seabed, one of the AUVs was programmed to collect bathymetry of the in-shore field, shown as a mosaic of depth soundings in Figure 8. The high pass included enough space around every side to account for more than enough room for turns at the end of tracks. Once the high pass was complete, the AUVs, carrying multiple sensors, gathered multiple data sets simultaneously, including side scan sonar imagery, sound velocity data, and magnetometer data when towing the "mag tail" sensor. The two most relevant sensors for the S/C/M missions were the side scan sonar and the towed magnetometer. All data sets were time-stamped and geo-rectified, resulting in a comprehensive demonstration of multiple, accurate data layers provided to support the S/C/M phase of an underwater technical survey. Unaffected by environmental factors normally associated with vessel-towed sensor operations, the two AUVs used in this demonstration were shown to be unsusceptible to surface conditions such as wind and sea state, pilot-imposed navigational error, vessel traffic, etc. Moving just a few meters above the seafloor, an AUV survey provides an efficient, economical, and safe alternative to traditional vessel-towed surveys by eliminating large support vessels, crews and the associated logistics. The raw data sets gathered by the AUV were processed in various software systems for post mission analysis (PMA) and imported into Orca Maritime's underwater geographic information system (UGIS) where the data sets were formatted for use in follow-on mission planning evolutions. Figure 9 shows a side scan sonar mosaic of the in-shore field, processed to create an imagery layer for the UGIS. Normally a mosaic of the side scan sonar imagery serves to identify any large objects or geographical

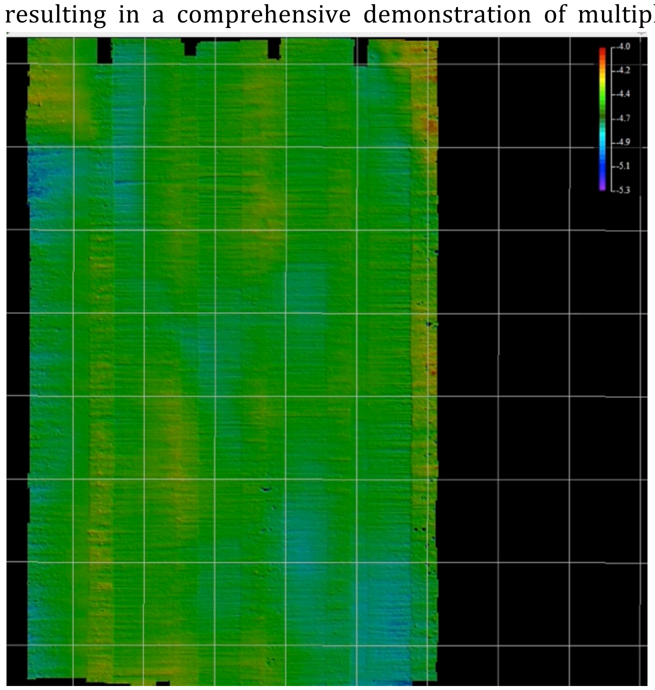

Figure 8. Bathymetry data of the in-shore field, collected with the Klein 3500 Interferometric sonar, installed in the Iver3 AUV.

features and to ensure that there are no gaps in the data. In this case, there were not many features or large obstructions in the field, so the mosaic is relatively homogenous and benign. In areas with large amounts of debris, which is the case in many ERW sites where amphibious landings or coastal bombardments took place, the mosaic gives an overview of the scope of the ERW contamination, especially when larger caliber munitions were involved. For this technology demonstration, since the targets were eight inches in diameter or smaller, they do not appear in the side scan sonar mosaic. In this case, contacts of interest (COI) were initially detected with the magnetometer and their positions were recorded for the follow-on R/I missions.

B. <u>Ease of operation and operator training.</u> The AUV operators in this demonstration have been trained on towed systems and AUVs. In some ways, the training requirement for operating an AUV is more technical and more extensive than the training for a towed system. On the other hand, for "ease of operation", the AUV has a clear advantage. As well-trained as a towed sensor operator may be, keeping a straight track in a vessel that is challenged with surface winds, currents and other vessel traffic in the area can be very stressful. Once an AUV is launched, the straightness of the tracks is out of the hands of the operator through it's mission, and the observed results for this demonstration were uniformly straight lines. Different levels of sophistication are available on the market for AUV track-keeping, including ring-laser gyro based inertial navigation systems. Such systems tend to increase the cost of an AUV and were not included in this demonstration. PMA of the data from the AUV is equivalent to other systems, as it is a sensor-specific task.

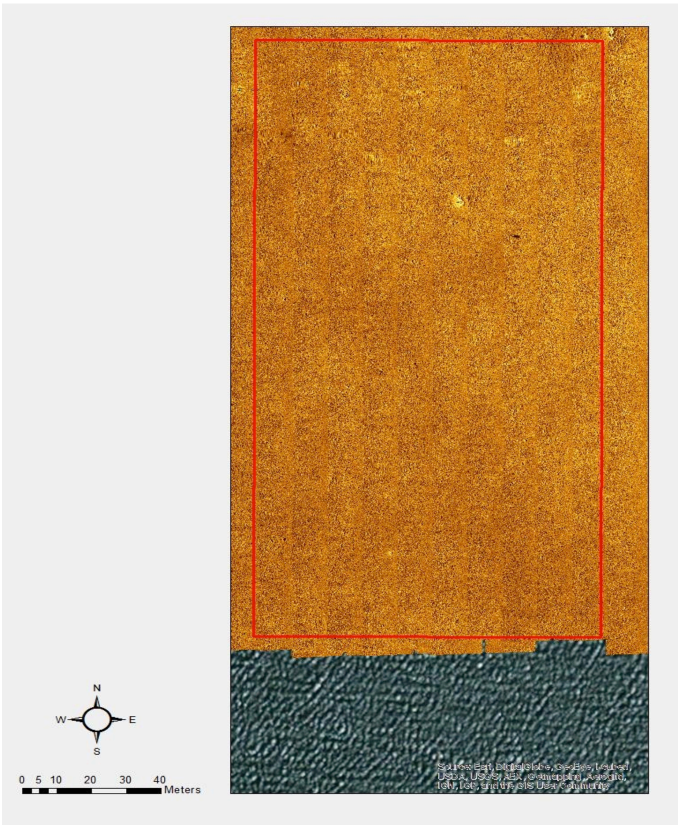

Figure 9. Side scan sonar mosaic from in-shore field.

C. <u>Ease of mobility and transportation.</u> The Iver3 is transported in three portable cases. When assembled, it is easily carried, launched and recovered by two persons. There are no hazardous materials associated with the system for shipping. No issues or challenges were associated with mobility or transportation of the system.

D. <u>Ease of servicing and maintenance.</u> The Iver3 AUVs used for this demonstration required only charging of the batteries overnight and rinsing with fresh water at the end of each mission. Obviously, periodic maintenance and repair is required for these systems. However, all routine maintenance is uncomplicated, and for more involved repairs, the system is very modular. Defective parts are quickly replaced with a spare, enabling the AUV to continue, often with a "field-swap" repair.

E. <u>Total hours run/operated and frequency of servicing and maintenance.</u> Table 2 below summarizes the total hours that each of the systems was operated and serviced.

AUV-mounted Sonar: Combined side scan and interferometric bathymetry sonar	
In-Shore	1 hour 30m Scale
Near-Shore	1 hour 30m Scale
Total field magnetometer	
In-Shore	2.5 hours 15m Scale 5m track spacing
Near-Shore	2.5 hours 15m Scale 5m track spacing
Transponder Location Survey	
In-Shore	40 minutes
Near-Shore	40 minutes
Daily Maintenance	
AUV	10 minutes
Equipment	15 minutes
Servicing	
Manufacturers recommendation based on time used	

Table 2. Hours of use for the AUV and associated sensors.

F. Engineering defects and replacement parts required during the operation. None.

G. Design defects. None.

H. Special tools required. All tools required to assemble and operate the Iver3 AUV are either common hand tools or provided with the system.

I. Spares availability and cost. Upon purchasing an Iver3 AUV, a robust spares kit is included in order to be able to conduct field repairs when necessary to continue operations. The cost of additional spares varies. Prior to deploying to a remote location for an extended period, the operating team should consult with OceanServer to refer to "mean time before failure" (MTBF) data to stock spares before the trip.

J. Compatibility with existing mine action equipment. The Iver3 AUV demonstrated that it could play a critical role in the S/C/M Phase of a technical survey in support of ERW remediation. The sonar and magnetometer data resulting from AUV missions have the same formats as if they were generated from towed systems. There were no compatibility issues associated with the Iver3 AUV noted.

5.1.1 Observations

A. Suitability of the Equipment.

Safety. By virtue of being an "unmanned" vessel, the AUV is inherently safe. The alternative is a towed body with equivalent sensors. For towed systems, in order to maintain a constant altitude above the seabed, a watch stander must pay attention to the "waterfall" display, and operate a winch to make adjustments to that altitude. The cable under tension can be a safety hazard, especially if the reel/winch system is operated manually. Towed systems that get snagged on the bottom put the tow cable under greater tension and can cause damage to the towed body or to personnel on deck. An AUV has no cable or the associated hazards.

Efficiency. Efficiency was demonstrated by the ability to simultaneously collect co-registered side scan sonar imagery and magnetometer data. The ability of the AUV to maintain a very straight track enabled the magnetometer surveys to be conducted with very closely spaced tracks. This allows for effective S/C/M missions with a magnetometer for relatively small targets. Vessel-towed sensors tend to have greater track-keeping errors, which result in missed areas, or "holidays" in the data. When navigational error is increased by the tow-vessel, more tracks must be conducted in order to ensure coverage of the area. This is a function of the vessel's/AUV's standard deviation of navigational error (SDNE). SDNE was not measured for the Iver3 or the tow-vessel for this demonstration, but in the experience of the demonstration team, AUV tracks are much straighter than surface vessel tracks, especially at slow speeds. This is addressed further in section 8. Finally, on two occasions, two AUVs were operated simultaneously in the same area, requiring no additional personnel, time or boats. The time saved through these last two points is a strong testament to the efficiency of AUVs in this application.

Economy. The Iver3, and any AUV with a side scan sonar, will cost more than most towed systems. Nevertheless, economy can be realized on larger projects when multiple AUVs are operated simultaneously, as described above. Multiple sensors collecting data in a single mission may reduce the number of actual surveys required. And over the long term of an extended technical survey project, the savings in time and personnel may well outweigh the increased cost of the AUV(s).

B. Major modifications or development required. No significant modifications or development is required for these systems to be used today to effectively support ERW remediation. Nevertheless, AUV development will continue in the areas of endurance, navigational accuracy, sensor integration, real-time data transfer, and many others. The popularity of these systems for military and industrial use, based on efficiency and safety, will continue to drive improvements in capability and reduce the costs of the systems. .

C. Further action required technically or organizationally. None noted.

D. Lessons Learned.

- During the PMA process, the AUV operators conducting the PMA were more accustomed to initially analyzing side scan sonar data. In this application, since both magnetic and side scan sonar data are collected simultaneously, either data set could be analyzed first. However, since ERW inherently has a magnetic signature, it was the magnetometer data set that was analyzed first to establish a COI list. This eliminated many side scan sonar "hits" that had promising features in the imagery, but had no co-registered magnetic signature. This enabled the PMA team to eliminate numerous sonar-generated candidates from the COI list. On subsequent missions, the side scan sonar was only used to see if the magnetic COI was on the surface of the seabed. Time was saved by not having to conduct PMA on the whole side scan sonar survey file. For the small areas used in this demonstration, the time saved was not significant, but for larger areas, this would add up. The quality of PMA for side scan sonar is affected by fatigue of the PMA operator. By reducing the PMA requirement to just checking the magnetic targets, PMA fatique is minimized.

- When towing the Marine Magnetics Explorer magnetometer, the endurance of the AUV is significantly reduced from it's advertised 8-14 hours, down to 5-6 hours.

5.2 AUV-Towed Magnetometer (Explorer, Marine Magnetics Corporation)

A. Ability of equipment to fulfill its function in the required operating environment. The Explorer, towed behind the Iver3, fulfilled its function as a magnetic sensor very well. In fact, the Marine Magnetics subject matter expert commented that it achieved near-equivalent results to the larger, more complex, multi-sensor SeaQuest. This is attributed to the accurate navigational capabilities of the AUV, according to the Marine Magnetics representative. The Explorer was "flown" two meters above the bottom with very narrow (five meter) track spacing. Since there was very little navigational error, the tracks were straight, the altitude was effectively constant, and there were no "holidays". The Explorer detected all but one of the targets in both fields. Both missed targets were the smallest ones. This event may serve as a "calibration" exercise for this AUV-Explorer configuration for operations intended to detect targets of this small size.

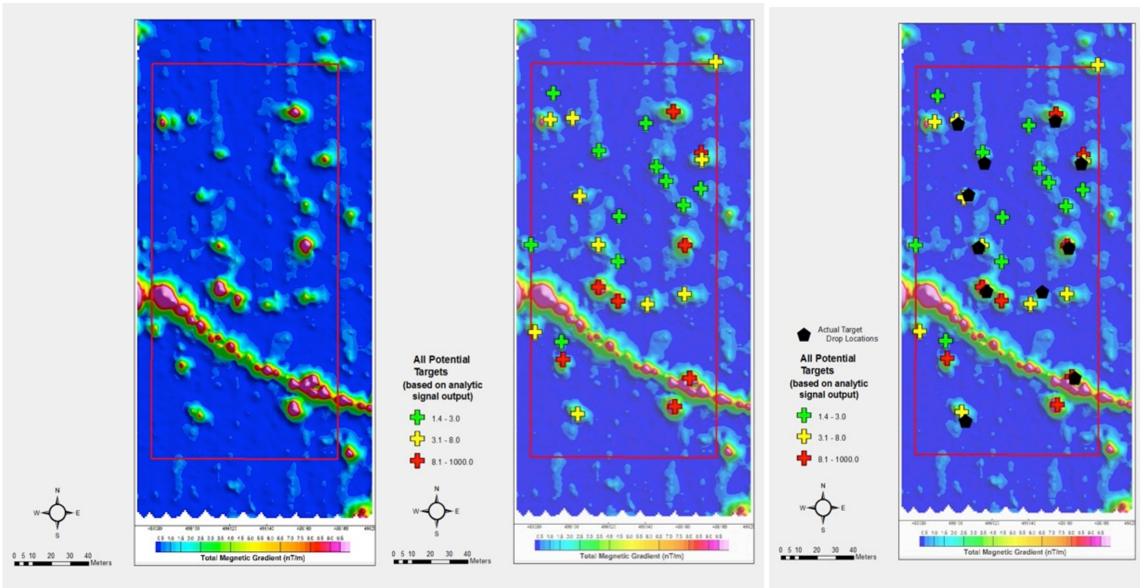

Figure 10. Marine Magnetics Explorer magnetic sensor GIS layers from the AUV-towed survey in the in-shore field: A. the processed data from the Explorer AUV- towed sensor; B. the same layer with operator-called detection positions overlaid; C. the same layer with target lay positions overlaid.

Regarding the missed target in the in-shore field, it was ultimately determined that the target, which was one of the smallest size targets, was directly on top of the large magnetic feature that shows in all of the screens in Figure 10, running from just below mid-field on the left edge of the area to the lower right corner.

For the near-shore field AUV-towed survey, a new technology was employed to improve the navigation of the Iver3. A set of acoustic transponders is being developed by TrackServer, Inc., to enable the Iver3 AUV to maintain or improve upon it's positional accuracy during missions without surfacing at the end of each track. In its current configuration, the Iver3 surfaces at the end of each track in order to attain a new GPS fix before beginning a next track. For shallow surveys, this does not cause a significant delay in survey operations. In fact, the time required to surface, attain a new GPS fix, turn around and dive for the next track is generally

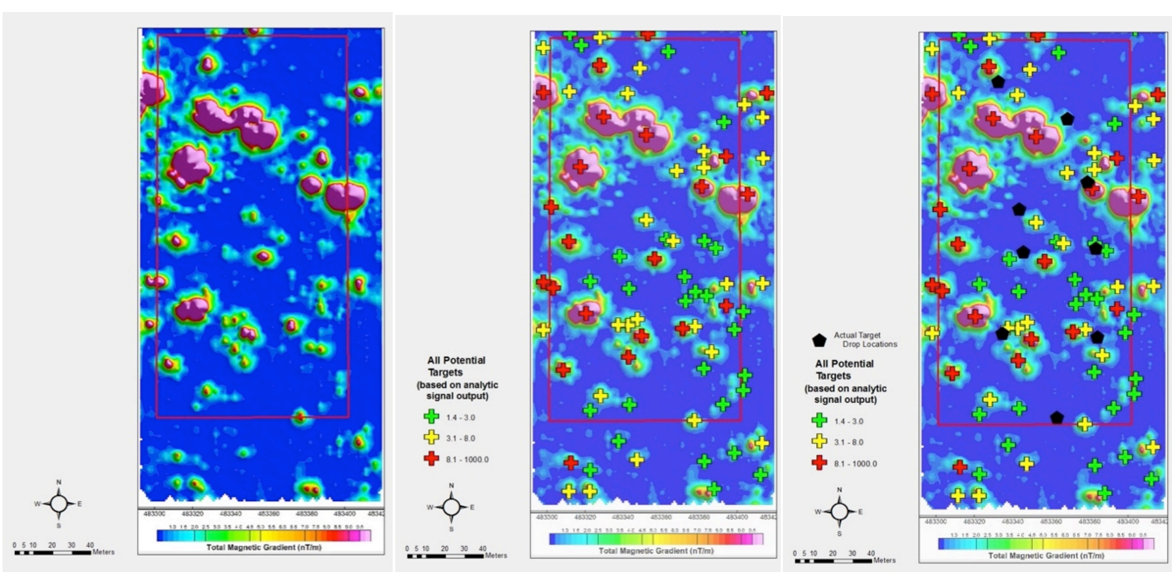

Figure 11. Marine Magnetics Explorer magnetometer data from the near-shore field. From left to right: The processed magnetic data from the magnetometer; all of the magnetic anomalies called by the operator overlaid on the data; and the target positions overlaid in the GIS.

shorter than the time required for a typical surface vessel, towing a magnetometer, to turn around and line up for its next track. But for deeper surveys, the surfacing at the end of each track adds time to the survey. From the results displayed in Figure 11, there is significant error indicated between the target lay positions and the corresponding magnetic anomalies called by the operator. It is not clear whether this error is attributable to the performance of the acoustic transponders or inaccuracies in the recorded lay positions.

In any case, as Figure 11 shows, the magnetometer did effectively detect many magnetic anomalies, including eight of nine targets laid. In this near-shore field, a large number of false alarms were also detected. This is not unusual for an area heavily used for military training or contaminated with ERW. For the purpose of this demonstration, despite the large number of false alarms, to save time for follow-on R/I trials, only those targets that corresponded to ground truth were passed to the R/I teams. It is understood that additional time would be required to R/I all magnetic COIs that met the project's detection criteria. In heavily contaminated areas, the ultimate value of a survey (regardless of the sensor) must be considered if the resulting COI list does not provide the basis for a manageable follow-on effort.

B. Ease of operation and operator training. Since the tow cable is a fixed length for the AUV-tow configuration, the only task for the operator is connecting the Explorer to the AUV. After the mission is complete, some training is required to operate the software used to analyze the data and produce COIs for the UGIS.

C. Ease of mobility and transportation. At seven pounds, the Explorer is very portable by any operator.

D. Ease of servicing and maintenance. The Explorer requires no maintenance except for visual inspection prior to use and fresh water rinse after the survey.

E. Total hours run/operated and frequency of servicing and maintenance. As indicated in Table 2 in paragraph 5.1.E, the Explorer logged five hours of tow time; two and a half hours for the survey in the near-shore field, and two and a half hours for the survey in the in-shore field. With the exception of fresh water rinsing, no maintenance was required or conducted on the Explorer.

F. Engineering defects and replacement parts required during the operation. None.

G. Design defects. None.

H. Special tools required. None.

I. Spares availability and cost. The Explorer and the cable that attaches it to the AUV are the only parts to the system demonstrated. They are both fairly robust and no spares were considered or required.

J. Compatibility with existing mine action equipment. The data set collected with the Explorer magnetometer was imported into the UGIS

5.2.1 Observations

A. Suitability of the Equipment.

Safety. The Explorer has no hazardous components. Since it weighs only seven pounds, it poses no lift injury hazard.

Efficiency. The Explorer demonstrates efficiency as a component of an ERW technical survey by acting as a fixed extension of the AUV. Data collected is nearly co-registered with the data from the sensors that are hard-mounted to the AUV – only differing by the four-meter tow cable between the two, assuming that horizontal and vertical movement from the AUV track axis is negligible. This equates to conducting two surveys in one.

Economy. The relatively low cost of an Explorer is a great advantage over larger, more expensive systems, including the SeaQuest. However, in order for the Explorer to perform at the same level as the SeaQuest, it's navigational error, in all three dimensions, must be minimal. Towing an Explorer from a small boat, for instance, may not yield the same results as it does from an AUV, which is able to maintain speed, altitude and track with very low error. Therefore, the economy may be tied to users that have a compatible AUV, which presently includes only the Iver3.

B. Major modifications or development required. None.

C. Further action required technically or organizationally. None noted.

D. Lessons Learned.

- When towed behind a very stable platform, the Explorer can achieve detection performance of a more sophisticated magnetometer, or gradiometer, as shown by the comparison of the Explorer to the SeaQuest in this technology demonstration.

5.3 Vessel-Towed Gradiometer (SeaQuest, Marine Magnetics Corporation)

Figure 12. Marine Magnetics SeaQuest magnetometer on the pier.

A. Ability of equipment to fulfill its function in the required operating environment. The Marine Magnetics SeaQuest is a multi-sensor towed gradiometer was able to fulfill its function as a detection tool for metallic objects representing ERW during this technology demonstration. The sensor/operator combination for this event detected 10 out of the eleven targets laid in the in-shore field, and called one false alarm that met the threshold criteria for this test. Establishing the criteria for determining potential ERW in any given environment from processed magnetometer data is a task that requires an above-average level of expertise in magnetometry. In the case of this technology demonstration, the individual processing the data had a master's degree in Geophysics, in addition to being the Marine Magnetics representative, whose magnetometers were being used in the demonstration. That combination is obviously a higher qualification than necessary. Nevertheless, some field training in different magnetic environments is essential in order to "filter out" background magnetic field "noise" to make the ERW contacts of interest discernable. A series of layers from the demonstration UGIS are presented as Figure 13. All layers are included in full size in Annex C.

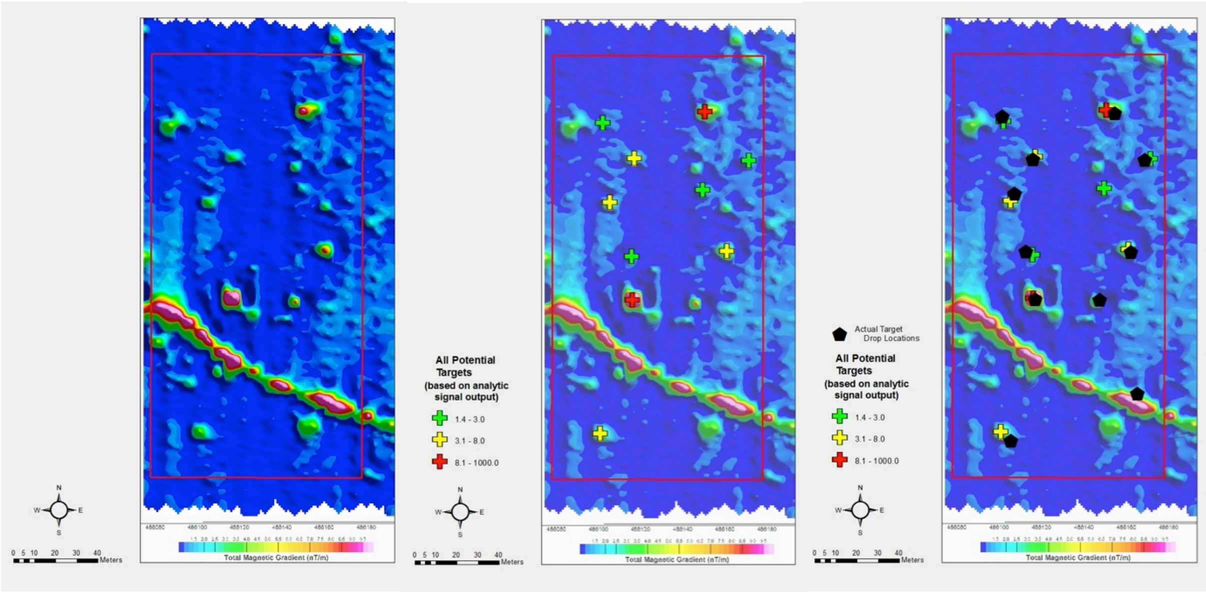

Figure 13. Marine Magnetics SeaQuest multi-sensor gradiometer sensor data from the in-shore field: A. the processed data from the SeaQuest towed sensor; B. the same layer with operator-called detection positions overlaid; C. the same layer with target lay positions overlaid.

B. Ease of operation and operator training. The basic operation of the SeaQuest gradiometer was fairly easy. An operator from Marine Magnetics did accompany the equipment, which made for a smooth evolution. There are very few moving parts, so the set-up goes quickly.

Very little training was conducted on the use of the unit for this demonstration since Marine Magnetics provided an expert operator with the unit. Some basic instructions were given to the tow vessel driver on what to watch on the screen while towing the unit.

The area where the SeaQuest was demonstrated had a very flat bottom. Therefore, there were no depth changes required during the course of any single track, and the manual reel used for the tow cable was perfectly adequate. However, as with any towed system, when the water depth changes along the survey tracks, careful cable-length management is required to keep the sensor from impacting the bottom, and maintaining a constant altitude for optimal detection performance. This was not a challenge for this demonstration. But for deeper operations, or operations where the depth changes along the tracks, a power winch with a slip-ring connection would be an essential component of the system to manage the tow cable.
Since the demonstration area was relatively close to the boat ramp, the demonstration team was able to simply tow the SeaQuest at short stay to the demonstration area. Once they arrived, they streamed the SeaQuest at its optimal depth for the objective targets. For further transit distances, the SeaQuest would need to be loaded on board, then launched and recovered from the deck of the vessel. Vessels used for this purpose must have a davit or winch to raise and lower the 150-pound unit.

Another challenge presented when operating the SeaQuest system in deeper water, or when the tow cable length changes during an individual track because of a depth change, is the positional accuracy of the sensors. Maintaining an accurate "layback" measurement is difficult and therefore, positional error may be introduced in the magnetic features detected by the sensors. Unfortunately, the near-shore field was not surveyed with the SeaQuest system during this demonstration due to time constraints.

C. Ease of mobility and transportation. The SeaQuest dimensions and 150-pound weight make it a challenge to handle for a small team. Nevertheless, it was transported from the demonstration headquarters to the boat ramp via small pick-up truck and carried to the pier by two persons. For extended distances over ground, a cart or dolly is recommended.

D. Ease of servicing and maintenance. No maintenance was conducted on the SeaQuest magnetometer, with exception of a fresh water rinse after the towing operation.

E. Total hours run/operated and frequency of servicing and maintenance. The SeaQuest magnetometer was run for four hours during the survey of the 200m x 100m area. Track spacing was set at 5m, based on the size of the targets in the field.

F. Engineering defects and replacement parts required during the operation. No defects to the SeaQuest were experienced during the demonstration.

G. Design defects. No design defects were noted during the demonstration.

H. Special tools required. All tools required to assemble and operate the SeaQuest magnetometer were either common hand tools or provided with the set.

I. Spares availability and cost. Spares were not required for the demonstration.

J. Compatibility with existing mine action equipment. This magnetometer is considered compatible with other mine action equipment in that it detects valid ferrous targets, which other mine action equipment either replicates or is used to follow-up the magnetic detection with imaging capability. Data collected with this magnetometer was displayed in the software systems used in the demonstration. Thus, it was compatible from a record-keeping standpoint as well.

5.3.1 Observations

A. Suitability of the Equipment.

Safety. The SeaQuest system is safe to operate. The only caveat is that it does weigh 150 pounds and is an awkward shape to lift, even for two or three persons. This could pose a lift hazard. In a smaller sized boat, handling the SeaQuest for launch and recovery requires close attention to avoid a potentially dangerous weight shift.

Efficiency. The SeaQuest is not particularly efficient, given the other alternatives in this technology demonstration. In the case of a technical survey, if an Iver3 AUV is not part of the S/C/M kit, then the more effective towed sensor is the SeaQuest.

Economy. The SeaQuest is significantly more expensive than the Explorer. However, for the Explorer to achieve near-equivalent results, it must be towed by an extremely stable platform, such as an AUV or a vessel with dynamic positioning (DP) capability. The SeaQuest requires neither of these. It is able to collect high quality magnetic anomaly data from any vessel that is capable of towing it. This is a good option for areas where 10-meter or greater vessels are available for hire, and the technical survey team does not have an AUV or DP vessel.

B. Major modifications or development required. None.

C. Further action required technically or organizationally. None.

5.4 Remotely Operated Vehicle (vLBV300 ROV, SeaBotix, Inc.)

A. Ability of equipment to fulfill its function in the required operating environment. The ROV performed exceptionally well in conducting its role as an R/I tool. The vLBV300 was configured, not only with the stock video camera, but also a GoPro Hero 3+ camera, the Tritech SeaPrince scanning sonar, and the Tritech MicronNav USBL navigation system. The process of reacquiring and identifying COIs with the ROV was conducted from a 27-foot support vessel. With a list of COIs, the ROV team consists of two or three personnel, depending on the operating environment. If the support vessel can be anchored and the sea conditions are light, then a crew of only two persons can operate the ROV, one driving the ROV, and one minding the tether. The COI positions are entered into the navigation system of the ROV, and the boat is stationed near the first COI's position. If the condition of ERW is such that there is a risk of explosion, the appropriate standoff distance must be established in order to anchor the support vessel at a safe distance. Reacquiring the COI can either be accomplished using the ROV's navigation system, in which case, the ROV can be driven to the location stored in the navigation system. Otherwise, a clump with a buoy attached to it may be lowered into the water from the support vessel at the position of the COI. In this case, the ROV follows the line from the buoy to the bottom and the operator looks for the COI using either the scanning sonar, or, if visibility permits, the camera. In the worst case, when visibility does not allow the ROV operator to see far enough to locate the COI, the scanning sonar is activated and selected as the main screen on the ROV console. Figure 14 shows an example of the ROV console screen with the sonar display. If water visibility does not permit the operator to see the COI with the video camera, a sonar screen capture may be the only visual reference for a follow-on remediation effort. When visibility does permit, as was the case in the nearshore field, the ROV operator can drive the ROV close enough to capture video of the COI. Figure 15 shows two examples of ROV video screen captures.

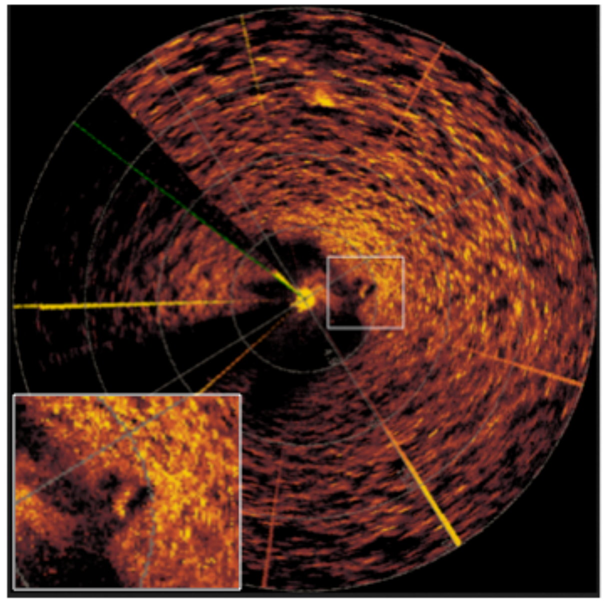

Figure 14. Screen capture from ROV console of scanning sonar image. White square is added afterwards and enlarged in lower left corner to show the COI detected by the sonar.

Figure 15. Screen captures of simulated ERW targets used in the technology demonstration. On the left, a two-inch diameter target; on the right, a six-inch diameter target.

B. Ease of operation and operator training. This inspection-class ROV is fairly easy to learn for basic operation in calm conditions and the relatively shallow waters of the near-shore/in-shore environments. Currents, surface waves and deeper water all can pose a challenge to an inexperienced ROV operator. Formal training is not considered a requirement to operate this particular ROV, although a three-day class is offered by the manufacturer. Practice in various conditions will provide the requisite expertise over time. The installed navigation system, on the other hand, requires some level of familiarity with Ultra Short Baseline (USBL) concepts and the associated field orientation of the operation. A manual is provided with the navigation system, but some practical, hands-on training is required in order to demonstrate proficiency.

C. Ease of mobility and transportation. The SeaBotix vLBV300 transports in six medium-sized plastic cases, including a spare umbilical reel, all of which can be shipped by normal methods and carried by one or two persons.

D. Ease of servicing and maintenance. Periodic maintenance and casualty repair of the ROV require training from the manufacturer in order to ensure proper performance once it is returned to service.

E. Total hours run/operated and frequency of servicing and maintenance. The ROV had six hours of run time for the technology demonstration, four hours in the near-shore area, and two hours in the in-shore area. Only post-mission maintenance of the ROV was required: fresh water rinse.

F. Engineering defects and replacement parts required during the operation. None

G. Design defects. Although not a design defect, it is worth mentioning that, in low/no visibility, the scanning sonar is a critical detection tool on the ROV. In this technology demonstration, the scanning sonar was installed on top of the ROV. For the in-shore field, there were occasions when the ROV approached a COI based on an extended (20 meter) detection distance. But once the ROV approached to within one or two meters of the COI, the scanning sonar's beam passed over the target. If given the option, it is preferable to install a scanning sonar on the bottom of the ROV to avoid this.

H. Special tools required. All tools required to operate and maintain the ROV are provided with the kit.

I. Spares availability and cost. Spares were not required for the demonstration.

J. Compatibility with existing mine action equipment. This ROV is considered compatible with other mine action equipment. Overlays from the UGIS can be installed as background information on the console screen, and the final products from the ROV can be entered into the GIS, either as metadata (video clip or photo), or as an overlay in the UGIS (sonar image).

5.4.1 Observations

A. Suitability of the equipment.

Safety. Any capable inspection-class ROV demonstrates safety in the obvious role of conducting underwater investigation, or R/I, in the technical survey process in the place of a diver. Bottom time limitations, hypothermia and the inherent risks to working underwater (decompression sickness, embolism, dangerous sealife, sharp coral, etc.) are avoided by employing an ROV.

Efficiency. The vLBV300 also works faster than the average diver. Descent, ascent and transit across the bottom are all done quickly and efficiently by a skilled operator. In addition, the ROV records the mission on video and/or sonar, so that a date/time stamped record of the dive is available for review and inclusion in the project's digital files.

Economy. There are a number of economic advantages to using an ROV for technical survey operations. As mentioned earlier, an effective R/I mission can be completed with an ROV by two persons in many cases, and by three persons in all cases involving in-shore and near-shore operations. Since bottom time is virtually unlimited with an ROV, subject only to the availability of power (fuel for the generator), the same two or three people can operate the ROV and collect underwater information all day without replacement because of spent bottom time, air or fatigue. The equipment load-out for ROV operations is much smaller than for a dive team's SCUBA equipment. This makes for lower shipping costs and, in many cases, a smaller boat requirement.

B. <u>Major modifications or development required</u>. None.

C. <u>Further action required technically or organizationally</u>. None.

D. <u>Lessons Learned</u>. The top-mounted scanning sonar results in loss of the smaller COIs when they are within a meter of the ROV. The sonar mounted on the ROV for this demonstration has no bottom-mount option. Therefore, this must be taken into consideration when using it for technical survey in conditions of low/no underwater visibility.

5.5 Diver Sonar and Navigation System (Navigator, Shark Marine Technologies, Inc.)

Figure 16. Navigator Screen with multi-function display.

A. <u>Ability of equipment to fulfill its function in the required operating environment.</u> During the in-shore and near-shore demonstration events the Navigator system was used to reacquire and identify COIs that were detected and classified from previous side scan sonar and magnetometer surveys. The Navigator system did successfully perform this task in both areas. This system is in production and is used by a number of different organizations, including military explosive ordnance disposal units. By design, the Navigator is a diver-operated system. It serves as a "toolbox" of sensors and diver-viewed screen options to guide the diver during his mission to reacquire and identify COIs. As described, the R/I mission is a component of ERW technical survey. The Navigator has also been used during remediation/removal operations, based on its sensors and displays available to the diver. Prior to entering the water, all COI positions and sonar snippets are stored in the Navigator's memory to enable the dive team to plan a route to reacquire and identify the various COIs. Figure 16 shows the various information sets available to the diver operating the Navigator as he swims from COI to COI. In this example, the trail of blue dots represents the recorded position of the diver during his dive. Also visible in this figure are the time, depth, water temperature, background map representing the results of the magnetometer survey, battery status, diver heading, bearing and range to the next COI (called "TARGET" in the display) and designator for the COI, in this case, M33. The diver's position is attained at the surface using the Navigator's GPS antenna, then maintained throughout the dive with a doppler. Additionally, the diver can send the GPS antenna to the surface via a thin cable that is stored on a spool attachment on the Navigator. Figure 17 shows an example of a sonar snippet stored in the Navigator to give the diver an idea of the shape of the COI and display of the surrounding area. In this case, the bottom is very smooth, and the COI stands out. In a more cluttered bottom, the snippet helps distinguish between debris or natural features and the COI. Some analysis, using the magnetometer survey layer, must be done prior to the dive in order to pick out the

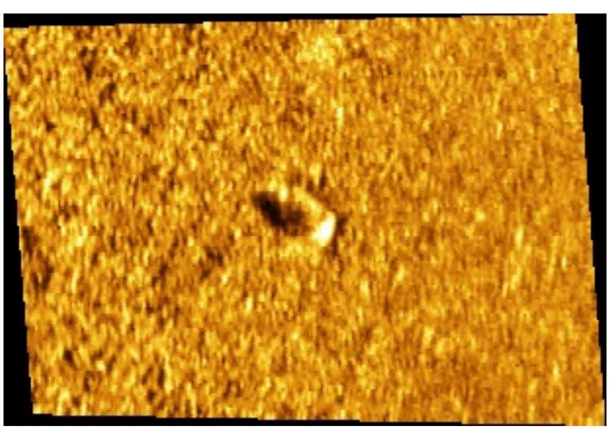

Figure 17. Screen capture of sonar snippet from Navigator.

object that is suspected as the COI. Navigation error between sensors/surveys becomes increasingly important in these cases. Therefore, collecting both side scan sonar imagery and magnetometer data from the same host vehicle (as was the case with the AUV surveys) serves this process well, since the COI's sonar image and magnetic signal positions are co-registered, and, therefore, identical.

For the in-shore survey, diver visibility was near zero requiring the diver to be within inches of the screen, making it challenging to see the whole screen. Shark Marine does make an underwater head-mounted display (not present at the time of the demo) that would have been of benefit due to the poor visibility. During the two dives made, a number of the COIs were reacquired and identified. As with the ROV, the first sensor is often the scanning sonar, since its range is greater when visibility is reduced. The left frame of Figure 18, below, shows a recorded screen capture from the Navigator of one of the COIs. Once the diver has this on the screen, he can use it as a guide as he swims toward the COI position. Once there, if visibility permits, he can take a photo or video of the contact with the Navigator, an example of which is shown in the right frame of Figure 18.

Figure 18. Left: Screen capture of Navigator's scanning sonar ensonifying a simulated ERW target. Prominent shadow is cast behind (above in image) the target. Right: Screen capture of simulated ERW target from Navigator's video recorder.

For the near-shore area demonstration, the same arrangement was planned for R/I missions using the Navigator. Unfortunately, two of the five divers for the event had trouble descending because of ear-related difficulties. This limited the demonstration time of the Navigator, although it adequately performed in the in-shore field. There is no reason to believe it would not serve well in the deeper water. However, the fact that the Navigator is a diver-dependent tool, and that diver availability was limited on the day of this particular event, emphasizes the advantage of having an ROV, at least as a back-up system, for cases like this. Granted, the ROV in this technology demonstration was not fitted with a magnetometer. Nevertheless, it was able to achieve the basic R/I functions, including recorded sonar images and video of the targets as reported above.

B. Ease of operation and operator training. The Navigator was operated by the manufacturer from Shark Marine for this technology demonstration. Although the commands and indicators on the Navigator screen are fairly intuitive, dedicated training must be performed by divers intending to use it in order to develop adequate expertise in its use, particularly when visibility is limited.

C. Ease of mobility and transportation. The Navigator packs in standard plastic shipping cases that are easily shipped, in this case, from Canada to San Diego, with no special requirements.

D. Ease of servicing and maintenance. No maintenance was required for this short demonstration, except for a thorough fresh-water rinse at the end of each event.

E. Total hours run/operated and frequency of servicing and maintenance. The Navigator was employed for a total of approximately four hours, including both in-shore and near-shore events.

F. Engineering defects and replacement parts required during the operation. None.

G. Design defects. None.

H. Special tools required. None.

I. Spares availability and cost. Refer to manufacturer.

J. Compatibility with existing mine action equipment. This Navigator is considered compatible with other mine action equipment.

5.5.1 Observations

A. Suitability of the equipment.

Safety. The Navigator equipment itself introduces no particular risk to a technical survey operation. However, since it must be operated by a diver, the inherent risks associated with diving must be considered when using the Navigator.

Efficiency. Efficiency is realized with the Navigator in that it can carry multiple sensors at one time to aid the diver in reacquiring targets. In addition to providing a background map and navigation method, the scanning sonar and metal detector/magnetometer options saves time by preventing a return to the boat to get one of those, especially if the diver arrives at the location of the COI and discovers that it may be buried. He can confirm that on the same dive with this kit. Also, if the desire of the project manager is to merge the R/I phase of the technical survey with actual remediation, the Navigator would be a good tool for that.

Economy. This system is not particularly economical but may be the only option for low to zero visibility diving operations.

B. Major modifications or development required. None.

C. Further action required technically or organizationally. None.

D. Lessons Learned. The system has greater application for military operations and the final stage of remediation (i.e. ERW removal) when visibility is poor.

C. Ease of mobility and transportation. This system was the most mobile of all the systems demonstrated. Two briefcase-sized plastic cases and a laptop computer comprised the entire system.

D. Ease of servicing and maintenance. The only service observed was the changing of batteries during this demonstration, which took less than a minute. Plugging the batteries into a small charger was also very simple.

E. Total hours run/operated and frequency of servicing and maintenance. The system had approximately one hour of operation time during this demonstration. The only maintenance required was a fresh water rinse upon return to the shore, as it had lightly dipped into the water on its last landing.

F. Engineering defects and replacement parts required during the operation. None.

G. Design defects. None.

5.6 Detection Results

Table 3 summarizes the detection results of the AUV-mounted side scan sonar, the AUV-towed smaller magnetometer and the larger, vessel-towed magnetometer. It should be noted that these results reflect the performance of these systems under one set of circumstances with a very small sample size, and may not convey identically to other projects and environments. Several factors affect the performance of these two sensors (side scan sonar and magnetometers). Three primary factors are:

- Seabed sediment type. The amount of burial that takes place depends largely on the bottom. In softer bottoms where burial is more likely, a side scan sonar is less effective, since it relies on some portion of the target to be "proud" of the bottom. In these circumstances, the magnetometer may be the primary sensor for detecting targets, since they are less affected by target burial.

- Clutter density. In seabeds that have extensive bottom clutter (e.g. rocks, coral, debris, etc.), the side scan sonar operator is challenged to discern ERW targets from non-ERW objects, both natural and man-made. Even if detection is achieved, the project may take much longer, based on high false alarm rates. The magnetometer may be the preferred primary detection sensor in these cases. However, as the table indicates, in the relatively smooth, flat bottom conditions experienced in this demonstration, both the side scan sonar and the AUV-towed magnetometer showed high false alarm rates: 14 and 17 respectively, in fields that had 20 actual ERW targets collectively. The false alarm calls from the side scan sonar were not identical to the magnetometer false alarm calls, indicating that each sensor can be vulnerable to it's own "version" of a false alarm, even in the same area. Ultimately, to ensure the highest level of clearance, each false alarm (from any detection sensor used) must be verified. As mentioned above, this adds time to an ERW clearance project.

- Target size. The targets chosen for this demonstration only represent ERW with diameters between 2 inches and 8 inches. This is by no means a comprehensive representation of worldwide ERW contamination. This must be taken into account for project planning.

Statistic / System	Targets Detected				Targets Missed				Target Detection Rate (%)				False Alarms
	8 in.	6 in.	4 in.	2 in.	8 in.	6 in.	4 in.	2 in.	8 in.	6 in.	4 in.	2 in.	≤ 8 in.
AUV-mounted Side Scan Sonar (Iver3 AUV w/Klein 3500)	4	6	2	2	0	0	2	4	100	100	50	33	14
AUV-towed Magnetometer (Marine Magnetics Explorer)	4	5	4	5	0	1	0	1	100	83	100	83	17
Vessel-towed Magnetometer (Marine Magnetics SeaQuest)	2	2	3	2	0	1	0	1	100	67	100	67	N/A*

Table 3. Detection Results

* Not Available. The SeaQuest data was processed after the PMA team had already processed the Explorer data. Although ground truth positions were not revealed for the SeaQuest PMA, the PMA operator did see the earlier magnetic data, meaning that the demonstration was technically not "blind." Therefore, false alarm information is not listed for this sensor.

6 Operational and Organizational Considerations

Figure 19 summarizes the proposed sequence of events in an underwater technical survey using technologies demonstrated in San Diego during this trial. It is clear that an underwater geographic information system (UGIS) is central to the process, and, in fact, would be initiated prior to the technical survey. Non-technical survey information, such as existing nautical charts, data from previous remediation efforts, historical battle maps and environmentally important features (coral, fish habitats, endangered flora areas, etc.) are all layers of information that could begin to populate the UGIS in preparation for the technical survey. The information flow associated with Phase 1 of the Technical Survey described in section 2 of this report and depicted here actually applies whether unmanned systems or more traditional systems are employed for the Search / Classify / Map mission. However, navigational error is reduced and information layers import more cleanly into the UGIS by using an AUV. And conducting Phase 2 with an ROV instead of divers produces information for the UGIS that divers would not normally be able to collect: geospatially rectified photos and video of the ERW contacts of interest. These are key pieces of information for follow-on remediation/removal efforts. What is clear from a data collection and organization standpoint is that a team using new technologies such as AUVs and ROVs to conduct an underwater technical survey must be well-versed in the use of a UGIS.

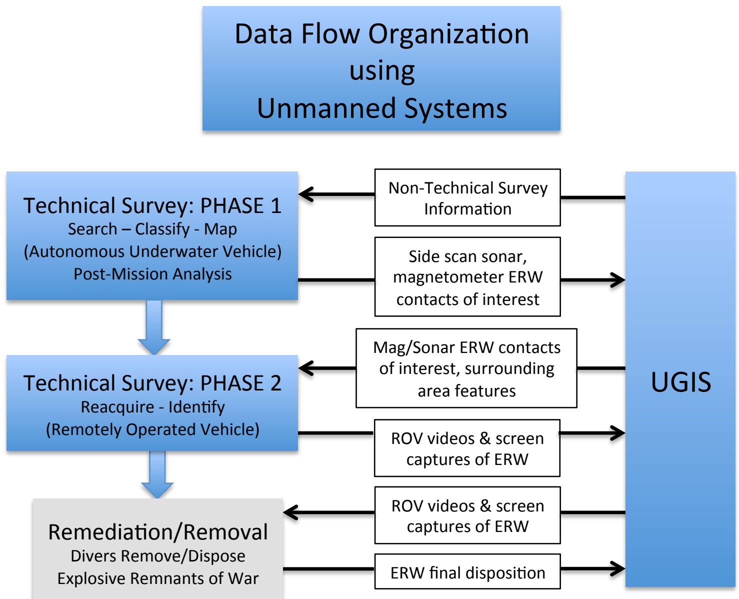

Figure 19. Unmanned Systems Data Flow Chart

7 Software

7.1 CleanSweep (Oceanic Imaging Consultants, Inc.)

CleanSweep is a sophisticated hydrographic data processing software program and thus is not a software package that one can learn in a day. It is quite adept at post processing bathymetric as well as side scan sonar data to enhance the imagery and finally export the images to a GIS. One of the major benefits to CleanSweep is its ability to "adjust" the navigation "error" after data in the field has been collected. This works very well when the user wants to "drape" side scan data on top of bathymetry to make a 3D view of the area. Adjusting navigation errors will make the output look much more "clean" and easier to view.

7.2 UXO Marine (Geosoft, Inc.)

UXO Marine is a very complex software program that is suited for someone who has a very good understanding of geophysics and magnetometers. UXO Marine provides a dedicated workflow and specialized tools to process and visualize magnetic data for effective detection and analysis of targets in marine site investigation surveys. The ability to calculate analytic signal from any combination of measured and calculated gradients helps to reduce noise and produce a cleaner analytical signal for automated and manual target selection.

7.3. ArcGIS (Esri)

ArcGIS is the worldwide standard for GIS. The base software is not overly complicated and only requires minimal training. ArcGIS is very powerful, but is very user-friendly for basic-level functions. ArcGIS is able to import most forms of data without any issues so that layers of data can be viewed on top of, or through, one another easily.

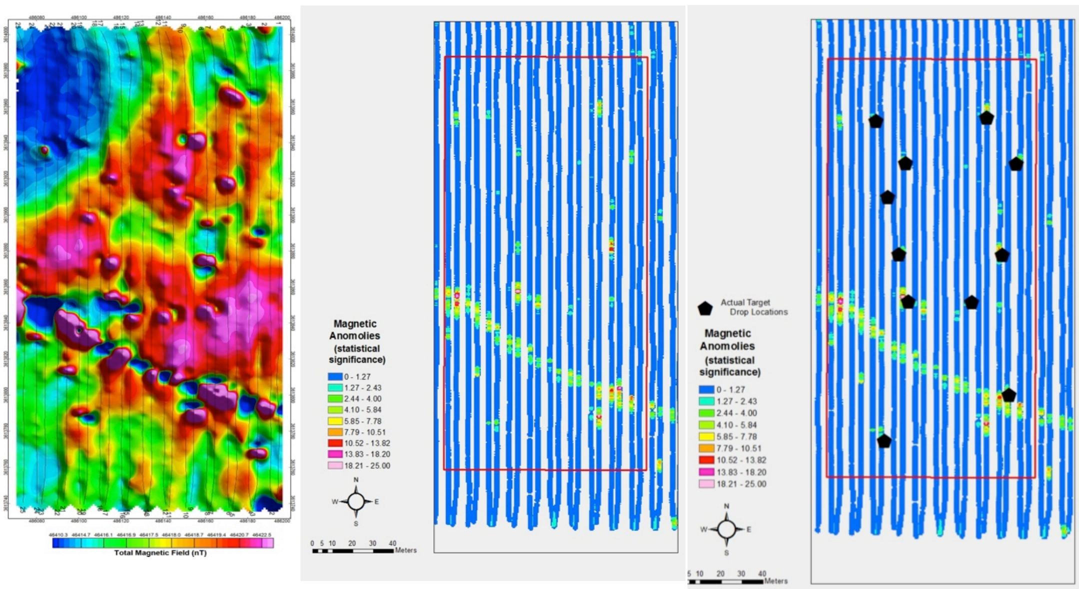

Figure 20. Magnetic data from the in-shore field displayed in its raw form, exported from the unit's operating software (left); displayed in statistical significance form in ArcGIS (center); and showing the simulated ERW target positions overlaid on the ArcGIS display.

8 Recommendations

8.1 ERW Technical Survey with technologies employed during this demonstration

A. <u>Sensor selection and prioritization.</u> This technology demonstration provided a good example of the effectiveness of the two main sensors used for underwater technical surveys in support of ERW remediation efforts: the magnetometer and the side scan sonar. The results of the demonstration included successful detections in both cases, but also suggested a prioritization of these sensors, similar to ERW efforts on land. Specifically, although a technical survey team may prefer a visual image, like the product of a side scan sonar or ROV screen capture, to indicate the presence of ERW, the survey cannot be considered satisfactory unless a magnetometer of sufficient sensitivity has been employed in a thorough, methodical pattern over the area.

Ideally, technology will eventually lead to the capability for towed or autonomous systems to detect explosives underwater, with enough range/swath to be practical. In the mean time, the next most reliable sensor for detecting underwater ERW is the magnetometer, which enables the technical survey team to detect the ferrous metal component in ERW. In areas considered to be high in natural clutter (coral, rocks, etc.), or where burial is likely, the need for a magnetometer is fundamental. Unfortunately, since many areas with ERW also have substantial quantities of inert shrapnel, a high false alarm rate may accompany the ERW detections without any real means to discern the two without a diver or ROV. But, since a magnetometer will penetrate the seabed, which neither side scan nor video/photography will do, the magnetometer must be considered the primary full-coverage sensor in most cases.

Lastly, when using an AUV that can collect both magnetometry and side scan sonar imagery simultaneously, it is critical to select track spacing for the single survey that fits the prioritized sensor. In other words, if the magnetometer is the sensor with which you must achieve 100% coverage in an area, then the AUV tracks should be planned for the magnetometer's sensitivity. In such cases, the side scan sonar will collect far more data than necessary, and perhaps pose a data management challenge. On the other hand, as stated above, if buried ERW is not a concern, and the minimum objective target size is large enough, the technical survey can be conducted more quickly by planning tracks that meet the side scan sonar coverage requirements.

The recommendation of this report is that these considerations go into the planning stages of an underwater technical survey.

B. <u>The cost-effectiveness of unmanned technologies in support of technical surveys for ERW remediation.</u>
The technologies demonstrated in San Diego during this event, with the exception of the airborne magnetometer system, are in fairly wide use in various industries today, even if they are not considered "standard" equipment for ERW technical survey work. The main criteria used in this demonstration to assess "suitability" were safety, efficiency and economy. It is difficult to deny that unmanned systems, specifically AUVs and ROVs, are safer for conducting surveys than people working underwater. The most obvious component in this category is the portable ROV for R/I missions, instead of divers. The reduction in personnel, the removal of personnel from exposure to diving hazards, and the underwater duration that ROVs offer, are clear advantages in safety for ERW technical surveys over divers. And the cost of a medium-sized, inspection-class ROV, like the one demonstrated here, is approximately equal to a full set of dive gear for a team of 15 divers.

The technology that requires a more broad-level perspective for cost-effectiveness is the AUV. The cost of an AUV can be significantly more than the cost of a basic towed side scan sonar. Therefore, the following qualifiers must be considered when determining whether or not to purchase, or use, an AUV, or multiple AUVs in conducting underwater ERW technical surveys. The points below do not equate to any exact value. That is for the technical survey planner to determine. For the most part, larger scale projects benefit from the use of AUVs, but there are other advantages that equate to cost savings:

- An AUV will typically have at least two sensors installed, which can be used simultaneously. The example in this demonstration was the Iver3, which had a side scan sonar, swath bathymetry (interferometric) sonar, and it towed a magnetometer. This resulted in conducting three surveys in one – for some circumstances. There are cases where water depth or the shape of survey area may not allow this level of consolidation, but clearly, three surveys in one equates to cost savings.

- Once an AUV is launched, very little operational action is required by the crew. Therefore, it is standard operating procedures for Navy units (for one) to operate two AUVs simultaneously with one crew and one support vessel. This obviously doubles the effort described in the paragraph above, meaning: if two sensors are engaged per AUV, four surveys are taking place with one crew in the time that it takes to conduct one survey using more traditional methods. This is a common cost-savings measure practiced by AUV operators.

- Co-registered data sets result in time savings downstream in the remediation process. Specifically, when a magnetometer data set is collected separately from a side scan sonar survey, there is positional error between the two data sets. This causes uncertainty in the localization of ERW targets, which requires time to reconcile. It may mean that divers or ROV operators have to spend more time ensuring that they have the right mark. Or it may just mean additional GIS work to align the two data sets. When multiple tracks are involved with such surveys, as they normally are, the error between the two "layers" is not constant, so the GIS work may be significant. When one vehicle collects both data sets in the same survey, there is zero relative error between the data sets. Consequently, the AUV-collected co-registered data sets save time.

- AUVs drive straighter lines than human-driven vessels. Even vessels that are equipped with "auto-pilot" instrumentation do not maintain track position well at slow speeds. Currents and wind push auto-piloted vessels off track – they remain on course and maintain a constant heading, but their position on the track is not kept by the auto-pilot. The track-keeping required for that level of accuracy on a surface at slow speeds is only achievable with dynamic positioning (DP) equipment, which is very expensive. The result of straighter tracks is ultimately less tracks. In order to develop an appropriate "coverage" plan with any given sensor, the standard deviation of navigational error (SDNE) must be taken into account. Larger SDNE means more tracks to compensate for the anticipated gaps, or "holidays", in the bends of non-straight tracks. In this way, an AUV typically requires less tracks, again, saving time, and producing more accurate object location results.

- AUVs maintain a constant height above the bottom. This equates to a more constant swath and results in better mosaics for the project GIS. Vessel-towed sensors require a watch stander to monitor the towed body's height above bottom. As the water gets shallower along the track, the watch stander must bring in the tow cable, either with a winch or manually; and as the water gets deeper, cable is let out. This causes an "hourglass" affect on the side scan sonar register, which is difficult to eliminate in the aggregate mosaic without running additional tracks. This is another factor to consider about the value of using an AUV.

- With the reduced navigation error associated with AUV tracks, surveys are much more repeatable. That is, from survey to survey, the imagery will overlay without much error between the layers. This is particularly useful when producing "before" and "after" imagery for a remediation effort.

8.2 Hydrographic data processing

There are many software choices out there that are adequate. Some of the most popular choices are:

-CLEANSWEEP from OIC (http://www.oicinc.com/oic-cleansweep.html)
-HYPACK from Hypack, Inc.: (http://www.hypack.com)
-FLEDERMAUS from QPS (http://www.qps.nl/display/fledermaus/main)
-SONARWIZ from Chesapeake Technology (http://www.chesapeaketech.com/index_splash.php)
-HIPS and SIPS from Caris (http://www.caris.com/products/hips-sips/index.cfm)

Each one of these products has its benefits and drawbacks, including a large difference in price between them. It is recommended that for any hydrographic processing that is done with any of these software choices, time should be spent prior to a large scale project by taking training classes. Regardless if the person doing the work is already familiar with hydrographic data, if they have not used particular software, training is recommended to save time and money.

8.3 Magnetometer data processing

-UXO MARINE from GeoSoft (http://www.geosoft.com/products/software-extensions/uxo-marine/overview) is the industry standard for calculating analytic signal from any combination of measured and calculated gradients. However, it does take knowledge and training to understand the many options available to the user. Training would be required to use this software on a regular basis.

-OTHER: As an alternative to using GeoSoft there are also other means to determine the locations of potential targets. These are Surfer by Golden Software, ArcGIS, HyPACK, and SonarWiz, just to name a few. The output data from these programs may be slightly "noisier", but the trade off in price may be worth it. In order to determine which software would be used, the project manager needs to determine the size of the potential objects in the field as well as the amount of time available for running the surveys.

8.4 GIS software

-ArcGIS software is the worldwide standard for GIS data. There are several different version of this software including a lower priced one and options for non-profit companies to get major discounts on the software. All magnetometer, bathymetry, and side scan data as well as photos, videos and even sub bottom profile data can be stored in one geo-database which could be accessed worldwide (depending on where it is stored) for analysis and project planning in the future. ArcGIS is also the basis for the Information Management System for Mine Action (IMSMA), GICHD's standard mine action software. IMSMA was not available for this demonstration, but, as an ArcGIS-based software program, it should be compatible with the results achieved and recorded during this demonstration.

ANNEX A

Demonstration Plan

Document Number: TEP-15-01

Technical Evaluation Plan (TEP)

for

Sensor Technology Demonstration

in support of

Explosive Remnants of War (ERW)

Technical Survey Plan

Revision: 0.0

6 March 2015

Prepared By:
Orca Maritime Inc.

Prepared for:
Geneva International Center for Humanitarian Demining

Technical Evaluation Plan (TEP) for
Sensor Technology Demonstration

Document Number: TEP-15-01
Revision 0.0

SUBMITTED BY: ______________________ 27 FEB 2015

Kurt Nelson
Event Director
Orca Maritime Inc.

Date

APPROVED BY: ______________________ ______________

Justin Smith
Underwater EOD Operations,
Geneva International Centre for
Humanitarian Demining

Date

1 Introduction

1.1 Program Overview

1.2 Background

Throughout the world, explosive remnants of war (ERW) remains an international problem. Land remediation of ERW has been addressed and programs and procedures have been installed to mitigate the threat. But as countries and industries move off shore to exploit the untapped resources that lie beneath the ocean floor, underwater ERW is coming to the forefront as an immediate threat to operations in the energy, mining, fishing, and tourism industries. ERW from amphibious battles, historic ordnance dump sites, sunken ships and downed aircraft laden with ERW, naval mines, littoral "live fire" training areas and island bombing ranges pose a danger to the expansion of ocean-based industry development.

With regard to underwater ordnance remediation, very little has been done to identify efficient and cost effective methods of identifying and mapping ERW concentration areas. Current methods are relatively low-tech, slow, inaccurate, and expensive. Like remediation operations on land, underwater site management is crucial to safe and expeditious clean up efforts. Accurate mapping is the foundation on which a robust remediation plan is built. By establishing an underwater geographic information system (UGIS), remediation progress and hazard removal are monitored and managed through a systematic approach. The UGIS displays not only detected ERW, but also any other information that is important to the project, such as project boundaries, sensitive environmental areas, depth changes, etc. Through periodic remapping during the course of a clean-up operation, remediation teams can ensure that hazardous items are removed while simultaneously monitoring the environmental impact of remediation operations, enabling them to take the necessary precautions to minimize potential damage to sensitive underwater ecosystems.

Efforts to identify and implement commercial-of-the-shelf (COTS) mapping equipment and data processing software is key to establishing an international standard that can be universally adopted and used safely and effectively throughout the world.

1.3 Purpose Statement

This demonstration will assess the potential of new technologies and confirm the performance and characteristics of COTS equipment and software. The results of this demonstration can be used by planning staff at UN headquarters and National Mine Action Authorities (NMAA), and by program designers and donors to establish equipment options, inform procurement decision makers, and establish Quality Assurance/Quality Control (QA/QC) requirements. The need to evaluate underwater Search, Classify and Map (SCM) technology is crucial to establishing universal standards in data collection, analysis, storage, and underwater site management. The equipment and software tested during this demonstration are not intended to be an "only" solution, or cover the spectrum of potential alternatives. They have been selected as one potential "set" of equipment and software to employ for ERW remediation, based on the experience of Orca Maritime in underwater EOD/underwater mapping operations and discussions with the GICHD sponsor of the Technical Demonstration.

1.4 Demonstration Objectives

- Provide an independent assessment of the suitability and effectiveness of underwater sensor equipment for use in the global remediation efforts of ERW in the "In-shore" zone (0-5m depth) and "Near-shore" zone (5-50m depth) areas. Specifically, the following sensors will demonstrate detection capabilities against representative (inert) underwater ERW samples:
  - high frequency interferometric (side scan/bathymetry) sonar from autonomous unmanned vehicles (AUVs);
  - digital side scan sonar, towed from a surface vessel;
  - Strategic Intelligence Forward-looking Technology (SIFT) magnetometer from an unmanned aerial vehicle (UAV);
  - total field magnetometer towed by a surface vessel and AUV; and
  - still underwater camera.
- Evaluate represented sensor technologies and verify their functionality, applicability, and utility within the operational parameters of the test environment.
- Introduce remotely operated vehicle (ROV) technology to investigate and record with video footage suspected ERW at locations "handed off" from detection sensors.
- Test diver-held sonar and navigation system used by divers to investigate suspected ERW at locations "handed off" from detection sensors.
- Integrate detection sensor data, investigation information (video, diver sonar recordings) and other geospatially referenced information (overhead imagery, nautical charts, etc.) in an underwater geographic information system (UGIS) program.

To achieve these objectives, the demonstration will accomplish the following:

- Conduct open water testing to verify functionality of all system components and capabilities in a simulated operational environment. These open-water missions are defined and discussed in Section 5 of this document.
- Process all data from represented sensors and render it in layers and/or icons in a comprehensive UGIS for display on a standard personal computer.

2 Support and Administration

2.1 Security of Information

Orca Maritime, Inc., will provide secure storage of proprietary and/or business confidential information if required by individual demonstration participants.

2.2 Security of Equipment

Orca Maritime, Inc., will provide secure storage for demonstration equipment if required by responsibility of the individual demonstration participants. Vessel support during the demonstration week will be provided by Orca Maritime Inc.

3 Demonstration Management and Participants

3.1 Event Director / Operations

- Serve as the overall demonstration lead for the planning and execution of the demonstration plan.
- Carry direct reporting responsibility to the sponsor.
- Assure demonstration events are conducted in accordance with the scheduled plan including use of resources (equipment, facilities, and personnel); any deviations are noted, their impact assessed, and necessary corrective action taken as necessary.
- Ensure that all required data is effectively and efficiently collected to support the required acceptance decision.
- Provide a daily operations review.
- Note unusual events during the demonstration that may have some effect on the proper evaluation of equipment.
- Compile results, analyze data, and document sensor capabilities.
- Deliver demonstration report to sponsor.

3.2 Underwater Systems Lead

- Manage system assets and on-water schedule.
- Provide daily notifications to requisite port authorities.
- Manage the seeding and recovery of bottom targets from the operations areas.
- Ensure that sensor demonstrations are conducted in accordance with the TEP including required resources (equipment, facilities, and personnel); managing demonstration deviations, assessing deviation impact, and taking necessary corrective action as necessary.

3.3 Data Recorder/GIS Analyst

- Assist Event Director with data review.
- Ensure that data is collected, processed and archived appropriately within the UGIS.
- Review and ensure that data forms/collection tools are appropriate for the analysis required.
- Transfer collected data to analysis tools, as required.
- Organize and provide GIS products in visual and/or other formats that support and document results, conclusions, and recommendations for inclusion in the final report.
- Interface with the Event Director prior to, during, and after testing to ensure the test data is backed up, stored safely, and retrievable.

3.4 Equipment Operators

- Operate all equipment within specifications to accomplish demonstration objectives as directed by Event Director.

- Ensure all at-sea operations are conducted safely.

3.5 Support Vessel Operators

- Brief the location of safety equipment aboard the surface vessels, emergency SOPs, and the expected weather forecast for the day.
- Maintain vessels to allow for safe sensor operations.
- Operate vessels safely, adhering to safe boating rules and regulations.
- Ensure all at-sea operations are conducted safely.

3.6 Underwater Target Maintenance Dive Team

- Deploy and maintain target simulators as directed by Event Director.
- Maintain and distribute target locations to Data Recorder/Analyst.
- Ensure all dive operations are conducted safely and within the parameters outlined in the Orca Maritime Safe Diving Practices Manual.

3.7 Participants

Table 1 lists the individuals participating in the demonstration.

Table 1. Personnel

Rank/Name	Role	Organization	Email	Phone
Justin Smith	Sponsor	GICHD	josmithEOD@gmail.com	(951) 386-6095
Kurt Nelson	Event Director	Orca Maritime	knelson@orcamaritime.com	(619) 628-0068
Tony Rodgers	Operations	Orca Maritime	arodgers@orcamaritime.com	(619) 628-0068
Chad Nelson	U/W Tech Lead - Diver	Orca Maritime	cnelson@orcamaritime.com	(619) 628-0068
Chestley Howell	Boat Operator - Diver	Orca Maritime	chowell@orcamaritime.com	(619) 628-0068
Kim Flax	U/W Tech - Diver	Orca Maritime	kflax@orcamaritime.com	(619) 628-0068
Martha Rodgers	UGIS Lead	Orca Maritime	mrodgers@orcamaritime.com	(619) 628-0068
Daryl Slocum	Participant	OceanServer	slocum@ocean-server.com	(619) 312-5522
Cory Stephanson	Participant	BDS	cory@broadbanddiscovery.com	(831) 438-7237
Jim Garrington	Participant	Shark Marine	jim@sharkmarine.com	(905) 328-2294
Mike Aitken	Participant	Shark Marine	maitken@sharkmarine.com	
Doug Hrvoic	Participant	Marine Mag	dh@marinemagnetics.com	(416) 722-3481

4 Equipment and Materials

Table 2 lists the sensor and support equipment .

Table 2. Equipment and Materials

Equipment	Source
IVER3 AUV	Orca Maritime
IVER3 AUV	OceanServer Technologies
Seabotix vLBV300 ROV	Orca Maritime
Seabotix LBV200 ROV	Orca Maritime
Explorer Total Field Magnetometer (AUV towed)	Marine Magnetics
Total Field Magnetometer (AUV module)	Marine Magnetics
SeaQuest 3-axis Magnetometer (vessel towed)	Marine Magnetics
SIFT Magnetometer (airborne)	Broadband Discovery Systems
Marine Sonic Technology HD Side Scan Sonar (vessel towed)	Orca Maritime
Navigator Diver Operated Sonar	Shark Marine
27' Support Vessel	Orca Maritime
21' Support Vessel (operated by Orca Maritime)	Adept Process Service
Marine Band Radios	Orca Maritime
First Aid Kit	Orca Maritime
Personal Protective and Safety Equipment	Participants Responsibility
Dive Equipment (SCUBA)[1]	Participants Responsibility

[1] Orca will obtain permitting for diving operations in San Diego Bay

5 Schedule

(See Appendix A for specific events/objectives for each day)

6 Reports

6.1 General

Reports required in connection with this demonstration will be distributed to all participants. The trial report will be posted on the GICHD website in the online equipment catalogue.

6.2 Status Reports

The Event Director will review operations for each day. If equipment failures occur that affect the demonstration, the Event Director will review the failure and its potential impact on the demonstration schedule, note the system performance, and recommended corrective action.

6.3 Sensor Technology Demonstration Report

Upon completion of the demonstration event, the Event Director will gather sensor performance data from all participants and provide a written evaluation documenting the techniques and procedures used in gathering bottom data, equipment performance and shortfalls, and UGIS utility with regard to underwater site management.

6.4 Test Site / Facilities

The physical location of the test fields will be in San Diego bay (In-shore field) and off shore of the Silver Strand (Near-shore field). Orca Maritime will provide facilities for lab/bench testing and maintenance if required.

6.5 Disclosure Policy

Proprietary Information. Requests for access to proprietary information will be referred to the proprietor agency for disposition.

7 Safety

In the conduct of all operations associated with this project, safety is paramount. It is the responsibility of all participants to consider any and all safety aspects when planning and executing any operations and to ensure that all personnel involved understand that operations are not to be conducted until safe conditions exist. No operations will be conducted if any participants or equipment will be placed in undue danger. If an unsafe situation should develop, appropriate corrective action will be taken immediately and the Event Director will be notified.

Maintaining a safe working environment is the shared responsibility of all demonstration participants. The Event Director has the responsibility and authority to manage the safe conduct of all demonstration participants and make on-scene decisions concerning all technical and safety aspects of operations. The Event Director will brief all participating personnel on safety considerations and procedures at the beginning of the demonstration, obtaining a signed responsibility waiver form from all participants. If new information becomes available during operations, the Event Director will conduct an immediate review for safety aspects, and take appropriate action, to include suspending operations until all issues are resolved. If unsafe conditions are encountered, the Event Director has the responsibility to stop operations, correct the problem, then resume operations after a safety review. During each day of at-sea operations the vessel will inform the team of any new or changed risks associated with the weather.

7.1 Event Director

- Evaluate environmental conditions and declare them adequate or unsafe before beginning operations.
- Review all documentation for safety considerations.

- If new information becomes available during operations, conduct an immediate review for safety aspects, and take appropriate action, to include suspending operations until all issues are resolved.
- If unsafe conditions are encountered, stop operations and correct the problem.
- Brief all participants on safety considerations and procedures including lost UUV search procedures.
- Brief personnel on the applicable safety risks and risk controls.

7.2 Demonstration Participants

- Maintain situational awareness and take action if the safety of personnel or equipment is compromised.
- Ensure CPR & First Aid trained personnel are present.
- Ensure First Aid kit is available and stocked.
- All personnel are safety observers for at-sea operations aboard the vessels.
- Each member of the demonstration team has the authority to stop testing should an unsafe condition arise.

7.3 Boat Operators

- Brief the location of safety equipment aboard the surface vessels, emergency procedures, and the expected weather forecast for the day.
- Ensure all at-sea operations are conducted safely.
- **The vessel operator will have the final authority to stop operations if he/she considers conditions, both environmental and/or man-made, to be too hazardous to safely continue operations.**

7.4 Communications Plan

Communications will consist of marine-band radios as primary and cell phones as secondary forms of communication.

7.5 Lost AUV Procedures

A SeaBotix vLBV300 ROV will be on standby for AUV recovery if a vehicle is lost. SeaBotix ROVs are maintained at, and operated by, Orca Maritime.

7.6 Hazards of On-water Operations

Local environmental conditions are not considered unusual or hazardous for the equipment being demonstrated or the personnel involved. No hazards are anticipated for the demonstration program. The most likely sources of risk are operator fatigue. Remote hazards may include failure of the support craft, launch and recovery of the AUVs, and personnel slipping around piers and support craft.

8 Environmental Impact

Primary sensors demonstrated during this event are the Klein 3500 interferometric side scan/bathymetry sonar, Marine Magnetics Explorer total-field magnetometer and Marine Magnetics 3-axis magnetometer.

As reported in ConocoPhilips Alaska, Inc., 2008:

"side scan sonars operate in an extremely high frequency range (over 120 kHz) relative to marine mammal hearing (Richardson et al., 1995; Southall et al., 2007). The frequency range from these side scan sonars is beyond the hearing range of mysticetes (baleen whales) and pinnipeds. Therefore, these sonars are not expected to affect bowhead, gray, humpback, minke, and other baleen whales and pinniped species in the proposed project area. The frequency range from these side scan sonars falls within the upper end of odontocete (toothed whale) hearing spectrum (Richardson et al., 1995), which means that they are not perceived as loud acoustic signals with frequencies below 120 kHz by these animals. Further, in addition to spreading loss for acoustic propagation in the water column, high frequency acoustic energies are more quickly absorbed through the water column than sounds with lower frequencies (Urick, 1983). Therefore, the potential effects from side scan sonar to marine mammals would be negligible."

A study conducted using magnetometers attached to marine mammals to measure dynamic attitude (Fourati et al., 2008) posed no threat or harm to the marine mammals in the study.

9 Operational Area and Test Targets

The evaluation will take place in in-shore and near-shore simulated underwater ERW fields (see figure 1). The in-shore field has approximately 3-4 meters of depth. The near-shore field has approximately 20-28 meters of depth.

Simulated targets in each test field include:

- 2 x 60mm
- 2 x 82mm
- 1 x 120mm
- 1 x 160mm
- 1 x 105mm
- 1 x 122mm
- 1 x 130mm
- 1 x 155mm

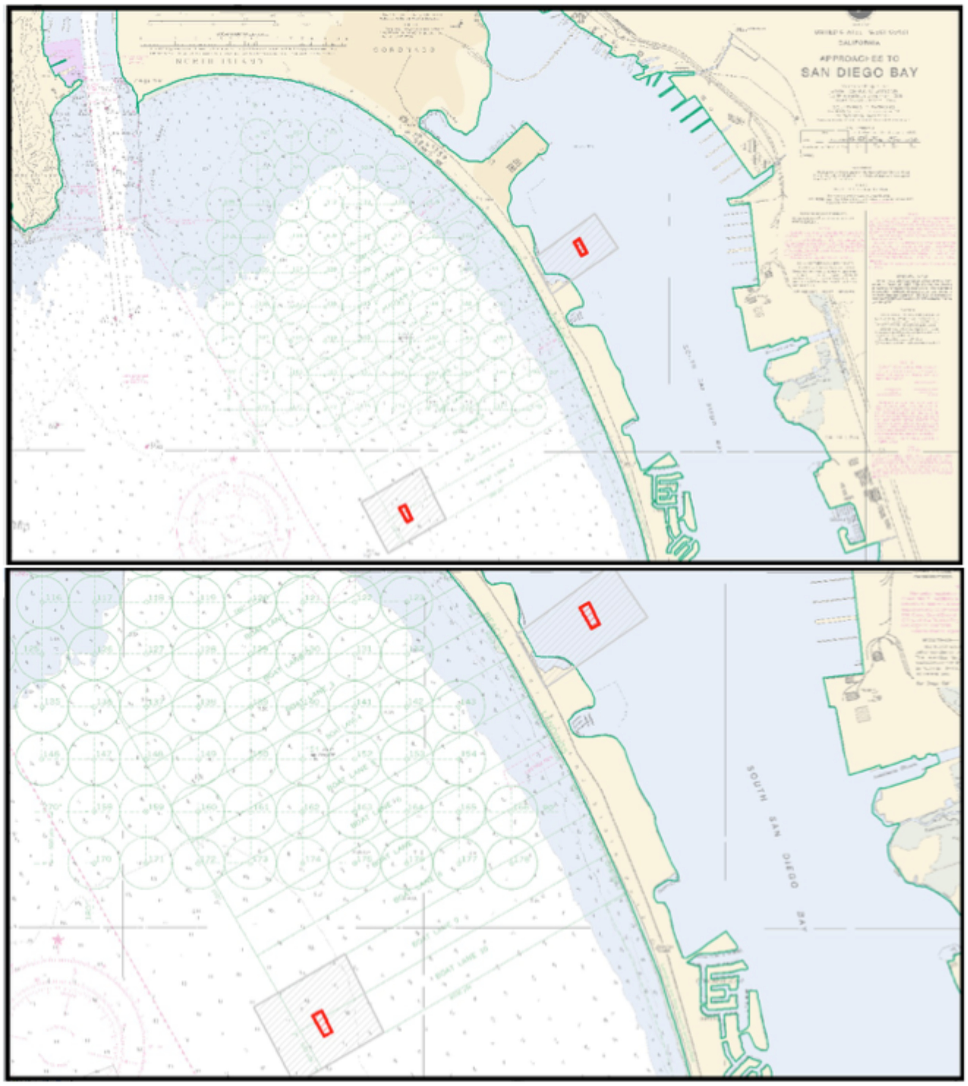

Figure 1. Areas of Operation – San Diego Training Fields

ANNEX B

Schedule of Events

Week 1: 23-27 March, 2015 (Orca Maritime / OceanServer / Marine Magnetics)

<u>Day 1: 23 March</u>

Objectives:

1. Introduce all Technical Demonstration participants, review objectives and schedule

2. Place all simulated UXO in In-shore test field and Near-shore test field according to trusted agent plan. Simulated UXO positions not to be revealed to detection sensor processing personnel.

Events:

0800 – 1000: Technical Demonstration week 1 kick-off meeting at Orca Maritime Headquarters.

1100 - 1300: Orca Maritime dive team placement of 10 simulated UXO items in Near-shore test field

1400 – 1700: Orca Maritime dive team placement of 10 simulated UXO items in In-shore test field

<u>Day 2: 24 March</u>

Objectives:

1. Demonstrate Iver3 AUV with Klein 3500 interferometric sonar and Marine Magnetics AUV Module total field magnetometer capability to detect simulated UXO items, 60mm – 160mm, in In-shore zone.

2. Demonstrate Iver3 AUV with Klein 3500 interferometric sonar and Marine Magnetics AUV towed total field magnetometer capability to detect simulated UXO items, 60mm – 160mm, in Near-shore zone.

Events:

0800 – 1700: Orca Maritime AUV team conducts three AUV missions with Iver3 AUV (full sensor package) in Near-shore test field.

0800 – 1700: OceanServer AUV team conducts three AUV missions with Iver3 AUV (full sensor package) in In-shore test field.

<u>Day 3: 25 March</u>

Objectives:

1. Demonstrate Iver3 AUV with Klein 3500 interferometric sonar and Marine Magnetics AUV Module total field magnetometer capability to detect simulated UXO items, 60mm – 160mm, in Near-shore zone.

2. Demonstrate Iver3 AUV with Klein 3500 interferometric sonar and Marine Magnetics AUV towed total field magnetometer capability to detect simulated UXO items, 60mm – 160mm, in In-shore zone.

Events:

0800 – 1700: OceanServer AUV team conducts three AUV missions with Iver3 AUV (full sensor package) in Near-shore test field.

0800 – 1700: Orca Maritime AUV team conducts three AUV missions with Iver3 AUV (full sensor package) in In-shore test field.

0800 – 1700: Process data collected 24 March.

Day 4: 26 March

Objectives:

1. Demonstrate Marine Magnetics SeaQuest Magnetometer in the Near-shore test field.

2. Demonstrate LBV200 ROV to reacquire and identify simulated UXO items, 60mm – 160mm, in In-shore zone.

Events:

0800 - 1700: Marine Magnetics tech conducts three magnetometer surveys with SeaQuest in Near-shore test field.

0800 - 1700: Orca Maritime ROV team conducts reacquire and identify operations using the LBV200 ROV in the In-shore test field.

0800 – 1700: Process data from 25 March.

Day 5: 27 March

Objectives:

1. Demonstrate Marine Magnetics SeaQuest Magnetometer in the In-shore test field.

2. Demonstrate LBV200 ROV to reacquire and identify simulated UXO items, 60mm – 160mm, in Near-shore zone.

Events:

0800 - 1700: Marine Magnetics tech conducts three magnetometer surveys with SeaQuest in In-shore test field.

0800 - 1700: Orca Maritime ROV team conducts reacquire and identify operations using the LBV200 ROV in the Near-shore test field.

0800 – 1700: Process data from 26 March.

Week 2: 30 March – 3 April, 2015 (Orca Maritime / Shark Marine / ~~Broadband~~)

Day 6: 30 March

Objectives:

1. Introduce all Technical Demonstration participants, review objectives and schedule

Events:

0800 – 1000: Technical Demonstration Week 2 kick-off meeting at Orca Maritime Headquarters.

0800 – 1700: Process data from 27 March.

Day 7: 31 March

Objectives:

1. Demonstrate Shark Marine Navigator system capability to reacquire simulated UXO items, 60mm – 160mm, in In-shore test field.

2. Demonstrate vLBV300 ROV to reacquire and identify simulated UXO items, 60mm – 160mm, in Near-shore zone.

Events:

0800 – 1700: Orca Maritime / Shark Marine dive team conducts reacquire mission using the Navigator in the In-shore test field.

0800 - 1700: Orca Maritime ROV team conducts reacquire and identify operations using the vLBV300 ROV in the Near-shore test field.

0800 – 1700: Process data collected 30 March.

Day 8: 1 April

Objectives:

1. Demonstrate Shark Marine Navigator system capability to reacquire simulated UXO items, 60mm – 160mm, in Near-shore test field.

2. Demonstrate vLBV300 ROV to reacquire and identify simulated UXO items, 60mm – 160mm, in In-shore zone.

Events:

0800 – 1700: Orca Maritime / Shark Marine dive team conducts reacquire mission using the Navigator in the Near-shore test field..

0800 - 1700: Orca Maritime ROV team conducts reacquire and identify operations using the vLBV300 ROV in the In-shore test field.

0800 – 1700: Process data collected 31 March.

Day 9: 2 April

Objectives:

1. ~~Demonstrate Marine Sonic 900 kHz – 18 kHz HDS towed side scan sonar in the Near-shore test field.~~

Events:

0800 - 1700: ~~Orca Maritime survey team conducts side scan operations in the Near-Shore test field.~~

0800 – 1700: Process data collected 1 April.

Day 10: 3 April

Objectives:

1. ~~Demonstrate Marine Sonic 900 kHz – 18 kHz HDS towed side scan sonar in the In-shore test field.~~

Events:

0800 - 1700: Orca Maritime survey team conducts side scan operations in the In-Shore test field.
0800 – 1700: Process data collected 2 April.

Week 3: 6 April, 2015 (Orca Maritime)

Day 11: 6 April

Objectives:

1. Recover all simulated UXO in In-shore test field and Near-shore test fields.

Events:

0800 – 1000: Orca Maritime dive team recovery of 10 simulated UXO items in Near-shore test field

1000 – 1200: Orca Maritime dive team recovery of 10 simulated UXO items in In-shore test field

0800 – 1700: Process data collected 3 April and load data into the UGIS.

ANNEX C

Survey Data

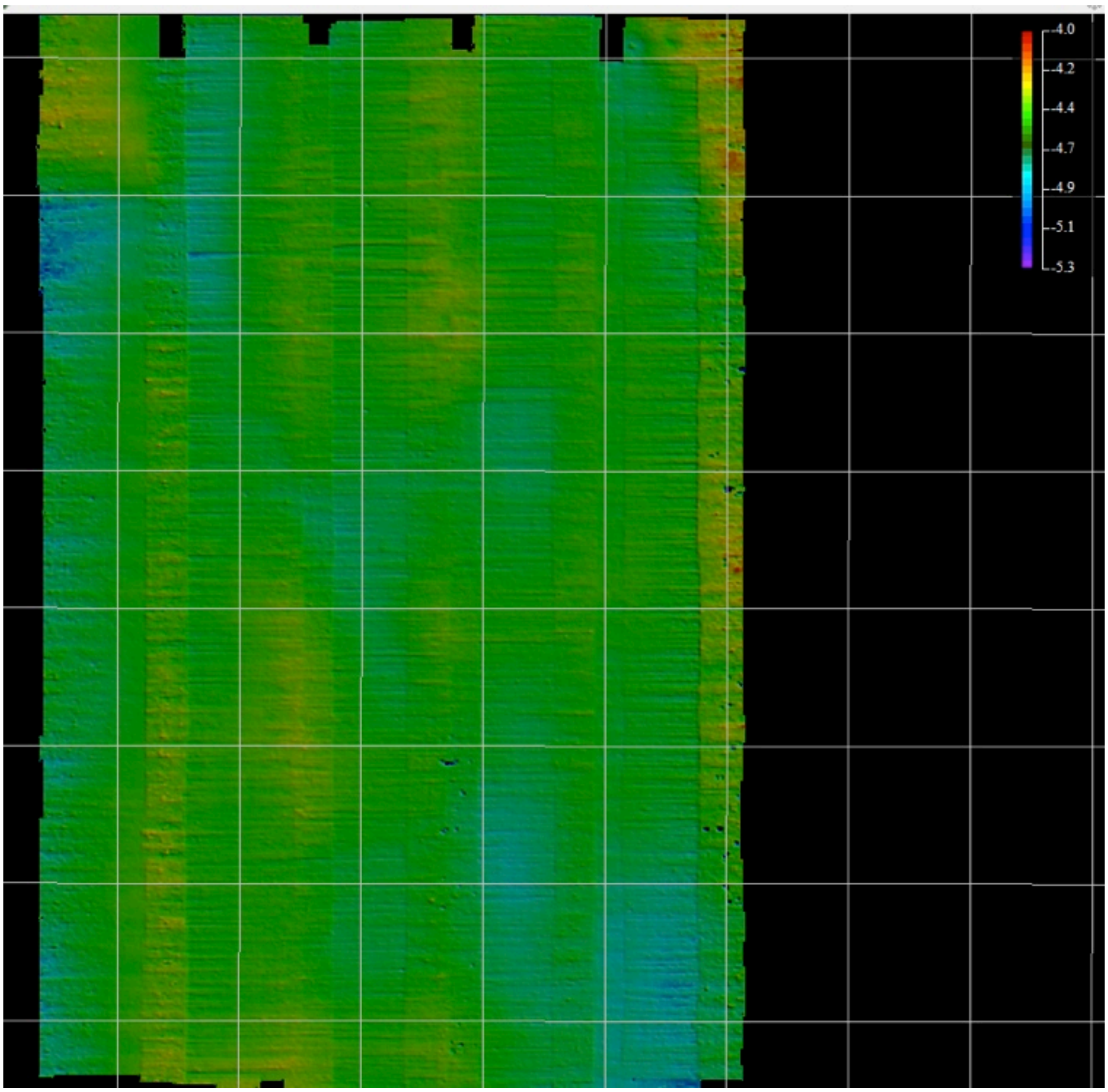

Figure C-1. Bathymetry survey from in-shore area, collected with AUV.

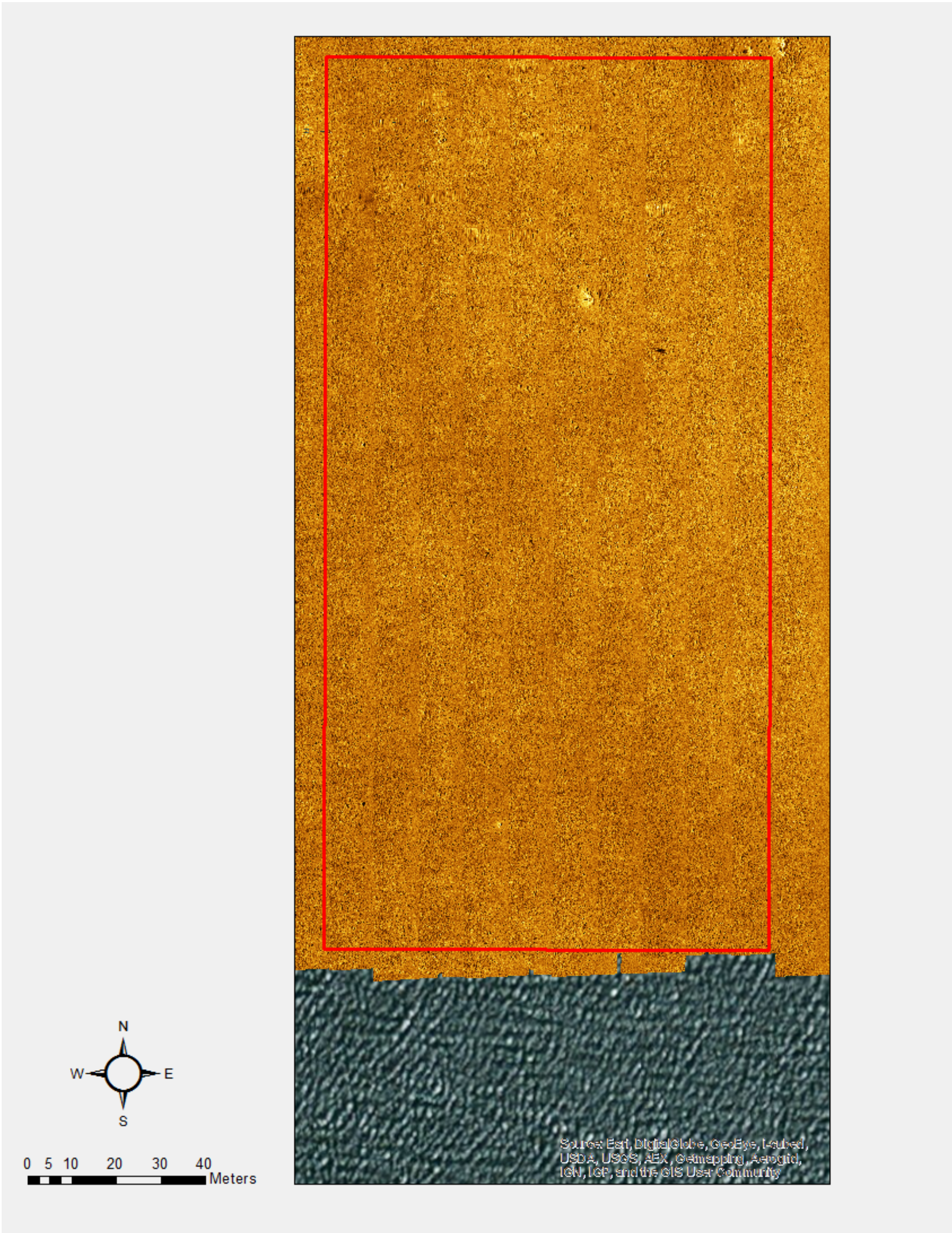

Figure C-2. Side scan sonar mosaic from in-shore area, collected with AUV.

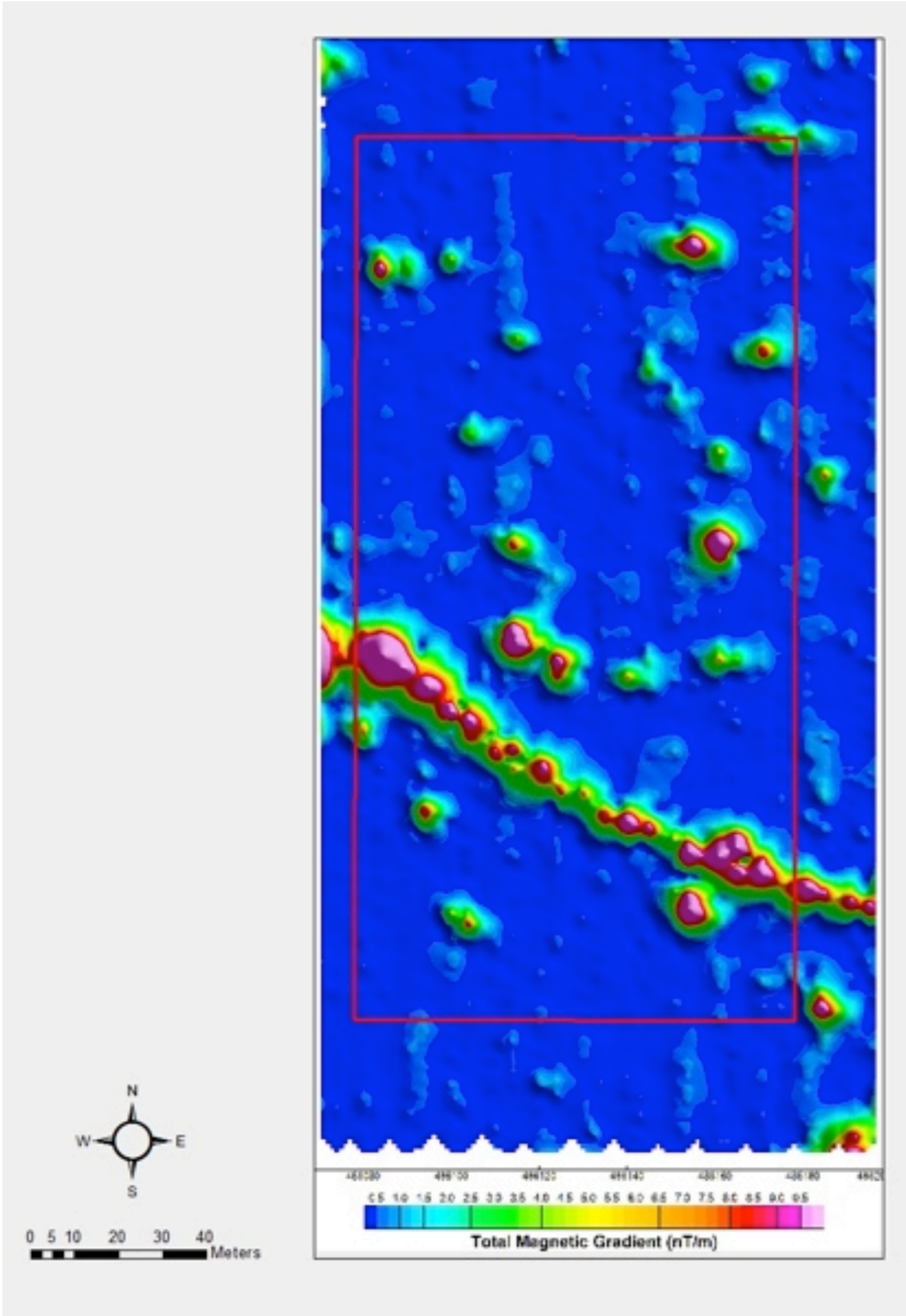

Figure C-3. Processed total field magnetometer data from AUV-towed Marine Magnetics Explorer magnetic sensor in the in-shore field survey.

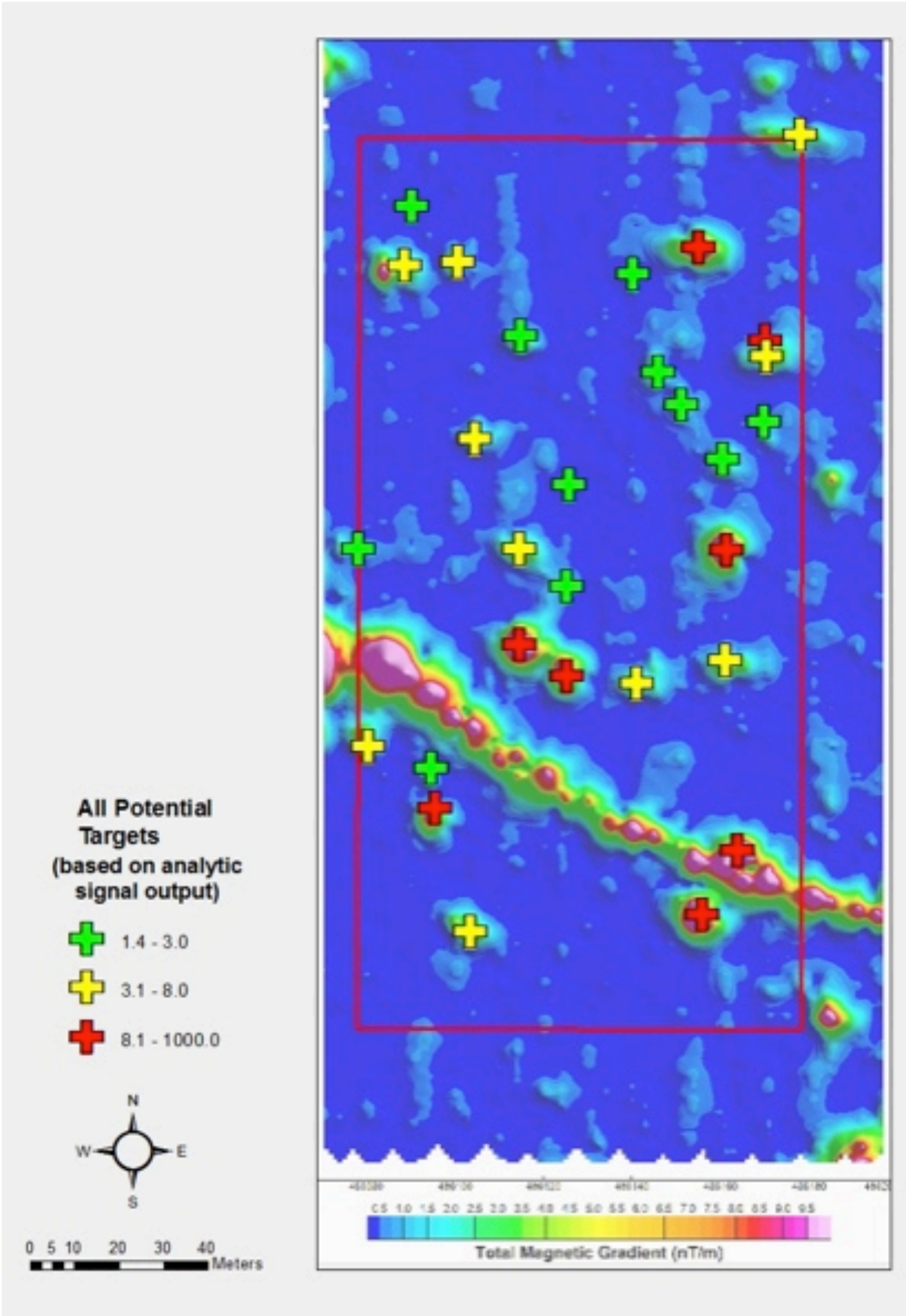

Figure C-4. Processed total field magnetometer data from AUV-towed Marine Magnetics Explorer magnetic sensor in the in-shore field survey with operator-called detection positions overlaid.

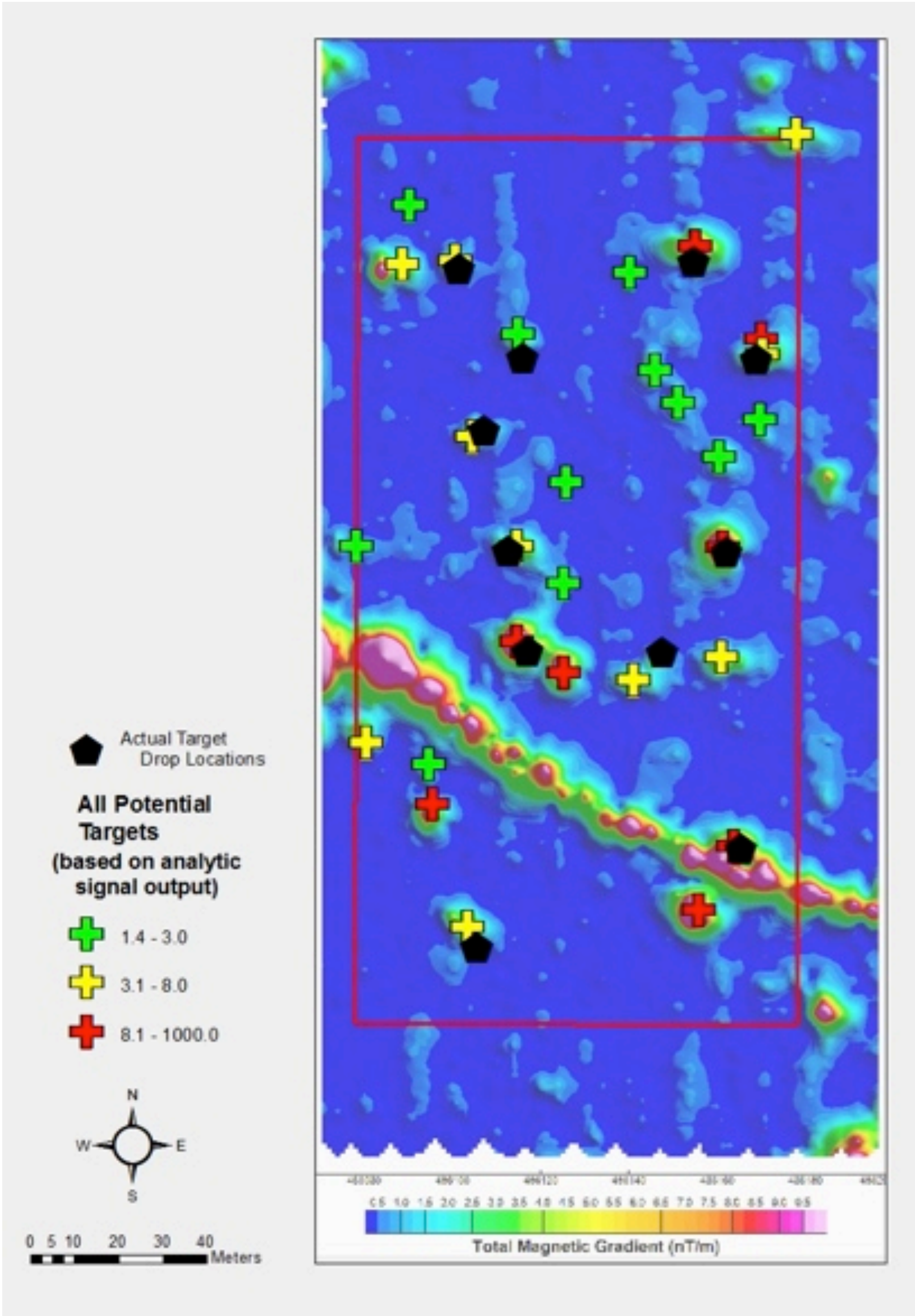

Figure C-5. Processed total field magnetometer data from AUV-towed Marine Magnetics Explorer magnetic sensor from the in-shore field survey with operator-called detection positions and simulated ERW target lay positions overlaid.

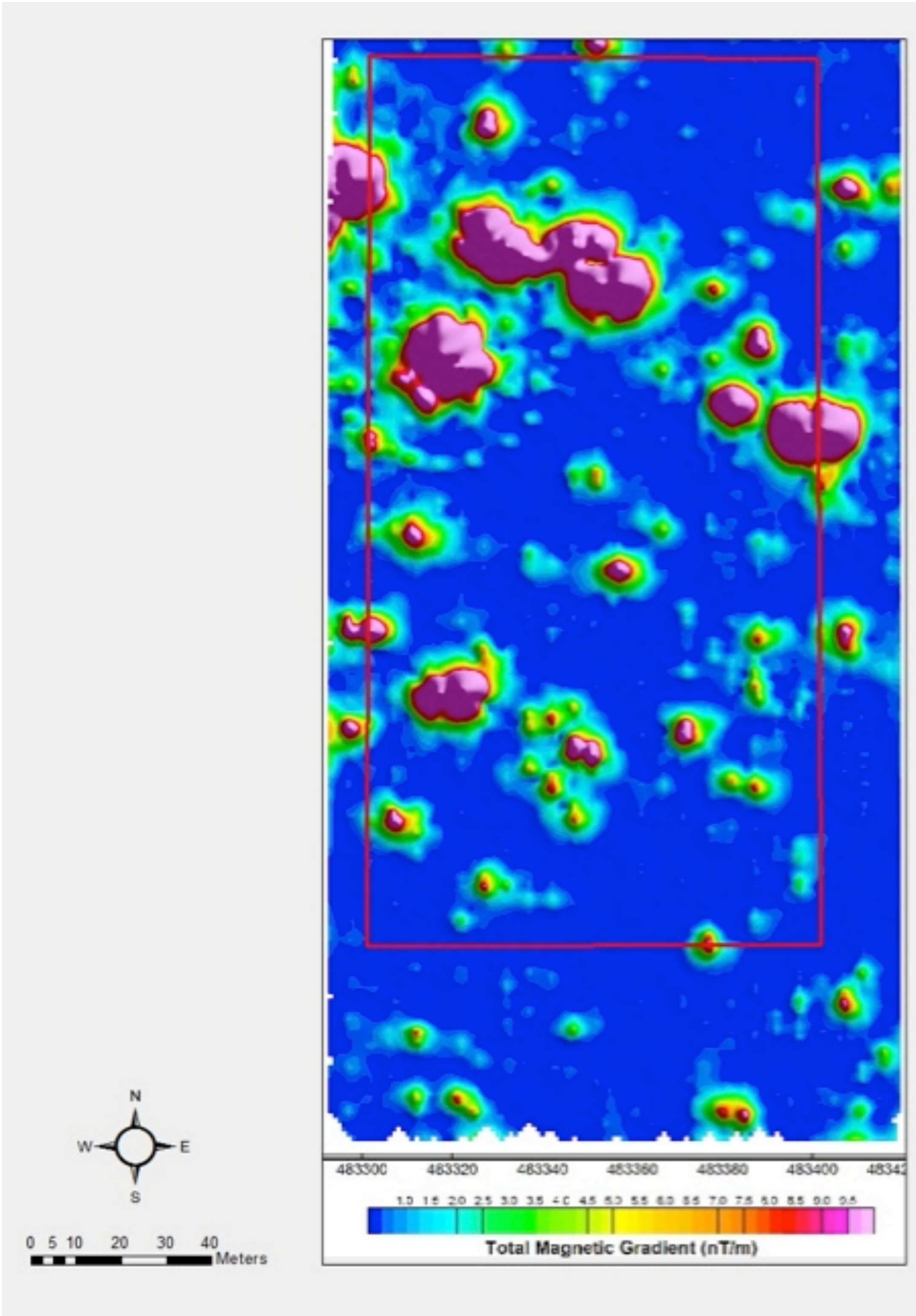

Figure C-6. Processed total field magnetometer data from AUV-towed Marine Magnetics Explorer from the near-shore field survey.

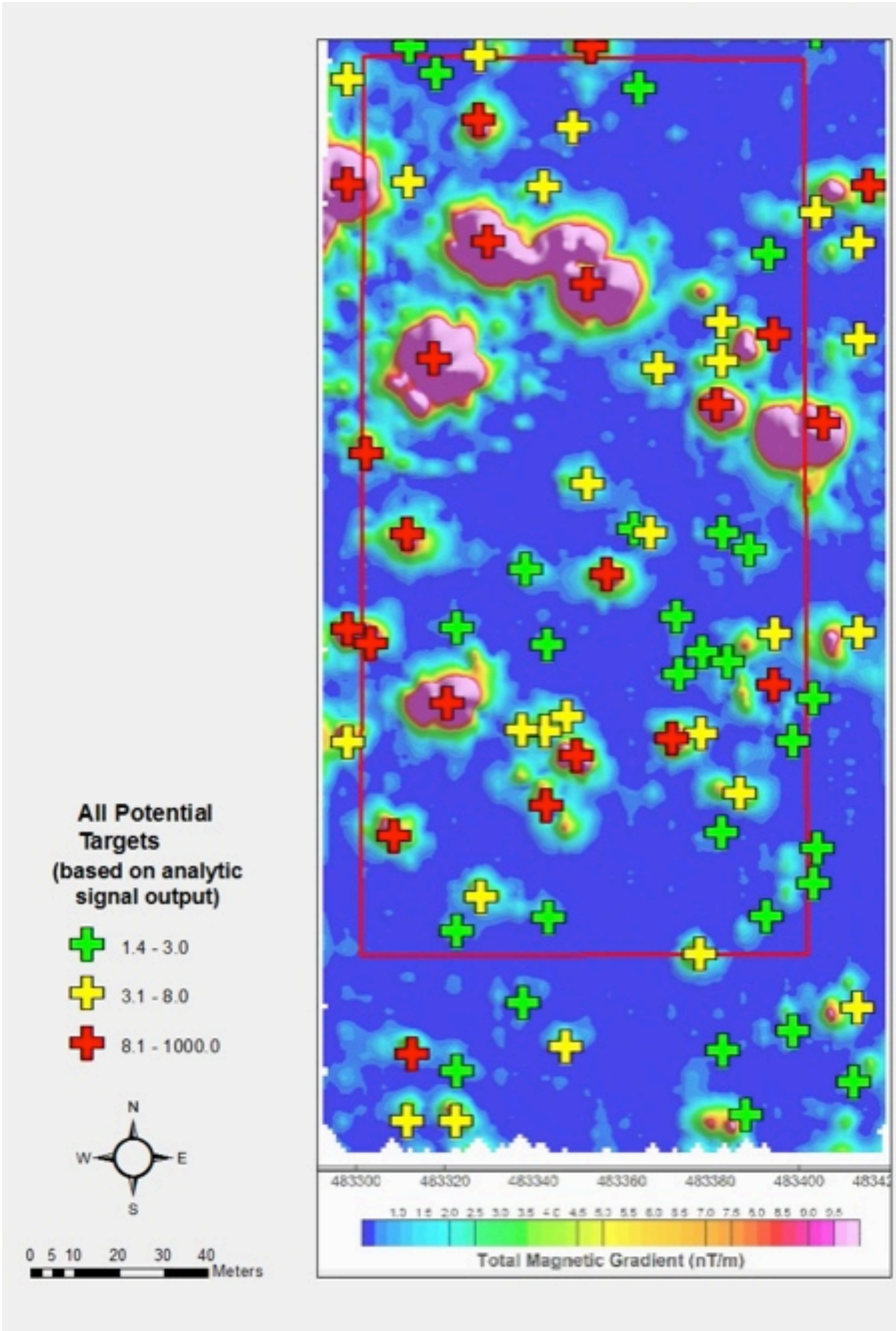

Figure C-7. Processed total field magnetometer data from AUV-towed Marine Magnetics Explorer from the near-shore field survey with operator-called magnetic anomalies overlaid.

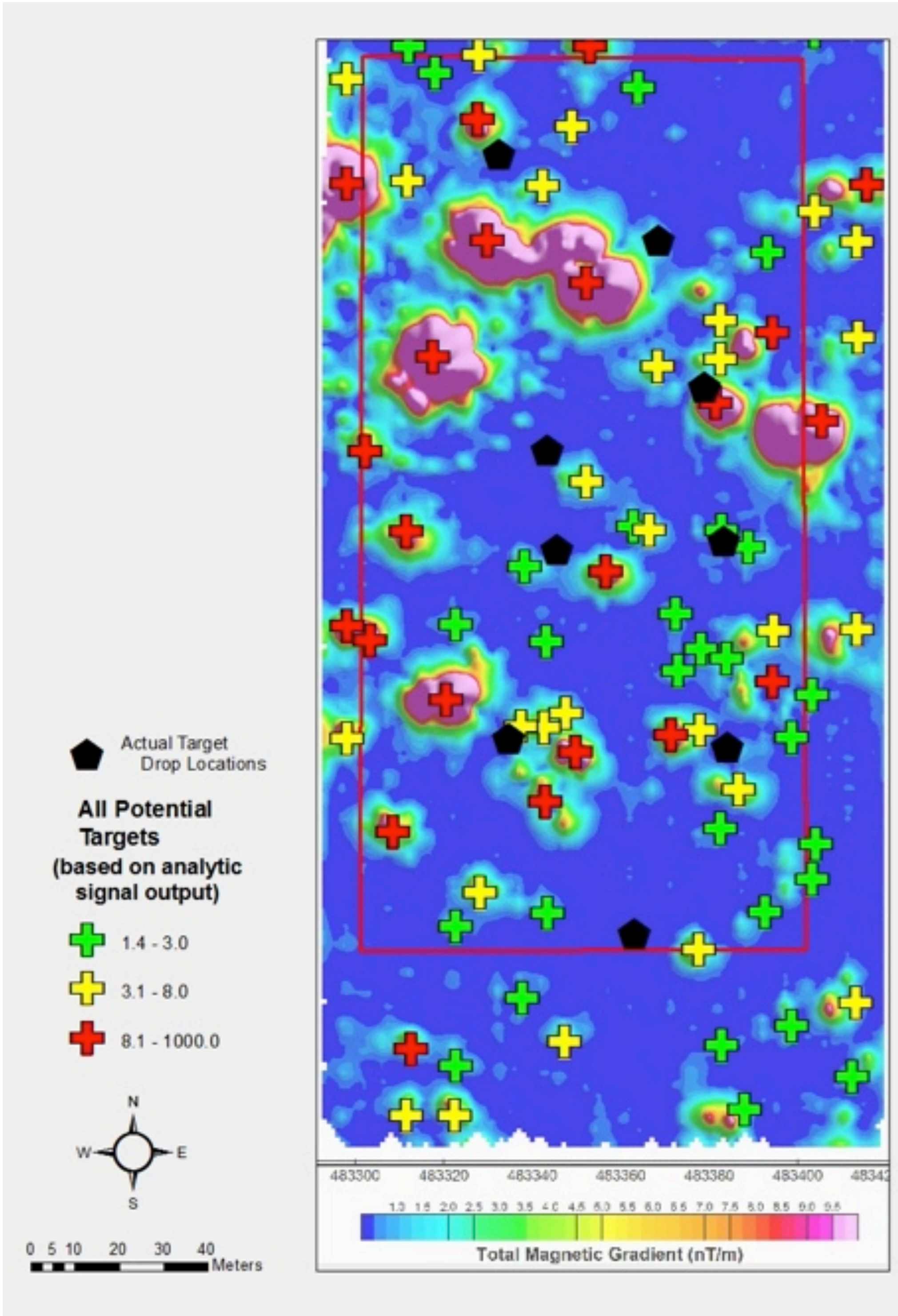

Figure C-8. Processed total field magnetometer data from AUV-towed Marine Magnetics Explorer from the near-shore field survey with operator-called magnetic anomalies and simulated ERW target lay positions overlaid.

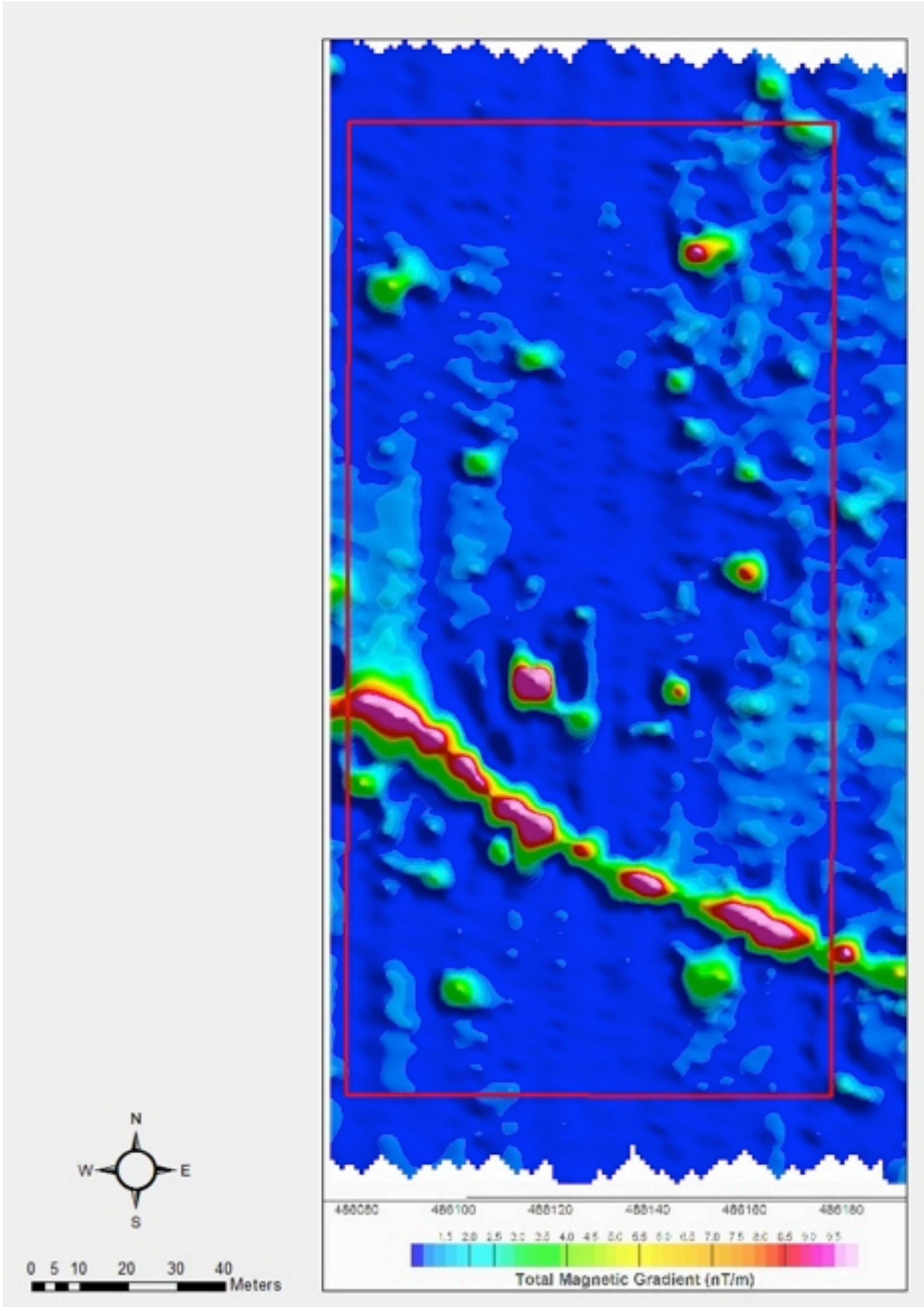

Figure C-9. Processed multi-sensor gradiometer data from vessel-towed Marine Magnetics SeaQuest from the in-shore field survey.

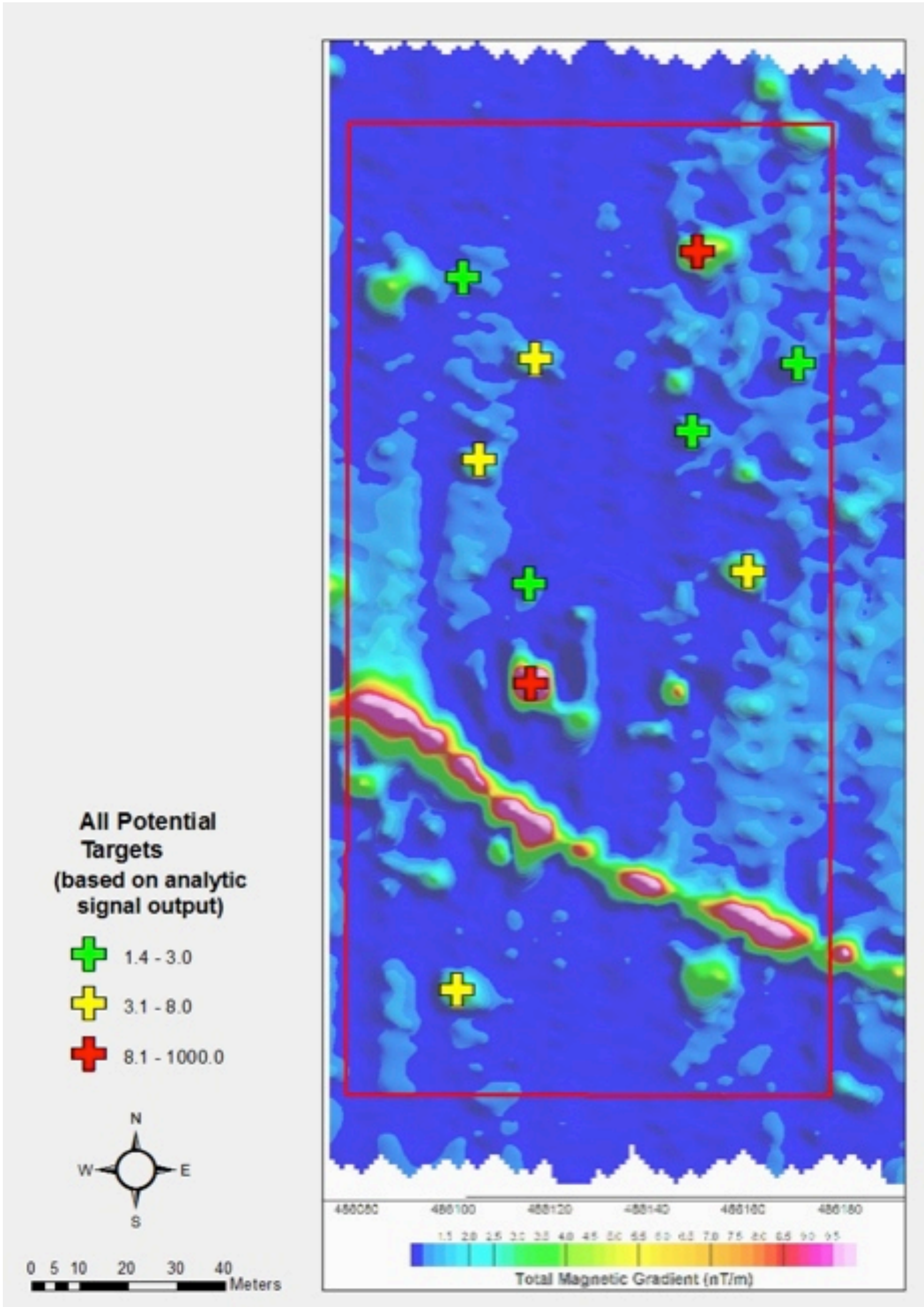

Figure C-20. Processed multi-sensor gradiometer data from vessel-towed Marine Magnetics SeaQuest from the in-shore field survey with operator-called magnetic anomalies overlaid.

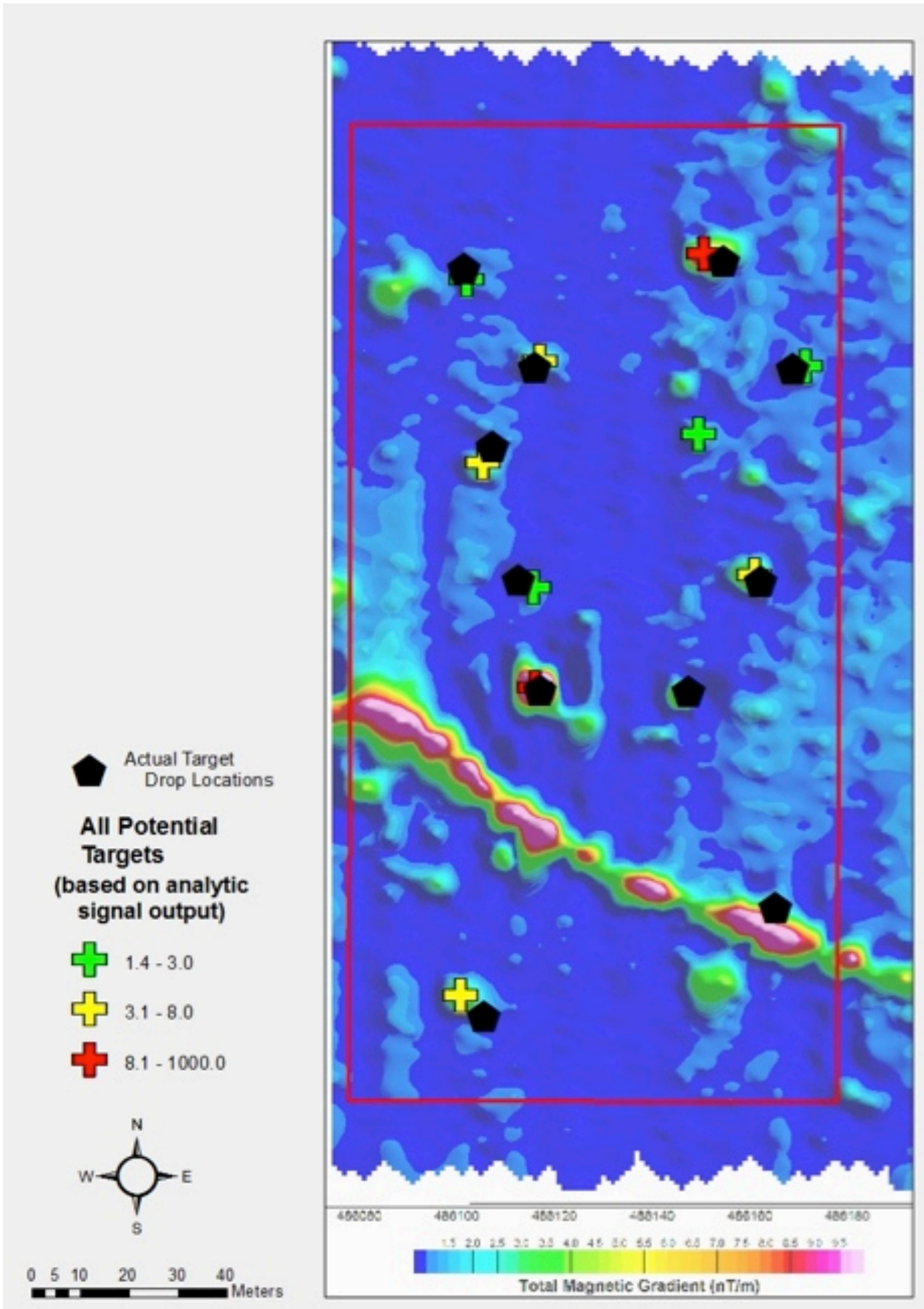

Figure C-11. Processed multi-sensor gradiometer data from vessel-towed Marine Magnetics SeaQuest from the in-shore field survey with operator-called magnetic anomalies and simulated ERW target lay positions overlaid.

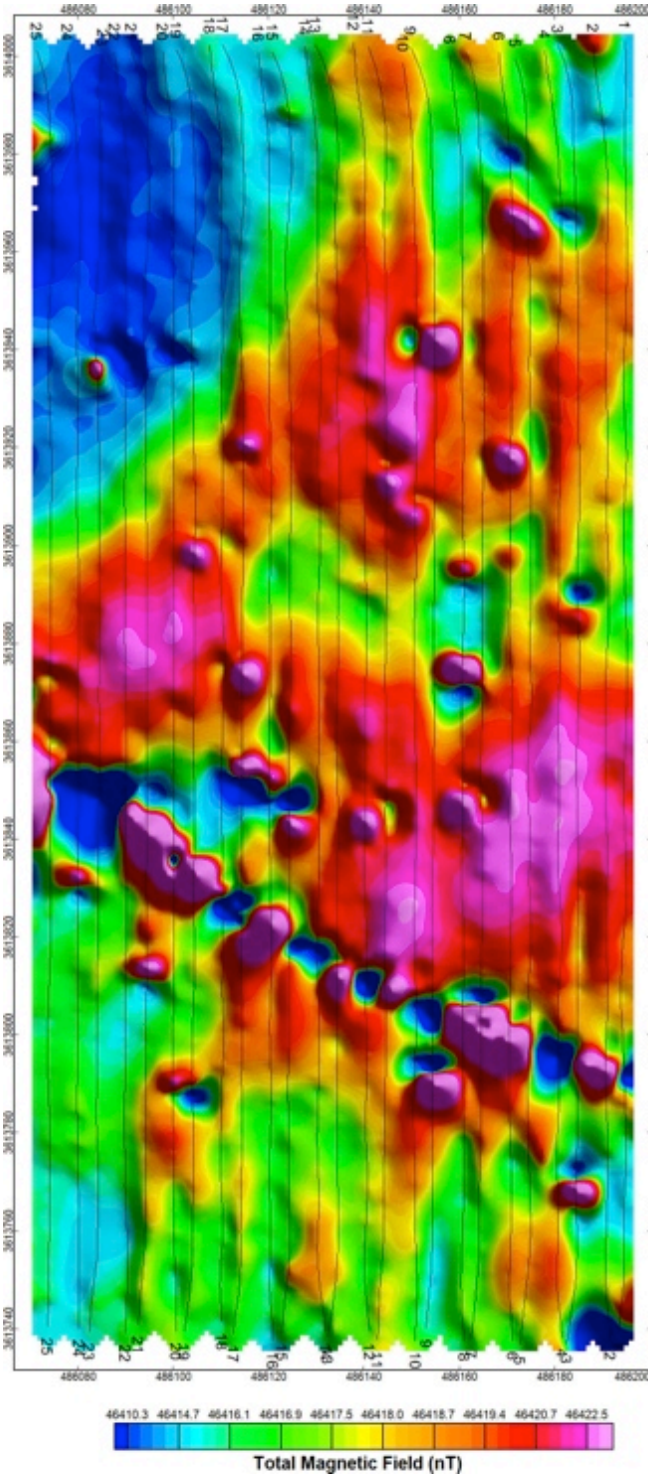

Figure C-14. Unprocessed magnetometer data from the in-shore field survey, collected with the AUV-towed total field magnetometer.

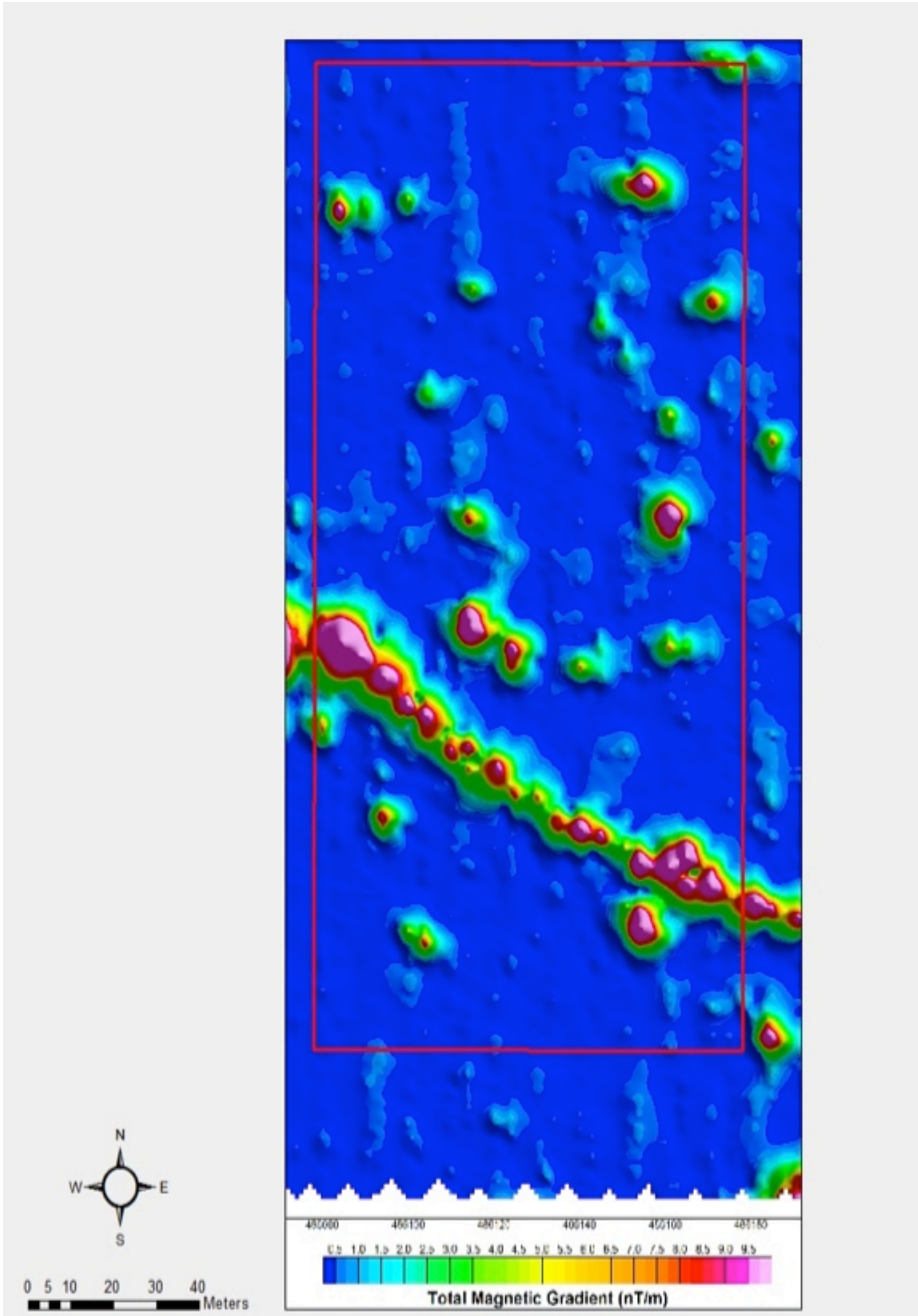

Figure C-15. AUV-towed total field magnetometer data after processing with GeoSoft UXO Marine software.

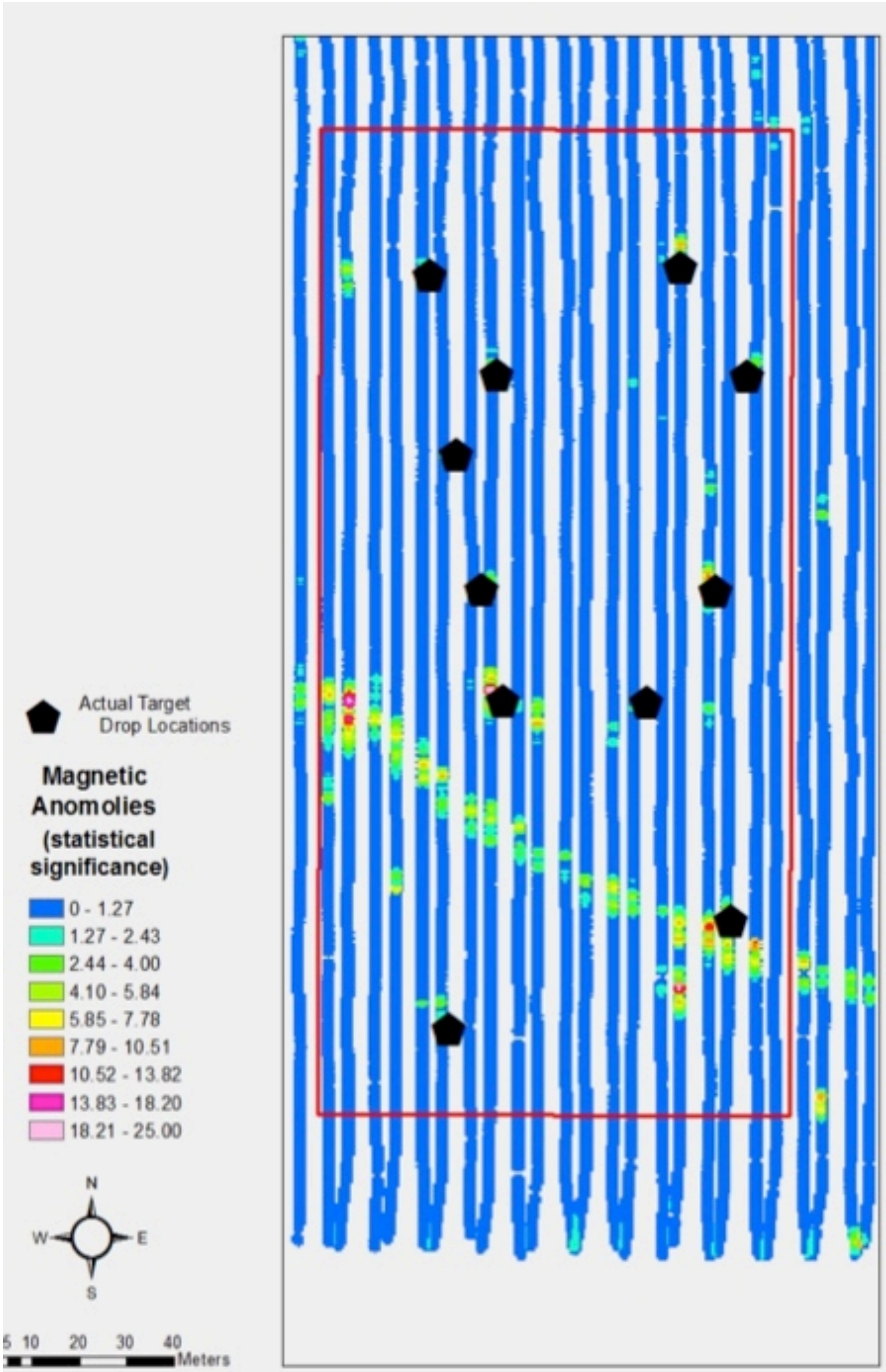

Figure C-16. AUV-towed total field magnetometer data after processing with ArcGIS software.

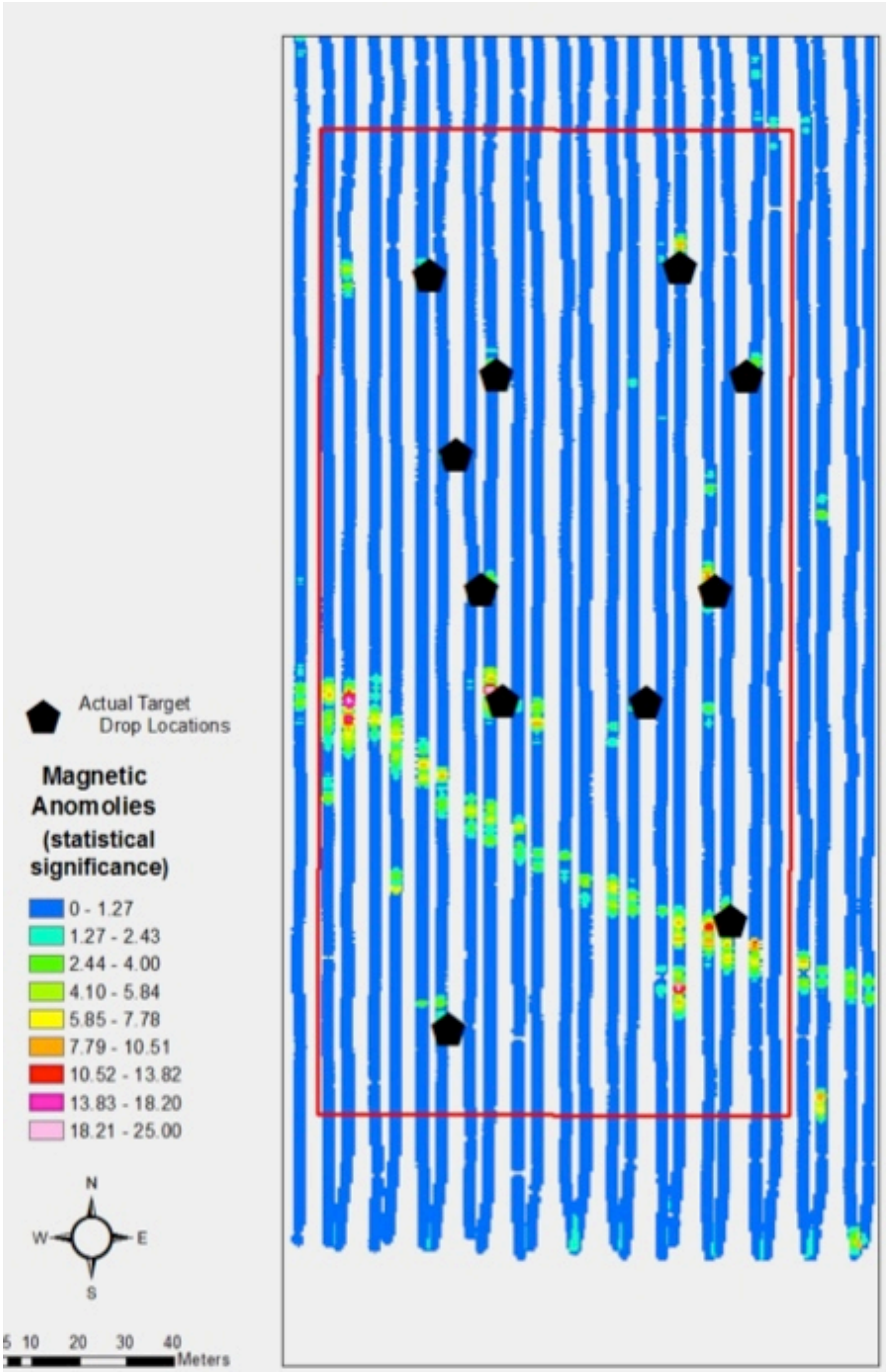

Figure C-17. AUV-towed total field magnetometer data after processing with ArcGIS software with simulated ERW target lay positions overlaid.

ANNEX D

Manufacturer's Information

Marine Magnetics Corp.
135 Spy Court
Markham, Ontario, L3R 5H6
Canada
www.marinemagnetics.com

Ocean Server Technology, Inc.
151 Martine Street
Fall River, Massachusetts 02723 USA
www.ocean-server.com

SeaBotix Inc.
2877 Historic Decatur Road, Suite 100
San Diego, California 92106 USA
www.SeaBotix.com

Shark Marine Technologies, Inc.
4-23 Nihan Drive
St. Catharines, Ontario, L2N 1L2
Canada
www.sharkmarine.com

Software Developer's Information

Environmental Systems Research Institute (ESRI)
380 New York Street
Redlands California 92373 USA
www.esri.com

Geosoft, Inc.
Queens Quay Terminal
207 Queens Quay West
Suite 810, PO Box 131
Toronto, ON Canada M5J 1A7
www.geosoft.com

Oceanic Imaging Consultants
1144 10th Avenue, Suite 200
Honolulu, Hawaii 96816 USA
www.oicinc.com

ANNEX E

About Orca Maritime

As new underwater technologies emerge, Orca Maritime serves as a "field laboratory" to test and evaluate new equipment and associated software, providing detailed feedback to the research and development industry regarding equipment and technology applicability in all operational environments. Orca Maritime's background makes them uniquely qualified for the task of identifying and evaluating those technologies for use in explosive remnants of war (ERW) remediation. For this reason, Orca Maritime was chosen as a working group member to assist GICHD in developing the IMAS underwater ERW remediation standards.

Orca Maritime continues to leverage the latest technologies by maintaining close relationships with leading undersea robotic manufacturers and the international mine countermeasure community. These close business relationships help to provide commercial and governmental interests with the latest lightweight and highly portable/low logistic underwater security and environmental data monitoring capability available as well as innovative underwater mapping techniques, to enhance underwater site management and maritime domain awareness.

Orca Maritime was established by Anthony Rodgers and Kurt Nelson, two retired U. S. Navy Master Explosive Ordnance Disposal Technicians, who are regarded as two of the foremost subject matter experts regarding the deployment and operation of autonomous underwater vehicles (AUVs). In September 2002, Rodgers and Nelson were selected to commission Naval Special Clearance Team ONE (NSCT-1) as Commanding Officer and Command Master Chief. NSCT-1 was an elite special operations unit comprised of U. S. Navy EOD, SEALs, Special Warfare Combat Craft (SWCC) Operators, Navy Divers, Recon Marines, Navy Marine Mammal systems and unmanned underwater vehicle operators. At the time, NSCT-1 was the U. S. Navy's only command dedicated to hunting sea mines in the littoral waters from 200 ft to the beach using AUVs, marine mammals and combat divers. PMS EOD introduced the REMUS 100 UUVs to NSCT-1 shortly after commissioning as a new technology that could be applied successfully to the shallow water and very shallow water (VSW) EOD Mine Countermeasures mission. Rodgers and Nelson took this new technology from the vehicle selection process, through the development of the concept of operations (CONOPS), development of tactics, techniques and procedures (TTPs), to the formation of a combat ready UUV platoon. The UUV platoon at (then) COMINEWARCOM was established on the model developed at NSCT-1.

After retiring from the Navy, Anthony Rodgers and Kurt Nelson established Orca Maritime, Inc. in Imperial Beach, CA. Orca Maritime collects, processes and analyzes underwater data, using UUVs, ROVs, diver collected data and off-the-shelf software to build unique underwater layers for GIS programs. This critical information serves port decision makers, first responders and facility owners in the maritime industry.

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