# MARINE TOWED ARRAY TECHNOLOGY DEMONSTRATION AT THE FORMER NAVAL DUCK TARGET FACILITY

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# LIST OF ACRONYMS

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|---|---|
| ASR | Archives Search Report |
| BRAC | Base Realignment and Closure |
| C&P | Cost & Performance |
| CAD | Computer Assisted Design |
| CCC | Civilial Conservation Corps |
| CEHNC | Army Corps of Engineers, Huntsville Center |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| COTS | Commercial Off-The-Shelf |
| CTT | Closed Transferred and Transferring |
| DEM | Digital Elevation Model |
| DIDSON | Dual-Frequency Identification Sonar |
| DoD | Department of Defense |
| DOQ | Digital Ortho Quadrangle |
| EE/CA | Engineering Evaluation/Cost Analysis |
| EMI | Electromagnetic Inductions |
| ERDC | Engineer Research and Development Center, Division of the Army Corps of Engineers |
| ESTCP | Environmental Security Technology Certification Program |
| FRF | Field Research Facility, Associated with ERDC |
| FUDS | Formerly Used Defense Site |
| Gb | giga-byte |
| GPS | Global Positioning System |
| GUI | Graphic User Interface |
| IMU | Inertial Measurement Unit |
| knot | nautical mile/hour |
| Kw | kilowatt |
| lb | pound |
| Mb | megabyte |
| MHz | megahertz |
| MTA | Marine Towed Array |
| MTADS | Multi-sensor Towed Array Detection System |
| NAVFAC | Naval Facilities Command |
| OE | Ordnance and Explosives |
| OESO | Ordnance and Environmental Support Office |
| OSHA | Occupational Safety and Health Administration |
| PCB | Printed Circuit Board |
| PDU | Power Distribution Unit |
| PI | Principal Investigator |
| SCAR | Sub-Caliber Aerial Rocket |
| SCI | Structural Composites Incorporated |
| SERDP | Strategic Environmental Research and Development Program |
| SOP | Standard Operating Proceedure |
| SUXOS | Senior UXO Supervisor |
| UXO | Unexploded Ordnance |
| VCT | Vehicle Control Technologies, Incorporated |


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- **EOTI.** Wayne Lewallen brought an outstanding team of UXO divers to the demonstration. They were responsible for reacquiring all the targets, digging them out of the mud, documenting and disposing of them.

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# ABSTRACT

Between May 9 and May 19, 2005 the Marine Towed Array conducted a UXO survey of the Currituck Sound west of the Former Duck Naval Target Facility. The Range (700 X 1000 m) stretched from the Sound shore to the Ocean shore. It was used for 25 years (1941-1965) as an air-to-ground rocket and bombing range. In 1972, more than 2,000,000 lb of ordnance was removed from the Range before it was transferred to the Army for development of a research station, the Army Corps of Engineers Field Research Facility. In the mid 1990s, further EE/CA studies documented the continued presence of buried UXO on and near this facility. It was a goal of this demonstration to determine the presence of and map out the distribution of UXO in the Currituck Sound, which resulted from undershoots of the Range by approaching aircraft.

AETC conducted UXO surveys using both the magnetometer and EM arrays in the Sound from the shallow water limit to a distance of ~ 700 m offshore (more than 1.5 km west of the original target bull's eye). The effective shallow water survey limit for the Towed Array is ~1.25 m (4 ft). After a slow start because of equipment malfunctions, survey rates of 35 acres/day were achieved on the final three full days of survey. This is slightly short of the projected goal of 40 survey acres per day. The most important effects in determining survey production rates are the ferry distances to and from the dock each day, the length of the survey lanes (and the turn arounds), and the water depth. The most important of these for this demonstration was the amount of survey work that was done in very shallow water. Working in very shallow water requires that survey speeds be reduced by ~50%, and that turns be made very carefully (to keep the survey platform from impacting the bottom). About half of the survey lines were >1 km long, the remainder were 600 m long. After the first 3 survey days, we moored the boat and survey platform near the southern end of the survey area, thus requiring only a few minutes of ferry time to and from the survey area.

A series of UXO surrogates (seventeen sections of steel pipe) and twenty-four 46 cm long sections of rebar were installed by divers in a relatively uncluttered area. Their positions were carefully measured by the divers using GPS from a boat. These positions were compared to the positions that resulted from the target-fitting algorithms using the MTADS DAS to analyze the survey data. The data files for analysis were prepared as mapped target files using Oasis montaj© for preliminary data processing to "clean up" the data set. The known target positions were reproduced in the target files to approximately the predicted level of accuracy, 25 cm in the horizontal plane for magnetometry data and 35 cm for the EM data. Although the S/N ratio was poorer than expected for the EM array, all of the pipe and rebar targets were easily detectable with each array.

Target analysis of the magnetometry and EM data led to selection of ~500 potential UXO targets. These data were used to prepare the master dig list. Targets predicted to lie deeper than 0.6 m in the sediment were excluded from the list, as were targets predicted to be larger than a 5 in Zuni rocket. A list of 150 targets was prepared, with the intention of 100 of them being dug. A priority was placed on targets analyzed in shallow water, because there was a prior agreement that we would attempt to split the dig list with about 50% of the targets in shallow water and 50% in deeper water. Only 20 targets in shallow water qualified for the dig list. The next 80


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targets in water deeper than 2.5 m accentuated (but not exclusively) larger targets (with predicted sizes in the range of Mk76s to 5 in rockets.

Recovery operations were carried out by two 3-man dive teams. They worked between 20 May and 3 June. First they were trained in the use of the AETC GPS equipment to reacquire and flag the targets from the dig list. They used classical EOD/UXO diver techniques to recover the targets. First, the diver using a fluxgate magnetometer attempted to verify the existence of a target adjacent to the flag. If it was not readily apparent, he began a spiraling search pattern to locate the signal. If it was not found within 2 m of the flag, the flagged position was to be declared as a "dry hole." In all 100 cases the target was located < 1m from the flag.

Only 2 of the first 100 targets were not recovered. In one instance, although the target was demonstrated to be present using the magnetometer, it was deeper than predicted. The diver using a small hand shovel could not uncover the target because the walls of the hole kept falling in. In other cases where the targets were deeper than predicted, the diver was able to sufficiently uncover the targets so that a rope could be attached and the targets were pulled out of the mud using a small winch on the dive boat. The other target that was not recovered was too large to lift with the available winch. Two additional targets were dug to replace these targets. We discovered after ~20 targets were dug (including 7 crab traps) that the signatures of crab traps could be identified in the magnetometry data. This was verified by digging three more predicted crab pots. At that point 13 more predicted crab pots were removed from the dig list and replaced with the next 13 targets on the list. Overall, almost exactly 50% of the recovered targets were ordnance or ordnance components. These included 8 Mk23s, 22 SCAR and 2.75-in rockets, 5 Mk76s, and 1 100-lb bomb, 1 75-mm rocket W.H. and 1 Zuni W.H.

All recovered targets were removed to a secure area on the Field Research Facility and photographed for documentation. Ordnance items were challenged using explosive shaped charges (jet perforators). The ordnance scrap was certified as explosives clean and shipped for disposal.

All major goals and objectives of this demonstration were achieved.


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# 1.0 Introduction

## 1.1 Background

As a result of past military training and weapons-testing activities, UXO is present at sites designated for Base Realignment And Closure (BRAC) and at Formerly Used Defense Sites (FUDS). Many of these sites associated with military practice and test ranges contain significant land areas with a marine component. Although it is known that between 10 and 20 million acres of dry land UXO contamination are associated with Closed, Transferred, and Transferring (CTT) ranges, the fraction of this area that is underwater and inaccessible to standard UXO search technologies is poorly defined; however, it likely exceeds a million acres. The marine environment presents a complex challenge for UXO search technologies, because it includes wetlands, fresh water ponds and lakes, estuaries, rivers, coastal bays, tidal flats, and ocean shores, including shallow water coral reefs.

Although much of the marine UXO contamination has resulted from overshoots of land ranges, off-shore areas also have been used as ranges. Furthermore, we must acknowledge that historically it was common to dispose of excess or unwanted munitions (often resulting from land clearances) by simply dumping the materials into an adjacent body of water. This is evident in many areas by simple inspection of the shoreline adjacent to target and practice ranges. In addition to UXO challenges associated specifically with ranges, there exist significant examples of UXO contamination associated with dredging and beach replenishment operations, as well as confined areas associated with military bases and ammunition manufacturing and shipping operations that have potential or known underwater UXO contamination.

There currently exist no proven automated technologies for conducting UXO geophysical surveys that result in documented mapped data files showing the extent, densities, and types of ordnance contamination for the underwater environment. The application of automated survey technologies has become routine on land-based ranges using hand-held, man-portable, vehicular-towed, or airborne sensor arrays coupled to GPS (or other types of) navigation systems for precise location positioning. Currently, underwater UXO searches are typically conducted by divers using hand-held magnetometers. Discovered targets are either prosecuted as they are found or they are marked with weights and floats for later prosecution.

## 1.2 Demonstration Objectives

This program began as a SERDP project[1,2] and transitioned 15 months later to ESTCP project UX-2003-24.[3] In June 2005 we completed the first of two field demonstrations associated with this program. The objective of this demonstration, as described in the Demonstration Test Plan,[4] is to evaluate the performance of the marine towed array UXO survey equipment developed for this project on a typical UXO range. The range that we chose has a documented many-year history of UXO impacts with a wide range of ordnance types and sizes. By digging at least 100 targets following the survey, we intended to validate the system performance against these various ordnance types. The Demonstration took place in the Currituck Sound, 350-800 meters west of the Former Naval Duck Target Facility bull's eye. Figure 1 shows a map of the area published in 1996 by Parsons Environmental Science[5] following an EE/CA study of ordnance


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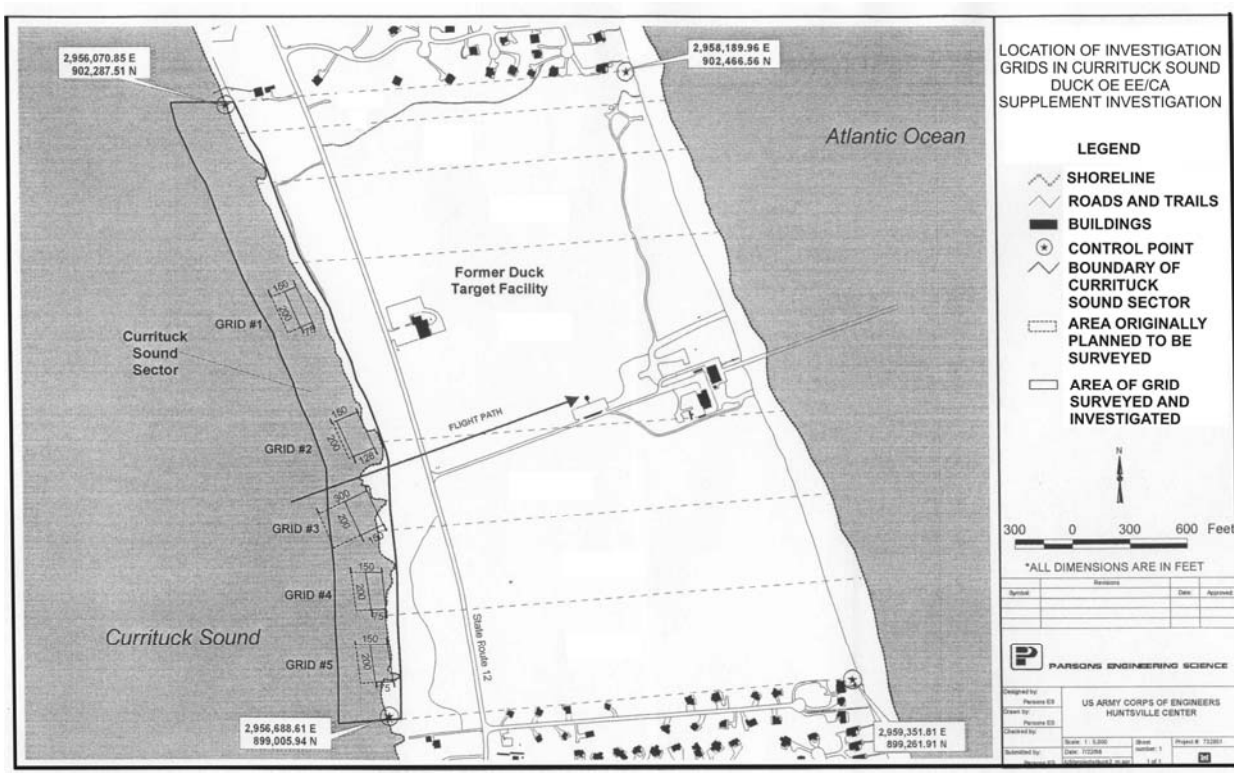


**Figure 1. Map of the Former Duck Targe Range showing current roads and structures associated with the FRF and the Duck Volunteer Fire Department. The map is from a 1992 EE/CA study carried out by Parsons Engineering.**

contamination on the site. The area was completely uninhabited and without roads during the period that it was used as a range. By size standards for air-to-ground ranges, this range is very small, occupying only about 175 acres. The presumed flight path for ordnance drops was along the west-east long arrow shown in Figure 1. The actual location of the target bull's eye lay along this line about 250 meters beyond the arrow point near the barrier dune at the top of the beach. The black squares at the top and bottom of Figure 1 are currently-existing vacation homes. There are no fences or barriers separating the homes from the former range. There are, however, "Dud Ammunition Area" signs posted along the highway warning against entry onto the property.

This information relates the regulatory history of the Former Duck Target Facility. Except for State Highway 12 and the area that includes the Fire Station/Duck Police Station and adjacent parking lots, the land areas associated with the Former Duck Target Facility are posted as Ammunition Dud Areas, with a cable barrier along the road. The public has walking access to the Atlantic Ocean beach approaching either from the north or south, but only up to the primary dune line. The barrier dune was established following World War II by the CCC. It has seldom been breached by overwash in this part of the state. However, winter and spring storms continually remold the beach, often removing or replacing several feet of sand in one or two days. To our knowledge, there have been no discoveries of ordnance on the beach eastward of the barrier dune in recent times.


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There is no formal control established over the areas of the Currituck Sound immediately adjacent to the Former Duck Naval Target Range. Signs posted at the shoreline again warn that the land area is an ammunition dud area. The overhead power lines, which are on shore along the western edge of the island, are moved off shore into the sound west of the shoreline. The current mayor of the recently-incorporated Town of Duck stated that the Town has ownership of the Sound west of the shoreline for a distance of 1000 ft.

There are water sports rental marinas within one mile north and 0.25 miles south of the FRF. These facilities rent wind surfing boards, jet skis, small sail boats, canoes, and other craft, for recreation on the Sound. During tourist season (June-September), these craft are often found within the waters that we surveyed. The only interference to our operations during the demonstration was from a commercial crab fisherman who had crab pots stretching in a north-south line through the middle of our survey area. Following completion of our surveys west of the line of crab pots we asked him to move the pots west by 100 meters so that we could continue to survey. He complied.

The Currituck Sound to the west of the target range is relatively shallow with a gently sloping bottom. One meter water depths are not reached until 150-200 meters off shore in the Sound. The Sound between the mainland and the barrier island is 2-3 miles wide. Maximum water depths in this part of the Sound do not exceed 4 meters. Figure 2 shows a Digital Elevation Model (water depths) superimposed upon a section of a 1999 digital orthoquad (DOQ) aerial photograph of the area. The bathymetry data were compiled from the depth sounder measurements made from the MTA tow vessel during the magnetometry and EMI surveys during this demonstration. The Sound bottom is a fairly soft mud very near the shoreline until the water depths reach ~1 meter. At this point there is an abrupt drop off to a depth of 2.5-3.5 meters. In deeper water there are some shoal areas that are slightly shallower and a few localized slightly deeper regions. The Sound bottom (beyond the drop off) is described by the UXO divers as hard-packed sand with occasional patches of shells. It was our goal to survey from the shallow access limit for our equipment out from the shore until the UXO signals either disappeared or nearly disappeared, thus mapping out the UXO debris field resulting from undershoots of the bull's eye. How well this was accomplished is described later in the report.

Much of the ordnance dispensed on this range was various sized rockets (from 2.25 in SCARs to 11.75-in Tiny Tims). See Sections 3.3 below. By today's standards, these were all primitive unguided ordnance, much of which was likely fired from up to several miles away. We conducted a preliminary reconnaissance survey of the Sound offshore from the target area in June of 2004.[6] See Section 3.5 below. It was apparent from this study that significant ordnance and ordnance debris contamination exists in the Sound to at least 1500 meters west of the bull's eye. The greatest observed concentration of ordnance was along the presumed incoming flight path shown in Figure 1 towards the bull's eye.

To evaluate the target location ability of the MTA we installed a group (17) of UXO surrogate objects tethered along a 300 foot long rope. Their positions were accurately established by GPS way pointing. This process is described in Section 3.6. In addition, 23 sections of 3/8 inch diameter rebar (18 inches long) were vertically driven into the sand. The rebar positions were


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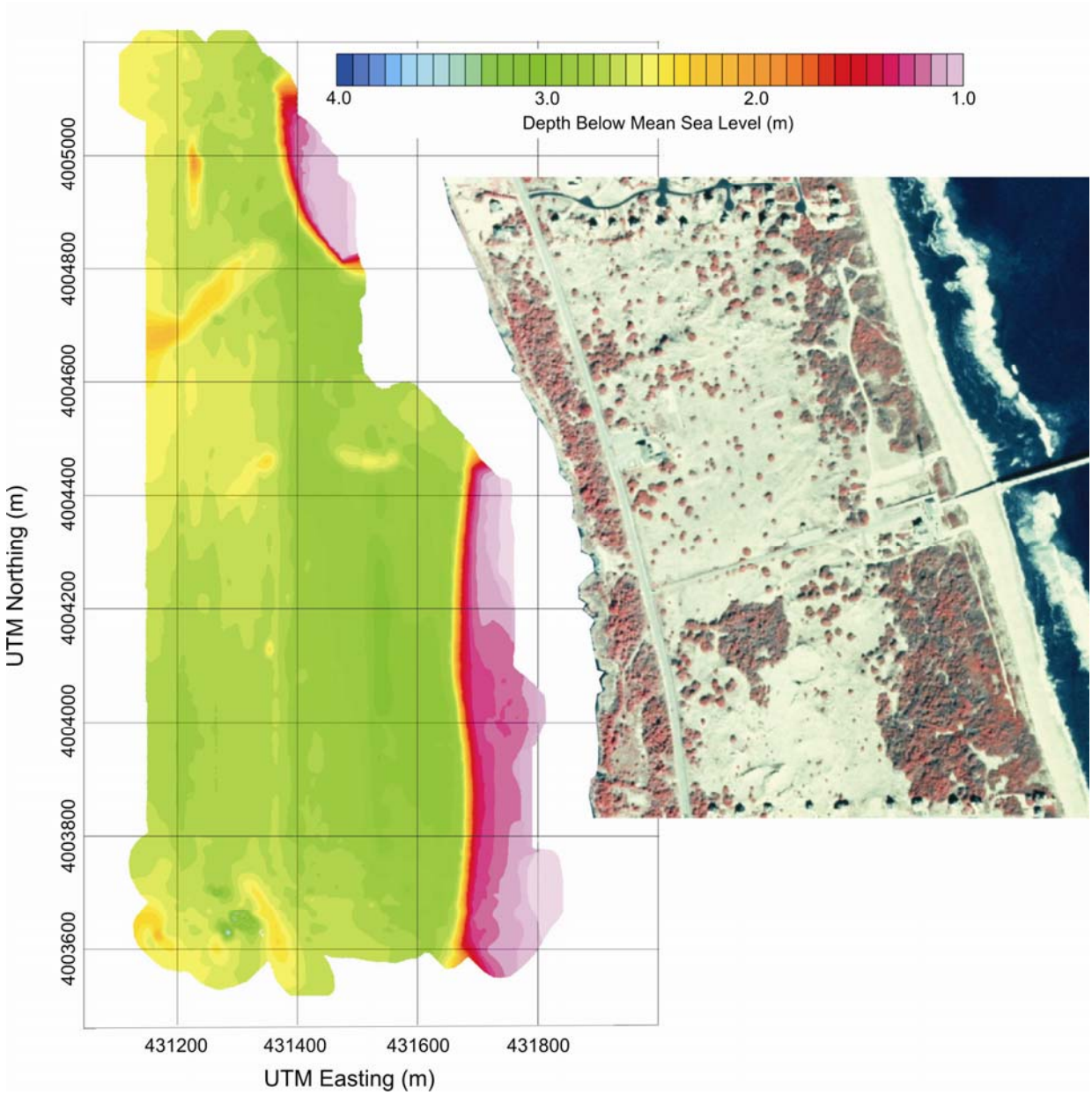


**Figure 2. Water depths in the sound are shown in a false color plot. The 1999 Digital Orthoquad Photo shows the relative location of the FRF and the Duck Fire Department. The bathymetry data that were collected during the magntometer and EMI surveys show that the survey area extenced ~250 meters north and south of the range boundaries.**

also established by GPS. The surrogate UXO targets and the rebar markers and their method of installation are described in Section 3.6.2.

The Demonstration Test Plan[4] called for digging a group of 100 UXO targets, The UXO divers were instructed to estimate the location accuracies of their flagged positions when they were recovered and to determine the target distance below the sediment surface. This information was to be recorded on the target-specific dig sheet.


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In addition to the ability of the survey system to accurately locate the seeded targets, an extensive list of system performance metrics was established to evaluate the success of the MTA system development and operation. These are described in detail in Section 3.1.

## 1.3 Regulatory Issues

The regulatory issues involving UXO contamination are most frequently associated with the BRAC and FUDS properties involving the transfer of DoD property to other agencies or to the civilian sector. When transfer of responsibility to non-DoD government agencies or to the civilian sector takes place, the DoD lands fall under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 requires adherence to CERCLA provisions. The basic issues center upon the assumption of liability for ordnance contamination on the previously DoD-controlled sites.

The former US Naval Duck Target Facility is a 176-acre range located on the Outer Banks of North Carolina about 1 mile north of the town of Duck. The site was used by US Navy aircraft as a bombing and rocket target range between 1941 and 1965. This area has been under continuous DoD control since it was established as a training range in 1941. In a 1971 clearance operation, 2,187,000 pounds of ordnance were recovered from the site and buried in pits on the site. At that time, the control of the land passed from the Navy to the Army Corps of Engineers and subsequently a 600 m long research pier was constructed from the beach reaching eastward into the Atlantic Ocean. The pier and the associated buildings became the Army Corps of Engineers Field Research Facility (FRF), a marine research establishment.

In spite of the fact that the range has remained under DoD control, the area was declared a FUDS property, which allowed an EE/CA evaluation and further clearances during the 1990s. These were undertaken, in part, because the property fronts on the north and south range boundaries with private beach homes that primarily support summer tourist visitors. Areas on the former range have been cleared to allow the building of a paved road along the Currituck Sound shoreline and the building of the Duck Volunteer Fire Station on the range property.

Following the discovery and recovery of several 2.75 in rocket warheads by children playing in the shallow waters of the sound in 1993, an Interim Removal Action was undertaken in 1993 and an Archives Search Report (ASR)[7] was prepared for CEHNC in 1994. An EE/CA[5] prepared by Parsons Engineering Science was issued in 1996. This study was followed in 1998 by a supplemental EE/CA report.[8] In the latter study, five grid areas (totaling 2.3 acres) within ~100 feet of the Currituck Sound shoreline were surveyed using fluxgate magnetometers. Positive magnetic anomalies (less than 6 inches deep in the sediment) were recovered. In this operation 250 OE-related items were recovered, including 14 that were labeled as potentially hazardous OE. The latter items were consolidated on the beach and destroyed by detonation using donor explosives.

## 1.4 Stakeholder/End-User Issues

The stakeholders and end-users are the Army Corps of Engineers ERDC Field Research Facility, the citizens of Duck, and the many tourists that use the Sound adjacent to the FRF. Following


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the EE/CA study and the Supplemental EE/CA study, only a cursory clearance was completed on land. The latter study documented UXO contamination along the shoreline in the Sound adjacent to the shore. The FRF property (only the land area) remains posted; institutional controls will presumably have to be maintained on the FRF property for the foreseeable future.

Based upon the results of this demonstration, there is also documented UXO contamination of the Sound for a distance of more than 700 meters beyond the shoreline. The targets that we removed included a variety of both practice and inert ordnance. The larger recovered items included 5 in Zuni and 3 in rocket warheads, a 100 lb GP bomb, and many other smaller ordnance. All were either practice or inert rounds; however numerous unfired 2.75 in rockets were recovered, some of which retained their original propellant charges.

We intentionally did not dig any targets that were predicted to be deeper than 0.6 meters in the sediment or larger than the 5 in Zuni warhead. The survey resulted in identification of >2 dozen targets that we believe are most likely 11.75 in diameter Tiny Tim rocket-assisted bombs. These targets are predicted to be buried up to 6 m deep in the sediment; they primarily lie along the flight path. The explosives safety exclusion zone associated with these items significantly exceeds the dimensions of the FRF. Additionally, their weight is substantially greater than we could lift with the equipment that we had on site.

It was beyond the scope of this demonstration to clear all discovered targets from the Sound. We report in this document the coordinates and predicted depths and sizes of ~ 350 additional targets that we did not attempt to dig. Currently, the Sound, unlike the FRF, is public property with unrestricted and unposted access to the public. As a result of this demonstration consideration should be given to extending institutional controls into the Sound for up to a kilometer off the shoreline. Alternatively, the remaining identified targets could be removed from the off shore Sound areas.


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# 2.0 Technology Description

## 2.1 Technology Development and Application

This technology development had its genesis in SERDP Project UX-1322.[1] The SERDP project involved a concept study to evaluate the feasibility of various sensor deployment options, and an engineering study to develop preliminary designs for the sensor array platforms, and the requirements for a tow vessel. In addition, we carried out both first principles studies of the performance of EMI arrays in salt water and empirical parameterization studies using inert ordnance and EMI breadboard coil systems to validate our predictions.[2]

The system concept study was carried out in conjunction with Vehicle Control Technologies, Inc. (VCT). The preliminary design resulting from the concept feasibility study is a wing-shaped fiberglass structure designed to be towed from a position well forward of the wing using a flexible tow cable. Pitch stability, Figure 3, is provided by the (yellow) wing extensions. Weighted skids on the bottom provide stability to ward off inevitable bottom collisions. Roll and depth control are provided by the elevators (red) on the trailing edge of the wing extensions. Elevator positions are controlled by two actuators (grey). We briefly considered and rejected a boom structure to mount GPS antennas directly on the sensor platform. We ultimately concluded that both the magnetometers and the EM sensor arrays could be mounted in a single platform. The EM array is embedded in the structure; the magnetometers are in bottles (blue) that extend through the top of the wing surface.

The most difficult design specifications to evaluate were the components of the vertical and horizontal sensor position error budget with the GPS antennas on the tow vessel. The resulting concept design is shown in Figure 4. Included are general descriptions of the positioning sensors that are required to derive the coordinates of the individual sensors. The precise descriptions of the different positioning sensors are discussed in various SERDP project interim reports and in the Project Final Report. The most sensitive measurement that must be made is the angle that the tow cable forms relative to the long dimension of the tow vessel, $\psi_c$, in Figure 3. The contributions to the complete positioning error budget have been treated in a separate study, which has been continually refined as the individual component choices were made and their performances evaluated. At the end of the SERDP Project, it was our prediction that we would be able to locate the sensor positions in the horizontal plane to <15 cm and in the vertical plane to <20 cm using this design.

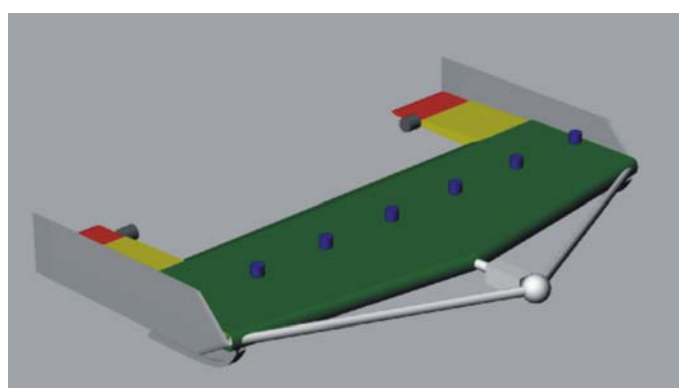

**Figure 3. Perspective drawing of the 4-meter sensor platform concept.**

To accomplish the project goals we drew on the engineering and theoretical modeling resources of our organization and on engineering and design support from our subcontractors VCT and Geonics, Ltd. Each of the studies listed below is an internal report documenting the project developments. The


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documents are available in association with the Project Final Report:[2]

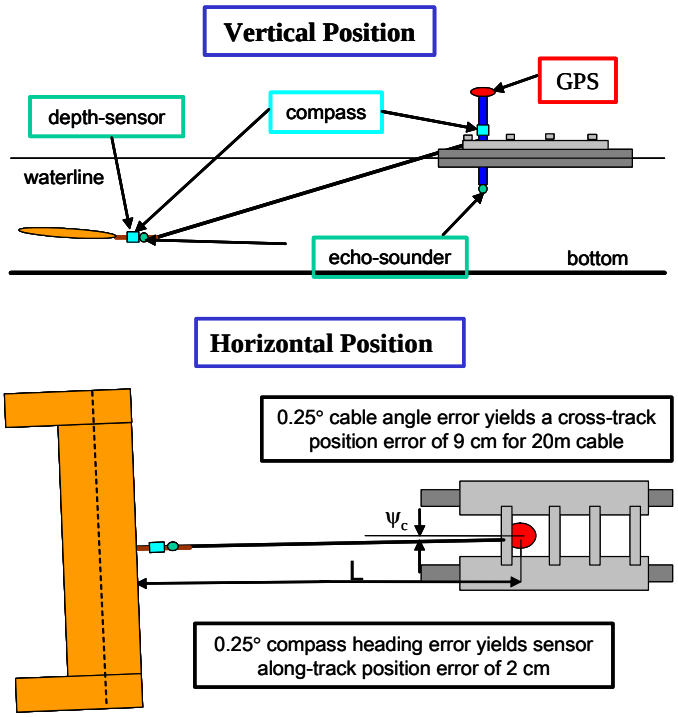


**Figure 4. Sensor platform deployment concept resulting from SERDP Project UX-1322.**

- Modeling of Electromagnetic Response of EMI Sensors Employed in a Salt Water Environment, AETC Report, 01/04;
- Concept Design for a Marine UXO Sensor Platform, VCT Tech Memo 02-06;
- Concept Design for a Marine UXO Sensor Platform – Autopilot for 2-m and 4-m Concept Vehicles, VCT Tech Memo 03-01 and VCT Tech Memo 03-02;
- EM68 – Marine EMI UXO Detector Project Development Interim Report, Geonics Report, April 2003;
- Report of Overlapping Receiver Coil Study, Geonics Report, 29 August 2003;
- EM68 – Marine EMI UXO Detector Project Development Report, Geonics Report, September 2003;
- EM68 Instructions for Control & Logging Program, Geonics Report, September 2003; and
- Evaluation of Performance and Capabilities of the DIDSON Imaging Sonar, AETC Report, 12/03.

The majority of the actual development work on the Marine Towed Array took place during the ESTCP Project[3] 200324. Structural Composites, Inc. (SCI) joined the effort at the beginning of the ESTCP project. SCI is a group of companies in Melbourne, FL that functions both as a composite materials design house and a manufacturing firm. Working with the sensor platform concept designs and the results of the system hydrodynamic performance modeling, SCI developed a preliminary engineering design. This design was submitted to a Finite Element Analysis to validate the predicted system performance and the planned system design. Following the final system design review, SCI was contracted to produce the sensor platform.

We contracted with a separate firm, Ocean Marine Industries, to design the cable system for towing the sensor platform and to design the sensor interface container. The latter component is a waterproof cylinder that mounts on the sensor platform. Using underwater connectors, this unit serves as a bulkhead interface, mating all of the sensor leads on the sensor platform to the tow cable electrical input connectors. In addition, this container houses a magnetic compass, the Honeywell IMU, and some printed circuit amplifier boards.


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The selection of the individual system components either flowed logically from the requirements developed in the modeling and engineering design studies, or resulted from testing of component performances using borrowed or rented components. In several instances, it was necessary to evaluate the interaction between the components, such as the actuators/cables and the magnetometers, when they were both operating.

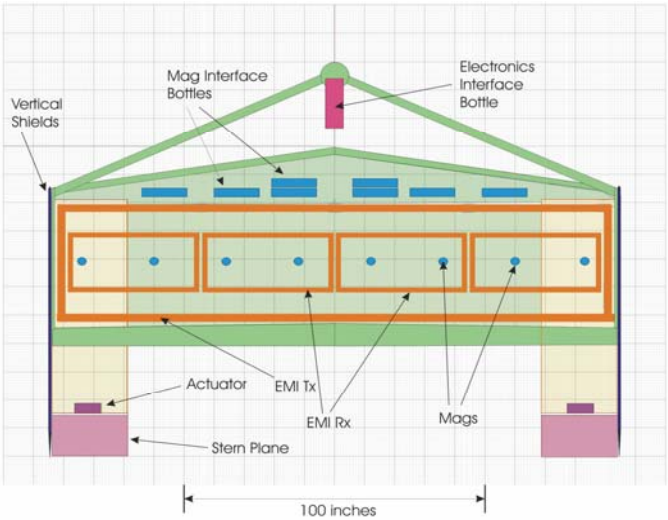


**Figure 5. Schematic drawing of the marine sensor platform.**

Figure 5 shows a CAD drawing of the engineering design plan approved for Structural Composites to fabricate. To improve the sensitivity of the EMI system, the receiver coils were increased in size to a full 1 m in width. Allowing for the necessary separations between coils, for the required internal mounting structures, and for the receiver coils to nest inside the transmit coil expanded the width of the entire sensor platform structure (including the vertical end structures) to slightly over 4.7 m. Figure 6 shows an image of the entire structure floating in the water beside the pontoon boat. Figure 7 shows another image with the hatch covers removed. In the latter image several of the sensor components are identified.

To tow the sensor platform, we chose a 30 ft long pontoon boat manufactured by Crest. This is the maximum width boat that can be transported over the road without special wide load permits. A third pontoon was added to the tow vessel to increase stability in the water and to decrease water draft. A 175 hp outboard engine was chosen for propulsion. Most of the furniture was stripped from the deck and the deck railings removed on the forward half of the boat so that the sensor platform could be stored and transported on the deck. A marine winch was installed on the deck to lift and deploy the sensor platform. Marine hardware was

**Figure 6. Assembled marine sensor platform is shown floating beside the tow boat.**

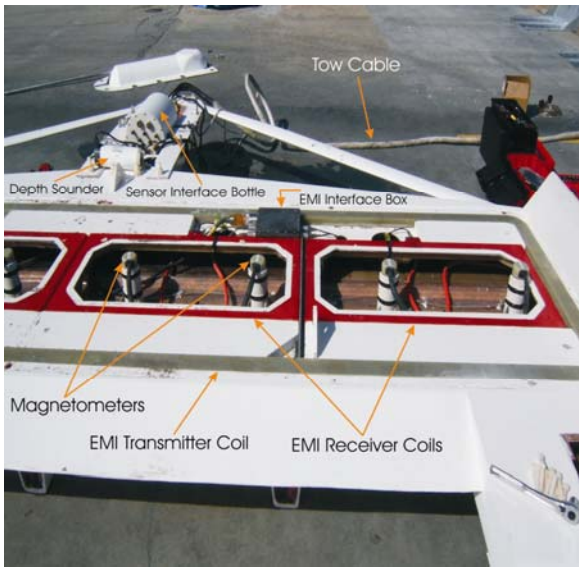


**Figure 7. Marine sensor platform with the hatch covers removed.**


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installed to serve as tie-downs for the instrument racks and the generator. Mounting fixtures were designed and built for the tow point fixture, the GPS antennas, the depth sounder, and the imaging sonar.

The number of sensor systems operating and the complexity of the data streams on the MTA far exceed any of the previously-developed MTADS arrays. This requires that we have multiple computer systems on board, multiple data racks to accommodate them, and the full-time attention of one person to monitor the data flow.

The pilot display system, which is mounted on the console in front of the boat driver, Figure 8, is very similar to that developed and implemented in the Airborne MTADS system for the helicopter pilot. The survey tracks are developed, based upon the survey dimensions and the chosen track spacing, and loaded into the display computer. The computer receives position, heading, and velocity updates from the GPS above the tow point, which it uses to plot the survey course over the survey grid in real time for the driver. The relationship of the pilot display to the other navigation instruments and the driver is shown in Figure 9.

**Figure 8. The pilot navigation display screen shows prior and current tracks (red), the off-track distance, both numerically and as a color bar, and other information such as the GPS fix quality. The display is usually rescaled during turns to aid in lining up on the next survey line.**

**Figure 9. The driver has a close view of the pilot navigation display (right of the steering wheel) the water depth gauge (left of the steering wheel) and the engine console gauges. The 4.5-kw generator, which is tied down near the bow, provides power for all the electronics.**

The Didson Imaging Sonar and the Geonics EM68 units were provided with independent GUIs to control their setups, operation, and data recording. These Windows-based systems were too complex to attempt to integrate with our Geometrics Maglog-based Data Acquisition System. We adapted the Didson and Geonics units to accept a GPS time stamp for their recorded data streams. This assures that we can correlate the multiple data sets with each other during analysis. Because it is also necessary to monitor these systems in real time, their data logging displays are set up on the computers, which can be displayed by the data technician as the data are recorded.

All the computers, the power distribution and control units, and the ancillary electronics are set up in two shock-mounted weather proof racks. The computer screens can be split to simultaneously display four separate input data streams. These units are shown in Figures 10


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and 11**,** as is their relationship to the driver's console. The person monitoring these systems assures the fidelity of each of the data streams. His highest priority duty, however, is to monitor and control the sensor platform depth and attitude. This is particularly critical in turns and when the water depth is changing.

**Figure 10. The instrument racks house the computers, electronics, and the power distribution systems. They are set up so that both persons manning the boat have access to all data and can maintain close communication.**

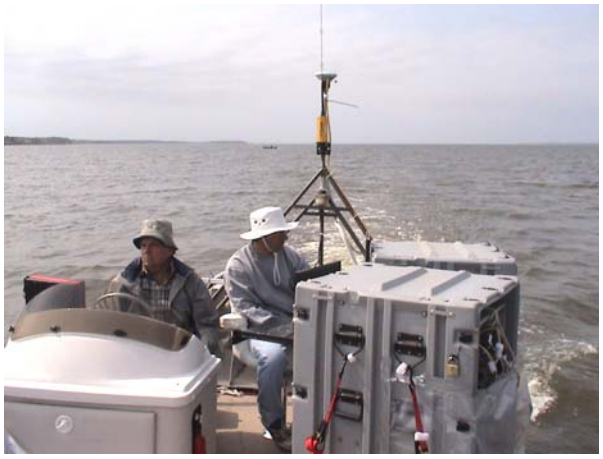

**Figure 11. Two persons are required to man the boat during surveys. The driver tracks the survey grid and monitors the water depth while the other person monitors all the data streams and the sensor platform performance.**

The Didson Imaging Sonar can broadcast at two frequencies, 1.1 and 1.8 MHz. The lower frequency is referred to as the detection mode; the higher as the identification mode. The two modes differ not only in the transmitted frequency but in the number of beams that are projected and the framing rates. The framing rates also depend upon distance windows being monitored. Overall, framing rates of 1-30 Hz are possible. All data are digitally recorded and are available for later playback or conversion to other data formats (using Didson software utilities). During surveys, data are recorded from this system at 30 Mb/minute (1.8 Gb/hour) at a 5 Hz framing rate. The Didson unit is mounted at the bow of the tow boat, between the right and center pontoons. It looks forward and is pointed down at a $30^{o}$ angle.

The EM68 transmits a bipolar signal at 7.5 Hz. Data are recorded from each of the four receiver coils into 26 time-delay bins. The timing of these windows is based upon a log scale. Any subset of these time windows can be chosen for presentation on a waterfall display on the provided GUI display. This transmit and receive sequence is effectively equivalent to the Geonics EM63 cart-based sensor. On the marine sensor, we had adaptations made such that rather than using 26 time windows, data can be recorded (over the same full-scale decay period) into 13, 8, or 6 time channels. The positions and widths of these time channels are established in the operational software. We conducted calibration tests with the EM68 using various sized steel and aluminum spheres. These results were used to develop an EM forward model for use in the MTADS DAS target analysis for EM data. The forward fit models are used for the target fitting algorithms in the MTADS DAS. During the demonstration survey in Duck the EM68 data were recorded using all 26 time channels.


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The primary DAQ computer operates a version of the Geometrics Maglog software adapted for this application. Maglog has been the primary DAQ GUI for all prior MTADS platforms. All the sensors from the marine platform, including the magnetometers, are recorded in this utility. Additionally, the GPS data and data from the depth sounder are logged using this GUI. Figure 12 shows a screen clip from the Maglog operating system recording data from the 8 magnetometers. In the Marine Towed Array, magnetometer data are sampled at 20 Hz.

The primary control software for the sensor platform autopilot was developed by VCT. The model, which was extensively described in the SERDP UX1322 Final Report, was incorporated into a new GUI that we developed to allow us to control and monitor the platform behavior. Three primary operational control algorithms were developed for the sensor platform GUI. The first allows us to operate the platform at an operator-specified depth below the surface. The second mode is designed to operate the sensor platform at a specified height above the bottom. The third mode is referred to as the Emergency Rise mode. This can either be called from the keyboard or automatically invoked by pressing the Emergency Rise button on the electronics rack console panel. This mode is intended for use if we observe a bottom obstruction that is likely to cause an impact with the sensor platform.

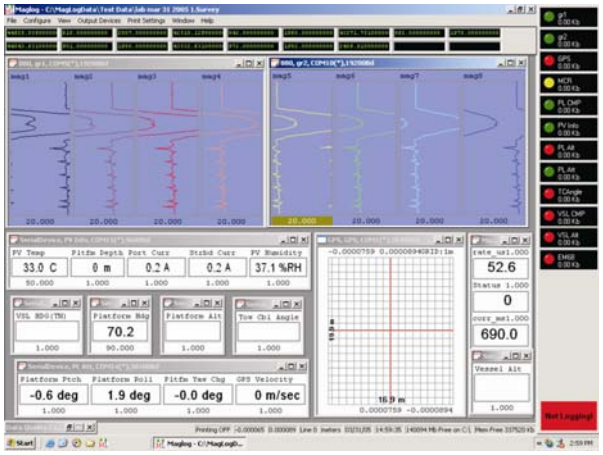


**Figure 12. Screen clip from the Maglog data acquisition computer. Signals from the 8 magnetometers are presented in a waterfall display. The GPS course-over-ground is graphically displayed, while all other sensor data are numerically presented.**

Figure 13 shows the use of the autopilot to control the sensor platform depth and attitude. These results were from a shakedown test on Lake Jordan in central North Carolina. In the center panel the tow vessel speed is plotted. During the first 110 seconds of the plot the boat was set to a speed of 1.8 m/s (3.5 knots); at 410 sec the speed was increased to 2.2 m/s (4.3 knots). Wind gusts or changes in depth commands affect the speed by small amounts. The upper panel shows that the autopilot was operating in depth (below surface) mode. The command depths are shown in red. The sensor platform response to these commands is shown in blue. In general, it takes about 10 sec for the platform to respond to a commanded depth change of 1 m. To depths of 5 m, the commanded depth is maintained to better than 10 cm. The platform (with 20 m of cable, the 2 ft wide elevators, and the hook-up to the center tow point on the sensor platform) will not quite maintain the commanded 6 m depth. The design goal for these conditions was a maximum depth of 5 m. Lengthening the cable or moving the tow point further aft would allow deeper operation. In the bottom panel the elevator pitch angle is shown in green. The commanded depth changes invoke an $8^o$ elevator command. The autopilot returns this to the smaller value required to maintain depth when the command depth is reached. The actuators that control the elevators have a $\pm 15^o$ freedom of movement. $7^o$ of the $15^o$ are reserved for priority control of the platform roll. In general, the platform roll is maintained to within $0.5^o$ of level. The autopilot


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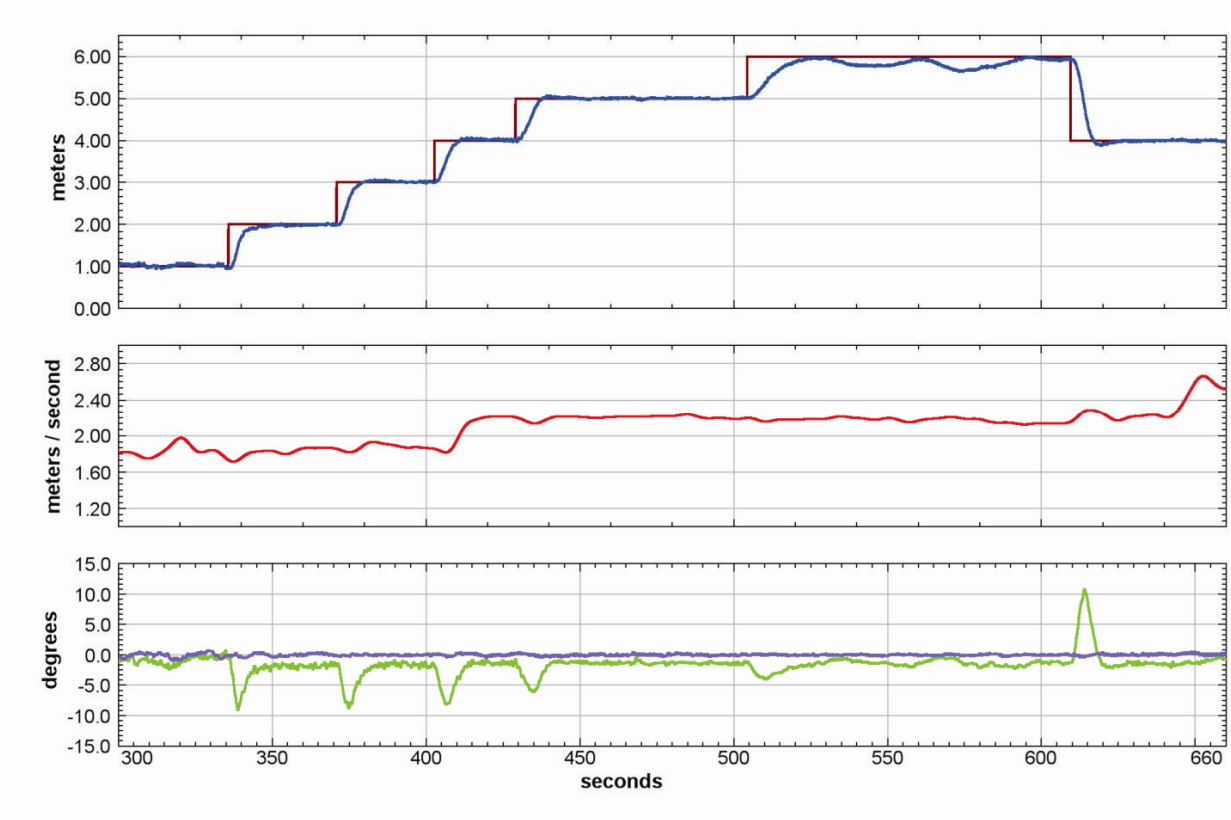


**Figure 13. The sensor platform response to changes in the depth command is shown.**

shows a similar level of control over the sensor platform when operating in height above the bottom mode.

In case that there is a severe impact of the platform with some bottom structure, we have designed and installed a breakaway link in the tow cable attachment to the tow point structure. We bought several diameters of cable, had each cut into 6-in pieces, with thimbles installed at each end. The manufacturer tested several of each size to destruction. The remainder we use to create the weak link with the tow cable, Figure 14. The weak-link cables shown in Figure 14 break at ~1100 lb tension. We broke 3 of these links during the progress of the surveys of this demonstration. These were primarily the result of working in very shallow water and hanging one wing of the sensor platform in the sand during a turn.

The tow cable is terminated at an electrical bulkhead at the rear of the tow boat using break-away connectors that are designed to part under 50 lb of tension. These cables can be wet re-mated. During the surveys at Duck, in each case that the weak link broke, we were able to stop the boat before the bulkhead connectors parted. If they had parted, the orange buoy shown in Figure 14, is connected to the connectors, and would have allowed us to retrieve and reconnect them.

## 2.2 Previous Testing of the Technology

The first full-scale marine tests of the system took place in the bay (Indian River) between the mainland and the barrier island near Melbourne, FL, in January 2005. Some of the results of these tests have been described above. Others are discussed below. Before these tests, the tow


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vessel and some of the system components were tested in a shakedown cruise on Lake Jordan in the fall of 2005. Lake Jordan is about 25 mi west of our offices. Since the shakedown tests in Melbourne, we have carried out further tests of the complete system on Lake Jordan. This lake has a steeply sloping bottom and is very deep in many areas. The bottom is very rugged (boulders and tree snags) and thus is not suitable for studies in a bottom-following mode or for making measurements over seed targets.

**Figure 14. The tow point structure at the rear of the tow vessel is shown. The weak link cable is shown between the shackles at the left. Note the digital encoder (yellow) that is used to precisely measure the angle between the tow cable and the tow vessel.**

The shakedown tests in Melbourne were cut short because of a water leak failure of the connectors on both of the actuator cables. Because we had only one spare, the operation was shut down about halfway through the intended testing program. These cable problems were solved by redesigning the coupling at the sensor interface bottle. Several autopilot problems were solved during the Melbourne shakedown. The autopilot software was modified to give the roll control priority and to open up to $7^{o}$ the amount of elevator split function (aileron operation) that was reserved for roll control.

The most unexpected discovery in the Melbourne shakedown was the boat behavior using the winch to launch and recover the sensor platform. We had on-loaded and off-loaded the sensor platform several times while the boat was sitting on the trailer with no difficulty. We decided after several attempts to recover the sensor platform with both the boat and the sensor platform in the water that our planned procedure using the winch was too unsafe to use as we designed it. We now have a second small boat trailer, which we use to transport the sensor platform and to launch and recover it at the same time that the pontoon boat is launched.

## 2.3 Factors Affecting Cost and Performance

We currently project a survey production rate of 5-8 acres/hour assuming a 5 kt survey speed and a 4 m lane spacing. The actual production rate also depends upon the length of the survey lines and the time lost in turns.

There are two major factors affecting survey production rate and therefore the production cost. The first is the ferry distance from the survey site to the launch or docking point. Depending upon the water depths, the ferry speed is 2 to 5 kt. The second and more important factor is the ability to efficiently deploy and recover the system at the beginning and end of each survey day. The daily survey production time is cut effectively in half if the system must be launched and recovered from the boat trailers at the beginning and end of the survey day. This requires that the sensor platform be opened and the cabling disconnected and that the extension components


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containing the sensor interface bottle be disassembled. The 160 lb tow cable must be disconnected and stowed. All this is required if the system must be transported on the trailers.

The assembly and disassembly operations each require ~1.5 hr. For this demonstration, it was our intention to leave the system fully assembled and in the water at night during the entire survey operation. At night, arrangements were made to tie up at a dock with the tow cable stowed on the mounts at the back of the boat. This approach, when successful requires only about 30 min of start-up and check-out each morning. In the evening, a similar amount of time is required to download all the data, stow all the equipment on deck, and secure the covers on the electronics racks.

Another issue that affects performance is having the necessary spare components and equipment to recover from breakdowns or component failures during survey operations. We have spared effectively all critical components for the system, as well as important electronics, circuit boards, etc. We have the tools and personnel necessary to carry out most repairs in the field. For this demonstration, the FRF provided us with office space, secure outdoor storage, indoor storage for sensitive components, and a mechanical repair bay if extensive repairs were required.

## 2.4 Advantages and Limitations of the Technology

The Marine Towed Array system that we describe in this report offers the first efficient and automated modern UXO survey capability that can provide fully geo-referenced survey products to support shallow water UXO clearance operations.

As it is constructed, the Marine Towed Array is a very complex R&D system, effectively a pre-prototype. It is electronically complex, quite heavy, and too expensive to be a competitive commercial instrument as it is currently constituted. However, we have learned enough from its performance and operation to design a field-worthy prototype that would likely weigh 60-70% less, deploy only a single type of sensor, and be self-contained and transportable on a single boat trailer. Most importantly, the sensor platform must be deployable and recoverable from the tow vessel, while in the water. This would allow high speed ferrying of the system between the dock and the survey point and would allow us to navigate in shallower water.

The current system should continue to be used for another 1-2 years to fully explore its capabilities and limitations and to build up a success rate in varying applications that will make it easier to successfully transition to the commercial community.

We used three different docks/marinas during the demonstration at Duck. Each was plagued by difficult access because of shallow water. The reconnaissance trips that we made before the demonstration began indicated that water depths at these (rather primitive) facilities would be adequate. However, during the two weeks of the demonstration surveys strong north and west winds prevailed. These winds effectively lowered the water level 12-18 in. in the Sound during most of the operation.


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# 3.0 Demonstration Design

## 3.1 Performance Objectives

The primary objectives of the first demonstration of the Marine Towed Array focused on developing approaches for efficient deployment of the system and achieving an acceptable survey production rate with minimal missed survey areas on a UXO-contaminated range. This was also the first test of the system that carried through the data preprocessing and data reduction steps, preparation of geo-referenced digital survey maps, target analysis, preparation of dig lists, and training and oversight of marine dig teams using real survey data. In a successful survey we would create a complete record of the entire survey area with magnetometry data, EM data, and digital sonar imaging data. It was our goal to cooperatively use all three types of data in the analysis of targets to make decisions about including and prioritizing targets on the dig list.

The data preprocessing workup was carried out entirely using the Oasis montaj© utility. The GUI scripts that were written for data manipulation and processing of Airborne MTADS data were further adapted for use with the Marine Towed Array. Before the demonstration we tested the utility with laboratory-generated and field-generated marine data to assure that all preprocessing up through the creation of mapped data files could carried out using Geosoft utilities.

The Geosoft target analysis utilities for magnetometry data are still in beta test for vehicular and airborne magnetometry data and they have not been adapted for marine array data. The Geosoft routines have not been completed to allow target fitting using EM data. Therefore, once mapped data files were created, targets analysis shifted to the MTADS DAS GUI. As part of this project we adapted the MTADS DAS to analyze EM data from the EM68, and also to analyze targets from magnetometry data using the DAS.

This demonstration was the first test of the magnetometer and EM68 marine arrays with realistic UXO range data. It was our intent to proceed cautiously, relying on the surrogate targets in the datasets from both the magnetometer and EM surveys to test both the system location accuracies and the fitting algorithm predictions relating to object size and depth. We do not have magnetometry signature library data for fitting the majority of the intermediate and larger rocket ordnance expected on this range and we do not have any library signatures or fits for any of the ordnance on this range using the EM68 array. The magnetometry and EM datasets were independently analyzed; however, for target selection for the dig list, we jointly considered the images and fits target by target for each target being considered for recovery (a subjective cooperative analysis). The DIDSON data clips for the targets on the dig list were scanned to determine if any parts of the targets stood proud of the bottom and whether potential classification information was available from the sonar images. This final step, for reasons explained later in the report took place after the dig list was transmitted to the UXO dive crews.

We prepared UXO target surrogates (see below) for the smaller of the UXO items expected on this range. We had considerable uncertainty about how accurately we (or anyone else) could site


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seed targets in several feet of water. It is equally uncertain how precisely either seed targets or targets from a dig list can be reacquired and marked for retrieval. We worked out a plan for installation of the surrogate ordnance targets that involved installing them from a boat and using long fiberglass poles to stake their positions, with the intent of using GPS to locate their positions before pulling out the poles. In practice this approach did not work. In Section 3.6.2 we describe the technique that was jointly developed while on site with the divers to accurately install both the rebar and the pipe targets.

**Figure 15. Pipe sections (surrogate targets) are shown interspersed between inert ordnance items.**

For this demonstration, surrogate targets (steel pipe sections) were prepared that cover the general range of sizes from a 60-mm mortar to a 105-mm projectile. The pipe sections, see Figure 15 and Table 1, were not specifically prepared to mimic individual ordnance items, but were prepared to have the approximately correct length-to-diameter ratios for ordnance items in this size class. The photograph in Figure 15 compares the pipe sections with inert ordnance items. Table 1 provides the dimensions of the pipe sections.

In addition to the pipe sections that were seeded into the site near the south border of the FRF, we installed 24 pieces of 3/8 in diameter rebar. These were driven vertically into the sediment until they were flush with the bottom along the south border of the site. Their installation is also described in Section 3.6.2.

**Table 1. Dimensions of the pipe sections prepared as surrogate targets**

| Outside Diameter (in) | Wall Thickness (in) | Length (in) | Number Prepared |
|---|---|---|---|
| 4.5 | 0.188 | 18 | 4 |
| 3.5 | 0.188 | 18 | 4 |
| 1.875 | 0.125 | 15 | 4 |
| 2.375 | 0.188 | 12 | 4 |

Based upon all the targets analyzed in the magnetometry and EM survey data, a master dig list was prepared, which contained 150 targets. Although, based upon the Demonstration Plan, we anticipated recovering 100 targets, the additional targets were included assuming that some targets from the list would have to be excluded.

Several criteria were considered in selecting targets for the dig list. Although the dig team intended to bring an auger and suction dredge to the site for excavation of sediment, these tools are experimental items for this application. They have not been proven on UXO ranges. We anticipated that the dig teams would likely ultimately rely on the hand tools that are typically used by divers for these types of operations. They did not expect to be able to prosecute targets that were buried more than 2 ft deep in the sediment. The initial cost estimates provided by EOTI for target recovery assumed that half the targets would be recovered from wading and that half would require boats to support diving.


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The explosives safety exclusion zone for the largest targets expected at this site (the 11.75 in diameter Tiny Tim) is larger than the entire FRF. We decided to exclude these large targets from the dig list, and to limit target depths in the sediment to ≤ 0.6 m.

**Figure 16. A dive team prepares to recover one of the shallow water targets marked with a white flag on an 8 ft fiberglass pole. The team had previously reacquired the target from the dig list and flagged it using the GPS equipment.**

The 0.5 in diameter fiberglass rods, Figure 16, were used to mark the targets for recovery following their reacquisition by the dig teams. Initially, the diver uses a magnetometer to establish that the target is adjacent to the pole. If it is not located immediately, he uses an outwardly spiraling search pattern to locate the target. Assuming an appropriate target is located at a distance that conforms to the analysis predictions, its location, direction, and distance from the pole is recorded on the dig sheet. When the target is subsequently uncovered, the information on the dig sheet is verified or corrected. Recovered targets were consolidated in a secure area prepared for this purpose at the FRF. The visibility in the water was too poor to allow useful underwater photography.

The top-level performance objectives for the demonstration were established in Table 3 of the Demonstration Test Plan. As directed in the Demonstration Plan Guidance, the objectives were divided into two groups, "qualitative and quantitative." Because of our lack of experience in operating the fully-outfitted Marine Towed Array, it was difficult to establish reliable values for the quantitative metrics for the system performance. For purposes of reporting performance in this document, we have broken the objectives in Table 3 from the Demonstration Plan into two tables; in this document Table 2 deals with the quantitative objectives, Table 3 deals with a more extensive tabulation of qualitative performance criteria. The information in Table 3 is expanded because our experience during the demonstration caused us to make several alterations in our demonstration plan and to the approaches to accomplish several tasks that addressed the overall goals of the demonstration.

***3.1.1 Performance Against Quantitative Objectives:*** The installation of the seed targets is described in Section 3.6. Because the targets were installed in shallow water (1.3-1.7 m), the techniques developed by the EOD divers for their placement provided accurate locations. We believe the reported ("ground truth)" locations for the rebar targets are accurate to ±10 cm and for the pipe sections to ±20 cm. During the target analysis it became apparent that both the rebar and the pipes had magnetic signatures dominated by substantial remnant moments. This may have affected the magnetometer position analysis by a small amount. Size information from the magnetometer target analysis was effectively useless because of the large permanent moments of all the objects. More importantly, the magnetometer survey of the pipe sections was done on a particularly windy day and only partial signatures of pipes 1, 2, 3, and 8 were obtained. The offsets between the way pointed and the analyzed positions for the rebar and pipe targets were 22 and 36 cm in the magnetometer survey. Excluding the 4 partial pipe signatures,


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**Table 2. Quantitative performance objectives for the demonstration**

| Primary Performance Criteria | Expected Performance | Actual Performance |
|---|---|---|
| Data preprocessing and creation of mapped data files | Accomplish Overnight | Updated maps were always created each night for next day use. |
| Target analysis and preparation of the dig list | Accomplish by second day | Dig List completed 1 day following final EM survey. |
| Magnetometry survey production rates | 8 acres/hr while surveying, 40 acres/survey day | In deep water, routine production was 7.5 acres/hr not including turns, 5 acres/hr with turns. In shallow water production rates are 50% lower. The best 4 survey days averaged >35 acres/day. See the text for detail. |
| EM survey production rates | 8 acres/hr while surveying, 40 acres/survey day | In deep water, routine production was 7.5 acres/hr not including turns, 5 acres/hr with turns. In shallow water production rates are 50% lower. The best 4 survey days averaged >35 acres/day. See the text for detail. |
| Detection of surrogate targets | All surrogate targets will be clearly detectible in mag and EM datasets | All pipe and rebar targets were clearly detectible. See the text for comments re the EM S/N ratio. |
| Target location accuracies | ±25 cm, overall, including placement (seeds), survey analysis, and way pointing | In Mag data, average miss distances for rebar and pipes were 22 & 36 cm. In EM data, averge miss distances for rebar and pipes were 24 & 48 cm. See the text for details. |
| Survey Coverage/Missed Areas | In areas intended for complete coverage, >95% coverage will be accomplished, e.g. <1 survey lane in 20 will have to be repeated | Overall missed area in mag survey was <4%, in the EM survey <5%. Most missed areas were near the turn-arounds and during high cross winds. Coverage was more difficult in very shallow water. |
| Depth station keeping | Command depth (or altitude) will be maintained within 0.15 m 95% of the time | In deep water (>2 m) altitude above the bottom was maintained within 10 cm. In shallow water all surveys were done at a command depth of 0.5 m. |
| Line station keeping | During acceptable weather, 4 m survey lanes will reduce missed areas to <5% | Line station keeping was generally less than 1-m off-track. More difficulties were encountered in high cross winds and at the beginning of lines. |

the location accuracies of both the pipe and rebar targets were within the 25 cm position error budget predicted before the demonstration. Table 4 provides the comparisons between the way pointed and analyzed positions in the magnetometer survey.


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**Table 3. Qualitative performance objectives for the demonstration**

| Operational Component | Objective | Measurement Metric |
|---|---|---|
| Logistics and Support | Pre-establish necessary support logistics | Time lost during demonstration to correct deficiencies |
| | Efficient boat and survey platform deployment and recovery | Time lost at the beginning and end of each day to deploy and secure the system |
| | Provide system support and communication while at sea | Lost survey time to correct problems |
| | Provide onshore logistics to support data processing and data products | Timely processing of survey data and timely preparation for products for the dig teams |
| | Efficient dive team interface | Timely availability of dig lists, provision for recovery of dug targets, and provision for efficient UXO demolition. Unnecessary to call for military EOD support. |
| Equipment Component Performance | Platform attitude and position control to support precise navigation and location requirements | Number of breakdowns and work stoppages because of equipment failures or lack of spare components. Measured ability to maintain programmed altitude or depth. |
| | Efficient performance and integration of ancillary components | Time lost or survey integrety compromised because of GPS, DIDSON sonar, boat-mounted depth sounders, or the pilot guidance system performance |
| Survey Operations | Maintain consistently high survey production rate. | Will be measured and reported as hourly and daily survey rates and also fraction of the day actually taking survey data |
| | Maximize coverage area and minimize missed areas | Will be measured using course-over-ground plots |
| | Achieve detection goals for individual targets | Mag and EM sensors will be evaluated against the emplaced seed targets and the two sensors performances will be measured against each other |
| | Pilot guidance system provides capability to achieve survey goals without need for exteranl cues (flags on the perimeter) | Performance will be evaluated with course-over-ground plots in varying sea states and weather conditions |
| Data Acquisition Performance | Efficient integration of all components supporting the pilot guidance display, the platform autopilot, and the data acquisition system | Will be evaluated by the ability to lay out and survey to a prepared grid, by the extent and severity of track misregisterations, and by the ability to fly the platform on a straight and level course |
| | Conduct an efficient EMI survey | EMI survey performance and detection capability will be measured against the magnetometer survey performance (depth and size of targets detected) |
| | Successful performance of the imaging sonar | Performance will be evaluated in varying sea states and survey speeds to image objects detected by other sensors |
| Data Products | Overnight data preprocessing | Preprocess and correct survey data & create mapped data files |
| | Timely target analysis | Target analyses completed for preparation of dig list. Use of mag, EM, and sonar data in analysis. |
| | Timely preparation of dig products | Prioritized dig lists, dig sheets, and GPS way pointing files created in time for dig team training |
| | Interface between survey and dig teams | Dig teams trained and tested using GPS to reacquire and mark targets |
| Target Recovery | Successful way pointing and recovery of the first 100 targets on the dig list | No false alarms (dry holes). Teams able to acquire and recover targets predicted to be <0.6 m deep. All targets recovered are small enough and appropriate for consolidating at the FRF |
| | Dig sheets aid in survey performance evaluation | Divers record depths and locations of recovered targets relative to the way point marker |
| | Successful target demolition | All recovered targets are consolidated to the FRF and photographed for documentation. All UXO are consolidated and successfully challenged with explosives. All target scrap is recovered and removed from the site. |


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In the EM dataset the remnant moments of the pipes and the rebar were not an issue. The analyzed position accuracies were expected to be larger than in the mag survey, primarily because of the 1 m horizontal dimension of the receiver coils. The pipe and rebar targets were covered by multiple EM survey passes, providing complete signatures for all for all objects. The S/N ratio in the EM data was substantially worse than we expected, primarily because of noise created by a synchronization problem in the data acquisition software provided with the instrument. An updated version of the data acquisition software was provided by Geonics immediately before the demonstration. It corrected some other earlier problems with the system, but created the timing synchronization problem among the 4 receiver coils. We have not been able to correct the problem in a way that would allow us to fully noise correct the datasets taken

**Table 4. Comparison of the pipe and rebar stakeout and analyzed positions in the magnetometer survey**

| ID | HE (m) | Size (m) | Moment | Fit Quality | Analyst Comments | Measured Coordinates | | Staked Out Coordinates | | | Miss Distance (m) | Easting Offset (m) | Northing Offset (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | UTM X(m) | UTM Y(m) | Easting (m) | Northing (m) | HAE (m) | | | |
| 1 | -42.78 | 0.183 | 3.2675 | 0.776 | Rebar #1 | 431751.28 | 4003800.07 | 431751.15 | 4003799.98 | -41.27 | 0.15 | -0.13 | -0.09 |
| 2 | -42.74 | 0.183 | 3.2548 | 0.896 | Rebar #2 | 431750.94 | 4003804.37 | 431750.97 | 4003804.01 | -41.31 | 0.36 | 0.03 | -0.36 |
| 3 | -42.70 | 0.152 | 1.8492 | 0.913 | Rebar #3 | 431750.33 | 4003808.94 | 431750.24 | 4003808.79 | -41.32 | 0.18 | -0.09 | -0.15 |
| 4 | -42.76 | 0.185 | 3.3234 | 0.925 | Rebar #4 | 431749.85 | 4003813.63 | 431749.54 | 4003813.41 | -41.34 | 0.39 | -0.31 | -0.23 |
| 5 | -42.77 | 0.227 | 6.2274 | 0.917 | Rebar #5 | 431749.27 | 4003817.83 | 431749.08 | 4003817.70 | -41.34 | 0.23 | -0.19 | -0.14 |
| 6 | -42.75 | 0.233 | 6.7297 | 0.938 | Rebar #6 | 431748.59 | 4003822.75 | 431748.43 | 4003822.60 | -41.40 | 0.22 | -0.16 | -0.15 |
| 7 | -42.80 | 0.238 | 7.1657 | 0.869 | Rebar #7 | 431748.12 | 4003828.91 | 431748.03 | 4003828.76 | -41.38 | 0.18 | -0.09 | -0.15 |
| 8 | -42.86 | 0.152 | 1.8587 | 0.844 | Rebar #8 | 431747.84 | 4003834.38 | 431747.71 | 4003834.47 | -41.38 | 0.16 | -0.13 | 0.09 |
| 9 | -42.96 | 0.179 | 3.051 | 0.670 | Rebar #9 | 431747.54 | 4003839.66 | 431747.85 | 4003839.77 | -41.35 | 0.33 | 0.31 | 0.11 |
| 10 | -42.81 | 0.164 | 2.3149 | 0.812 | Rebar #10 | 431747.46 | 4003845.51 | 431747.60 | 4003845.54 | -41.35 | 0.14 | 0.13 | 0.03 |
| 11 | -42.96 | 0.227 | 6.158 | 0.781 | Rebar #11 | 431747.38 | 4003851.16 | 431747.59 | 4003851.04 | -41.36 | 0.24 | 0.21 | -0.12 |
| 12 | -42.98 | 0.247 | 7.9884 | 0.741 | Rebar #12 | 431747.08 | 4003856.67 | 431747.29 | 4003856.63 | -41.33 | 0.21 | 0.21 | -0.04 |
| 13 | -42.88 | 0.225 | 6.0604 | 0.804 | Rebar #13 | 431746.92 | 4003861.84 | 431747.02 | 4003861.93 | -41.44 | 0.13 | 0.10 | 0.09 |
| 14 | -43.06 | 0.178 | 3.0023 | 0.840 | Rebar #14 | 431746.74 | 4003866.75 | 431746.80 | 4003866.65 | -41.33 | 0.11 | 0.06 | -0.10 |
| 15 | -42.78 | 0.23 | 6.4742 | 0.846 | Rebar #15 | 431746.49 | 4003871.69 | 431746.58 | 4003871.62 | -41.29 | 0.12 | 0.09 | -0.07 |
| 16 | -42.77 | 0.267 | 10.104 | 0.836 | Rebar #16 | 431746.17 | 4003876.85 | 431746.27 | 4003876.69 | -41.31 | 0.19 | 0.10 | -0.16 |
| 17 | -42.73 | 0.211 | 4.9436 | 0.804 | Rebar #17 | 431745.95 | 4003881.70 | 431746.02 | 4003881.46 | -41.26 | 0.25 | 0.07 | -0.24 |
| 18 | -42.59 | 0.133 | 1.2429 | 0.801 | Rebar #18 | 431745.68 | 4003886.82 | 431745.78 | 4003886.76 | -41.27 | 0.12 | 0.10 | -0.06 |
| 19 | -42.66 | 0.177 | 2.9581 | 0.934 | Rebar #19 | 431745.51 | 4003892.23 | 431745.51 | 4003891.88 | -41.25 | 0.36 | 0.00 | -0.35 |
| 20 | -42.58 | 0.192 | 3.7376 | 0.916 | Rebar #20 | 431745.36 | 4003896.54 | 431745.24 | 4003896.23 | -41.25 | 0.33 | -0.12 | -0.31 |
| 21 | -42.56 | 0.148 | 1.7247 | 0.949 | Rebar #21 | 431745.31 | 4003901.58 | 431745.03 | 4003901.39 | -41.23 | 0.34 | -0.28 | -0.19 |
| 22 | -42.81 | 0.19 | 3.6296 | 0.861 | Rebar #22 | 431744.76 | 4003906.77 | 431744.76 | 4003906.78 | -41.26 | 0.01 | -0.01 | 0.01 |
| 23 | -42.89 | 0.241 | 7.4097 | 0.716 | Rebar #23 | 431744.34 | 4003911.56 | 431744.61 | 4003911.23 | -41.95 | 0.43 | 0.27 | -0.33 |
| | | | | | | | | | | Average Offset | 0.22 | 0.14 | 0.16 |

| ID | HE (m) | Size (m) | Moment | Fit Quality | Analyst Comments | Measured Coordinates | | Staked Out Coordinates | | | Miss Distance (m) | Easting Offset (m) | Northing Offset (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | UTM X(m) | UTM Y(m) | Easting (m) | Northing (m) | HAE (m) | | | |
| 24 | -42.56 | 0.191 | 3.6845 | 0.967 | Pipe 1 Partial, L | 431693.22 | 4003833.17 | 431693.45 | 4003832.52 | -42.08 | 0.69 | 0.23 | -0.65 |
| 25 | -42.49 | 0.149 | 1.7356 | 0.950 | Pipe 2 Partial, ML | 431694.15 | 4003837.40 | 431694.31 | 4003836.99 | -42.05 | 0.44 | 0.16 | -0.41 |
| 26 | -42.55 | 0.05 | 0.0648 | 0.664 | Pipe 3 Partial, MS | 431695.63 | 4003842.82 | 431695.34 | 4003842.14 | -42.47 | 0.74 | -0.29 | -0.68 |
| 27 | -42.41 | 0.055 | 0.0866 | 0.892 | Pipe 4, S | 431696.82 | 4003847.46 | 431696.48 | 4003847.21 | -42.45 | 0.42 | -0.34 | -0.25 |
| 28 | -42.47 | 0.143 | 1.5595 | 0.945 | Pipe 5, L | 431697.51 | 4003852.58 | 431697.47 | 4003852.28 | -42.49 | 0.30 | -0.04 | -0.30 |
| 29 | -42.52 | 0.178 | 2.9594 | 0.965 | Pipe 6, ML | 431698.85 | 4003857.53 | 431698.58 | 4003857.35 | -42.00 | 0.32 | -0.27 | -0.18 |
| 30 | -42.57 | 0.146 | 1.6339 | 0.914 | Pipe 7, MS | 431699.38 | 4003862.83 | 431699.51 | 4003862.51 | -42.25 | 0.35 | 0.13 | -0.32 |
| 31 | -43.02 | 0.116 | 0.818 | 0.862 | Pipe 8 Partial S | 431701.19 | 4003868.05 | 431700.62 | 4003867.92 | -42.10 | 0.58 | -0.57 | -0.13 |
| 32 | -42.49 | 0.195 | 3.913 | 0.924 | Pipe 9, L | 431701.83 | 4003873.16 | 431701.67 | 4003873.15 | -41.98 | 0.16 | -0.16 | -0.01 |
| 33 | -42.52 | 0.172 | 2.6941 | 0.808 | Pipe 10, ML | 431702.98 | 4003878.37 | 431702.82 | 4003878.39 | -41.92 | 0.16 | -0.16 | 0.02 |
| 34 | -42.49 | 0.18 | 3.1073 | 0.811 | Pipe 11, MS | 431704.25 | 4003883.55 | 431703.97 | 4003883.53 | -42.01 | 0.28 | -0.28 | -0.02 |
| 35 | -42.55 | 0.091 | 0.4043 | 0.732 | Pipe 12, S | 431705.38 | 4003888.65 | 431705.22 | 4003888.60 | -42.08 | 0.17 | -0.16 | -0.05 |
| 36 | -42.44 | 0.192 | 3.7615 | 0.865 | Pipe 13, L | 431706.26 | 4003894.10 | 431706.36 | 4003894.14 | -41.91 | 0.11 | 0.10 | 0.04 |
| 37 | -42.60 | 0.209 | 4.8147 | 0.765 | Pipe 14, ML | 431707.99 | 4003899.48 | 431707.71 | 4003899.32 | -42.00 | 0.32 | -0.28 | -0.16 |
| 38 | -42.44 | 0.088 | 0.3634 | 0.678 | Pipe 15, MS | 431708.74 | 4003904.06 | 431708.62 | 4003904.21 | -41.96 | 0.19 | -0.12 | 0.15 |
| 39 | -42.59 | 0.103 | 0.5747 | 0.675 | Pipe 16, S | 431709.52 | 4003909.58 | 431709.78 | 4003909.62 | -42.04 | 0.27 | 0.26 | 0.04 |
| 40 | -42.69 | 0.08 | 0.2735 | 0.423 | Pipe 17 | 431710.48 | 4003914.26 | 431711.01 | 4003914.49 | -42.00 | 0.57 | 0.53 | 0.23 |
| | | | | | | | | | | Average Offset | 0.36 | 0.24 | 0.21 |


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during this demonstration. To recover useful signals for target analysis of the EM data required that we sum all 26 time channels, making the system similar to data collected by an EM61 for analysis purposes.

The EM signals from the rebar sections are much smaller than those of the pipe sections, Table 5. About half of the rebar signatures are captured by only one receiver coil; the remainder appear in two adjacent coils. Even though the S/N is only 3/1 to 6/1 for the rebar targets, the analysis fits are relatively good and the average discrepancy between the way pointed positions and the analyzed positions is 24 cm – this is effectively equivalent to the magnetometer dataset results. The pipe signals were significantly larger (30-150 mv) and appear in 3 or 4 adjacent receiver coils. Additionally, there were 3 separate survey passes over the line of pipe targets. Slight misregisterations among these passes contributed to an average offset between the way pointed and analyzed positions of 48 cm. These were dominated by Easting errors, which

**Table 5. Comparison of the pipe and rebar stakeout and analyzed positions in the EM survey**

| | Target ID | HAE (m) | Fe Size (m) | Non Fe Size (m) | Fit Quality | Measured Coordinates | | Staked Out Coordinates | | | Miss Distance (m) | Easting Offset (m) | Northing Offset (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | UTM X(m) | UTM Y(m) | Easting (m) | Northing (m) | HAE (m) | | | |
| Rebar 1 | 75 | -42.06 | 0.041 | 0.041 | 0.266 | 431750.98 | 4003800.04 | 431751.15 | 4003799.98 | -41.27 | 0.18 | 0.17 | -0.06 |
| Rebar 2 | 76 | -42.27 | 0.061 | 0.078 | 0.497 | 431751.04 | 4003804.11 | 431750.97 | 4003804.01 | -41.31 | 0.12 | -0.07 | -0.10 |
| Rebar 3 | 77 | -41.87 | 0.034 | 0.033 | 0.382 | 431750.39 | 4003808.64 | 431750.24 | 4003808.79 | -41.32 | 0.21 | -0.15 | 0.15 |
| Rebar 4 | 78 | -42.14 | 0.044 | 0.046 | 0.193 | 431749.64 | 4003813.36 | 431749.54 | 4003813.41 | -41.34 | 0.11 | -0.10 | 0.04 |
| Rebar 5 | 79 | -41.67 | 0.026 | 0.023 | 0.339 | 431749.24 | 4003817.69 | 431749.08 | 4003817.70 | -41.34 | 0.16 | -0.16 | 0.00 |
| Rebar 6 | 80 | -41.80 | 0.031 | 0.028 | 0.311 | 431748.28 | 4003822.35 | 431748.43 | 4003822.60 | -41.40 | 0.29 | 0.15 | 0.25 |
| Rebar 7 | 81 | -41.45 | 0.021 | 0.018 | 0.398 | 431747.86 | 4003828.87 | 431748.03 | 4003828.76 | -41.38 | 0.20 | 0.17 | -0.11 |
| Rebar 8 | 82 | -41.48 | 0.021 | 0.018 | 0.473 | 431747.60 | 4003834.70 | 431747.71 | 4003834.47 | -41.38 | 0.26 | 0.11 | -0.23 |
| Rebar 9 | 83 | -42.16 | 0.048 | 0.053 | 0.369 | 431747.62 | 4003839.91 | 431747.85 | 4003839.77 | -41.35 | 0.27 | 0.23 | -0.14 |
| Rebar 10 | 84 | -41.76 | 0.027 | 0.024 | 0.282 | 431747.43 | 4003845.57 | 431747.60 | 4003845.54 | -41.35 | 0.17 | 0.16 | -0.03 |
| Rebar 11 | 85 | -42.14 | 0.042 | 0.044 | 0.308 | 431747.59 | 4003851.15 | 431747.59 | 4003851.04 | -41.36 | 0.11 | 0.00 | -0.11 |
| Rebar 12 | 86 | -42.28 | 0.051 | 0.058 | 0.360 | 431747.34 | 4003856.79 | 431747.29 | 4003856.63 | -41.33 | 0.17 | -0.05 | -0.16 |
| Rebar 13 | 87 | -42.29 | 0.051 | 0.058 | 0.296 | 431747.14 | 4003861.91 | 431747.02 | 4003861.93 | -41.44 | 0.13 | -0.12 | 0.02 |
| Rebar 14 | 88 | -41.53 | 0.020 | 0.017 | 0.349 | 431747.29 | 4003867.15 | 431746.80 | 4003866.65 | -41.33 | 0.70 | -0.49 | -0.50 |
| Rebar 15 | 89 | -42.39 | 0.056 | 0.068 | 0.285 | 431746.80 | 4003871.68 | 431746.58 | 4003871.62 | -41.29 | 0.23 | -0.22 | -0.06 |
| Rebar 16 | 90 | -41.85 | 0.029 | 0.026 | 0.235 | 431746.11 | 4003876.79 | 431746.27 | 4003876.69 | -41.31 | 0.19 | 0.16 | -0.10 |
| Rebar 17 | 91 | -42.39 | 0.058 | 0.071 | 0.286 | 431746.00 | 4003881.56 | 431746.02 | 4003881.46 | -41.26 | 0.10 | 0.02 | -0.10 |
| Rebar 18 | 92 | -41.47 | 0.020 | 0.017 | 0.418 | 431745.11 | 4003887.02 | 431745.78 | 4003886.76 | -41.27 | 0.72 | 0.67 | -0.26 |
| Rebar 19 | 93 | -41.58 | 0.023 | 0.020 | 0.401 | 431745.82 | 4003892.21 | 431745.51 | 4003891.88 | -41.25 | 0.45 | -0.31 | -0.33 |
| Rebar 20 | 94 | -41.52 | 0.022 | 0.018 | 0.462 | 431745.41 | 4003896.50 | 431745.24 | 4003896.23 | -41.25 | 0.32 | -0.17 | -0.27 |
| Rebar21 | 95 | -42.02 | 0.039 | 0.039 | 0.381 | 431745.10 | 4003901.58 | 431745.03 | 4003901.39 | -41.23 | 0.21 | -0.07 | -0.19 |
| Rebar 22 | 96 | -41.93 | 0.036 | 0.035 | 0.317 | 431744.79 | 4003906.67 | 431744.76 | 4003906.78 | -41.26 | 0.12 | -0.03 | 0.11 |
| Rebar 23 | 97 | -41.93 | 0.036 | 0.035 | 0.407 | 431744.40 | 4003911.24 | 431744.61 | 4003911.23 | -41.95 | 0.21 | 0.21 | -0.02 |
| | | | | | | | | | | Average Offset | 0.24 | 0.16 | 0.14 |

| | Target ID | HAE (m) | Fe Size (m) | Non Fe Size (m) | Fit Quality | Measured Coordinates | | Staked Out Coordinates | | | Miss Distance (m) | Easting Offset (m) | Northing Offset (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | UTM X(m) | UTM Y(m) | Easting (m) | Northing (m) | HAE (m) | | | |
| Pipe 1 | 58 | -42.13 | 0.086 | 0.139 | 0.733 | 431692.75 | 4003832.91 | 431693.45 | 4003832.52 | -42.08 | 0.80 | 0.70 | -0.39 |
| Pipe 2 | 59 | -42.28 | 0.102 | 0.188 | 0.760 | 431693.69 | 4003837.15 | 431694.31 | 4003836.99 | -42.05 | 0.64 | 0.62 | -0.16 |
| Pipe 3 | 60 | -41.44 | 0.016 | 0.014 | 0.095 | 431694.79 | 4003842.25 | 431695.34 | 4003842.14 | -42.47 | 0.56 | 0.55 | -0.11 |
| Pipe 4 | 61 | -42.66 | 0.095 | 0.166 | 0.404 | 431696.11 | 4003847.37 | 431696.48 | 4003847.21 | -42.45 | 0.40 | 0.37 | -0.16 |
| Pipe 5 | 62 | -42.69 | 0.157 | 0.376 | 0.581 | 431697.35 | 4003852.37 | 431697.47 | 4003852.28 | -42.49 | 0.15 | 0.12 | -0.09 |
| Pipe 6 | 63 | -42.29 | 0.106 | 0.200 | 0.749 | 431698.30 | 4003857.31 | 431698.58 | 4003857.35 | -42.00 | 0.28 | 0.28 | 0.04 |
| Pipe 7 | 64 | -42.25 | 0.059 | 0.073 | 0.325 | 431699.49 | 4003862.83 | 431699.51 | 4003862.51 | -42.25 | 0.32 | 0.02 | -0.32 |
| Pipe 8 | 65 | -42.35 | 0.068 | 0.092 | 0.347 | 431700.31 | 4003867.85 | 431700.62 | 4003867.92 | -42.10 | 0.32 | 0.31 | 0.07 |
| Pipe 9 | 66 | -42.15 | 0.099 | 0.179 | 0.839 | 431701.62 | 4003873.25 | 431701.67 | 4003873.15 | -41.98 | 0.11 | 0.05 | -0.10 |
| Pipe 10 | 67 | -42.32 | 0.104 | 0.193 | 0.701 | 431702.83 | 4003878.29 | 431702.82 | 4003878.39 | -41.92 | 0.10 | -0.01 | 0.10 |
| Pipe 11 | 68 | -41.78 | 0.033 | 0.031 | 0.284 | 431704.74 | 4003883.66 | 431703.97 | 4003883.53 | -42.01 | 0.78 | -0.77 | -0.13 |
| Pipe 12 | 69 | -41.90 | 0.045 | 0.049 | 0.483 | 431705.24 | 4003888.34 | 431705.22 | 4003888.60 | -42.08 | 0.26 | -0.02 | 0.26 |
| Pipe 13 | 70 | -41.97 | 0.086 | 0.138 | 0.704 | 431706.21 | 4003894.06 | 431706.36 | 4003894.14 | -41.91 | 0.17 | 0.15 | 0.08 |
| Pipe 14 | 71 | -43.50 | 0.278 | 0.875 | 0.097 | 431707.18 | 4003899.72 | 431707.71 | 4003899.32 | -42.00 | 0.66 | 0.53 | -0.40 |
| Pipe 15 | 72 | -41.57 | 0.030 | 0.027 | 0.506 | 431707.50 | 4003904.22 | 431708.62 | 4003904.21 | -41.96 | 1.12 | 1.12 | -0.01 |
| Pipe 16 | 73 | -41.56 | 0.030 | 0.027 | 0.341 | 431708.98 | 4003910.25 | 431709.78 | 4003909.62 | -42.04 | 1.02 | 0.80 | -0.63 |
| Pipe 17 | 74 | -42.28 | 0.073 | 0.104 | 0.495 | 431710.48 | 4003914.57 | 431711.01 | 4003914.49 | -42.00 | 0.53 | 0.53 | -0.08 |
| | | | | | | | | | | Average Offset | 0.48 | 0.41 | 0.19 |


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reflected the side-to-side rocking of the boat (the GPS antennas on their high masts) in a crosswind.

All the magnetometer and EM surveying took place between 9 May and 18 May. On May 9, 10, and 11 and the morning of the 12th only a very small amount of survey data was collected because of start up and component malfunction problems. These are discussed in the next section of this report. The number of survey lines completed and the effective survey production rates are summarized in Table 6. A total of 154.2 acres was surveyed using the magnetometer array; 47.4 acres were completed with the EM array. Survey rates were somewhat lower when surveying shorter lines on the eastern side of the survey area. Survey rates were also significantly lower when surveying in the shallowest water (primarily on 18 May). On 13, 14, 16, and 17 May when surveying took place all day long, the survey production rate averaged 35.5 acres/day. This is near the maximum rate that can be expected using this equipment when lines of ~1 km length are being surveyed.

**Table 6. Summary of the survey production rate information**

| Survey Date | Survey Lines Completed | Area Surveyed (ha) | Survey Rate ha/hr - acres/hr |
|---|---|---|---|
| Mon 9-May | 5 | 2.60 | 2.04 - 5.04 |
| Tue 10-May | 3 | 1.56 | 2.01 - 4.97 |
| Wed 11-May | 11 | 5.72 | 3.52 - 8.70 |
| Thur 12-May | 17 | 8.84 | 2.04 - 5.04 |
| Fri 13-May | 22 | 11.44 | 2.97 -7.34 |
| Sat 14-May | 24 | 12.48 | 2.06 - 5.09 |
| Mon 16-May | 62 | 18.60 | 2.22 - 5.47 |
| Tue 17-May | 50 | 15.00 | 1.73 - 4.27 |
| Wed 18-May | 18 | 5.40 | 1.14 -2.82 |

The data preprocessing, target analysis, preparation of the dig lists and the other data products were routinely accomplished. These tasks were very little different operationally, than has been the case for MTADS surveys for many years.

The EM data had S/N limitations because of malfunctions in the data acquisition software. In addition, the sensitivity of the EM array is limited because of the standoff distance between the sensor and the bottom sediments. In water deeper than 2 m all survey operations were carried out while station keeping 1.25 m above the bottom. When the sonar altimeter (and the EM coils are 1.25 m above the bottom, the bottom of the skids are less than 1 m above the bottom. The $1/R^6$ fall-off in signal with the EM system, combined with the S/N problem resulted in ~ 40% of the magnetometer targets being undetectable in the EM data. For these reasons the targets in the dig list were based primarily upon the magnetometry analysis. In very shallow water, when the sensor platform was almost dragging the bottom, the relative detection capability of the EM array was significantly higher.

***3.1.2 Performance Against Qualitative Objectives:*** During the first three and one-half days of the survey, operations were hampered by a combination of hardware component and logistics problems. As a result of prior reconnaissance visits to the site, we decided that we would work from a semi-improved boat launch ramp at the Duck News Café for launching and recovery of the tow vessel and the sensor platform and for docking it overnight. The ramp, which is about 2 mi north of the FRF, is in a relatively secluded area with no other marine traffic. We launched the 17 ft skiff (the chase boat) from this ramp and ferried to the FRF on 8 May. The first 1.5 mi traveled after leaving the ramp was so shallow that we determined that the launch ramp could not be used for the larger vessel.


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The following day we contracted with the North Duck Watersports Marina to launch from their facility and to dock our equipment at one of their slips. This was the site that we used for the June 2004 reconnaissance survey of the FRF. The marina was in a state of significant disrepair because of winter storms – repair work was just beginning for the summer season. We initially launched both the boat and platform from this ramp and docked there on 9, 10, and 11 May. The first half mile traveling south from the marina is also quite shallow and difficult to navigate, Figure 17. During this period the winds continued from the north and west until the water level in the Sound had dropped by ~18 in. This made navigation out of the marina effectively impossible. On 12 May the owner of the Sunset Grill agreed to let us moor our equipment at the end of his dock. There is no boat ramp associated with this facility; however it is only about 300 m from the south end of the survey area where we installed the seed targets. We used this dock, Figure 18, to moor the equipment until the end of the demonstration. The equipment was brought ashore using the ramp at the North Duck Watersports.

**Figure 17. The dive boat is assisting the return of the MTA vessel to the North Duck Watersports dock.**

**Figure 18. The MTA equipment is shown moored at the Sunset Grill dock about 250 meters southwest of the survey area.**

The startup hardware problems that delayed the beginning of the full-scale survey work involved a combination of difficulties establishing the correct setup protocols between the GPS base station and the rover units in the boat. This problem was further complicated by failures in two separate electronic circuit boards in the data acquisition system. Following the final diagnosis of the hardware problems and replacement of the components from the spares inventory, the GPS malfunctions were worked out in communication with the factory. During the surveys we had constant communication between the survey vessel, the chase boat, and the office facility using mobile radios. Additionally, all groups had cell phones to aid in communication.

The sensor platform autopilot control system and the navigation and survey control display systems operated flawlessly during the surveys (once the GPS setup problems were solved). In water depths greater than 2 m, the survey platform was operated in altitude mode set for an elevation above the bottom of 1.25 m. This altitude positioned the bottom of the skids <1 m above the bottom. After breaking 3 cable weak links in turns, we began commanding the platform to rise during turns. The difficulty (engaging the platform wing with the bottom) resulted from the rapidly rising bottom in the north-east border of the survey. Accomplishing turns required turning into this rising bottom structure. Commanding the platform to rise at the


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end of a survey line and return to altitude mode as the new survey line was approached did not increase the time required to make a turn. In water depths <2 m, the platform was commanded to a depth of 0.5 m below the surface. This leaves the top of the platform just below the surface, and is about as shallow as it can be operated. Surveying in very shallow water is slow, often taking place at 1.2-1.6 m/sec. At this speed some loss of accuracy in positioning likely takes place because the tow cable may be intermittently dragging on the bottom. In deeper water surveying routinely takes place at 2.2-2.5 m/sec, depending on wind and water conditions.

During the entire survey period the prevailing winds were from the northeast, north, or northwest. They were unusually strong (often 15-20 kt) and often prevailed throughout the day. The typical calm mornings usually experienced at this time of year, changing to a gentle land breeze, which switches to a sea breeze at midday and then calming again at sunset, was never the case. There were a few relatively calm early mornings. For this reason we typically tried to be on site by 6:00 AM. This prevailing wind pattern pushes water out of the Sound; the water level dropped as much as 18 in at times with strong north and northwest winds. Winds had little effect on the surface roughness except when they were out of the west or northwest. With west winds, a surface chop of >1 ft quickly built up. While we found little difficulty surveying in these waves, the cross winds, combined with the waves coming in from the west at times created enough vessel roll that the GPS antennas rocked side-to-side by more than 1 m.

The Didson imaging sonar was not deployed for the first three survey days while hardware and logistics problems were being solved. Beginning on 12 May, it was deployed for the majority of surveys. A total of more than 23 hours of digital sonar data were recorded on DVDs. Reviewing the sonar data is very time consuming. If it is played back for review, it cannot be reviewed at more than twice the speed that it was taken or objects in the images are not apparent. There was not time to review the sonar data during the compressed time period when target analysis was being carried out.

The MTADS DAS software was modified to record the survey time corresponding with each target that was entered into the target list. This time stamp was used to "look up" the target position (time) in the sonar image data. None of the ordnance targets on the dig list had associated sonar images. The ordnance have been resident in the bay for 40-60 years. If they were proud of the bottom when they landed, the many years of sediment collection in the sound from run off and sand and dust storms would have covered them. Particularly during the winter with strong north and east winds, there is a constant airborne sand content from the beach and from the waves breaking on the shore.

There were several dozen images in the sonar data of objects obviously extending 1-2 ft above the bottom. In many cases these objects were clearly square, and became immediately recognizable as derelict crab traps (locally called crab pots) after a few of the targets had been dug. If there had been time to review the sonar data before the targets were dug, about half of the dug crab pots could have been taken off the list. As the digging progressed it also became apparent that the crab pots could be recognized in the magnetometry data. When this discovery was made there were 8 currently flagged targets. We correctly predicted that 3 of these were crab pots. At this point 13 remaining targets, which were clearly crab pots, were removed from the dig list.


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The interface between the survey team and the dig teams functioned very smoothly. The dive teams were trained in target reacquisition using the AETC GPS equipment with an initial group of 6 shallow water targets. Following this, all targets on the dig list were way pointed and staked by the dig teams alone (using 8 or 16 ft fiberglass poles with flags to mark target positions). The dig teams found metallic objects at all way pointed positions. In one case, even though there was a substantial signal on the search mag at the bottom of the hole, the target was too deep to uncover using shovels. In a second case an uncovered large metallic object was too heavy to lift with the small wench that they had available. There were a few examples of metallic mesh runway matting that were recovered. In all other cases, the target objects were recovered and stored in a secure area provided at the FRF. At the end of the operation, all ordnance items were challenged with explosive shape charges. All metallic scrap was collected and stored in 55 gal drums for disposal. These operations are described in Section 3.6.5.

## 3.2 Selecting the Test Site

The selection criteria established for the demonstration site selection include:

- The site must be a current or former DoD range that is expected to have UXO and ordnance clutter present within the survey area
- The water depths on the site should be consistent with the design parameters of the project and the demonstration equipment, e.g. 1-5 m
- The bottom conditions on the site should not pose an extreme danger to the equipment or preclude opportunity to complete survey operations that would allow a fair evaluation of the system performance
- The expected water conditions should be compatible with the operating capabilities of the demonstration equipment
- There should be reasonable access to necessary support infrastructure, and
- There should be local and organizational buy-in to the proposed work.

The site chosen for this demonstration, the Former Duck Naval Target Range meets most, but not all, of the preferred selection criteria. The site was definitely a heavily-used DoD airborne air-to-ground rocket and bombing range for many years, see Section 3.3 below. There was a high (but unproven) probability of significant UXO contamination in the Currituck Sound immediately west of the range (e.g., the proposed survey area). This issue was addressed by conducting preliminary studies; see Section 3.5 below.

The proposed survey area lies in a relatively protected area west of the barrier island shore. The three miles of open water to the west of the shoreline allows the potential for buildup of significant surface waves during windy periods, but the area was expected to meet Sea State 1 conditions the majority of the time. The bottom was believed (based upon marine charts) to be primarily gently-sloping mud with water depths increasing to 10-12 feet within 0.5 miles from shore. Some of the necessary infrastructure support is available. Mr. Bill Birkmeier, Chief of the FRF (the current DoD tenant on the site), provided continual support during our preparation activities. He further committed to provide office space during our operation, protected space for


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overnight equipment storage and repair, and secure areas for an explosives locker and temporary ordnance consolidation.

Unfortunately, there is no potential for launching our survey equipment from the FRF property. The nearest launch ramps into the Sound for boats are 1.5 and 2.5 mi north of the survey area. One of these, North Duck Watersports, is a water sports rental marina with an improved concrete boat ramp, other, the Duck News Café, is a restaurant with a primitive dock and boat ramp for customer tie ups. Additionally, there is another water sports rental dock immediately south of the FRF site; this dock is associated with the Sunset Grill. It does not have a usable boat ramp. We negotiated agreement with the owner of the Duck News Cafe for use of the ramp. We chose this facility because permission was given to moor our equipment overnight adjacent to the ramp; which would not require us to remove either the boat or the sensor platform from the water unless repairs were needed. The Police Chief in the Town of Duck agreed to provide intermittent security checks on our equipment during the evening shift. The Police Department also agreed to provide any necessary escort service and to temporarily close roads for us to transport UXO, if needed.

## 3.3 Test Site History

The site known as the Duck Naval Target Range was acquired by the US Navy by order of Condemnation Number 53 on 23 April 1941. It has been under DoD control continuously since that time. The range constituted about 175 acres of the Outer Banks about 1 mile north of the current town of Duck, NC. The range included the entire island between the Atlantic Ocean on the east and the Currituck Sound on the west, stretching for about 3,000 feet north to south. During the period of 1941 to 1965 aircraft from the Norfolk Navy yard flew to the Duck Target to conduct bombing and rocket launch practice runs. The flight path for the aerial bombardment approaches was reported to be from the mainland flying eastward toward the target and continuing the flight path out over the ocean.

In 1973 the entire Range was transferred to the Department of the Army (Civil Works) by the General Services Administration. The Army Corps of Engineers established the FRF on the former target range to conduct marine and marine wetlands research. They built a 600 ft pier on concrete pilings extending into the ocean to a water depth of 20 feet. The FRF is currently under the direction of the Army ERDC in Vicksburg, MS. During the period since the transfer of the property in 1973, several UXO-related actions have occurred; these were carried out under the direction of the Army Corps of Engineers. Operations were briefly described in Section 1.3. These Environmental actions culminated in a supplemental EE/CA study of UXO contamination at the Currituck Bay shoreline. A future risk assessment was carried out as part of the EE/CA study; it is briefly described in Section 1.3. To our knowledge, other than occasional but continuing ordnance discoveries on the FRF property, there have been no subsequent UXO operations on the FRF.

The presumed flight path pointing toward the presumed target location at the middle of the island is shown as Figure 1 in Section 1.2. This image is adapted from the 1996 EE/CA study carried out and reported by Parsons Engineering Science, Inc.


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We made a search of commercially-available aerial photography records for the area of the Duck Target Range. The earliest available image from the Earth Explorer EROS Data Center was an aerial photograph taken on 18 June 1961. It is available only as a print or a photographic negative; it has not been reduced to a digital orthophotograph with reliable coordinates. A small portion of this photograph is reproduced in Figure 19. The orange circle, which we superimposed on the photo, outlines a series of structures (20 poles or platforms) in an X-shaped pattern with a 21st pole or platform at the center. The center of the X is perhaps 50-100 ft west of the barrier dune line. The barrier dune was established in the early 1950s by the CCC; it consisted of a pair of fences parallel to the beach. These fences effectively trapped sand and permanently established the barrier dune.

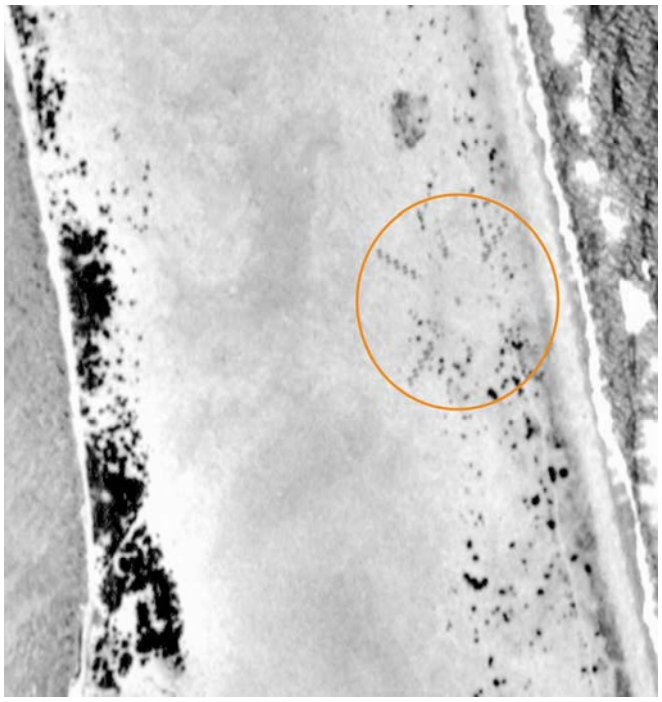

**Figure 19. Portion of a 1961 aerial photo showing structures likely associated with the bull's eye for the Duck Target Range. The orange circle is super-imposed to highlight these structures.**

Very few landmarks from 1961 in or near the Target Range have survived. We have worked from a series of subsequent aerial photos from the 1970s and 1980s, as well as the 1993 NAPP aerial photo, which is available as a DOQ. By mapping identifiable groups of landmarks on these photos (sometimes from several miles distant) and using them to scale the photos against each other, we have fixed the presumed X-shaped bull's eye shown in Figure 19 as being about 95 m northwest of the northwest corner of the current FRF main administration building, See Figure 20.

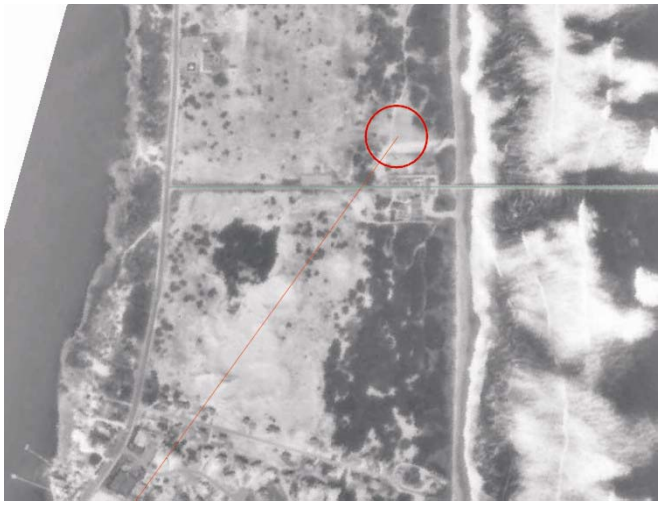

**Figure 20. Portion of a 1993 aerial photo (NAPP 6103-14) showing the likely position of the Duck Target bull's eye (center of the red circle). The orange and green lines are superimposed tie lines used with other photos to fix common landmarks.**

The most important UXO remedial actions of relevance to this demonstration were those conducted in the 1972 EOD clearance before the property passed from control of the Navy to the Army Corps of Engineers. Apparently, this operation began with a surface clearance of ordnance and


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metallic scrap. The area was then reported to have been plowed using bulldozers with 8ft plows, and the newly exposed ordnance was also removed. These actions revealed the extensive range of rockets and bombs that had been either dropped or fired onto the range. Reportedly 2,187,000 lbs of ordnance was recovered. All ordnance, including scrap metal, and several vehicles were reportedly buried in 10 pits at various locations on the site. Table 7 enumerates the types of the ordnance and associated fuzing that are consistent with the reported ordnance recoveries made during the clearance.

Following the discovery and recovery of several 2.75 in rocket warheads by children playing in the shallow waters of the sound in 1993, the Army Corps conducted an Interim Removal Action and an Archives Search Report (ASR)[7] was prepared for CEHNC in 1994. An EE/CA[5] was prepared by Parsons Engineering Science and issued in 1996. This was followed in 1998 by a supplemental EE/CA report.[8] In this latter study, five grid areas (totaling 2.3 acres) within ~100 ft of the Currituck Sound shoreline at the western edge of the impact range were surveyed using fluxgate magnetometers. The initially-planned survey areas are shown in Figure 1.

Positive magnetic anomalies (less than 6 inches deep in the sediment) were excavated and removed. 250 OE-related items were recovered, including 14 that were labeled as potentially hazardous OE. The latter items were destroyed by detonation using donor explosives.

The EE/CA report of 1996[5] described a UXO survey operation using EM61s that was carried out on the Target Range. 92 test grids, covering 29.8 acres (17% of the Target Range) were surveyed. Target analysis identified 3,757 buried anomalies that were potentially UXO. Of these 3,757 declared anomalies (from the 29.8-acre survey), eventually 320 were dug. The same types of ordnance and the relative distributions of types were similar to those described in the 1972 clearance. The only new information that is available from this study is the relative distribution of anomalies (ordnance) recovered from the various grids, which were scattered across the site.

**Table 7. Ordnance types expected at the Duck range based upon the ASR and EE/CA studies**

| Ordnance | Model/Type | Fuze |
|---|---|---|
| 2.25-in Rocket | MK 16, Mod 4, 5, 6<br>MK 3, Mod 0, 2, 3 | |
| 2.75-in Rocket | MK 1, Mod 0, 1, 3, 4, 5 | MK 176 Mod 0, 1<br>MK 181 Mod 0, (Nose) |
| 3.5-in Rocket | MK 1, 2 | |
| 5.0-in Rocket | MK 6, Mod 1,4 | MK 149 Mod 0, 1 (Nose)<br>MK 3 Mod 1 (Base) |
| | MK 25, Mod 1,3 | MK 149 Mod 0, 1 (Nose) |
| | MK 29, Mod 0, 2 | MK 166, Mod 0,2 (Base) |
| 11.75-in Rocket (Tiny Tim) | MK3, Mod 0, 1, 2 | |
| Signal, Flare, Drift | AN-MK 4 | M29 Percussion |
| 3-lb Practice Bomb | AN-MK 5, MK 4<br>AN-MK 23 | |
| 4.5-lb Practice Bomb | AN-MK 4 | |
| 5.0-lb Practice Bomb | MK 106, Mod 0 | M 173 |
| 25-lb Practice Bomb | AN-MK 76 | |
| 100-lb Practice Bomb | AN-MK 15, Mod 4 | M 108 (Nose) |
| 250-lb Practice Bomb | AN-MK 86, Mod 0 | M 108 (Nose) |

## 3.4 Present Operations

Present operations at the Former Duck Target Range include the Duck Fire Department and Police Station and the FRF. There are no ongoing operations that involve live ordnance. The Currituck Sound west of the FRF is public property.


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## 3.5 Pre-Demonstration Testing and Analysis

To confirm that UXO and ordnance debris were present in the Sound west of the shoreline and to determine its relative location and distribution, we conducted a reconnaissance survey of parts of the area in June 2004. We rented a 19 ft flat bottom fiberglass boat from a local marina in Duck. The boat was wide enough to accommodate an array of three 858 magnetometers on a 75 cm spacing. Using plywood, dimensional lumber, and brass or silicon-bronze screws, we constructed a jig to hold the magnetometers and GPS sensors.

**Figure 21. The 3-magnetometer array, GPS equipment, pilot guidance system, and data acquisition computers are shown mounted in the survey boat.**

The magnetometers rested on the bottom of the boat, positioned flush with the water surface (Figure 21). A shelter at the back of the boat was constructed from plywood to protect the electronics from water spray. This rig was used to conduct a reconnaissance survey, including both a contiguous survey block and a set of transects, west of the Range bull's eye, Figure 22. Figure 23 shows a 1999 DOQ image of the FRF with the reconnaissance survey superimposed as a magnetic anomaly image. The water depths varied from about 2 feet deep at the eastern edge of the survey to about 9 feet deep along the western edge.

**Figure 22. The 3-magnetometer array is shown surveying on Currituck Sound just south of the Former Duck Target Range boundary.**

The information in Figure 23 clearly showed a high density of large ferrous anomalies. These had a highest density along the presumed flight path towards the bull's eye on the island. This information was sufficient to justify a comprehensive UXO survey of the Sound west of the Former Naval Target Range.

## 3.6 Testing and Evaluation Plan

***3.6.1 Demonstration Mobilization and Setup:*** In preparation for the demonstration, all equipment was mobilized to the FRF on Sunday, May 8. Mr. Bill Birkmeier, Chief of the FRF provided effectively complete logistics support for our demonstration. Spaces were provided for parking vehicles, boats, and trailers in a fenced secure area. An indoor equipment bay was provided for equipment repairs, and access was provided to an electronics shop for electronics troubleshooting and repair.


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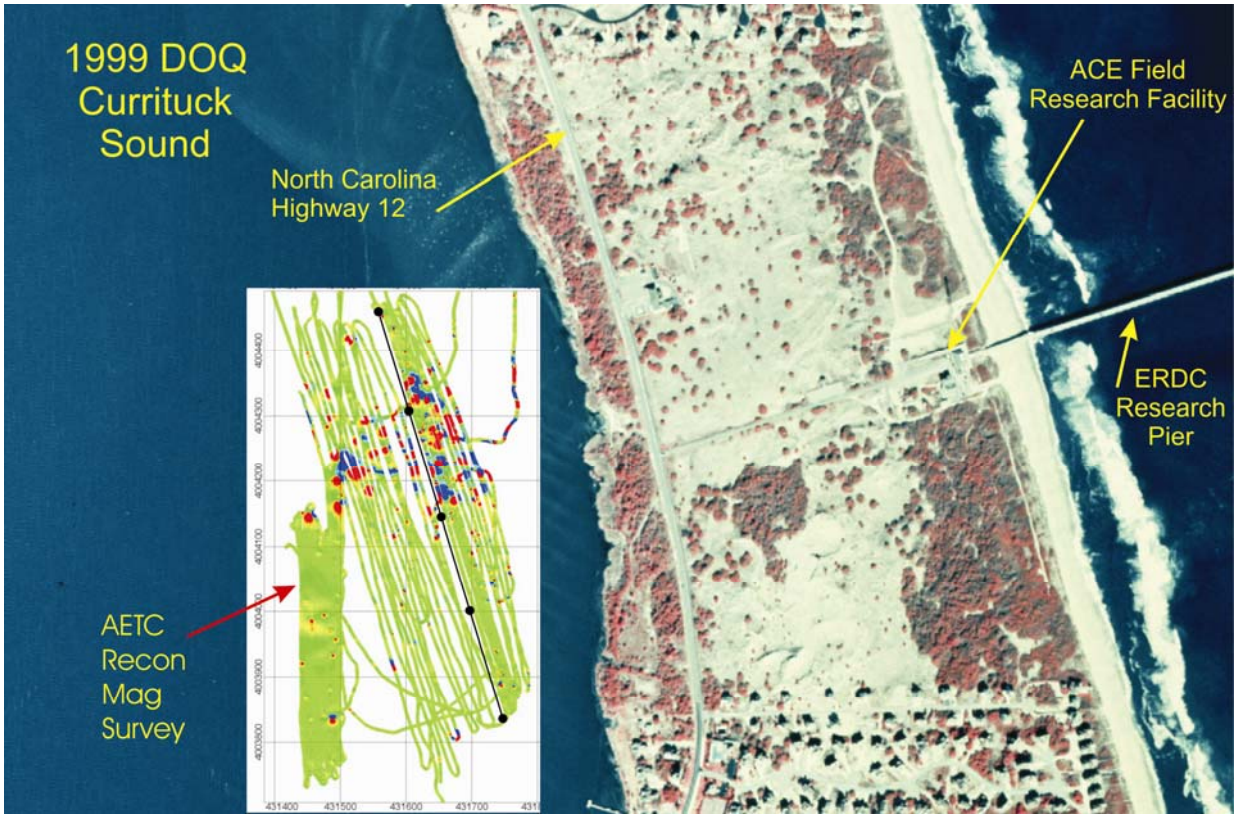


**Figure 23. DOQ of the FRF on the Former Duck Target Range. Magnetic anomaly data from the survey is shown superimposed.**

In addition, an office area was provided to set up our data processing and target analysis computers. It had access to the Net. We mobilized portable electrical generators to the site to provide power both on the boat and on land, as required. A first-order survey control point is available near the entrance gate to the FRF. Figure 24 shows the GPS and relay radio set up on this point in support of the demonstration surveys. A secure area on the FRF was provided as a collection point for recovered UXO. It is adjacent to the demolition pit where the ordnance recovered in the 1996 EE/CA study was rendered safe.

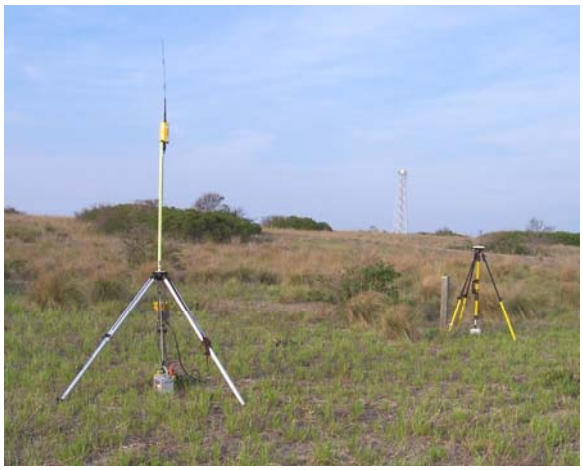

**Figure 24. The GPS base station is set up on the control point to the right of the relay radio.**


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***3.6.2 Prove out Site Installation:*** Based upon the maps from the reconnaissance survey (Figure 22) we decided to install the seed targets near the southern boundary of the site because the clutter density of ferrous objects was minimal in this area.

**Figure 25. The dive team is playing out 300 ft of line from the orange buoy in preparation for establishing the line of pipe seed targets.**

As noted earlier, our attempt to precisely install the pipe targets from the boat was unsuccessful because we could not hold the boat steady enough in a strong wind to pull the rope tight and keep it straight while dispensing the pipe targets. Based upon the divers experience in conducting similar operations, the following approach was taken and proved to be successful.

**Figure 26. Divers are stretching a 300 ft line containing pipe sections every 16 ft in preparation for obtaining GPS coordinates of their positions.**

First the pipes were tethered at 16 ft intervals along a 300 ft length of line. An (orange) buoy, Figure 25, was tethered to a different piece of 300-ft line and secured to the bottom by a weight. The other end of the line was attached to the first pipe segment; it was set on the bottom and a flag was placed vertically through it. The pipe targets were dispensed from the boat to divers in the water who stretched them out along a line from the flag at the first pipe, Figure 26. The divers then placed flags vertically through each pipe into the sand. The position of each flag was then determined using GPS equipment in the boat and divers in the water to steady the GPS pole position while each position was recorded. The flags were then removed from the pipes and each pipe was tipped over to lie flush with the bottom.

A similar approach was used to establish the rebar positions. A 300 ft rope, with a knot every 15 ft was stretched between two flags. A flag was positioned at each knot and the diver used his foot to push a piece of rebar vertically into the sand at each flag. The flag positions were obtained using GPS, and then the flags were removed from the sand.

Figure 27 shows a CRT screen clip from the MTADS DAS target analysis of seed target regions showing the EM and magnetometer surveys of the pipe and rebar targets. The staked out coordinates of these targets were compared with their analyzed positions in Tables 4 and 5 above.


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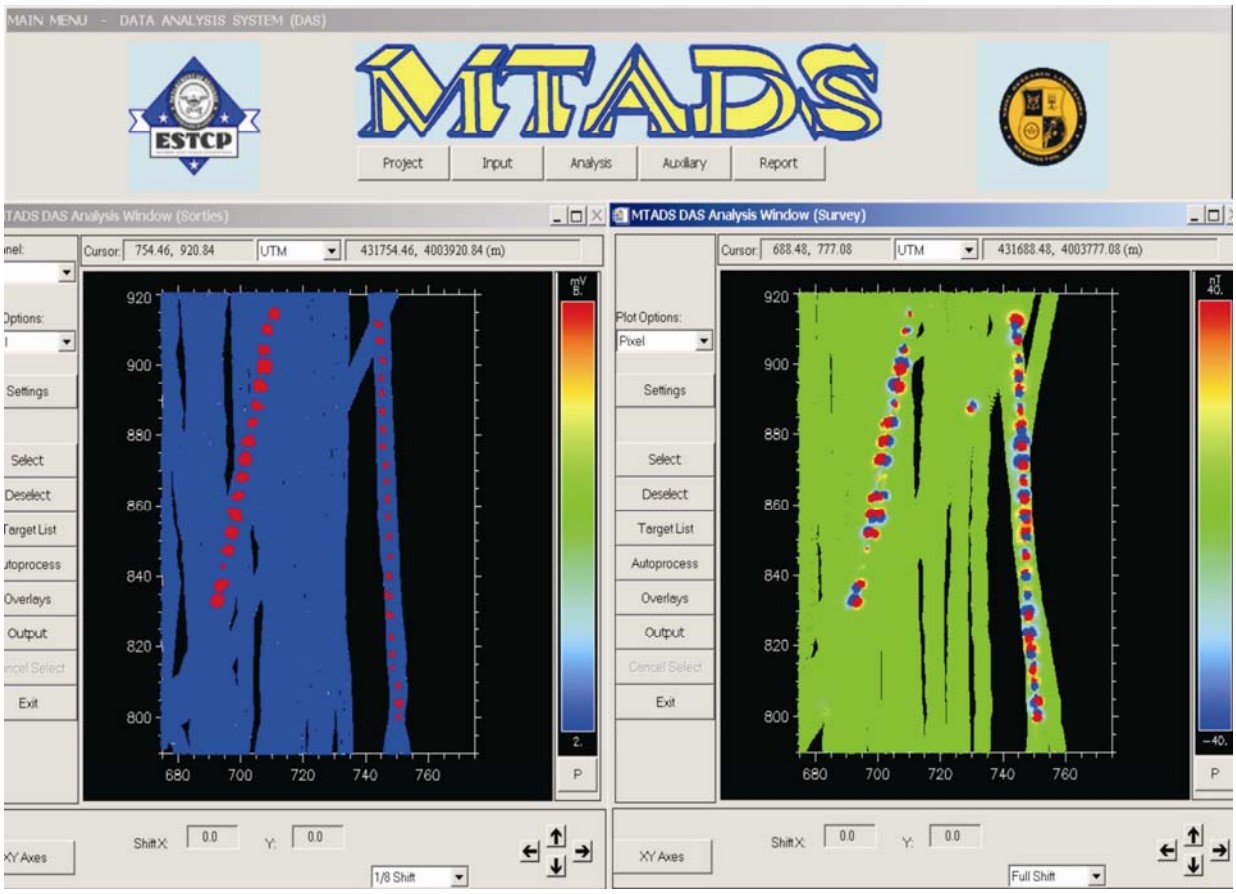


**Figure 27. Screen clip showing the target analysis windows from the MTADS DAS. The image on the left is from the EM survey showing the pipe signatures on the left and the rebar signatures on the right. The same targets are shown on the right from the magnetometry survey.**

***3.6.3 Period of Operation:*** The demonstration, including the survey data processing, target analysis, preparation of survey products, the target reacquisition and flagging, the target recovery operations, and the target documentation, and demolition and demobilization took place between 7 May and 3 June 2005. A daily log of these operations is summarized in Table 8.

This survey log is reproduced in electronic format in Appendix B. In addition, the table that shows the survey file names with the start and stop times, the survey tracks included in the files, and the Easting coordinates of the survey tracks is included in the Appendix B. Appendix B also includes a Table of the imaging sonar Didson files with the start and stop times of each survey file.

***3.6.4 Survey Areas Characterized:*** A magnetic anomaly image map of the magnetometer survey is shown in Figure 28. The survey area is superimposed upon a portion of a DOQ photo that shows the FRF and the areas immediately to the North and South of the Range that are currently residential communities with beach cottages and vacation homes. A total of approximately 155 acres were surveyed with the magnetometer array. The signatures of the pipes and the rebar sections are visible near the lower right corner of the survey image.


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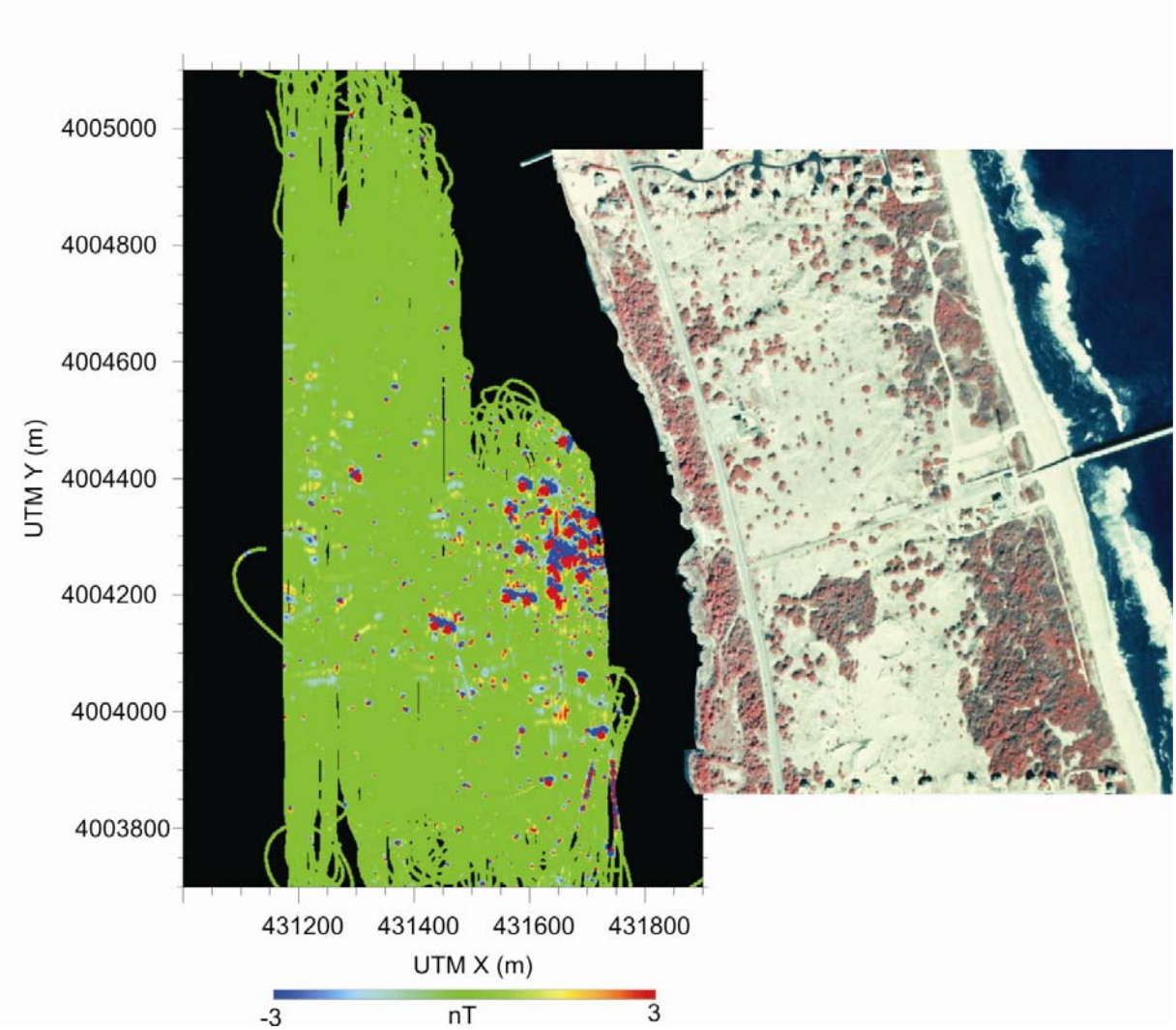


**Figure 28. Magnetic anomaly image map of the magnetometer survey. A portion of the 1993 DOQ of the FRF is superimposed.**

At the scale shown in Figure 28 the survey is dominated by the massive signatures that are primarily clustered in the eastern half of the survey along the incoming flight path. The analysis fits to these targets indicate that they are extremely large and the majority are very deeply buried, (3-6 m) into the sediment. The most probable identifications for these signatures are either the 11.75 in diameter Tiny Tim rocket assisted bombs, or sections of metal mesh runway matting. The fact that they are buried this deeply suggests in favor of them being ordnance. For reasons explained above these massive targets were not dug. Several of the items recovered in the dig program were either the rocket venturis or nose caps from Tiny Tims, thus demonstrating again their presence on the site.


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Figures 29 and 30 show portions of the mapped data file from the magnetometer survey on a larger scale. The targets shown in these images, with the exception of Target 414 are typical of the targets that appeared on the dig list. The fitting parameters associated with these targets are provided in the complete target list in Appendix C. Figure 29 shows an image near the western edge of the survey, which is along the approaching flight path to the Range. This 1 hectare plot shows nine clear targets. Five did not appear on the dig list, four were dug. Targets 23 and 26 were intact (except for buoys) crab pots, Target 24 was a pair of pliers, and Target 44 was a BDU 33, demonstrating that ordnance still exists more than a mile west of the bull's eye. Some of the survey lines in the image appear wavy. This appearance results from the rolling of the survey boat from side-to-side as waves approach from the west. The wavy appearance is created by the GPS antennas on top of the masts rocking from side to side. The survey platform does not actually respond to this rocking motion. Parts of the survey lines in this image were taken on 3 separate days, thus reflecting differences in weather conditions. The images appear to show

**Table 8. Log of Demonstration Operations**

| Dates | Action | Comments |
|---|---|---|
| 6 May, Friday | Rent Vehicles | Triangle Rent A Car |
| | Pack out Vehicles and Boat | Jim and Chet |
| 7 May, Saturday | 1000, Prepare Boat for Travel | |
| | 1130, Nagi K. arrives from Illinois | |
| | 1200, Depart Cary | Two Vehicles, with boat and sensor platform |
| | 1600. Pick up FRF Keys from Birkmeier | Kitty Hawk Shopping Center |
| | 1630, Park Trailers at FRF | Unload Supplies into Office at FRF |
| 8 May, Sunday | 900, Launch 19-ft rented "support boat" from Duck News Launch Slip. | Winds 10-20 kts. Waves 1-ft+, this slip is unsatisfactory, too shallow for 2 mi from dock |
| | Attempted to install pipes and rebar from boats and failed. | Divers will attempt while wading on 9 May. |
| | Made deal with Duck Watersports to launch and dock at their facility | Launching and slip rental, $300. |
| 9 May Monday | 800, 2 Divers and Chet left Duck Watersports to install rebar and pipes. | 1200, Completed and Returned |
| | 900, Dave arrives from Raleigh | |
| | Nagi, Jim, and Dave assemble sensor platform | |
| | 1300, Launch equipment from boat ramp | Lost 1 hour booting maglog computer |
| | Surveyed ~10 lines over rebar/pipes. | |
| | Hung platform, popped shear link | 1.5 hr to retrieve new one from dock and install |
| | Broke off gas line- patched with duct tape | Lewallen bought gas line, West Marine in Nagshead |
| | Surveyed Lines 34-38, returned to dock | |
| | Down load files, moved trailers to FRF | |
| 10 May, Tuesday | Dave, Jim, Chet launched system | Nagi in office |
| | Resurveyed pipes and rebar with both mag and EM. | |
| | Surveyed lines 39-41 (mag) Dave returned to office with data (chase boat) | Lost GPS on restart, could not recover, returned to dock |
| 11 May, Wednesday | Lost 3 hours booting Maglog and getting GPS RTK fix | |
| | Mag survey 8 survey lines | |
| 12 May, Thursday | 0630 Arrive at Duck Watersports | |
| | Maglog and GPS problems again | Installed Whip antenna on GPS, changed GPS bootup routine |
| | Mag survey underway by 0830, Dave & Chet | AM strong West winds, calm for 2 hr, then strong from North |
| | John Curtis w. McD in AM | Transferred to Survey boat 1200, back to dock 1300 |
| | 1430, Wind/Waves to high to survey | Completed 28 Mag Survey Lines |
| | 1530, Return to Dock | |


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**Table 8. Continued**

| Dates | Action | Comments |
|---|---|---|
| 13 May, Friday | 0630 Arrive at Duck Watersports | |
| | 1 hr to clear dock bulkhead | Water low, Winds NE 15-20 |
| | Continuing GPS and Maglog Problems, Surveying started 1230 | Changed Serial Card in Maglog, Discovered GPS boot routine that repeatably works. |
| | Dave & Chet, Mag survey start at 1230 | Completed 22 survey lines |
| | Jim in office to analyze pipes and rebar | Created spreadsheet, needs new nav correction |
| | Jim, explore options for new mooring site for the equipment | Permission to use Sunset Café, mooring at end of dock for boats and platform. |
| 14 May, Saturday | 0800, Arrive Duck Watersports, Dave, Chet, Jim, Ken | |
| | Mag survey starts at 0900 | Six survey lines, file to office with Dave 1030 |
| | Mag survey lines until 1600 | Completed lines 72-94 |
| | Ken swam pipes, reflagged the N&S ends | Placed extra flag in line farther North of pipes |
| | Mag survey of pipes again | 4 passes, all pipe signatures are visible in data |
| 15 May, Sunday | Created Graphics, Boat Pictures, Rebar/Pipes Site Map, Mag site map | Emails to Prog Office/Curtis, Fedex to Prog Office |
| 16 May, Monday | New shorter survey lines set up | Starts at old line 200, 600 m cut from North end |
| | Jim & Dave, Mag Survey New Lines 1-16, see build up of targets at >line 12 | Chet, Failed EM power supply being replaced on dock |
| | Jim/Chet start EM survey | Survey Lines 1-46, Lines 42-46 are in shallow water |
| 17 May, Tuesday | Dave/Chet Mag Survey in Shallow Water | New survey lines 17-59 |
| | Mag Survey on Long Lines | Old survey lines 94-100 |
| | EM Survey on Long Lines | Old survey lines 94-100 |
| | Jim, all data thru 15 May processed and targets analyzed | ~200 analyzed mag targets (only 3 in shallow water) EM data ready to analyze |
| | Set up survey product templets | Dig List format, dig sheet format, .csv file for TSCE |
| 18 May, Wednesday | EM Survey, Chet/Dave | Lines 42-59 |
| | 1030, Final Mag Mapped Data File | |
| | 1400, Mag Target Analysis Complete | |
| | 1500, Dig Lists Completed | Prepare 6-target training list, and 27 target shallow water target list |
| | Wayne L. and Ken M. train with TSCE | |
| | Jim in office | EM files cleaned up through 17 May |
| 19 May, Thursday | Jim in office | Examine EM/mag targets jointly |
| | Complete dig sheets, final target lists, .csv files, and load TSCE. | Targts reacquired & flags placed from 6-target list |
| | Dave and Nagi Depart | |
| | Pull out pontoon boat and sensor platform at North Duck Watersports | Disassemble platform, pack components on boat/vehicles, move trailers to FRF |
| 20 May, Friday | 5 of 6 shallow targets dug | Recovered 4 ordnance items, deep target left for winch boat |
| | Shallow water targets reacquired & flagged | |
| | 1030, Jim Chet depart FRF with trailers | 1530, Trailers parked at AETC |
| 24 May, Monday | Completed digging of all shallow water targets | |
| 31 May, Monday | Target recovery completed | 100 targets dug and consolidated at the FRF |
| 1 June, Wednesday | Targets cleaned up and photographed | Demo pits dug, ordnance arranged |
| 2 June Thursday | Explosives arrive | ordnance demo completed, scrap inspected and certified, put in barrels for shipment |
| 3 June Froday | UXO teams demobilize | Clean up site, pack out, return rental equipment, depart the site. |

individual data pixels. The magnetometer data are actually taken at 20 Hz; with a forward speed of ~2 m/sec, actual data points down-the-track are spaced ~10 cm apart. The data in Figures 29 and 30 have been subsampled to create the images that are shown.


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Figure 30 shows a 2-hectare image towards the eastern side of the survey. This image, which is more severely subsampled than Figure 29, shows the transition from deeper water (2.5-3.5 m) to shallower water (1.5-2.0 m). In the shallower water the survey speed is slowed from 2.2-2.5 m/sec to 1.5-1.8 m/s. The platform autopilot is changed from altitude mode (1.25 m above the bottom) to depth mode (0.5 m below the surface). Surveying becomes difficult at water depths less than 1.25m and effectively impossible in water depths < 1.0 m. Only 5 of these targets were on the dig list. Targets 187, 189, and 191 were intact crab pots. Target 190 was removed from the dig list after it became apparent that the crab pot signatures could be recognized in the magnetometry images. In all, 13 targets were removed from the dig list because it was concluded that they were crab pots. Target 304 was on the dig list, but appeared below the cut off point when 100 targets had been dug.

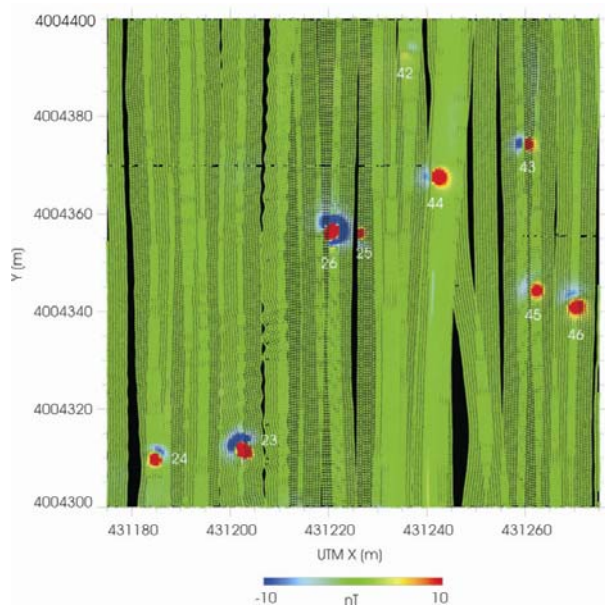


**Figure 29. Magnetic anomaly image of a 1 hectare section of the mapped data file near the western edge of the magnetometer survey.**

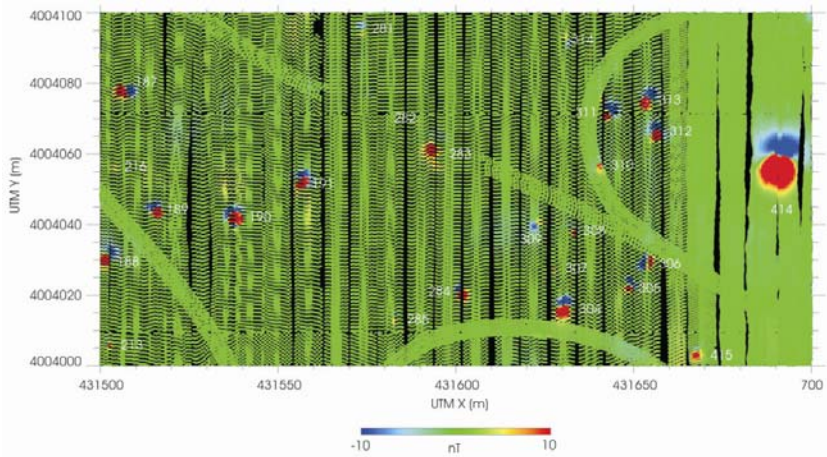


**Figure 30. Magnetic anomaly image of a 2 hectare section of the mapped data file near the western edge of the magnetometer survey.**

Figure 31 shows an anomaly image of the EM survey superimposed on the 1999 DOQ image of the FRF. The bright red streak lying east-west at the eastern edge of the survey at UTM Northing position of ~4,004,270 m is from an FRF shielded cable stretching from the shore to a water depth monitoring station ~300 m offshore. The cable appears to end at an Easting of ~431,650 m. This is the point of the drop off into deep water and the signature in deeper water is not visible on this presentation scale. The Didson sonar imager clearly imaged the cable on most passes back-and-forth across it. The line of pipe signatures appears in the lower right side of the EM anomaly image, the rebar signatures are not visible at this scale.

On 8, 9, and 10 May the EM array was used to survey 66 survey lines. These lines were concentrated on the eastern side of the survey area, which had been conducted with the magnetometer array. This was done in an attempt to get as much shallow water survey information as possible with the EM array. The survey was continued on the east side until it


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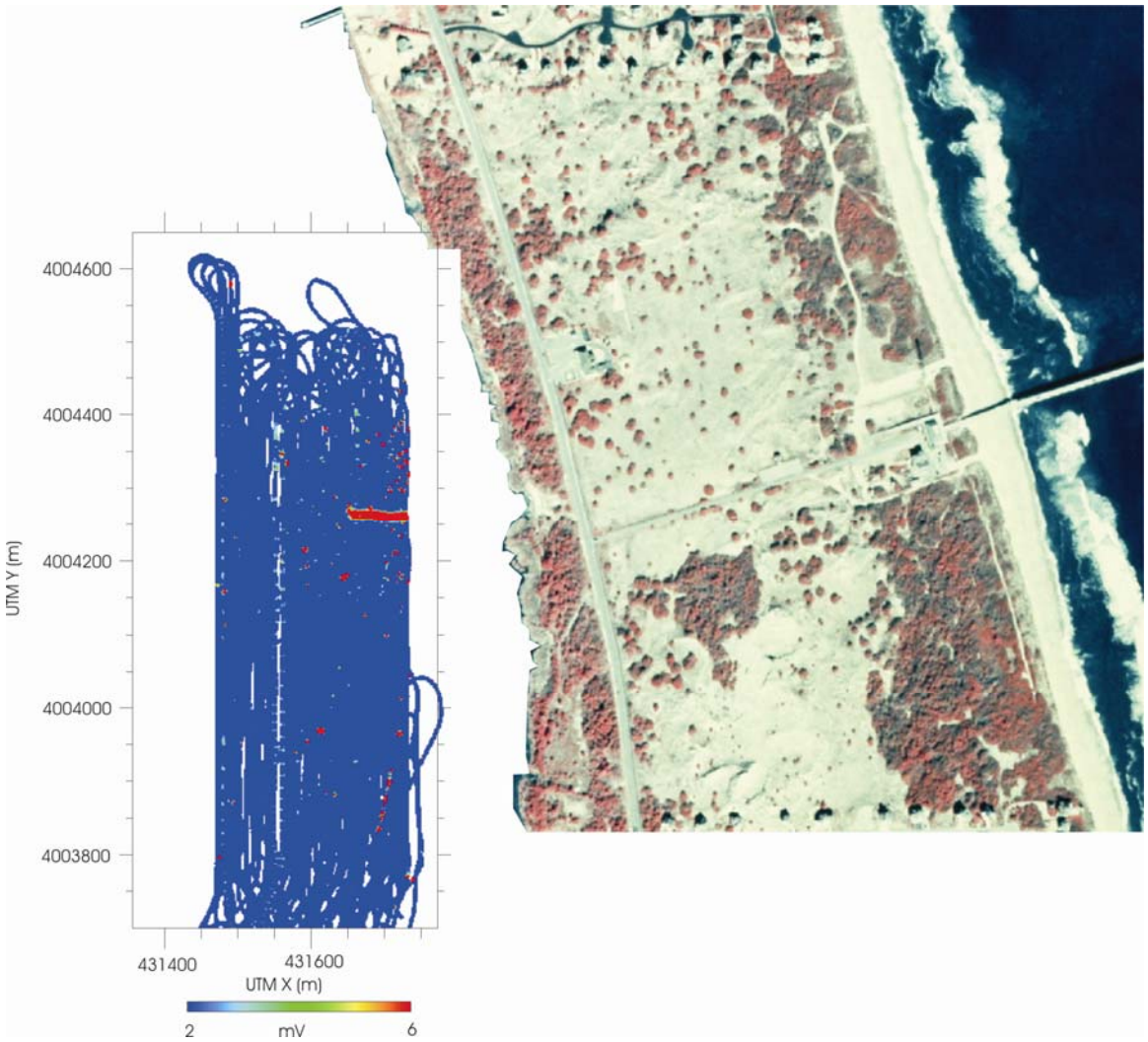


**Figure 31. The EM survey anomaly image map is shown superimposed on the 1999 DOQ of the FRF.**

was concluded that the shallow water survey limit had been reached. In total, ~ 50 acres were surveyed with the EM array.

The most obvious differences between the magnetometer and EM survey images at the coarse scale level of Figures 28 and 31 are the presence of the cable signature in the EM survey, which is not apparent in the magnetometer image (Figure 28) and conversely, the presence of the massive anomaly signatures in the magnetometer survey image, which appear to be absent in the EM survey.

Figure 32 shows a 1.5 hectare image area from the MTADS DAS analysis windows for the mag and EM surveys that include part of the cable signature and the signals from 8 of the deep massive targets. None of the 8 targets are detectable in the EM data. The targets that are apparent in the EM data correspond to smaller shallow targets in the magnetometry analysis. Table 9 lists the pertinent magnetometry fitting information for these targets. It has been our experience with time domain EM survey systems such as the EM61, EM63, and other similar


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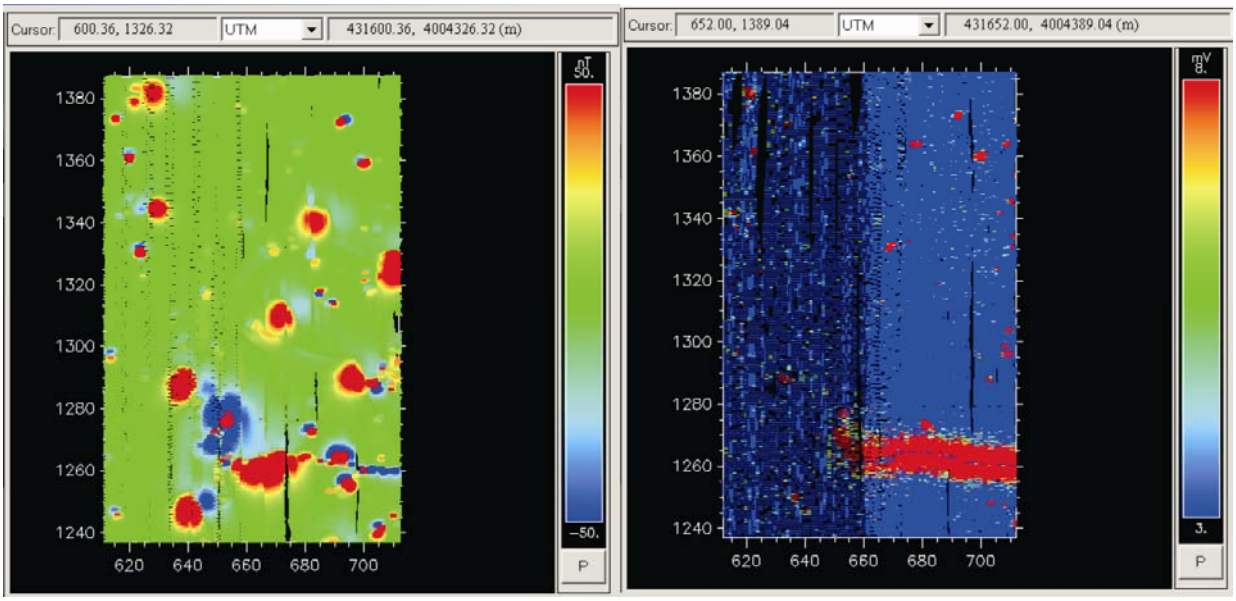


**Figure 32. 1.5 Hectare displays from the MTADS DAS analysis windows of the magnetometer and EM surveys showing the cable signature and the large deep target signatures.**

instruments; their detection limit for even large ordnance targets is limited to about 2.5 m between the sensor and the target.

The predicted depths of the targets in Table 9 are 3-6 m below the sediment surface. There is an extra standoff of ~1 m from the bottom to the sensor coils. It is not unexpected that these targets would be undetectable by the EM68. The weight and dimensions of an intact Tiny Tim are between that of a 1000 and a 2000 lb GP bomb. Dud Mk 84 bombs, falling ballisticaly, often are found at depths of 2-4 m. The Tiny Tim, near the end of its rocket assisted trajectory may be traveling considerably faster than the ballistic terminal velocity of a GP bomb. It would not be surprising to find them buried at depths of 6 m.

The sensor cable signature that dominates the EM images in Figures 31 and 32 is also visible in the magnetometry images. Its signature tends to be lost in the signatures of the large deep targets that dominate the same area. The magnetometry cable signature is also not composed of a single positive and negative, but rather seems to have multiple positive and negative components,

**Table 9. Target analysis information for the 8 large deep targets shown in the magnetometer survey shown in Figure 31**

| Target ID | Local X (m) | Local Y (m) | Size (m) | Moment | Fit Qual. | Target Depth (m) | Water Depth (m) | Peak Pos Signal (nT) | Peak Neg Signal (nT) |
|---|---|---|---|---|---|---|---|---|---|
| 324 | 642.23 | 1248.78 | 0.693 | 175.9594 | 0.944 | 3.39 | 2.89 | 257.00 | -61.90 |
| 325 | 639.75 | 1288.47 | 0.717 | 195.0389 | 0.953 | 3.54 | 2.88 | 282.00 | -41.80 |
| 333 | 628.23 | 1345.23 | 0.447 | 47.3242 | 0.969 | 2.95 | 2.87 | 97.40 | -29.90 |
| 336 | 630.24 | 1383.32 | 0.708 | 187.8008 | 0.924 | 6.02 | 2.88 | 65.00 | -18.70 |
| 358 | 685.49 | 1341.48 | 0.611 | 120.5254 | 0.836 | 6.08 | 1.40 | 73.10 | -24.10 |
| 364 | 712.37 | 1326.87 | 0.722 | 199.1618 | 0.672 | 5.48 | 1.12 | 243.60 | -15.90 |
| 365 | 673.75 | 1311.41 | 0.630 | 132.2617 | 0.928 | 4.90 | 1.84 | 89.60 | -25.20 |
| 368 | 716.58 | 1297.15 | 0.495 | 64.1834 | 0.811 | 3.91 | 1.11 | 71.80 | -49.60 |


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perhaps associated with its HAE as the bottom rises and falls.

The complete target reports from the analyses of the magnetometry and EM survey data are included in Appendix C. Table 10 below provides the summary spreadsheet for the targets that were on the dig list.

***3.6.5 Ordnance and Ordnance Residuals:*** All targets that were recovered by the dive teams were consolidated daily into a secure area provided by the FRF. All targets were inspected by the SUXOS and checked for consistency with the information provided on the Dig Sheets that were filled out by the dive teams. Information was extracted from the Dig Sheets to complete the ground truth columns in Table 10. On 31 May digital photographs were made of each recovered target. The photographs include a white board description of the targets and identify each target by its unique number on the dig list. Figure 33 shows a typical photograph. The complete group of digital photographs is included in Appendix D.

Inspection of the ordnance items showed that none contained high explosives. Propellant and propellant residues were present in some of the 2.25 in and 2.75 in rocket bodies. It is also possible that some of the practice ordnance (Mk76 and Mk23) contained spotting charges. The ordnance were prepared for demolition using the demolition pit previously established by Foster Wheeler during the 1996 EE/CA study. This area lies near the center of the FRF (a maximum distance from the road and from private homes) in a pit surrounded by sand dunes that are several feet high.

**Figure 33. Digital photograph of Target 287, a 100 lb bomb.**

Two pits were prepared for the demolition and the ordnance were split between them. The deeper pit contained the rocket bodies and other items that might contain propellant. The inert items were placed in the shallower pit, Figure 34. Explosives were provided by the Jet Research Lab (Austin, Texas); the Austin Powder Company provided the Nonel (Shocktube), the detonation cord, and the blasting caps. All explosives components were delivered by a dedicated truck to the FRF on June 2.

The jet perforators (shaped charges) were placed on each target, Figure 35. Extra jet perforators were used rather than paying for their return. The deeper pit was covered by 2 ft of sand and a layer of sandbags; the shallower pit was covered by a single layer of sandbags. This cover was provided to minimize the release of fragmentation from venting. The two pits were tied together by detonation cord and all items were disposed of in a single detonation, Figure 36. The detonation cord was initiated with a blasting cap attached to the shock tube that was run to a safe detonation/initiation area. Because the detonation area was surrounded by dunes, there are no


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**Table 10. Master Dig List from the demonstration with ground truth**

| Analysis Results | | | | | | | | | Field Results | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Target ID | UTM X(m) | UTM Y(m) | Size (m) | Target Depth (m) | Water Depth (m) | Peak Pos Signal (nT) | Peak Neg Signal (nT) | Analyst Comment | Ordnance | Not Ordnance | Field Rusults (Target Identity) |
| 22 | 431229.13 | 4004297.37 | 0.153 | 0.34 | 2.73 | 45.00 | -39.10 | Good target, 1 ft deep, 3.5 in rocket? | | X | Boat Anchor with 7 ft of chain |
| 23 | 431202.30 | 4004312.22 | 0.198 | 0.14 | 2.75 | 231.10 | -36.90 | Large target, nose down, 10 in deep, 5in rocket? dig this | | X | Crab Pot |
| 24 | 431185.06 | 4004310.38 | 0.109 | 0.13 | 2.68 | 30.80 | -9.10 | Good target, near surface, BDU 33?, dig this | | X | 6-in Pliers |
| 26 | 431221.05 | 4004356.76 | 0.219 | 0.21 | 2.66 | 327.70 | -51.70 | Large shallow target,nose down, clutter 1.5 m south, dig this | | X | Full Crab Pot |
| 32 | 431183.96 | 4004682.55 | 0.110 | 0.15 | 2.20 | 48.00 | -58.00 | Inverted target, shallow, 2.75 in W.H.? | | X | Iron Pipe |
| 33 | 431187.62 | 4004954.19 | 0.178 | -0.12 | 2.62 | 146.50 | -44.60 | Large target on surface, 5 in rocket?, dig this | | X | Crab Pot |
| 36 | 431188.73 | 4004989.75 | 0.200 | -0.16 | 2.63 | 100.80 | -37.90 | Large target, partial signature, on surface, dont dig? | | X | Crab Pot |
| 40 | 431256.74 | 4004612.96 | 0.097 | 0.18 | 2.63 | 16.20 | -6.50 | Inverted target, partial signature, BDU 33? | | X | Channel Iron |
| 44 | 431241.34 | 4004367.91 | 0.154 | 0.61 | 2.67 | 42.00 | -7.00 | Target at 1.6 ft E-W, BDU 33? | X | | BDU-33 |
| 53 | 431242.25 | 4004084.19 | 0.120 | 0.24 | 2.80 | 38.00 | -7.90 | good target at 1 ft, BDU 33? | X | | MK76 |
| 54 | 431266.64 | 4004079.75 | 0.133 | 0.55 | 2.79 | 17.30 | -12.20 | Partial signature, target at 1.5 ft, 3 in rocket? | | X | Anchor with 4 ft of chain |
| 67 | 431320.30 | 4004014.94 | 0.194 | 0.31 | 2.75 | 157.50 | -77.90 | Great Target E-W, shallow, 5 in Rocket? DIG THIS | X | | 75-mm Warhead |
| 80 | 431325.78 | 4004277.30 | 0.091 | 0.30 | 2.70 | 15.10 | -15.80 | Target 1 ft deep, SCAR?, dig | X | | Partial Fin Assembly |
| 81 | 431329.43 | 4004324.04 | 0.124 | 0.44 | 2.69 | 54.30 | -18.50 | Target lies E-W, 1.5 ft deep, 2.75 in? dig | | X | Crab Pot |
| 92 | 431290.84 | 4005022.51 | 0.181 | 0.21 | 2.74 | 43.20 | -34.90 | Large shallow inverted target, 5 in rocket?, dig? | | X | Crab Pot Frame |
| 94 | 431335.89 | 4004709.33 | 0.124 | 0.39 | 2.72 | 34.50 | -24.60 | 2.75 in W.H. 1 ft deep?, dig | | X | Scrap Metal |
| 98 | 431366.24 | 4004556.84 | 0.223 | 0.24 | 2.73 | 307.00 | -58.50 | 5 in Rocket, nose down shallow, dig this | | X | Crab Pot |
| 99 | 431351.68 | 4004535.79 | 0.164 | 0.41 | 2.68 | 57.70 | -73.00 | 3.5 in Rocket? remnant moment, 1.5 ft deep, dig this | | X | Crab Pot Frame |
| 102 | 431339.20 | 4004439.28 | 0.171 | 0.48 | 2.59 | 80.80 | -71.50 | 3.5 in Rocket?, 1.5 ft deep | X | | MK 76 |
| 106 | 431367.46 | 4004254.99 | 0.118 | 0.44 | 2.73 | 18.60 | -15.00 | 2.75 in W.H. 1.5 ft deep, dig | X | | Tiny Tim Venturi |
| 107 | 431373.65 | 4004228.45 | 0.084 | 0.34 | 2.75 | 9.90 | -3.40 | Small target at 1 ft | X | | Partial Fin Assembly |
| 110 | 431382.18 | 4004218.80 | 0.174 | 0.39 | 2.71 | 55.50 | -63.60 | Large shallow target, 3.5 in Rocket?, Dig This | X | | SCAR Rocket Motor |
| 111 | 431376.02 | 4004211.76 | 0.083 | 0.22 | 2.75 | 7.50 | -8.90 | Small shallow target, dig? | X | | Partial Fin Assembly |
| 115 | 431363.76 | 4004103.85 | 0.103 | 0.09 | 2.73 | 13.10 | -15.90 | Target with remnant moment on surface, dig | | X | Piece of Metal Grate, Runway Matting |
| 117 | 431384.93 | 4004004.98 | 0.212 | 0.23 | 2.81 | 118.50 | -103.00 | Large shallow target, DIG THIS | X | | Rocket Rail |
| 134 | 431415.56 | 4004192.11 | 0.127 | 0.19 | 2.85 | 27.60 | -25.90 | Target on surface, 2.75 in W.H.?, Dig This | | X | Iron Frame From Crab Pot |
| 135 | 431456.02 | 4004195.33 | 0.098 | 0.31 | 2.89 | 13.90 | -10.20 | Small Target at 1 ft, dig?, See 136 | | X | Metal Grate, Runway Matting |
| 136 | 431457.40 | 4004199.44 | 0.090 | 0.23 | 2.89 | 14.70 | -10.10 | Small target at 1 ft, DIG | | X | Boat Anchor |
| 137 | 431462.44 | 4004271.73 | 0.114 | 0.62 | 2.92 | 19.00 | -2.40 | 2.75 in W.H. nose down?, 2 ft deep | ? | | Large Item, Left in Place |
| 138 | 431433.44 | 4004264.08 | 0.097 | 0.27 | 2.83 | 11.40 | -10.10 | Small target, 1 ft deep, dig? | X | | Rocket Fins |
| 140 | 431470.07 | 4004292.91 | 0.153 | 0.31 | 2.93 | 88.90 | -12.70 | BDU 33? at 1 ft. dig this, note targets 139 | | X | Piece of Crab Pot |
| 142 | 431458.49 | 4004337.52 | 0.112 | 0.21 | 2.93 | 18.30 | -15.60 | 2.75in W.H.? shallow, dig this | | X | Cable, 10-ft long |
| 143 | 431444.05 | 4004345.34 | 0.141 | 0.10 | 2.91 | 43.20 | -33.50 | Target on surface, 3.5 in rocket? dig this | | X | Iron Frame From Crab Pot |
| 144 | 431464.28 | 4004407.72 | 0.188 | 0.00 | 2.92 | 183.60 | -38.50 | Target on surface, 5 in rocket?, dig this | | X | Crab Pot |
| 150 | 431454.75 | 4004659.54 | 0.219 | 0.19 | 2.86 | 171.90 | -92.00 | 5in Rocket? on the surface, Dig This | | X | Crab Pot Frame |
| 162 | 431533.77 | 4004355.40 | 0.170 | -0.07 | 2.97 | 76.90 | -69.70 | Target on surface, 3.5 in Rocket?, dig | ? | ? | Dug to 3 ft. Nothing Located, Target Still Rings Off |


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**Table 10. Continued**

| Analysis Results | | | | | | | | | Field Results | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Target ID | UTM X(m) | UTM Y(m) | Size (m) | Target Depth (m) | Water Depth (m) | Peak Pos Signal (nT) | Peak Neg Signal (nT) | Analyst Comment | Ordnance | Not Ordnance | Field Rusults (Target Identity) |
| 165 | 431504.60 | 4004345.22 | 0.131 | 0.09 | 2.90 | 27.90 | -23.60 | SCAR? on surface, dig | X | | SCAR Rocket |
| 168 | 431510.62 | 4004288.28 | 0.144 | 0.11 | 2.96 | 54.40 | -26.80 | Target on surface, BDU?, dig | X | | 2.25 Rocket |
| 169 | 431528.87 | 4004285.62 | 0.135 | 0.22 | 3.02 | 31.00 | -14.10 | Target on surface, BDU? dig | X | | Rear Portion of Tiny Tim Rkt Motor |
| 171 | 431511.01 | 4004245.45 | 0.095 | -0.05 | 2.96 | 15.90 | -14.40 | Small target on surface, Dig? | X | | Rocket Rail |
| 175 | 431549.39 | 4004284.65 | 0.178 | -0.23 | 3.08 | 44.70 | -263.90 | Mostly remnant moment, large on surface, careful of 176 | | X | Crab Pot |
| 176 | 431548.91 | 4004281.83 | 0.184 | -0.15 | 3.08 | 103.60 | -96.50 | Large target on surface, careful of 175, dig | X | | 2.25 Rocket |
| 177 | 431559.53 | 4004265.34 | 0.210 | -0.20 | 3.12 | 165.80 | -26.50 | Large target on surface, 5 in Rocket?, dig this | X | | SCAR Rocket Motor |
| 182 | 431530.68 | 4004176.88 | 0.101 | 0.02 | 3.07 | 11.10 | -13.80 | Target on surface, dig? | | X | Bait Basket |
| 186 | 431529.15 | 4004131.37 | 0.184 | 0.25 | 3.05 | 64.70 | -46.50 | Large target 1 ft deep, 3 in Rocket?, Dig | X | | SCAR With Rail |
| 187 | 431507.26 | 4004078.16 | 0.148 | 0.09 | 2.93 | 32.50 | -37.90 | Medium target, on surface, BDU?, dig | | X | Crab Pot |
| 189 | 431515.74 | 4004044.21 | 0.130 | 0.01 | 2.95 | 59.30 | -14.80 | Target on surface, SCAR? Dig | | X | Crab Pot |
| 191 | 431556.99 | 4004052.70 | 0.146 | -0.02 | 3.10 | 89.90 | -35.30 | Target on surface, 3 in Rocket?, Dig This | | X | Crab Pot |
| 198 | 431523.06 | 4003854.98 | 0.106 | 0.17 | 2.95 | 14.10 | -12.10 | Small shallow target, dig? | | X | 8-lb Anchor |
| 200 | 431402.07 | 4004459.26 | 0.246 | 0.37 | 2.93 | 313.20 | -88.30 | 5 in Rocket, Dig This | | X | Crab Pot |
| 205 | 431494.62 | 4003871.36 | 0.150 | 0.48 | 2.85 | 45.60 | -10.10 | Mk 76?, dig | X | | 4 ea., 2.75-in Rocket Motors, Possible Dispensor Dump |
| 206 | 431488.60 | 4003874.13 | 0.163 | 0.12 | 2.85 | 94.30 | -41.80 | Mk 76? See 205 5 m ESE, Dig | | X | Crab Pot |
| 218 | 431471.43 | 4004114.27 | 0.102 | 0.26 | 2.89 | 11.40 | -11.20 | 2.75 in W.H.? 1 ft deep, dig | X | | Partial Fin Assembly |
| 220 | 431496.24 | 4004116.36 | 0.108 | 0.24 | 2.92 | 15.30 | -12.80 | 2.75in W.H.? shallow, dig | | X | Metal Grate, Runway Matting |
| 226 | 431488.91 | 4004226.35 | 0.133 | 0.08 | 2.92 | 35.10 | -26.70 | 2.75 in W.H. on surface, dig | | X | Antique Boat Anchor |
| 229 | 431477.86 | 4004302.73 | 0.134 | 0.29 | 2.94 | 20.40 | -26.20 | 2.75 in W.H. 1 ft deep, dig | | X | Metal Grate, Runway Matting |
| 230 | 431496.37 | 4004323.31 | 0.129 | 0.32 | 2.92 | 19.90 | -20.40 | 2.75 in W.H. 1 ft deep, dig | | X | Metal Grate, Runway Matting |
| 231 | 431483.62 | 4004337.56 | 0.115 | 0.15 | 2.92 | 19.10 | -16.70 | good small target, dont dig | X | | SCAR |
| 248 | 431567.48 | 4004332.66 | 0.201 | 0.27 | 2.89 | 114.20 | -65.20 | 5 in rocket shallow, dig | ? | ? | Electronic Sensor |
| 253 | 431581.32 | 4004300.98 | 0.080 | 0.32 | 2.89 | 10.10 | -3.00 | small target, dont dig | | X | Steel Box, Corroded |
| 254 | 431613.59 | 4004297.16 | 0.166 | 0.35 | 2.91 | 42.80 | -46.30 | 2.75in W.H. at 1 ft., dig | | X | Steel Ring |
| 257 | 431603.16 | 4004275.68 | 0.149 | 0.12 | 2.90 | 76.60 | -30.60 | 2.75in W.H. on surface, dig | X | | Tiny Tim Nose, Photoboard incorrectly calls this Target 106 |
| 258 | 431601.80 | 4004270.29 | 0.150 | 0.39 | 2.91 | 26.60 | -29.00 | 2.75in W.H. 1.5 ft deep | | X | 12-inX12-inX1/16-in Steel Plate |
| 259 | 431604.15 | 4004266.37 | 0.131 | 0.15 | 2.91 | 29.20 | -35.20 | 2.75 in W.H. shallow, dig | | X | 5-inX10-inX3.8-in Steel Plate |
| 262 | 431615.55 | 4004246.39 | 0.163 | 0.29 | 2.91 | 47.20 | -42.30 | 2.75 in W.H. shallow, dig | X | | SCAR |
| 264 | 431568.22 | 4004239.46 | 0.172 | 0.33 | 2.94 | 57.90 | -57.40 | 2.75 in W.H. 1 ft deep, dig | X | | SCAR |
| 267 | 431582.62 | 4004214.42 | 0.155 | 0.32 | 2.95 | 40.60 | -31.80 | 2.75 in W.H. 1 ft deep, dig | X | | SCAR WITH Rail |
| 268 | 431591.52 | 4004215.34 | 0.158 | 0.21 | 2.95 | 95.60 | -14.60 | 2.75 in W.H. shallow, dig | X | | Tiny Tim, Left in Place |
| 277 | 431559.22 | 4004160.72 | 0.112 | 0.16 | 3.11 | 17.10 | -13.80 | good small target | | X | Suspension Band |
| 287 | 431579.55 | 4003938.26 | 0.165 | 0.25 | 2.99 | 89.40 | -13.70 | 2.75 in W.H., shallow, dig | X | | 100-lb Practice Bomb |
| 290 | 431598.97 | 4003881.89 | 0.127 | 0.22 | 2.99 | 38.10 | -12.80 | 2.75 in W.H., shallow, dig | X | | 5-in ZUNI Warhead |
| 293 | 431577.15 | 4003785.68 | 0.174 | 0.05 | 2.90 | 29.60 | -31.50 | 2.75 in W.H. on surface, dig | | X | Conical Bait Trap |
| 298 | 431620.29 | 4003884.42 | 0.178 | 0.25 | 3.01 | 68.90 | -60.00 | 2.75 in W.H. 1 ft deep, dig | | X | Crab Pot Frame |
| 330 | 431623.86 | 4004330.52 | 0.251 | 0.16 | 2.88 | 452.50 | -81.60 | 5 in rocket on surface, tail fins to South, dig | | X | Crab Pot |
| 334 | 431619.97 | 4004360.98 | 0.223 | 0.10 | 2.89 | 284.50 | -47.40 | 5 in Rocket on surface, tail fins to South, dig | | X | Full Crab Pot |


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**Table 10. Continued**

| Analysis Results | | | | | | | | | Field Results | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Target ID | UTM X(m) | UTM Y(m) | Size (m) | Target Depth (m) | Water Depth (m) | Peak Pos Signal (nT) | Peak Neg Signal (nT) | Analyst Comment | Ordnance | Not Ordnance | Field Rusults (Target Identity) |
| 352 | 431692.94 | 4004372.88 | 0.190 | 0.75 | 1.31 | 137.70 | -157.30 | 3 in Rocket 2 ft deep in 4 ft of water, dig | | X | Runway Matting |
| 362 | 431684.95 | 4004317.56 | 0.107 | 0.22 | 1.36 | 107.70 | -84.10 | Small shallow target in 4 ft of water, poor fit, DIG? | | X | Angle Iron |
| 367 | 431718.84 | 4004309.90 | 0.112 | 0.29 | 1.10 | 138.60 | -92.50 | Shallow target, dig this | X | | 2.25 Rocket |
| 370 | 431705.30 | 4004276.69 | 0.062 | 0.36 | 1.16 | 14.10 | -11.20 | Small target, 1 ft deep in 3 ft of water, poor fit, DIG? | | X | Crab Pot Frame |
| 371 | 431725.14 | 4004271.36 | 0.050 | 0.09 | 1.11 | 24.50 | -6.70 | Small target on surface in 3 ft of water | X | | MK23 Prac Bomb |
| 372 | 431681.95 | 4004273.26 | 0.180 | 0.15 | 1.40 | 232.70 | -223.20 | Large target shallow in 4 ft of water, partial signature, DI | | X | Suspension Band |
| 374 | 431693.72 | 4004256.96 | 0.185 | 0.33 | 1.22 | 510.90 | -415.60 | Large shallow target, dig this | | X | Tide Stick |
| 375 | 431710.39 | 4004245.57 | 0.104 | 0.74 | 1.15 | 61.30 | -7.10 | Small target 2 ft into mud in 3 ft of water, Dig? | X | | MK76 Prac Bomb |
| 376 | 431712.96 | 4004242.16 | 0.097 | 0.28 | 1.14 | 79.30 | -56.60 | Small target, shallow in 3 ft of water, DIG | | | Cylindrical Band (Iron) |
| 379 | 431720.50 | 4004234.34 | 0.065 | 0.13 | 1.14 | 46.60 | -20.10 | shallow target in 3 ft of water, DIG | X | | 2.75 Rocket Warhead |
| 381 | 431726.59 | 4004252.24 | 0.089 | 0.29 | 1.12 | 93.30 | -46.80 | Small shallow target in 3 ft of water, poor fit, DIG | X | | 2.25 Rocket |
| 382 | 431730.95 | 4004231.02 | 0.069 | 0.41 | 1.14 | 24.80 | -6.10 | Small target 1.5 ft into mud in 3 ft of water, Dig | X | | MK23 Prac Bomb |
| 384 | 431705.24 | 4004233.10 | 0.057 | 0.31 | 1.16 | 21.80 | -4.80 | Very small target 1 ft into mud in 3 ft of water | X | | MK23 Prac Bomb |
| 385 | 431732.78 | 4004221.52 | 0.041 | 0.07 | 1.13 | 20.40 | -6.20 | tiny target on surface in 3 ft of water | | X | Scrap Metal |
| 386 | 431718.59 | 4004209.94 | 0.093 | 0.42 | 1.16 | 93.80 | -16.50 | small target 1.5 ft in mud in 3 ft of water, dig | X | | 2.25 Rocket |
| 387 | 431707.09 | 4004211.72 | 0.073 | 0.42 | 1.17 | 29.20 | -6.30 | Small target 1 ft into mud in 3 ft of water, Dig | X | | Mk23 Prac Bomb |
| 394 | 431698.42 | 4004157.36 | 0.090 | 0.02 | 1.24 | 165.50 | -105.60 | small target on surface in 4 ft of water, DIG | | X | Angle Iron |
| 396 | 431720.65 | 4004180.71 | 0.069 | 0.18 | 1.19 | 41.20 | -13.40 | Very small target, very shallow in 3 ft of water | X | | MK23 Prac Bomb |
| 397 | 431728.13 | 4004199.49 | 0.070 | 0.46 | 1.17 | 26.10 | -2.00 | Very small target 1.5 ft in mud in 3 ft of water, Dig | X | | MK23 Prac Bomb |
| 399 | 431724.19 | 4004176.94 | 0.158 | 0.08 | 1.20 | 569.10 | -430.50 | Large target on surface in 4 ft of water, DIG THIS | X | | 2.25 Rocket |
| 400 | 431732.74 | 4004170.94 | 0.132 | 0.16 | 1.20 | 258.60 | -249.20 | Good target on surface in 4 ft of water, DIG THIS | X | | 2.25 Rocket |
| 401 | 431726.28 | 4004162.48 | 0.249 | 0.12 | 1.21 | 3440.90 | -534.10 | Rocket sized target on surface in 4 ft of water, DIG THIS | | X | Gear Mechanism |
| 408 | 431723.60 | 4004136.69 | 0.071 | 0.14 | 1.23 | 52.90 | -31.90 | Small target, shallow in 4 ft of water, DIG THIS | X | | 2.75 Rocket WH |
| 411 | 431755.16 | 4004060.02 | 0.068 | 0.23 | 1.24 | 30.20 | -5.10 | Small target on surface in 4 ft of water, DIG THIS | X | | MK23 Prac Bomb |
| 412 | 431736.22 | 4004056.83 | 0.183 | 0.43 | 1.26 | 271.00 | -119.20 | 3 in rocket 1.5 ft in mud in 4 ft of water, DIG THIS | X | | 2.75 Rocket WH |
| 413 | 431728.49 | 4004034.75 | 0.060 | 0.31 | 1.27 | 29.80 | -4.10 | Small target 1 ft deep in 4 ft of water, DIG THIS | X | | MK23 Prac Bomb |
| 416 | 431723.53 | 4004012.01 | 0.103 | 0.05 | 1.27 | 184.70 | -57.30 | Good target on surface in 4 ft of water, DIG THIS | X | | MK76 Prac Bomb |
| 424 | 431663.28 | 4003888.03 | 0.196 | 0.04 | 2.95 | 241.80 | -51.40 | large target on surface, DIG THIS | | X | Crab Pot |


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**Table 10. Continued**

| Targets on the Dig List That Were Not Dug | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Analysis Results | | | | | | | | |
| Target ID | UTM X(m) | UTM Y(m) | Size (m) | Target Depth (m) | Water Depth (m) | Peak Pos Signal (nT) | Peak Neg Signal (nT) | Analyst Comment |
| 1 | 431221.16 | 4003782.79 | 0.136 | 0.10 | 2.75 | 14.40 | -58.20 | Strongly inverted, zero depth, Mk76? |
| 2 | 431185.03 | 4003834.75 | 0.151 | 0.41 | 2.76 | 39.90 | -26.20 | Great target 15in deep, BDU 33 |
| 3 | 431208.66 | 4003990.53 | 0.132 | 0.23 | 2.85 | 38.50 | -6.10 | Strongly inverted, 10 in deep, 2.75 in? |
| 9 | 431201.20 | 4004087.06 | 0.115 | 0.14 | 2.81 | 21.80 | -12.90 | Shallow target, 2.75 in W.H.? |
| 13 | 431231.98 | 4004156.02 | 0.126 | -0.10 | 2.77 | 15.70 | -25.50 | Target on surface, dig, BDU 33? |
| 25 | 431226.47 | 4004355.82 | 0.093 | 0.23 | 2.64 | 19.00 | -4.60 | Inverted target, 1 ft deep, larger target 3 m west |
| 27 | 431216.17 | 4004448.01 | 0.100 | 0.16 | 2.63 | 21.30 | -13.20 | Good target, 1.5 ft deep, BDU 33?, dig this |
| 31 | 431193.28 | 4004568.07 | 0.093 | 0.15 | 2.54 | 16.70 | -11.50 | Small target shallow, 2.25 in SCAR? |
| 60 | 431330.61 | 4003889.89 | 0.091 | 0.33 | 2.75 | 21.50 | -4.90 | Small inverted target, 1 ft deep, dig? |
| 63 | 431299.82 | 4003928.78 | 0.087 | 0.37 | 2.77 | 15.40 | -6.60 | Small inverted target, 1+ ft deep |
| 75 | 431301.00 | 4004130.68 | 0.150 | 0.62 | 2.75 | 52.80 | -16.90 | Large target, 2 ft deep, 5 in rocket?, note targets 73 &74 |
| 96 | 431334.97 | 4004624.00 | 0.092 | 0.41 | 2.68 | 13.10 | -18.90 | Small target with remnant moment, 1.5 ft deep |
| 105 | 431342.85 | 4004269.08 | 0.102 | 0.36 | 2.73 | 24.90 | -13.70 | Small inverted target at 1 ft, dig? |
| 122 | 431439.23 | 4003807.49 | 0.086 | 0.33 | 2.80 | 14.00 | -2.20 | Small target 1 ft deep |
| 146 | 431439.75 | 4004504.45 | 0.090 | 0.14 | 2.86 | 13.40 | -6.70 | Small shallow target, dig? |
| 147 | 431428.41 | 4004508.90 | 0.106 | -0.01 | 2.87 | 19.10 | -23.80 | Small shallow target, dig? |
| 151 | 431466.13 | 4004737.19 | 0.188 | 0.55 | 2.90 | 79.40 | -15.10 | 5 in Rocket at 1.5 ft?, clutter 1 meter south, dig this |
| 159 | 431556.44 | 4004409.65 | 0.115 | 0.04 | 2.96 | 6.40 | -6.40 | SCAR?, on surface, dig? |
| 163 | 431542.82 | 4004347.43 | 0.092 | 0.01 | 2.99 | 12.30 | -10.60 | Small target on surface, dig? |
| 222 | 431482.12 | 4004158.00 | 0.145 | 0.21 | 2.96 | 46.30 | -19.80 | Mk 76? shallow, dig |
| 239 | 431487.01 | 4004554.82 | 0.119 | 0.24 | 2.81 | 19.40 | -6.80 | 2.75 in W.H., shallow, dig |
| 244 | 431588.75 | 4004358.01 | 0.187 | 0.13 | 2.88 | 175.90 | -28.70 | 5 in Rocket on surface, dig this |
| 297 | 431633.27 | 4003818.30 | 0.143 | 0.12 | 2.98 | 44.90 | -30.90 | 2.75 in W.H. on surface, dig |
| 296 | 431651.43 | 4003778.43 | 0.146 | 0.24 | 2.95 | 30.60 | -31.00 | 2.75 in W.H. 1 ft deep, dig |
| 300 | 431629.06 | 4003927.49 | 0.150 | 0.29 | 3.03 | 80.50 | -14.30 | 2.75 in W.H. 1 ft deep, dig |
| 303 | 431643.79 | 4003995.45 | 0.145 | 0.28 | 3.00 | 27.20 | -33.80 | 2.75 in W.H. 1 ft deep, dig |
| 304 | 431630.26 | 4004016.73 | 0.168 | 0.65 | 2.99 | 45.40 | -19.40 | 2.75 in W.H. 2 ft deep |
| 316 | 431612.59 | 4004138.60 | 0.166 | 0.31 | 3.01 | 46.30 | -47.90 | 2.75 in W.H. 1 ft deep, dig |
| 318 | 431638.60 | 4004152.32 | 0.124 | 0.70 | 2.94 | 18.60 | -9.10 | too deep to dig |
| 335 | 431616.02 | 4004373.55 | 0.165 | 0.19 | 2.89 | 96.80 | -20.10 | 2.75 in W.H. shallow, dig |
| 341 | 431632.41 | 4004434.37 | 0.157 | 0.30 | 2.87 | 29.70 | -33.70 | 2.75 in W.H. at 1.5 ft, dig |
| 363 | 431689.68 | 4004313.85 | 0.093 | 0.30 | 1.26 | 56.00 | -58.10 | Small target 1 ft into mud in 4 ft of water, poor fit, DIG? |
| 366 | 431723.46 | 4004315.93 | 0.086 | 0.16 | 1.11 | 89.20 | -50.00 | Small shallow target in 3 ft of water |
| 370 | 431705.30 | 4004276.69 | 0.062 | 0.36 | 1.16 | 14.10 | -11.20 | Small target, 1 ft deep in 3 ft of water, poor fit, DIG? |
| 380 | 431705.60 | 4004224.40 | 0.090 | 0.44 | 1.16 | 42.10 | -14.00 | Small target 2 ft in the mud in 3 ft of water |
| 395 | 431708.37 | 4004169.97 | 0.087 | 0.34 | 1.19 | 30.80 | -33.70 | Small target 1 ft in mud in 3 ft of water, DIG |
| 410 | 431704.21 | 4004100.10 | 0.237 | 0.83 | 1.29 | 262.80 | -222.20 | 5 in rocket 2 ft deep in 4 ft of water, DIG THIS |
| **Targets That Were Removed from the Dig List** | | | | | | | | |
| 8 | 431175.55 | 4004077.67 | 0.171 | 0.13 | 2.76 | 252.10 | -40.20 | Large shallow target,, BDU 33? |
| 50 | 431271.75 | 4004190.33 | 0.231 | 0.32 | 2.72 | 450.60 | -139.90 | Large shallow target, with clutter on top, 5 in?, dig this |
| 119 | 431371.98 | 4003773.60 | 0.245 | 0.06 | 2.73 | 466.70 | -111.70 | Large target on surface, tail fins above and slightly south, |
| 190 | 431537.59 | 4004042.10 | 0.246 | 0.21 | 3.11 | 282.00 | -42.50 | Large shallow target, 5 in Rocket?, Dig This |
| 194 | 431505.58 | 4003952.44 | 0.269 | 0.35 | 2.89 | 473.30 | -118.10 | Large Target, 1 ft deep, 5 in Rocket, Dig This |
| 202 | 431475.00 | 4003796.81 | 0.195 | -0.07 | 2.81 | 42.50 | -272.60 | 5 in Rocket on surface, tail fins to South, Dig |
| 219 | 431482.75 | 4004113.79 | 0.252 | 0.00 | 2.91 | 507.90 | -81.20 | 5 in Rocket on surface, tail fins to South, dig |
| 250 | 431605.51 | 4004340.08 | 0.167 | 0.25 | 2.89 | 124.10 | -20.80 | Mk 76?, 1 ft deep, dig |
| 249 | 431596.99 | 4004337.58 | 0.173 | 0.39 | 2.89 | 79.30 | -24.30 | Mk 76? 1.5 ft deep, dig |
| 252 | 431580.30 | 4004314.23 | 0.222 | 0.13 | 2.89 | 327.50 | -52.70 | 5 in rocket shallow, tail fins to South, Dig |
| 271 | 431595.26 | 4004199.82 | 0.180 | 0.21 | 2.96 | 58.30 | -91.80 | 5 in rocket shallow, dig |
| 270 | 431587.51 | 4004197.52 | 0.193 | 0.39 | 2.95 | 101.90 | -36.90 | 5 in Rocket, 1 ft deep, dig |
| 288 | 431578.33 | 4003926.69 | 0.171 | 0.06 | 2.99 | 180.80 | -27.20 | Mk 76? On surface, Dig This |


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photographs of the detonation. The detonation produced a medium report and a dust cloud, but there was no flash. A few of the rocket motors escaped the detonation pit and came to rest a few feet away. All ordnance scrap was collected, inspected for explosive residues, certified as explosives free, and packed into 55 gallon barrels for shipment to a smelter, Figure 36.

The UXO teams cleaned up the storage and detonation areas, packed out their belongings and departed the area on June 3.

**Figure 34. The recovered ordnance were arranged into two pits for demolition.**

**Figure 35. The ordnance with the shaped charges and detonation cord in place were covered with sand bags for detonation.**

**Figure 36. The ordnance was recovered, certified as explosives-free and packed in barrels for shipment.**

***3.6.6 Operating Parameters for the Technology:*** The shakedown studies with the system hardware and the modifications of the MTADS DAS and development of scripts for Oasis montaj to handle the marine data are considered as part of the development process and not a direct part of this demonstration. The development and approval process for the Demonstration Test Plan required about 1 man month of time by AETC and about 1.5 man weeks of time by EOTI. The logistics arrangement to support our operations in Duck required about 3 man weeks by AETC. In addition, one three-day trip was required to Duck (two people from AETC and one from EOTI) immediately prior to the demonstration to coordinate with our hosts, the organizations providing lease and rental equipment, the police department and the town officials, and owners of the various marinas and dock facilities.

During the survey part of the demonstration, four persons from AETC participated along with either one or two persons from EOTI. One person from AETC had a 100% data workup and processing role. Two (and sometimes three) persons operated the survey boat and equipment. One EOTI diver was also always present manning a chase boat during survey operations. The chase boat provided transportation from the survey vessel to the dock, ran errands to retrieve


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parts or equipment, and generally served as a backup to help in launching and docking the equipment morning and night. Both these operations often required a person in the water because of the poor facilities available for launching and docking. Early in the operation, there were at least two EOTI personnel on site – these persons provided the main labor component and advice in the installation of the seed targets.

During the target reacquisition and recovery operations there were always 6 or 7 EOTI diver-qualified personnel on the job. These same people supported the on shore operations involving ordnance and explosives handling. There was an overlap period; AETC and EOTI personnel were both involved in preparation of data files to support the ordnance reacquisition and training involving the use of the GPS equipment. This period lasted for approximately two days.

EOTI intended to evaluate two innovative technologies for uncovering targets from the sediments. The first was a power auger designed to be operated from the boat. The equipment was rented from a dive shop. The owners of the dive shop could never satisfactorily operate the equipment at their facility. Its rental was cancelled. The second excavator rented was a suction dredge. This unit, also rented by the dive shop, is intended for use by treasure hunters. The unit was underpowered and flimsy. Its performance on the job was deemed as unsatisfactory. A hand shovel was far more efficient for uncovering targets.


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# 4.0 Performance Assessment

## 4.1 Performance Criteria

**Table 11** below is reproduced from Table 7 in the Demonstration Test Plan.[4] The evaluation of the demonstration team performance against the performance criteria and demonstration objectives has been presented in Tables 2 and 3 in Section 3 and has been extensively discussed in Section 3.1. Overall, the first demonstration of the Marine Towed Array was outstandingly successful. All major objectives were met and the performance/production goals, in general, were met in a timely manner. In the remainder of this section we discuss the specific areas where we did not meet our full expectations, areas where we exceeded our anticipated performance, and areas where we were surprised, and how we reacted to the surprises.

In general, it took us several days to achieve our full daily survey production rate. This was a result of a combination of electronics hardware breakdowns and incorrectly setting up the GPS equipment. Because these problems were superimposed, diagnosing and solving them took more time than would be expected if they had occurred independently. Fortunately, we had spares for all failed electronics components and the equipment and expertise to implement repairs.

The projected survey production rate objective of 40 acres/day was mildly more ambitious than what we achieved on the final three full days of surveying (35 acres/day). The largest negative effect on the survey production rate was not weather or time lost in turns, but the slower survey speeds required for surveying in very shallow water. The Marine Towed Array is most effective when used to survey in water ≥ 1.25 m (3.5 ft) deep.

We surveyed fewer total acres than were projected in the Demonstration Test Plan. In actuality, the target density fell off faster than we anticipated north and south of the flight path. This led us to shorten the survey lines about half way through the survey. Additionally, we found the likely ordnance targets and clutter to be more concentrated close to shore than we anticipated. At the western edge of the area surveyed the density of ordnance targets had fallen to <1 UXO/hectare, based upon the UXO targets recovered by the divers. For these reasons we concentrated our efforts working in the very shallow water as close to shore as possible, especially with the EM array.

The performance of the EM68 array was the most serious disappointment associated with the demonstration. In comparison with the magnetometer array, the detection capability of the EM array as it is currently configured is significantly inferior. The performance of the EM68 suffers from the noise problems associated with the time synchronization described earlier in this report. In addition, we feel that the absolute sensitivity of the receive coils is less than will be required for fully satisfactory performance. During the system integration, our calibration studies with the array using the standard spheres led us to believe that the sensitivity would be adequate because we expected noise levels associated with geology and the sensor platform motions in the marine environment to be very low. In point of fact these sources of noise <u>are</u> very low as illustrated in survey data taken with the magnetometer array. We can routinely analyze targets with signal strengths of 1 nT or less from magnetometry data. Unlike the other MTADS EM


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**Table 11. Demonstration Performance Criteria**

| Performance Criteria | Description | Primary or Seconday | Level Achieved |
|---|---|---|---|
| Probability of Detection (Seed Targets and Rebar) | # of detections/# of emplaced items | Primary | 100% |
| Probability of False Alarm | # of false positives/# of UXO declarations | Primary | ~50% non-ordnance recoveries |
| Hazardous Materials | Number of UXO recoveries requiring explosive demolition | Secondary | All but 1 UXO item was challenged with shaped charge |
| Quantity of Materials Treated | Amount of metallic scrap for disposal | Secondary | Three 55 gal drums |
| Factors Affecting Technology Performance | Losses due to inadequate logistics support | Primary | ~5 hr due to poor marina access to deep water |
| | Losses due to weather | Secondary | None |
| | Losses due to breakdowns | Primary | ~1.5 days lost to GPS and hardware breakdowns and repair |
| | Losses due to inability to repair or recover | Primary | |
| | Losses due to injury | Primary | None |
| System Reliability | Component reliability | Primary | Good, except for GPS and 2 circuit boards |
| | Availability of spares | Primary | Failed components were all spared |
| | Availability of equipment and skilled personnel to carry out repairs | Primary | All repairs done on site by AETC |
| Ease of Use | Staff of 5 required to support survey including: | Primary | See Table 8 for personnel and division of labor and tasks |
| | Supervisor/PI | | |
| | Data acquisition (Expert in Electronics & Software) | | |
| | Survey operator (Experienced with marine equipment) | | |
| | Data processing/analysis (UXO Expert, facile with Oasis & MTADS DAS) | | |
| | Support Technician (OSHA Cert/Site Safety) | | EOTI personnel all certified |
| Versitility | System useful only for shallow water UXO survey | Primary | Subsequent to this operation, system has been used in water depths to 8.5 m |
| | Can be deployed in any similar setting having adequate launch and recover facilities | Secondary | Adequate marina access is definitely limiting |
| | System adaptability could be improved by creating abililty to launch and recover sensor platform at sea | Secondary | Not yet addressed |
| Maintenance | Requires mechanical proficiency and electronics and software experts | Primary | Will continue to be true for prototype system |
| Scale-Up Constraints | Commercialization likely requires re-engineering of the sensor platform | Secondary | Present system is suitable for a wide range of applications |

arrays, the environmental noise (and noise associated with the platform motion) is not the limiting noise source in the data. Even when the current synchronization-related noise problems are fixed and when the amplifier gains are increased, the electronics-associated noise may remain the limiting factor in detection with the marine EM array.


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The MTADS DAS was modified for the Marine EM array by preparing to make full use of the signal decay information in the 26 time channels to maximize our ability to classify targets based upon shape and composition. This approach was not viable because the S/N ratio associated with the individual time gates (early or late) would not support a meaningful analysis. The EM68 data were analyzed by summing the signal in all 26 time gates and carrying out a dipole fitting routine equivalent to that originally developed for the MTADS vehicular and man-portable arrays. This provided sufficient sensitivity and S/N ratio to carry out a useful target analysis of the EM survey data.

Figure 37 illustrates the effects discussed above. The images shown are screen clips from the magnetometry and EM MTADS DAS target analyses of the signatures of the southernmost pipe in the line of seeded targets. This is one of the large pipe sections, similar to a 105 mm projectile. The image on the right is the fit window showing the dipole fit to the data, the image on the left is from the detrend tool showing a north-south cut through the data, displaying the measured signals from the individual sensors. In each case, there are three survey passes, which at least partially "see" the target. In the EM data, three of the receiver coils detect the target on each pass; in the magnetometer data, ~4 of the magnetometers register at least part of the dipole signature from the target. In both data sets the boat is significantly rocking side-to-side on at least one of the passes, causing a misregistration in the Easting track of ~ 0.5 m.

For this large target lying flush with the bottom in shallow water, the S/N ratio for the magnetometry data approaches 100/1. In the EM data, the S/N is ~ 12/1. For the demonstration in Duck, the EM68 did not detect the large targets if they were deeply buried and it did not detect the smallest targets except when the sensor platform was almost touching the bottom. This situation will improve when the planned software and hardware modifications are made to the EM68. We anticipate that it will be able to detect small targets Mk23s and 60-mm mortars if they are not significantly buried in the sediment.

The detection sensitivity of the magnetometer array was a pleasant surprise. All the pipe and rebar seed targets were easily detectable. The smallest pipe sections displayed a S/N of 10/1. Eight of the 100 recovered targets in the dig list were Mk 23s. These small

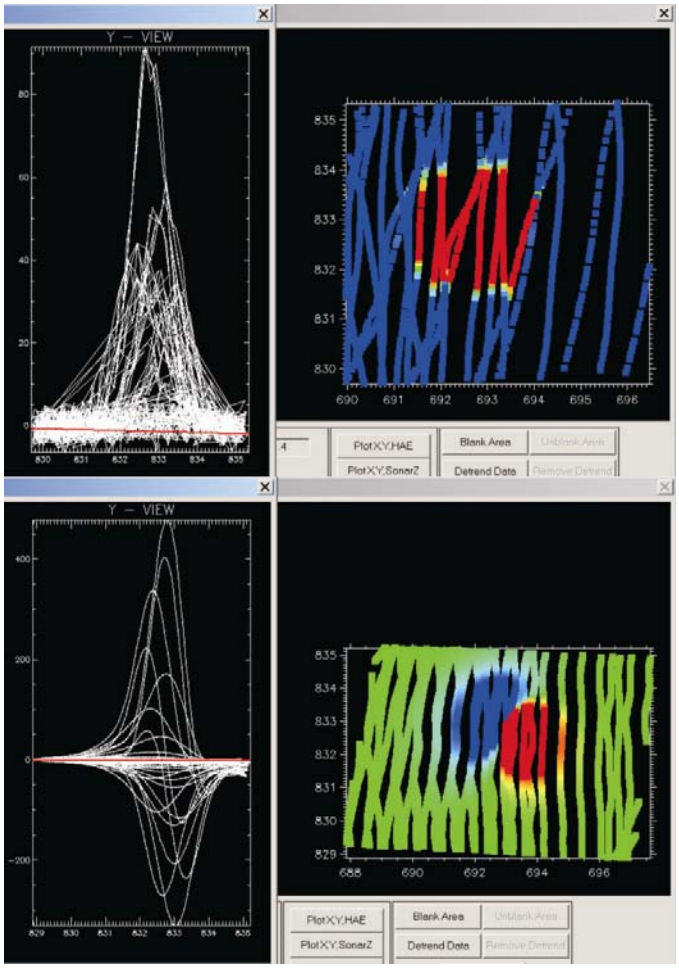


**Figure 37. EM (top) and magnetometry target analysis of pipe target number one.**


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spotter bombs weigh 3 lb and have a length of ~8 in. They are considerably smaller than a 60 mm mortar. Table 12 shows a summary of the identities of the recovered targets. Almost half of the recovered items were ordnance, or ordnance components. The number of derelict crab pots recovered was large because we did not discover that they could be identified in the magnetometry data until digging was about 50% complete. Many of them were included in the dig list because there were a lot of them and their signatures superficially resembled what we assumed would be the signature of the second largest target fired on this range, the 5 in Zuni rocket.

**Table 12. Summary of target recoveries made at the demonstration**

| Ordnance/Ordnance Related Targets | | Not-Ordnance Targets | |
|---|---|---|---|
| **Identity** | **Number Recovered** | **Identity** | **Number Recovered** |
| Mk 23 | 8 | Crab Pots & Parts | 24 |
| SCAR | 15 | Boat Anchors | 5 |
| 2.75" W.H. | 7 | Other Ferrous Scrap | 26 |
| BDU33/M76 | 5 | | |
| 100lb Bomb | 1 | | |
| 75mm W.H. | 1 | | |
| Zuni W.H. | 1 | | |
| Fins/Rails | 7 | | |

## 4.2 Performance Confirmation Methods

***4.2.1 Seed Targets:*** During the first day of the demonstration 17 pipe sections and 23 rebar sections were installed by divers near the south border of the survey area. This process was described above in Section 3.6.2. These targets were surveyed independently in survey files that only included passes over the targets and during the course of the general surveys. These data were added to the master survey files and the targets were analyzed as part of the target analysis process. The fitted coordinates for the targets have been compared with those measured by the divers. This process and the results have been discussed in several places earlier in this document.

***4.2.2 Dig Lists:*** The MTADS DAS process automatically creates a target file of all analyzed targets. During creation of the data products, this file is imported into an Excel spreadsheet and edited to create the dig list. The dig list supports the target reacquisition (way pointing) process to flag the targets for digging. Example of target reports are included in Appendix C of this document for the magnetometry and EM surveys. For the Marine Towed Array the target reports have been adapted to show the water depth at the target position, as well as the predicted depth of the target in the sediment. The MTADS DAS GUI deals exclusively with data mapped onto a local grid (in meters) with true north pointing up. This local grid is used for the display image for target analysis and is also mapped into the output graphics that are used to guide field operations and for inclusion in reports. Since targets are reacquired in the field using GPS, each unique target number is presented in the dig list both in local and in UTM coordinates.

Depth and size information is recorded on the Dig Sheets in metric units. The target sizes of many of the ordnance items have diameters defined in millimeters. EOD and UXO personnel have learned to think of ordnance sizes metrically, but invariably report depths, distances from the flag, sizes of objects (other than metrically-defined ordnance) and weights in feet, inches, and lbs. In spite of repeated instruction, EOD personnel in the field fail, at least 50% of the time to record the distance or the direction of the recovered item from the way point flag. Recording


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information on a Dig Sheet is particularly difficult in underwater recovery operations, for obvious reasons.

In selecting targets for the dig list, we attempted to use the following guidelines.

- The dig list should contain about equal numbers of targets that can be prosecuted from wading and from diving using a support boat. *The survey data limited the shallow water target selections to 20 targets.*
- The excavation limit for targets in the sediment is about two feet. *Targets were chosen with predicted depths of ≤ 0.6 m. In actuality, several of the targets were buried deeper than 0.6 m. In all but 2 cases the divers managed to extract the deeper targets.*
- Targets that are likely to be the two largest ordnance items (5 in and 11.75 in rockets) will be chosen far enough off shore that the highway traffic will not have to be stopped while they are excavated. *Targets were carefully chosen to exclude Tiny Tims and targets large enough to be 5 in rockets were chosen only in deeper water, farther from shore. Most of these chosen targets turned out to be crab pots.*
- A balanced range of both large and small targets will be chosen for the dig list. *Most of the shallow water targets happened to be smaller objects. The deep water dig lists were divided into larger and smaller target lists. The divers began digging from the larger target list – most of the targets that were not dug were from the smaller target list.*

***4.2.3 Validation:*** The UXO recovery teams were provided with four documents to guide them. The first of these was the electronic (.csv) file on the Trimble TSCE GPS computer. This information was used to reacquire and flag the targets. The second document includes the magnetic anomaly image maps (similar to that shown in Figure 29), which show the target signatures, target identities, and the positional relationship of the targets to each other. It has been our experience that these maps are invariably ignored or discarded by EOD or UXO personnel in the field. They are not considered helpful. The third object that is supplied is a printed copy of the dig list. This list is invariably used in the field; targets are checked off the list as they are prosecuted. Finally, a separate paper dig sheet is provided for each target. An example is shown as Figure 26 in the Demonstration Test Plan (Appendix A). It is expected that this document be filled out in the field at the time each target is dug. This is much more difficult when dealing with marine targets. It probably seldom happened. The appearance of most of the dig sheets that were turned in made it plain that they had been filled in after the fact (probably from notes that were taken in the field).

Targets for remediation were marked by the way point team using long fiberglass poles (either 8 ft or 16 ft long) with flags. The target numbers were written on the flag with a permanent marker. This approach worked well. The EOD teams were initially skeptical and wanted to use weights and floats. They quickly accepted the flags because they were easily visible from a distance and they were not lost because of wind, waves, or souvenir hunters. Many of the flags remained in the water for the full 4 weeks of the demonstration.

No targets were to be dug that were more than 2 m from the flag; if no target could be found within 2 m of the flag the hole was to be called a false alarm. In this demonstration targets were located within 1 m of the flag in all cases. Because of the poor visibility of the water, targets


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could not be photographed in place. This was not an issue because only 1 of the 100 targets was not brought ashore. It was too heavy to lift with the available winch. Its identity has been lost. The other targets were permanently labeled as they were brought into the boat. They were cleaned up where they were stored and digitally photographed. All photographs are included in Appendix D.

## 4.3 Data Analysis, Interpretation and Evaluation

Retrospectively, the dig sheets, target photographs, and descriptions of the dig results were compared with the information in the dig lists, the target analysis parameters, target signatures/images in data and the digital sonar images for each individual target. If there had been a significant time gap between the survey and the beginning of the dig operations a thorough review of the sonar image files and the target signatures might have led to a conclusion that many of the crab traps on the site could been correlated with their magnetometry signatures. This is conjecture, and not assuredly true. Many crab traps were partially disintegrated or mashed out of shape. Others had only their rebar skeletons remaining. They present almost a continuum of signatures.

A more likely benefit would have resulted if the digging had stopped after 15-20 targets had been dug. The intact crab traps were easily correlatable with their magnetic signatures. They are all 2 ft cubes and have a bait well that is constructed from a heavier mesh (hail screen). The trap and the bait well appear as separate dipoles in the magnetic signatures. They were mistaken in the original analysis as large ordnance with nearby tail fins (as often occurs in UXO range data).

All range clearances based upon digital survey data could benefit from feedback early in the digging phase. The particular mix of ordnance dispensed on a range and the underlying environmental range conditions make every site unique.

The other result of the retrospective correlation of the dig results with the data analysis leads to the conjecture that 2 of the 100 recovered targets might not have recovered the target that the dig list specified to be flagged. This is based upon the discrepancy in the size of the recovered object and its description on the dig sheet in comparison with the original analysis. This conjecture cannot be resolved without reacquiring and redigging the specified targets, however.


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# 5.0 Cost Assessment

## 5.1 Cost Reporting

The costs associated with the demonstration of the Marine Towed Array at the Former Duck Naval Target Range are reported in this section. The costs are split between two cost tracking tables. Table 13 reports costs accrued by AETC in support of the demonstration. Table 14 is a separate listing of costs generated by our subcontractor, EOTI associated with the target reacquisition, target digging and recovery, and target/scrap disposal operations.

EOTI also provided support personnel to assist with the installation of the seed targets, to assist with equipment launching and recovery, and to operate a chase/tender boat during our surveys. These costs are reported in Table 13.

The costs in Table 13 associated with equipment are required to be reported as Capital Costs. The Marine Towed Array was assembled as a development project. None of the costs for individual equipment purchases amounted to more than 20% of the total equipment costs. All components, even those purchased as COTS, were modified and integrated into the total assembly. The entire group of costs reported in the Capital Costs section, including purchases, equipment and software development, and component and system integration costs, represent the direct costs associated with the development and assembly of the system. They do not include certain costs associated with R&D issues necessary to address certain parts of the development. The several shakedown tests and subsequent fixes are subsumed in the Equipment Integration Costs category.

**Table 13. AETC Cost Tracking**

| COST CATGORY | Sub Category | Cost ($K) |
|---|---|---|
| START-UP COSTS | Site Characterization (Recon Survey) | 12 |
| | Evaluation Trips (4/05) | 5 |
| | Site Preparation | |
| | Order GPS Points | 0 |
| | Seed Targets | 7 |
| | Site Access | 1 |
| | Contracting Costs (Table 15) | |
| | Demonstration Plan | 20 |
| | Develop HASP | 5 |
| | Mobilization | |
| | Personnel | 4 |
| | Equipment Transport | 4 |
| | Permitting/Licenses | 1 |
| | Local Logistics | |
| CAPITAL COSTS | Capital Equipment Purchase | 600 |
| | Ancillary Equipment Purchase | 200 |
| | Equipment Developed In-house | 300 |
| | Equipment Integration Costs | 250 |
| | Software Development Costs | 150 |
| OPERATING COSTS (Specific to Demonstration) | Equipment Rental | 3 |
| | Equipment Maintenance | 5 |
| | Utilities | 0 |
| | Site Survey | 0 |
| | Personnel | 60.2 |
| | Data Processing & Products | |
| | Digging/Recovery Operations (Table 15) | |
| | Consumables/Supplies | 3 |
| | UXO/Scrap Processing (Table 15) | |
| | Offsite Disposal (Table 15) | |
| SHUT-DOWN COSTS | Return of Equipment (Table 15) | 3 |
| | Structure Disposal | |
| | Site Restoration (Table 15) | |
| | Decontamination (Table 15) | |
| | Equipment Repair/Replacement | 5 |
| | Demobilize Personnel/Equipment | 2 |
| | Develop Report | 20 |


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**Table 14. EOTI Cost Tracking**

PROJECT NAME: **DUCK UNDERWATER MTA DEMONSTRATION** YEAR: **2005**

PROJECT NUMBER COMPANY: **AETC**

**LABOR** ***Total $ 72,050.90***

| *Labor Category* | *Qty* | *Rate* | *Hrs* | *HPD HRS* | *HPD 4%* | *HPD HRS* | *HPD 8%* | *TOTAL* |
|---|---|---|---|---|---|---|---|---|
| PROJECT MANAGER | 1 | $ 75.97 | 127 | | $ - | | $ - | $ 9,648.19 |
| SUXOS | 1 | $ 64.21 | 160 | 112 | $ 287.66 | 8 | $ 41.09 | $ 10,602.36 |
| SUXOS OT | 1 | $ 96.32 | 47 | 47 | $ 181.08 | | $ - | $ 4,708.12 |
| UXOSO/QC | 1 | $ 54.23 | 80 | 64 | $ 138.83 | | $ - | $ 4,477.23 |
| UXOSO/QC OT | 1 | $ 81.34 | 21 | 21 | $ 68.33 | | $ - | $ 1,776.47 |
| UXOSO/QC DIVE | 1 | $ 103.03 | 23 | | $ - | 23 | $ 189.58 | $ 2,559.27 |
| UXO TECH III | 2 | $ 49.30 | 240 | 128 | $ 252.42 | | $ - | $ 12,084.42 |
| UXO TECH III OT | 2 | $ 73.95 | 78 | 78 | $ 230.72 | | $ - | $ 5,998.82 |
| UXO TECH III DIVE | 2 | $ 93.67 | 46 | | $ - | 46 | $ 344.71 | $ 4,653.53 |
| UXO TECH II | 2 | $ 41.13 | 222 | 144 | $ 236.91 | | $ - | $ 9,367.77 |
| UXO TECH II OT | 2 | $ 73.95 | 32 | 32 | $ 94.66 | | $ - | $ 2,461.06 |
| UXO TECH II DIVE | 2 | $ 78.15 | 44 | | $ - | 44 | $ 275.09 | $ 3,713.69 |

**ODC'S** ***Total ODC's $16,591.00***

| *Item Category* | *Qty* | *Rate* | *Units* | *Total* |
|---|---|---|---|---|
| BOAT RENTAL (LARGE)& OPERATOR | DAY | $ 200.00 | 12 | $ 2,400.00 |
| BOAT RENTAL (SMALL) | DAY | $ 120.00 | 21 | $ 2,520.00 |
| FEDEX | EA | $ 33.00 | 4 | $ 132.00 |
| SCHONSTEDTS (2) | DAY | $ 10.00 | 12 | $ 120.00 |
| TRUCK (2) | DAY | $ 174.00 | 12 | $ 2,088.00 |
| FUEL | DAY | $ 10.00 | 16 | $ 160.00 |
| EXPLOSIVES | EA | $ 2,455.00 | 1 | $ 2,455.00 |
| EXPLOSIVES DELIVERY | EA | $ 977.00 | 1 | $ 977.00 |
| DEMO KIT | DAY | $ 5.00 | 2 | $ 10.00 |
| CAMERA | DAY | $ 5.00 | 21 | $ 105.00 |
| FIELD TOOL KIT | DAY | $ 5.00 | 12 | $ 60.00 |
| FIELD SUPPLIES | DAY | $ 5.00 | 12 | $ 60.00 |
| DIVE EQUIPMENT (6) | DAY | $ 216.00 | 12 | $ 2,592.00 |
| EQUIPMENT MOB/DEMOB | EA | $ 1,100.00 | 1 | $ 1,100.00 |
| PHONE (2) | WK | $ 15.00 | 2 | $ 30.00 |
| RADIO (4) | WK | $ 15.00 | 2 | $ 30.00 |
| UNDERWATER MAG | DAY | $ 35.00 | 12 | $ 420.00 |
| UNDERWATER GRADIOMETER | DAY | $ 111.00 | 12 | $ 1,332.00 |

**TRV/LODG/PER DIEM** ***Total $ 15,154.51***

| *Item* | *Qty* | *Rate* | *Units* | *Total* |
|---|---|---|---|---|
| LODGING | DAY | $ 93.12 | 96 | $ 8,939.52 |
| PER DIEM | DAY | $ 43.00 | 96 | $ 4,128.00 |
| | | | | |
| AIR FARE | EA | $ 550.00 | 2 | $ 1,100.00 |
| MILEAGE | EA | $ 0.405 | 2437 | $ 986.99 |

***Overall Total $ 103,796.41***


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## 5.2 Cost Analysis

**5.2.1** ***Cost Comparison*:** Cost models for the Marine Towed Array will be developed based upon the system capital costs, mobilization/demobilization costs, and production costs using information similar to that presented above. This exercise can be more precisely done following the next demonstration of the system. It is not possible to develop a comparative cost analysis based upon a baseline alternative technology, because no alternative commercial technology exists that is capable of producing a comparable geophysical survey product.

**5.2.2** ***Cost Basis:*** The most logical cost basis for a service product based upon this technology would be based upon a capitalization cost to recover capital investment, a mobilization/demobilization cost, and a production cost (either per acre or per day). There would be some survey economies of scale probably with a breakpoint at a one-week survey operation.

An important component of the service product cost basis must be based upon an evaluation of the potential market for marine UXO services and the market share that this particular technology could be expected to capture. At present, although there are frequent inquiries about the potential availability of this technology for UXO marine survey services to the government and to other components in private industry, no market analysis has been carried out. To my knowledge, there is currently no inventory of approved government jobs requiring these services or budgeted money to pay for them.

**5.2.3** ***Cost Drivers:*** The primary cost drivers are labor costs and the recovery costs for the capital equipment. Each of these is driven by the complexity of the R&D system. A commercial system would be expected to be less complex to implement and operate, thus taking pressure off both of these drivers.

**5.4.4** ***Life Cycle Costs:*** At present it is not possible to develop a life cycle cost model for the Marine Towed Array. We do not have sufficient information to respond meaningfully to the contributing issues that are stated as necessary in the Report Guidance. Information gathered from this and the next planned demonstrations will serve to define a practical design for a commercial instrument, which can be used to estimate capital costs. Likewise, at that time, we will be better prepared to estimate operation, maintenance, mobilization/demobilization, and production costs.


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# 6.0 Implementation Issues

## 6.1 Environmental Checklist

The EE/CA[5] issued in 1996 for the FRF and the Supplemental EE/CA issued in 1998 for the Sound shoreline[8] by Parsons Engineering Science, for the US Army Corps of Engineers, Wilmington District, contains all necessary information relating to environmental and permitting issues and regulations required for this demonstration. The current operation is similar in that it involves a non-intrusive geophysical survey followed by intrusive UXO recovery and demolition operations.

To my knowledge, the regulations relating to UXO operations on FUDS properties have not significantly changed since 1998. During the spring 2005 IPRs, the Demonstration Test Plan for this operation was reviewed for the ESTCP advisory board. Dr. John Cullinane made inquiries within the Army ERDC chain of command and concluded that no special permits or permissions were required from his office for the intrusive operations in the Sound or for the ordnance demolition on the FRF facility, assuming that the operations were supported by the head of the facility.

Brent Knoblett made inquiries within DDESB as to whether new regulations that were being promulgated by DDESB would require their approval for the proposed operations. The conclusion was that since this was a technology demonstration, not a UXO cleanup operation that currently, DDESB permission would not be required for us to proceed.

Mr. John Dow of NOSSA made inquiries within his organization as to whether Navy approval would be required for the proposed demonstration on the Sound. His opinion and that of his office was that it would not. He volunteered, and subsequently personally carried out a review of the Demonstration Test Plan for the ESTCP Program Office, specifically focusing on the explosives safety aspects of the plan. He made minor suggestions that were incorporated into the final plan.

Mr. Roger Young of the Huntsville Corps made inquiries within his office to determine whether ACE approval of the proposed operation was required. He concluded that because (1) the operation was a technology demonstration, not a UXO cleanup, (2) because intrusive recoveries were to take place on the Sound, which does not fall under Army control, and (3) because permission was in place to deal with ordnance demolition on the FRF, and there were no plans for AETC to blow ordnance in place on public property that it was not necessary for his office to be involved.

## 6.2 Regulatory and Stakeholder Issues

There were no interactions with state or national regulators associated with this demonstration. It was our understanding that the waters of the Sound are under the jurisdiction of the State of North Carolina. Furthermore, it was our understanding that removal of Navy practice ordnance from the Sound for transport onto the FRF property would not require official approval of the


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North Carolina Environmental Department. It was our intention that if our UXO contractors found ordnance that they considered to be high-explosive filled and/or fuzed and that they considered to be too dangerous to move, that the coordinates of the UXO would be recorded and that Mr. Bill Birkemeier of the FRF would call either the Army or Navy/Marine EOD detachments in Cherry Point or Norfolk to deal with the ordnance. This is the procedure that is routinely used on the FRF facility when ordnance is discovered during operations on the facility.

The PI met with the Mayor (Mr. Allen Beres) and the Chief of Police (Mr. Dale Hamilton) in the Town of Duck during April 2005, and again at the beginning of the Demonstration in May. They were briefed on our planned operation and provided with copies of the draft Demonstration Test Plan for review and comment. Chief Hamilton offered the services of this office to provide routine evening surveillance of equipment if it was parked in areas with public access. Additionally, support was offered to provide escort or traffic control services, if needed, when we were transporting ordnance across the highway. The mayor informed us that based upon the charter for the town, which was incorporated in 2002, that the Town of Duck had jurisdictional control within 1000-ft of the Currituck Sound shoreline within the Town boundaries. The FRF falls within the Town boundaries. A primary purpose of this regulation was to allow the Town to control the jet ski traffic and noise. All rental jet ski operations are required to take place in the Sound beyond the 1000-ft limit. We informed the Mayor and the Chief that we did not intend to hold any public meetings relating to our operations and that all requests by the public or by the press for information would be referred to Mr. Bill Birkmeier of the FRF.

## 6.3 End User Issues

The most likely end users of this technology are the commercial UXO service provider firms, in association with ACE/Huntsville and the Regional Offices of the Corps. Other potential users include the NAVFAC and Navy/Marine Corps installation managers who are responsible for training ranges with marine UXO contamination problems. The results of this demonstration are being provided to members of the Army Corps, NAVFAC, and the Navy NOSSA office.

The instrument being used in this demonstration is a custom-built prototype. However, with a few exceptions it has been constructed with COTS components. The unique components in the Marine Towed Array are the fiberglass sensor platform, the tow cable, the EM68 sensor, and several custom-designed PCBs. Each of these components will be fully described in the Final Report, and could be purchased from the original manufacturers. There are no proprietary technologies embedded in the Marine Towed Array.


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# 8. Points of Contact

| Organization | Point of Contact | Role in Project | Phone/Fax/Email |
|---|---|---|---|
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| ERDC<br>CEERD-EM-J<br>3909 Halls Ferry Rd.<br>Vicksburg, MS 39180 | John Curtis | COR | Tel: 601-634-2855 Fax: 601-634-2575 Email: john.o.curtis@erdc.usace.army.mil |
| AETC<br>120 Quade Dr.<br>Cary, NC 27513 | Jim R. McDonald | PI | Tel: 919-653-0215X102<br>Cell: 919-673-6805<br>Fax: 919-653-0219<br>Email: jmcdonald@nc.aetc.com |
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| Vehicle Control Technologies<br>11180 Sunrise Valley Dr.<br>Suite 350 Reston, VA 20191 | Tom Tureaud | Hydromodeling | Tel: 703-620-0703 Cell: 703-927-0169<br>Fax: 703-620-1734<br>Email:ttureaud@vctinc.com |
| | Stacy Hills | Autopilot | Tel: 703-620-0703 Cell: 703-927-0169<br>Fax: 703-620-1734<br>Email:shills@vctinc.com |

# Points of Contact, Continued

| Organization | Point of Contact | Role in Project | Phone/Fax/Email |
|---|---|---|---|
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| Town of Duck | Allen Beres, Mayor | | Tel: 252-261-8743<br>Email: allan.beres@townofduck.com |
| Duck News Café 1564 Duck Rd. Duck NC 27949 | James Wentz | Owner, Launch Slip | Tel: 252-261-3358<br>Café: 252-255-0773 |
| North Duck Watersports<br>1446 Duck Rd. Duck, NC 27949 | James Meredith | Owner, Boat Ramp & Dock | Tel: 252-261-4200 |
| Sunset Grill & Raw Bar<br>1264 Duck Rd. Duck, NC 27949 | | Owner, Dock | Tel: 252-261-3901 |
| Triangle Rent A Car<br>5401 Hillsboro St.<br>Raleigh, NC | | | Tel: 919-851-2555 |
| Holiday Inn Express Hwy 158, MP 4 Kitty Hawk, NC 27949 | | | Tel: 252-262-4888 |