ESTCP
Cost and Performance Report

(MM-0324)

UXO Detection and Characterization in the Marine Environment

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ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

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COST & PERFORMANCE REPORT
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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COTS	commercial, off the shelf
CTT	closed, transferred, and transferring
DAQ	Data Acquisition
DAS	Data Analysis System
DGPS	Differential Global Positioning System
DIDSON	dual frequency identification sonor
DMM	discarded military munition
DoD	Department of Defense
EFA-NW	Environmental Field Activity-Northwest
EM	electromagnetic
EMI	electromagnetic induction
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GPS	Global Positioning System
GSA	General Services Administration
GUI	graphical user interface
HAE	height above ellipsoid
HASP	Health and Safety Plan
HE	high explosive
IMU	inertial measurement unit
JPHC	Jackson Park Housing Complex
kt	knot(s)
MEC	Munitions and Explosives of Concern
MLLW	mean lower low water
MTA	marine towed array
MTADS	Multisensor Towed Array Detection System
NAD	Naval Ammunition Depot
NAVFAC	Naval Facilities Command
NEODTD	Naval Explosives Ordnance Detection Technology Division

ACRONYMS AND ABBREVIATIONS (continued)

NHB	Naval Hospital Bremerton
NOSSA	Naval Ordnance Safety and Security Activity
NSWC	
nT	nanotesla
OU	operable unit
POS	prove-out-site
QA	Quality Assurance
QC	quality control
RI/FS	Remedial Investigation/Feasibility Study
SAIC	Science Applications International Corporation
SCI	Structural Composites, Inc.
SERDP	Strategic Environmental Research and Development Program
S/N	signal-to-noise
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mecator
UXO	unexploded ordnance
VCT	Vehicle Control Technologies, Inc.

ACKNOWLEDGEMENTS

This project (MM2003-24) was sponsored by ESTCP under Contract Number DACA72-03-C-0016 with AETC Incorporated. The contract was modified in 2007 when AETC was acquired by SAIC. The Principal Investigator for the project was Jim R. McDonald.

As funded, MM2003-24 called for the conduct of two large-scale field demonstrations. The first of these was at Duck, NC in the Currituck Sound adjacent to the Former Duck Navy Bombing Range. The results of this demonstration were comprehensively reported in a separate report to this one.

The Demonstration Report and the Cost and Performance Report for the second large-scale demonstration focus on a marine geophysical magnetometry survey of Ostrich Bay adjacent to the Former Naval Ammunition Depot – Puget Sound. The Puget Sound Demonstration was also supported by NAVFAC Northwest, the current manager of the site. The Navy Project Manager is Mr. Mark Murphy. All of the operations described in this report were developed and implemented in cooperation with both ESTCP and Mr. Murphy of NAVFAC Northwest.

The Demonstration Plan for the Project was developed in coordination with and approved by numerous stakeholders with an interest in the site. These included NAVFAC Northwest (Mr. Mark Murphy), EPA Region 10 (Mr. Harry Craig), the Washington State Department of Natural and Environmental Resources (DNER), and the Suquamish Tribe (Ms. Denise Taylor).

We would also like to express our appreciation for the support of Tetra Tech (Mr. Justin Peach) during our work on the Sound. Tetra Tech is the on site support contractor to NAVFAC for operations on Ostrich Bay. They provided assistance to us in location of local support equipment and facilities required for our operations. They also served as liaison to the Naval EOD Detachment – Bremerton. The EOD Detachment provided divers to intrusively investigate the group of 100 targets that were selected following the MTA survey.

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1.0 EXECUTIVE SUMMARY

The second demonstration of the marine towed array (MTA) took place June 12-30, 2006, on Ostrich Bay (Puget Sound) in the state of Washington. The bay is adjacent to the former Naval Ammunition Depot (NAD) Puget Sound, which for 50 years operated as an ordnance manufacturing and storage facility to supply Naval vessels operating from the West Coast. Munitions and explosives of concern (MEC) and munitions components were onloaded and off-loaded between three piers and lighters (powered barges) as part of the NAD operations. The facility was decommissioned in 1959; subsequently three of the four piers have been removed. In the 1980s, several thousand pounds of intact discarded military munitions (DMM) were removed from the immediate vicinity of Pier II, which still remains standing. For the past 10 years, DMM cleanup operations have been ongoing, mostly on the original land of the NAD. The NAD has subsequently been replaced with a high density Naval housing community and a hospital, the Naval Hospital Bremerton (NHB).

Naval Facilities Command (NAVFAC), working in cooperation with Environmental Protection Agency (EPA) Region 10, is preparing to extend the cleanup activities into Ostrich Bay. In preparation for these activities, NAVFAC Northwest has constructed an ordnance prove-out-site (POS) along the east side of Ostrich Bay in a 50×200 m area to evaluate various survey technologies for use in characterizing ordnance contamination in the bay. Science Applications International Corporation (SAIC) demonstrated the MTA during June 2006, first surveying the POS and presenting the analyzed data to NAVFAC for evaluation.

Following this, the MTA was used to conduct a blanket survey of all regions of the bay thought likely to contain DMM. Operations concentrated along the western shore where the four piers that originally served the NAD were located. The areas around the current Pier II were incompletely surveyed because of the very steep-walled dredge cuts that remain around the pier. Areas in the vicinity of the former Pier I, the former Railroad Pier, and the Current Pier II remain very highly contaminated with both large and small metallic anomalies.

Approximately 220 acres of the bay (75% of the total area) were surveyed with the MTA, all data were analyzed, and target lists with recommended targets for investigation were submitted to NAVFAC. Working with Naval Explosives Ordnance Detection Technology Division (NEODTD) and the Bangor Naval Explosive Ordnance Disposal (EOD) Detachment, NAVFAC dove on and characterized 108 selected targets from all regions of the Bay. Eight targets were confirmed to be DMM or DMM components. Seven of the eight DMM targets were recovered in the immediate vicinity of the former Pier I; one DMM target was recovered in the vicinity of the former Railroad Pier.

To eventually clean up DMM from the bay will require an initial surface cleanup of the areas under and adjacent to Pier I, Pier II, and the Railroad Pier and a resurvey of these relatively small areas to be followed by target reacquisition and recovery. The areas immediately adjacent to Pier I and the Railroad Pier may require multiple resurvey and cleanup cycles to confidently remove all DMM-related materials.

In this report we describe the MTA survey activities from June 2006, our data analyses, the survey products that supported the intrusive investigations, and our analysis of the results of the intrusive investigation results.

2.0 INTRODUCTION

2.1 BACKGROUND

2.1.1 UXO in the Marine Environment

As a result of past military training and weapons testing activities, unexploded ordnance (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. Others are associated with ordnance manufacturing or assembly sites, storage depots and distribution sites, or storage areas associated with dispersed ordnance (inert and training rounds and ordnance duds). The depot and storage sites are typically characterized by DMMs. 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, significant examples of UXO contamination are associated with dredging and beach replenishment operations, as well as confined areas associated with Naval bases and ammunition manufacturing and shipping operations that have potential or known underwater DMM contamination.

At the time of this demonstration there were no commercially available automated technologies for conducting UXO geophysical surveys that produced documented mapped data files showing the extent, densities, and types of ordnance contamination in typical underwater environments. The application of automated survey technologies has become routine on land-based ranges using handheld, man-portable, vehicular-towed, or airborne sensor arrays coupled to the Global Positioning System (GPS) or other types of navigation systems for precise location and positioning. Underwater UXO searches are typically conducted by divers using handheld magnetometers. For clearance operations, divers typically operate in narrow lanes defined by ropes or lines based on staked-out grids. Discovered targets are either prosecuted as they are found or they are marked with weights and floats for later prosecution.

2.1.2 The Environmental Problem

The second demonstration of the MTA under Environmental Security Technology Certification Program (ESTCP) Project MM2003-24, was on Ostrich Bay adjacent to the current Jackson Park Housing Complex (JPHC) and the NHB. This area has an ordnance history stretching back more than 100 years. The “Archive Search Report,” published in 2002 succinctly describes the site evolution. The NAD was established in 1904 and decommissioned in 1959. The depot served as a manufacturing assembly point and storage depot for Naval ordnance during its entire history. Component materials and chemicals for manufacturing and assembly of ordnance were off-loaded at three piers in Ostrich Bay from lighters, and finished ammunition was reloaded onto the shallow water barges for transport to deep water where it was subsequently loaded onto Naval ships. There is a long history of both chemical and UXO contamination on land areas associated with the depot and by DMM contamination in the Bay associated with the loading operations at the piers. Both the former NAD Puget Sound mainland areas and the associated areas in Ostrich Bay have become of concern with the state and federal environmental agencies, the Native Tribes of the area, and other stakeholders.

2.1.3 The MTA Technology

The development of the MTA is described in greater detail in Section 3 of this report and in the project final report. The MTA survey was designed to produce electronic displays of the magnetometry and electromagnetic (EMI) surveys of Ostrich Bay, lists of analyzed magnetic anomalies discovered in the bay, and a list of anomalies recommended for intrusive examination. This demonstration follows the first demonstration of the MTA on the Currituck Sound offshore from the former Duck Naval Bombing Range in North Carolina.

2.2 OBJECTIVES OF THIS DEMONSTRATION

Our objective for this demonstration was to conduct an efficient and high-quality marine ordnance survey of Ostrich Bay. Our demonstration began in 2006 with a survey and analysis of a marine POS prepared by NAVFAC on the eastern shore of the bay and a comprehensive (full coverage) survey of the eastern half of Ostrich Bay.

2.3 REGULATORY DRIVERS

The regulatory issues affecting the UXO problem are most frequently associated with the BRAC and FUDS processes involving the transfer of Department of Defense (DoD) property to other agencies or to the civilian sector. When the transfer of responsibility to other government agencies or to the civilian sector takes place, DoD land falls under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 requires adherence to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provisions. The basic issues center on the assumption of liability for ordnance contamination on the previously DoD-controlled sites.

MEC operations at the JPHC and the NHB continue to be conducted under CERCLA site guidelines. The areas on shore fall within Operable Units (OU)-1 and OU-3T (terrestrial). The offshore areas adjacent to JPHC and NHB are a part of the OU-3M (marine). OU-3M includes the approximate 79 acres of Navy property between the 0 feet mean lower low water (MLLW) line and the 4 fathom line in Ostrich Bay, and additionally includes areas of Ostrich Bay that have munitions contamination beyond the Navy property line.

The lands under Ostrich Bay beyond the Navy property line are under the jurisdiction of the State of Washington. To our knowledge all operations involving OU-3M have involved

NAVFAC Environmental Field Activity-Northwest (EFA-NW), EPA (Region 10), the Washington State Department of Natural Resources, and the Washington State biologist.

In addition to the stakeholder interests represented by the regulators and agencies, a representative of the Suquamish Tribe has been involved in all correspondence involving OU-3M operations. Homeowners, property owners, and recreational users of the bay are represented by various citizen groups that surround the bay. These groups have been officially informed of significant activities involved in OU-3M operations, and they are actively involved via e-mail exchanges with various government agencies associated with these operations.

In association with the installation of the POS and likely survey operations that were conducted on the site (and other areas of Ostrich Bay), a Biological Evaluation of the Jackson Park Navy Housing Area Ostrich Bay Geophysical Test Site, was developed by the senior Natural Resources Specialist at NAVFAC EFA-NW. In this study, the likely effects on threatened and endangered marine species of the sound and radiation-emitting instruments and the physical activities that were to be conducted on Ostrich Bay were evaluated. Species of concern included are the Chinook salmon, the Steller sea lion, the leatherback sea turtle, the humpback whale, the southern killer whale, the bull trout, and the bald eagle.

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3.0 TECHNOLOGY

3.1 TECHNOLOGY DESCRIPTION

MTA technology consists of the fielded hardware (Figure 1) and software for data acquisition. The software tools were specifically adapted for data processing and preparing the marine data for analysis. Specific software utilities support analyses of the magnetic anomalies, characterizing and classifying their signatures and preparing the various graphics and spreadsheet products to support subsequent target reacquisition and intrusive investigations, and the preparation of demonstration reports.

Figure 1. The 30 ft pontoon boat shown towing the sensor platform during a survey on Ostrich Bay. The sensor platform is submerged about 7 ft below the surface.

For the tow vessel, we chose a 30-foot long triple pontoon boat manufactured by Crest (Figure 2). This is the maximum width boat that can be transported over the road without special wide-load permits. A 140-horsepower outboard engine was chosen for propulsion. Most of the furniture was stripped from the deck, and the deck railings were 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 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.

Figure 2. Side view of the Crest Triple platoon boat tow vehicle. The tow point is located at the stern of the boat, aligned with the master GPS antenna attached to the mast**.**

The sensor platform is towed by a 16- or 22-m cable attached to a custom tow point fixture located at the center of the boat at the stern (Figure 2). The maximum operational design speed is 5 knots. Assuming the system is used to survey 4-m wide lanes at 5 knots, the survey production rate is 3.7+ hectares/hr, or slightly less than 10 acres/hr. The attitude and depth of the sensor platform is controlled by an autopilot operating from a computer on the tow vessel (Figure 3). The inputs to the autopilot include a tactical-grade inertial measurement unit (IMU) mounted on the sensor platform (determining pitch, roll, and yaw of the platform), depth sensors and digital magnetic compasses on the platform and on the tow vessel, and a dual antenna GPS system on the tow vessel.

Figure 3. All sensor data are recorded by the computers in these data racks mounted across from the drive console, near the port rail.

The autopilot, which controls the sensor platform, can be programmed to either maintain a fixed standoff distance (altitude) above the bottom or to maintain a fixed depth below the water surface. This system provides a truly unique capability for underwater UXO search systems. The survey products include digitally geo-referenced magnetic anomaly maps of metallic objects buried in the bottom sediments. The full array of dipole-based target analysis capabilities developed for the Multisensor Towed Array Detection System (MTADS) ground survey systems was adapted for this application.

Figure 4. The tow vessel console is located on the starboard side. The pilot is responsible for maintaining the survey course and avoiding bottom obstacles.

The number of sensor systems operating and the complexity of the data streams far exceed any of the previously developed MTADS arrays. This required multiple computer systems on board, multiple data racks to accommodate them, and the full-time attention of a technician to monitor the data flow (Figure 3). The survey plan and the real-time survey course are displayed on the Pilot Guidance display shown immediately to the right of the steering wheel in Figure 4. The digital readout from the forward depth sounder is shown to the left of the steering wheel.

The primary Data Acquisition (DAQ) System computer operates a version of the Geometrics Maglog® software adapted for this application. Maglog has been the primary DAQ graphical user interface (GUI) for all prior MTADS platforms. The sensors from the marine platform, except the EM68, are recorded in this utility. The GPS data and the depth sounder data are recorded using this GUI.

A new GUI was developed in Strategic Environmental Research and Development Program (SERDP) Project UX1322 to allow us to control and monitor the sensor platform behavior; it is extensively described in the SERDP UX1322 Final Report. 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. In this mode, the elevators are driven to their full up stops and held there until the platform ascends to 0.5 m below the surface. This mode is intended for use if we observe a bottom obstruction that is likely to cause an impact with the sensor platform.

The sensor platform is a 5 m wide fiberglass structure, which basically has an airplane wing cross-section. Figure 5 shows an image with the hatch covers removed. In this image several of the sensor components are identified. The sensor platform accommodates 8 cesium vapor full field marine magnetometers on a 0.6 m spacing and an electromagnetic EM array consisting of a 1×4.5 m transmit coil and four 0.5×1 m receiver coils.

Figure 5. The marine sensor platform with hatch covers removed. Many of the system components are identified.

We designed and installed a breakaway link in the tow cable (shown in Figure 2), which parts at 1100-lb tension in the event of a severe impact of the platform with some bottom structure. The electrical connectors from the tow cable to the bulkhead connector at the rear of the boat are designed to part at 50 lb; these cables can be wet re-mated.

The technology development was described in detail in the report of our initial demonstration, The MTA Technology Demonstration at the Former Naval Duck Target Facility and is summarized below.

The MTA system concept was developed in conjunction with Vehicle Control Technologies, Inc. (VCT), starting with support from SERDP Project UX-1322. We considered a wide range of platform design concepts and evaluated their potential performance against the top-level requirements in both static and dynamic hydro-code modeling studies. Design concepts included bottom-following platforms (sleds or roller designs), towed submerged platforms (with solid booms or flexible cables), and hybrid platforms dynamically suspended from a towed pontoon platform.

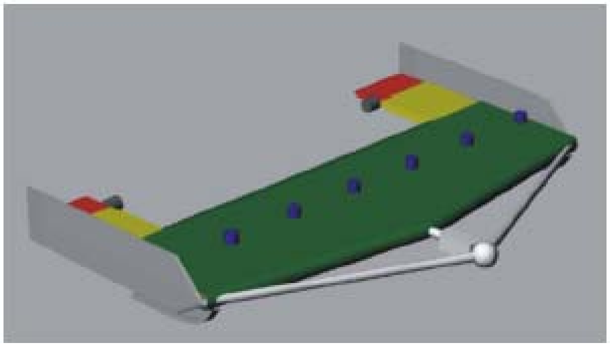

Figure 6. Perspective drawing of the 4-m sensor platform concept.

The preliminary design resulting from the concept study was a wing-shaped fiberglass structure (see Figure 6) designed to be towed from a position well forward of the wing using a flexible tow cable. Pitch stability is provided by the wing extensions (yellow). Weighted skids on the bottom of the platform 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. The elevators are controlled by two actuators (gray). The EM array is embedded in the structure; the magnetometers are in bottles (blue) that extend above the top of the wing surface and area covered by cowlings.

The concept design is shown in Figure 7, which includes general descriptions of the positioning sensors required to derive the coordinates of the individual sensors. The precise descriptions of the different positioning sensors are discussed in various SERDP project 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, ψc, in Figure 7. The contributions to the complete positioning error budget were treated in a separate study, which was continually refined as the individual component choices were made and their performances evaluated. At the end of the SERDP project, we predicted 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.

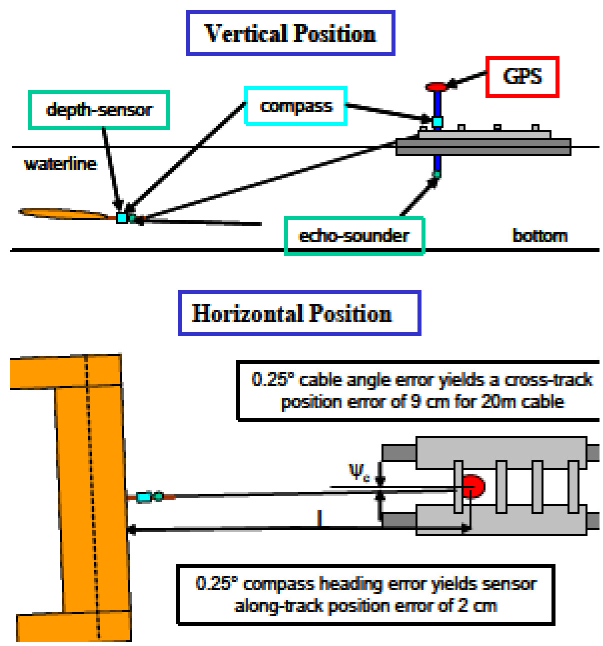

Figure 7. Sensor platform deployment concept resulting from SERDP Project UX-1322.

Most of the actual development work on the MTA took place during the ESTCP Project MM2003-24. Structural Composites, Inc. (SCI) joined the effort at the beginning of the ESTCP project. Working with the sensor platform concept designs and the results of the system hydrodynamic performance modeling, we developed a preliminary engineering design. This design was submitted to a finite element analysis to validate the predicted system performance and to refine the planned system design. Following the final system design review, SCI was contracted to manufacture 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 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.

Selection of the individual system components either flowed logically from the requirements developed in the modeling and engineering design studies or resulted from testing 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, while they were both operating.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The MTA system 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 MTA is a very complex R&D system. It is likely too electronically complex, too heavy, and too expensive to be a competitive commercial instrument as it is currently configured. However, we have learned enough from its design, performance, and operation to design a field-worthy prototype that would likely weigh 60-70% less and be self-contained and transportable with the tow vessel on a single boat trailer.

Mechanically, we currently recognize two shortcomings of the system. It requires the use of an improved boat launch ramp to deploy and recover, a problem in many marine areas. Because of the way the Currituck Sound is used in Duck, it was a significant challenge during our first demonstration. Because suitable facilities were not available, 2-3 hr of survey time was lost each day deploying and recovering the system. Very shallow water access and egress from marinas is an additional problem, as are very narrow access and turning requirements that are not compatible with the MTA with the sensor platform design.

A similar situation pertained to the Ostrich Bay demonstration. The closest marina with full capabilities for lifting and launching the MTA tow vessel with the sensor platform on the deck was in Seattle, 20 miles from the survey site. The MTA tow vessel was launched and driven at high speed to Silverdale where it was mated with the sensor platform. The Silverdale marina has an excellent boat launch ramp and docks; however, it is 6 miles from the survey site.

We therefore set up mooring buoys in Ostrich Bay adjacent to Pier II where the completely assembled MTA was moored each night. The only way that repairs could be done (if they required removing the platform from the water) was to ferry the entire system to Silverdale. Several repairs were made in the water at the mooring site using a diver in Ostrich Bay. As a result of our shakedown studies, we decided using our current hoist system on the MTA tow vessel was unsafe to launch and recover the sensor platform from the deck of the boat while it was in the water. This situation could be remedied; however, it will require a significant system redesign, which we have not undertaken. For the foreseeable future, the sensor platform will be transported (and launched and recovered) using a second boat trailer.

Developing a new attachment on the tow cable permitted us to deploy a 22-m cable, which allowed significantly extending our surveying capability into deeper waters. We were able to survey all areas in Ostrich Bay (except for a very small area southeast of Erland Point) by judiciously choosing the correct part of the tide cycle for working in deeper areas.

The cow catchers on the front of the platform serve to protect the leading edge of the platform from collision damage with boulders and broken off pilings. These fixtures are effectively sacrificial; a significant collision causes serious damage to them. Sometimes they can be repaired; however, either repair or replacement costs run about $800 each, requiring us to carry several spares.

4.0 PERFORMANCE OBJECTIVES

Unlike our first MTA demonstration in Duck, NC, our survey operations on Ostrich Bay were not directly coupled with an ordnance recovery operation. Our operations with the MTA were part of the larger site characterization and remediation project being conducted on land and on Ostrich Bay. The design and installation of a seeded target POS was sponsored by NAVFAC EFA-NW and implemented by NEODTD. Limited target investigations and removals were undertaken during subsequent phases of the EFA Northwest Project several months after the MTA survey concluded.

Our objectives in the 2006 MTA survey were focused on conducting an efficient and high-quality marine UXO survey of Ostrich Bay. We understood that additional geophysical marine ordnance surveys would be conducted by other commercial firms before any diver investigations and recovery operations were undertaken. These additional surveys allowed the MTA to be evaluated against other developing technologies. We also understood that the identity of the seed targets in the POS, their locations, and our detection performance on the POS would not be available to us until the diver investigations were completed and the NAVFAC report of these activities was published.

Tables 1 and 2 below show the Qualitative and Quantitative Demonstration Objectives that were defined in the Demonstration Work Plan. The right column in each table has been filled in with information evaluating the system performance relative to each of the planned objectives.

Table 1. Quantitative performance objectives for the 2006 MTA survey of Ostrich Bay.

Performance Objectives	Metric	Data Required	Success Criteria	Results
Magnetometry survey production rates	Measured and reported as hourly and daily survey rates and also fraction of day actually taking survey data	Survey area covered, time to complete survey	6 acres/hr while surveying in the open water areas	Overall survey rates in all areas was 3.2 acres/hr.
EM survey production rates	Measured and reported as hourly and daily survey rates and also fraction of day actually taking survey data	Survey area covered, time to complete survey	6 acres/hr while surveying in the open water areas	EM survey production rate on POS was 1.7 acres/hr.
Target location accuracies	Average error in position for detected targets	Location of seeded items	±35 cm overall while surveying with the short cable, ±60 cm when surveying with long cable	Accuracies were nearly equivalent with either cable. MTA location accuracies were better than target installation and reacquisition accuracies.
Survey coverage/missed areas	Measured using course-over-ground plots	Course-over-ground plots	In areas intended for complete coverage, >95% coverage to be accomplished	This was easily accomplished using fill-in surveys as required. This is described in other tables.
Depth station keeping	Percent of time maintaining depth	Depth measurement from sonar altimeter	Command depth (or altitude) to be maintained within 0.15 m 95% of the time	This was accomplished. Difficulties arose when command altitude changes could not be accomplished quickly enough to avoid bottom collisions.
Efficient performance and integration of ancillary components	Time lost or survey integrity compromised because of GPS, DIDSON*, boat-mounted depth sounders, or the pilot guidance system performance	Production log book	Maintain 6 acres/hr survey rates	Survey rate was 3.2 acres/hr.
Achieve detection goals for individual targets	Mag and EM sensors to be evaluated against the emplaced POS targets and the two sensors performances to be measured against each other	Ability to detect targets in the POS	All targets labeled as large or very large in the POS work plan to be detected	Target detection performance on the POS is described in the report text.

*DIDSON = dual frequency identification sonar

Table 2. Qualitative performance objectives for the 2006 MTA survey of Ostrich Bay.

Performance Objectives	Metric	Data Required	Success Criteria	Results
Pre-establish necessary support logistics	Time lost during demonstration to correct deficiencies	Production log book	No time lost to logistics	Accomplished
Efficient boat and survey platform deployment and recovery	Time lost at the beginning and end of each day to deploy and secure the system	Production log book	Minimal ferry times and time to deploy and secure system	Accomplished
Provide system support and communications while at sea	Lost survey time to correct problems	Survey log	Minimal time lost while communicating to the chase boat	Accomplished
Preprocess data and create mapped data files	Preprocess and correct survey data	Mapped data files	Accomplish overnight for quality assurance purposes	Accomplished overnight in all cases
Perform target analysis and prepare dig lists	Target analysis completed in preparation of reports to support intrusive work	Production log book	Accomplish within 2 weeks of survey	POS analysis completed on site; full bay completed on time
Detect POS targets	Percent of POS targets detected	Ability to detect calibration targets	Detect all targets labeled as large or very large in the POS work plan in mag and EM datasets	Target detection performance on the POS described in the report text
Pilot guidance system provides capability to achieve survey goals	Evaluate performance with course-over-ground plots in varying sea stats and weather conditions	Production log book	Minimal missed areas due to changes in weather conditions	Pilot guidance system effective in all survey conditions
Conduct an efficient EMI survey	Measure EMI survey performance and detection capability against the magnetometer survey performance.	Survey log	Ability of EMI system to detect the same objects as the magnetometer system	Failure of EMI after survey of POS
Successful performance of the imaging sonar	Evaluate performance with imaging areas around piers and moorings.	DIDSON video files	Ability to use DIDSON video files to identify underwater objects	Pillings around pier recognizable

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5.0 SITE DESCRIPTION

The second field demonstration of the MTA was on Ostrich Bay adjacent to the current JPHC and the NHB. This area has an ordnance history dating back more than 100 years. The Archive Search Report, published in 2002, succinctly describes the site history. The brief description below was adapted from this document.

5.1 SITE LOCATION AND HISTORY

The NAD Puget Sound was established in 1904 on 255 acres on the western shore of Ostrich Bay, 2 miles northwest of Bremerton, WA. Initial operations at the depot involved storing smokeless and black powder and producing relatively small caliber (3 in and 4 in) naval gun ammunition. In 1916, the facility was commissioned as the Naval Magazine Puget Sound; the depot then comprised 25 buildings, an ammunition-loading pier, and a narrow-gauge railroad to move materials around the facility. Over time the depot expanded to include more types of ammunition on the production line; high energy materials included Explosive D, TNT, and Composition A. When World War II began in 1939, the depot included 185 buildings with a work force of more than 200 people. At that time the production line produced ammunition ranging from 3-in to 16-in projectiles. The depot also stored large quantities of munitions that were not produced on site, including small arms ammunition and bombs. At the end of World War II, depot personnel had peaked at nearly 2000. After the war the depot use declined, and the newly-commissioned NAD Bangor become the main facility in the group.

Four piers were constructed and used during the history of the NAD Puget Sound to transfer explosive components and live ordnance back and forth between seagoing vessels and the facility and to support vessels awaiting dock space. Not being a deep water port, these transfers took place using barges (or lighters), which shuttled between the port and the ships docked at nearby deep water ports. Pier 1 was constructed prior to 1913 and was operational until 1959. It was demolished in the 1970s. Pier II was constructed in 1940 and was operational until 1959. A railroad transfer pier was also constructed in 1940. It was temporarily converted into a recreational fishing pier in 1982. The railroad pier has also subsequently been demolished. Piers I and II were used to unload ammunition and materials for manufacturing ammunition from barges using deck cranes. Ammunition from incoming war ships was unloaded onto barges, and the barges, or lighters, were piloted into the shallow waters of Ostrich Bay. During World War II, up to 200,000 lb of explosives were transferred each month using these three piers. The railroad pier was used to load and unload entire railroad cars from barges. Little or no ordnance was likely lost into the water during these operations. Figure 8 shows a historical photograph of the NAD complex and the features described above. The photograph is undated, but was likely taken in the late 1940s.

NAD Puget Sound was closed in 1959. In the years following closure, the size of the depot area was reduced by transfer of property to the General Services Administration (GSA) and sale of property to Washington State, Kitsap County, the City of Bremerton, and to private land owners. In 1975 the remaining property was transferred to the Puget Sound Naval Shipyard, renamed as the JPHC, and developed as high-density residential housing for military personnel. In 1977, 49 acres were transferred to the Naval Regional Medical Center, and the NHB was constructed on the site.

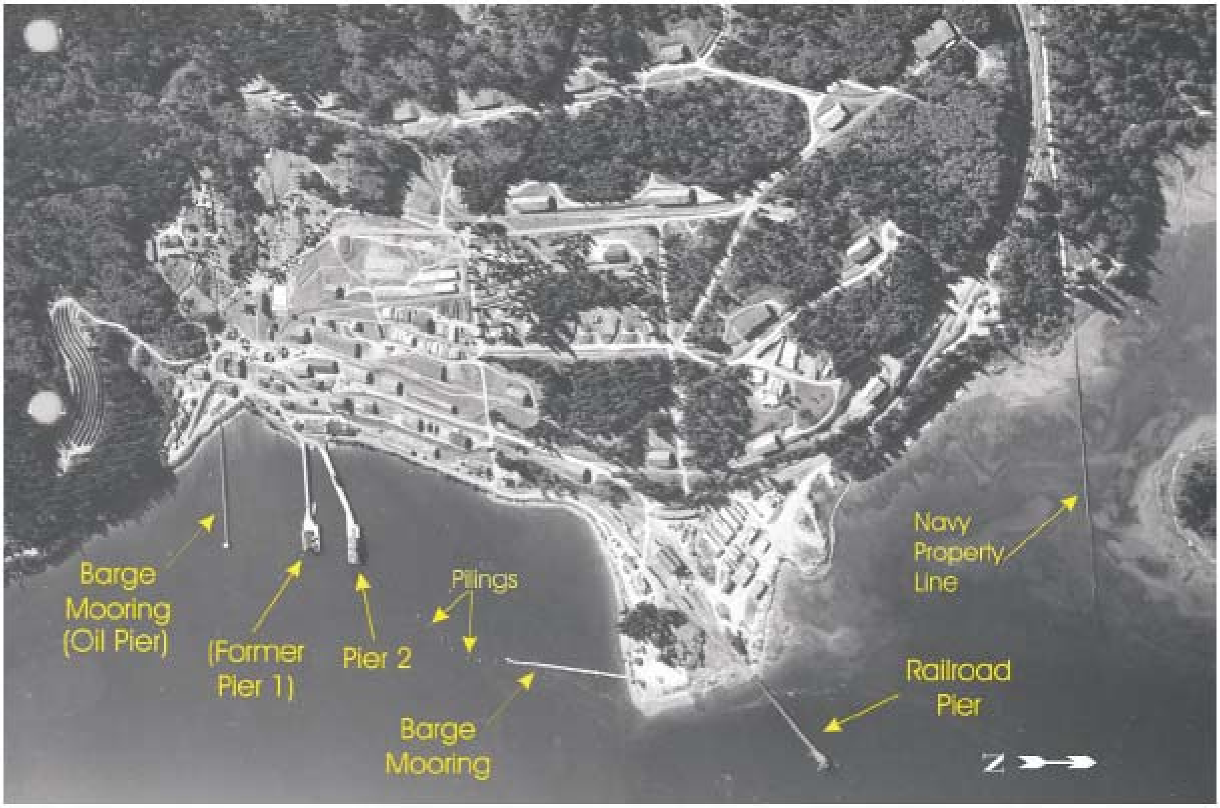

Figure 8. A part of Ostrich Bay adjacent to the Naval Ammunition Depot Puget Sound during the period of its peak operation.

All the labeled features except Pier 2 have been removed before our survey. Some of the pilings were broken off (above the bottom surface) rather than being removed.

Beginning in 1980, extensive ordnance cleanup activities were undertaken. These began on the bay to allow removal of many of the structures and to make the remaining structures safer for potential future uses. Following this work on the structures in the bay, the focus of the activities then moved onto the land where they remained for several years.

Most recently activities have been taking place in the bay again. In the fall of 1980 and the spring of 1981, Navy EOD divers conducted an extensive ordnance recovery operation in the area around Pier II and the dolphin piles to recover ordnance. Diver searches were conducted using jackstays or rods to probe the sediment every few inches. A total of 18,708 DMM items were recovered (summarized in Table 3). Of the nearly 20,000 ordnance items, only 58 were declared to be inert. Reports of the diver operations detail a total of 17,749 lb of DMM recoveries, with an estimated explosive weight of 3,877 lb.

The demonstration of the MTA is a small component of a larger set of studies and clearances that have been ongoing at the JPHC and the adjacent Ostrich Bay areas for nearly a decade. These operations have been conducted under CERCLA using two different types of actions: Record of Decision actions for OU-1 and a Time-Critical Removal Action for OU-3. In addition, limited investigations at the ammunition piers and in Ostrich Bay (within the Navy property boundaries) were conducted as part of the MEC clearance activities. The offshore activities are within OU-3M. The Final Archive Search Report and the Final Abandoned Ordnance Report, Volume 2, September 1999 to December 2001, document the historical record drawn on in preparation for the MTA demonstration.

Table 3. DMM recovered during the 1980-1981 clearance in Ostrich Bay.

Ordnance Description	Quantity Recovered
22 caliber cartridge	5
45 caliber cartridge	6105
45/70 caliber cartridge	15
30.06 caliber cartridge	973
50 caliber cartridge	1372
1.1-in, 75 caliber cartridge	29
20-mm high explosive (HE)	8022
Primers	245
Fuzes	142
Flares	102
Grenades	2
3-in propellant charge	2
5-in propellant charge	9
5-in training round	7
5-in/38 HE	41
MK 23 practice bomb	7
Hedgehog warhead	1
105-mm projectile (inert)	30
3-in/50 all up round	26
3-in/23 projectile	1
40-mm all up round	1554
100-lb general purpose (GP) bomb (inert)	1
500-lb GP bomb (inert)	11
1000-lb GP bomb (inert)	4
16-in projectile (inert)	2

During the first half of 2005, discussions took place involving NAVFAC Northwest, AETC, Inc., and the ESTCP Program Office exploring the possibility of the AETC MTA platform being used with the support of ESTCP to conduct a UXO survey operation on Ostrich Bay. AETC's active involvement began in late 2005 with preliminary studies that did not involve the MTA.

5.2 SITE GEOLOGY

Ostrich Bay is near the southern end of the series of bays, inlets, and marine estuaries that form the Puget Sound system. It is many miles from the ocean inlet, but because of very hide tides in the region (averaging 10-12 ft), the bays are filled and flushed twice each day and are fully marine. Species of concern in Ostrich Bay include killer whales and several species of fur-bearing marine life. The whole area is mountainous and of volcanic origin. The bottoms of the bays include areas very deep in homogeneous silt, and other areas have exposed outcroppings of bedrock. Magnetic geologic interferences are very localized and may be quite intense.

5.3 MUNITIONS CONTAMINATION

Our working premise in preparing for the MTA demonstration survey was that the ordnance expected to encounter would be described by the inventory of recovered ordnance from the 1981 clearance, which was conducted around the perimeter of Pier II. The range of ordnance recovered varied widely in size and type because the NAD Puget Sound was used for ordnance manufacture and assembly as well as a depot storage area for the Navy and Naval Air services.

Many of the ordnance types described in Table 3 are too small to be individually detected by the MTA during routine surveys. All the rifle and hand gun ammunition and the smaller military ordnance (including 20-mm, 30-mm, 40-mm projectiles and 50 caliber cartridges), are undetectable as single items by the MTA. The casings for these items are brass, and many of the full-up rounds contain little or no ferrous material. Following the EM survey of the POS, it was established that the remainder of the MTA operations would use only the marine magnetometers and therefore would be sensitive only to ferrous materials. We expected to be able to detect individual ordnance items equivalent to or larger than 105-mm or 5-in projectiles. Additionally, because of the manner that the smaller ordnance is assembled and shipped in clips or packed boxes, we expected to be able to detect groups (or clusters) of the smaller ordnance items.

6.0 TEST DESIGN

6.1 CONCEPTUAL EXPERIMENTAL DESIGN

The concept involved in the MTA UXO survey demonstration is quite simple and is basically described in the enumeration of the demonstration objectives in Section 3.1, Technology Description. In short, the intent of our demonstration was (1) to use the MTA to survey the POS and the Calibration Line and present results to NAVFAC showing that the MTA was qualified to conduct the remainder of the survey, (2) to use the MTA to conduct an efficient and comprehensive survey of the most likely MEC-contaminated areas of Ostrich Bay, and (3) to process and analyze the survey data and reduce it to a prioritized target list that NAVFAC could use to evaluate our success and subsequently use to remove potentially dangerous DMM from Ostrich Bay.

6.2 SITE PREPARATION

In the fall of 1980 and the spring of 1981, Navy EOD divers conducted an extensive ordnance recovery operation in the areas of Pier II and the dolphin piles to recover ordnance. These activities are described in Section 5.1, Site Location and History, of this report.

Figure 9. False color bathymetric image of Ostrich Bay overlaid on a recent aerial photograph of the area.

As part of the OU-3M study of the 79 acres of marine Navy property (to the 4 fathom line adjacent to the JPHC and the Naval Hospital), a bathymetric survey of Ostrich Bay was conducted in January 2004 (Figure 9). In November 2004 a sidescan sonar survey of Ostrich Bay was conducted as part of the same OU-3M project. Because GPS quality was typically Differential Global Positioning System (DGPS) or worse, the sum of the positional errors yielded an estimated positional accuracy of ±4 to 11 m. The report produces data clips of various bottom features. The stated purpose of the data was to provide future survey information that would allow them to avoid structural features.

The Naval Explosive Technology Ordnance Disposal Division, 2008 Stump Neck Road, Indian Head, MD, was chosen by NAVFAC Northwest to manage the installation of the POS to support future UXO survey activities. The document is titled "Work Plan for Marine Geophysical Prove-out Installation at OU 3M JPHC, Ostrich Bay." Using divers and surface support vessels, the installation activities were completed in April 2006. The specific locations of individual targets in each ordnance category was held confidential by NAVFAC Northwest until all potential users of the site completed their POS surveys. The Work Plan for the POS installation is included as Appendix E of the final report.

The installation of the POS and the performance of the two demonstrations at the site are described in the report "Ostrich Bay Underwater Geophysical Prove Out, After Action Report, Operable Unit 3 – Marine." This document in electronic format is also included in Appendix E of the final report.

6.3 SYSTEM SPECIFICATION

The MTA is an air foil shaped sensor platform that has two actuator-controlled elevators to control depth, altitude, and attitude. The sensor platform incorporates eight cesium vapor magnetometers (0.6-m horizontal spacing) and a time-domain EMI system with a single large transmitter coil and an array of four receiver coils. The sensor platform is towed by a 9.1-m pontoon boat (with a 22-m cable), which houses the DAQ and auxiliary electronics required for controlling and monitoring the sensor platform. We record all relevant data strings from the GPS antennas mounted at the bow and stern of the tow boat and the survey skiff. Maglog records the angular encoder information that determines the angle between the GPS antennas and the MTA tow cable. High-precision depth readings from the tow vessel and the sensor platform are recorded, as are the digital magnetic compass readings from compasses on the tow vessel and the sensor platform. The eight magnetometers are recorded by Maglog at 20 Hz. All output data from the IMU are recorded (positions, velocities, and accelerations for measuring platform pitch, roll, and yaw). All autopilot information (commands and calculated variables) are recorded by the autopilot computer. The pilot navigation computer measures the course-over-ground (water) and provides the output survey image for comparison with the planned survey course. Both this information and the water depth are displayed in real time to the boat driver.

All data preprocessing and cleanup were carried out using the Geosoft Oasis montaj suite of programs. Filtering was applied (as with all other MTADS data) to remove long-term sensor drifts, to null the zero levels of the magnetometers relative to each other, to remove (as appropriate) geological interferences, and to smooth electronic interferences. The only currently identified electronic noise is that from the actuator control cables. These occur at 15 Hz and are typically measured to be 0.1-1.0 nanotesla (nT) in the extreme port and starboard magnetometer data. These noise sources are apparent only on the two outboard sensors, which lie closest to the actuator cables. For comparison, helicopter rotor-associated noise (at 6.5 and 13 Hz) for the airborne MTADS varies between 2 and 20 nT, depending on the helicopter.

Fully corrected mapped data files are the output of the Oasis montaj processing steps described above. The default target analysis GUI is the MTADS Data Analysis System (DAS) that has been specially adapted for both the magnetometer and EMI data. The MTADS DAS is compatible with the Oasis mapped data files described above.

Following target analysis of the magnetometer data, dig lists were prepared. As with all target reports and dig lists, the analysis reports generated with this project contain complete descriptions of each target, including all fitting parameters and the analyst's observations and comments. Because the range of ordnance sizes on the site fairly continuously covers the size scale from 0.02 lb to 1000 lb, the predicted target size from our target analyses was of little value in differentiating between ordnance and non-ordnance.

6.4 DATA COLLECTION

In the final version of the Demonstration Test Plan, and in our agreement with the NAVFAC Site Manager, Mr. Mark Murphy, it was specified that we would first survey the POS and the calibration lane using both the magnetometer and the EMI arrays, process and analyze the data, and present NAVFAC with our analyzed results before beginning surveys in the remainder of the Bay. The POS was located in a 50×200-m area north of Madrona Point. The calibration lane was located along a N-S line about 110-m east of the western edge of the POS. Each site contained inert ordnance representative of those expected to be found in the Bay. The POS and calibration lane were installed by NAVFAC Northwest, working with EAC (a NAVFAC support contractor), the Bremerton EOD Detachment, and NEODTD who managed the installation activities. The Ground Truth in the POS was unknown to us until the NAVFAC Vendor Performance Document was released in final form.

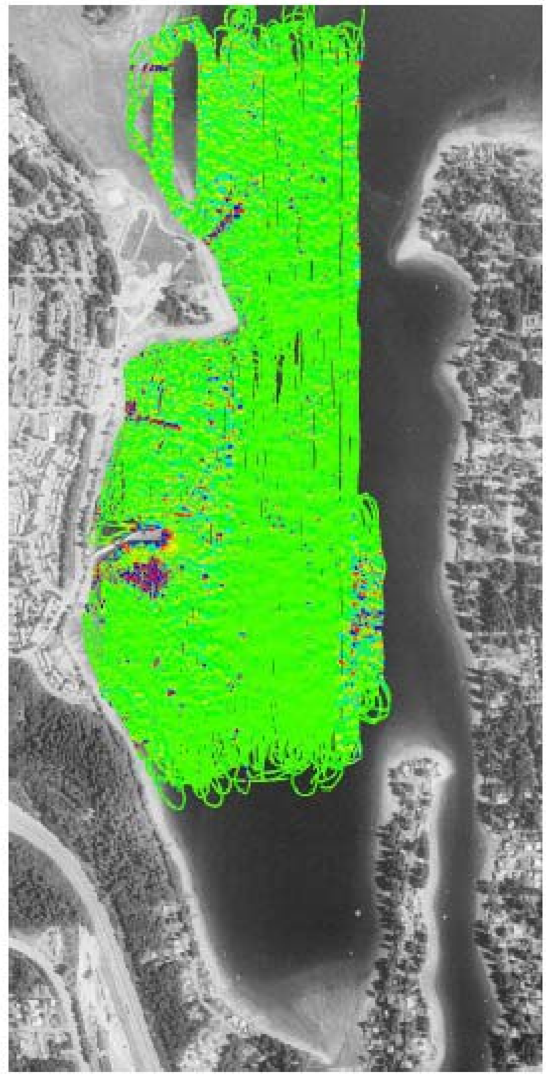

Figure 10. The MTA magnetometer survey superimposed on a recent aerial photograph of Ostrich Bay.

The daily log of our demonstration operations is shown in Table B1 in Appendix B. The log of the survey data files is shown in Table B2 in Appendix B. The magnetometer survey data for the bay is shown in Figure 10.

A total of about 214 acres of survey data were collected during 65 survey hr, based on the length of the edited survey data files. The EM array operated only for a short period of time while surveying the POS. The data quality was inferior, characterized by a high signal-to-noise (S/N) level. It was of minimal value in the POS analysis. No useful EM data were taken on the main survey site. When the sensor platform was pulled from the water, the EM interface box in the sensor platform was determined to be filled with sea water.

6.5 VALIDATION

Validation of the quality of the MTA Demonstration Survey was a two part process. The first step was the survey, analysis, reporting and performance grading of the POS. This was described and reported in Section 5.4.2 of the Final Report (see Tables 9 and 10). We were not aware of the specific performance (detection and location accuracy) of the POS survey until more than 1 year after all our work products had been submitted to NAVFAC.

The second component of the validation process was built around a diver investigation of 100 surveyed anomalies. We specifically describe in Chapter 6 of this report the data products that were submitted to NAVFAC and the techniques that were used to develop them. In general, we analyzed all anomalies from our survey data. All of those that might possibly conform to the characteristics of ordnance items (and additionally, many others) were included in our complete Target Report. We analyzed and classified targets in the report as to their probability of being intact ordnance. At the request of NAVFAC, we submitted a list of somewhat more than 100 targets that we recommended for investigation. This was labeled as our recommended Dig List. These spreadsheet products are included in the Final Report.

NAVFAC, working in cooperation with the EPA Region 10 representative, took our Target List and our recommended Dig List and independently developed their final list of 108 targets for intrusive diver investigation. The criteria for this selection process are also included in Section 7 of this report, as is our analysis of the results of the intrusive diver investigations.

7.0 DATA ANALYSIS AND PRODUCTS

The initial work products of the Demonstration were the analysis and reporting of the MTA survey results from the calibration lane and the POS. The data processing, target analysis, and preparation of the target lists and results were completed in real time following the surveys on June 18 and 19. The remainder of this chapter describes the work flow and processes used to accomplish these tasks. The POS analysis results were presented orally to NAVFAC (and EPA) in a briefing and delivered in written form to NAVFAC and the ESTCP Program Office on June 22, 2006. The ground truth for the POS was unknown to us until the After Action Report was released in Final Draft in April, 2007.

The target analysis for the entire survey was completed shortly after the survey, and the work products described below were submitted to the ESTCP Program Office and to NAVFAC to support the intrusive diver investigations. Details of this process are provided in Section 7.5 of this report.

7.1 DATA PREPROCESSING

Raw survey data were processed using Oasis montaj utilities and were available for inspection the morning following each day's survey. The techniques used to preprocess the raw data are equivalent to those that we have used for over a decade to prepare data from other marine surveys, from helicopter magnetometer array surveys, and from towed vehicular surveys. Data from outside the designated survey area are isolated, as are data from turnarounds and periods when the platform is not moving. The individual sensor baseline levels are correlated and a down-the-track smoothing filter is applied to the data. The data are leveled to a common null point (each time datasets are combined), and finally, the data are interpolated onto a (previously established) grid for loading into the target (anomaly) analysis software. Several other quality control (QC) checks are also applied each time a dataset is preprocessed. These include confirming that the appropriate layback values (associated with each cable deployment) are being used, that the angular encoder, platform yaw, and platform altitude values are correct and consistent. These are evaluated basically using data image inspections.

Course-over-ground plots and dipole image presentations of the data were prepared, which allowed additional QC evaluations to be made. Additional track files were prepared (as required) for insertion into the pilot/survey guidance display to allow resurvey of areas that were missed or areas where survey data quality were not acceptable.

Each day the master survey data file was updated to include all accepted survey data. The files were formatted for input to the MTADS DAS, at which time individual target analysis could begin. In this operation, separate master survey files were maintained for the POS survey, the calibration lane survey, and EM surveys. All remaining magnetometry data were incorporated into a master MTADS DAS data file. A landmark file was created from approximate coordinate positions tracking the Navy property line. This landmark file appears as a white demarcation line in MTADS DAS displays of the data.

7.2 TARGET SELECTION FOR DETECTION

The target analyses were carried out as two separate processes, one for the anomalies within the Navy property boundary and the second in areas of the Bay beyond the Navy Property boundary. The same evaluation criteria were applied to each dataset.

The MTADS DAS (version adapted for MTA analyses) was used for all target analyses in this demonstration. The MTADS DAS target fitting routine carries out an iterative fit of the sensor information in a data clip (defined by the analyst to encompass the visible anomaly) to a dipole signature. The input data to the fitting routine are based on three dimensional coordinates (the Universal Transverse Mecator [UTM] coordinates and height above ellipsoid [HAE] of each sensor reading) and the value of the sensor reading. This allows overlapping data from multiple passes of the sensor array (at differing heights above the bottom) to be appropriately considered. The fitting routine is also fully three dimensional, and the output of the fitting process reports the coordinate position of the center of the object (UTM coordinates and HAE), the apparent induced magnetic moment and the inclination and azimuth of the induced dipole, the fit quality of the dipole approximation, and a derived predicted caliber of the target (assuming a cylindrical shape with a length to diameter ratio of 4). Additionally, the maximum and minimum signal strength and the water depth at the target position are reported.

Following the initial fitting process, additional recorded sensor data from the vessel and the sensor platform are used to reduce the HAE value of the target fit to a burial depth of the object below the sediment surface. Before each target fit is logged, the analyst has the opportunity to record narrative observations relating to the target and a subjective numerical target classification approximation. In this demonstration, targets were classified on a four-point scale:

- One denotes a target with the highest probability of being ordnance.
- Two denotes a target that deviates from an excellent dipole fit but still has a good probability of being ordnance (perhaps it is located in a mildly cluttered environment).
- Three denotes an anomaly signature that strongly deviates from a simple ordnance dipole; it is unlikely to be ordnance but not conclusively so (it may lie in a highly cluttered field, or be mixed up with an overlapping signature from other nearby objects.
- Four is an analyst's declaration that the anomaly is conclusively not an ordnance item.

7.3 PARAMETER ESTIMATES

Based on the list of ordnance recovered from the UXO clearance around Pier II (Table 3) and on information provided about the targets included in the calibration lane (Table 7 of the Final Report) and presumably also in the POS, the ordnance size limits of interest varied from five different types of handgun and rifle cartridges to 1000-lb bombs and 16-in projectiles. As we have described earlier in the report, the individual examples of all the smaller cartridges, grenades, fuzes, etc are below the detection limit of the MTA with or without geological interference effects considered. Therefore, there are basically no threshold size limits that can be applied to filter targets from the list of potential ordnance items. The various parameter, display, analysis, and fitting options available to the data analyst for target fitting are discussed extensively in Section 7.2.

7.4 CLASSIFIER AND TRAINING

Classification of anomalies by probability of their being ordnance and by likely identity (size) was not done by any type of software-developed filter for data analysis in this demonstration. A single human analyst working with the MTADS DAS software utility analyzed all data and classified all targets using the parameters generated from the MTADS DAS anomaly fits and the additional available MTADS DAS analysis tools described above. Based on decades of experience, the analyst made subjective decisions and recorded the target classification decisions. The 1-4 scale (described above) was used for classifying the probability of analyzed targets being UXO.

Subsequent to submitting our data products (see Section 7.5), NAVFAC asked us to reclassify our analyzed targets based on the scheme shown in Table 9 of the Final Report. Table 9 was extracted from Reference 17, which was not available to us for more than a year after completion of the survey. At any rate, this size classification scheme was used to rank probable target size and is the one that ultimately was used by NAVFAC and EPA in developing the Diver Investigation List from our Target Reports and Dig Lists (see Section 7.5).

7.5 DATA PRODUCTS

In the Ostrich Bay magnetometry survey, many strong anomaly signatures were not analyzed (or at least were not reported as part of the Target Report). These included massively big objects that could not possibly be individual ordnance items; extended objects (likely pipes, cables, anchor chains, etc), and areas adjacent to piers that were so crowded with anomaly returns that they could not be sufficiently isolated for a meaningful analysis.

The Target Report for the Navy property contained 358 entries; the corresponding Target Report for the remainder of the surveyed area of the bay contained 273 targets. The Target Reports are included in Appendix F of the Final Report with file names of “Bay Side Target Report” and “Navy Side Target Report.”

We were encouraged to also prepare reports that included targets that we recommended for intrusive diver investigations. We submitted separate lists for each of the datasets (Navy Side and Bay Side). It was our understanding that the Navy intended to investigate about 100 targets. Our recommended lists are included in Appendix F of the Final Report with the file names of “Bay Side Dig List” and “Navy Side Dig List.” The Navy property dig list contained 65 entries, and the Bay Side list contained 58 entries.

Following submission of our inclusive Target Lists and the recommended Dig Lists, NAVFAC, working in conjunction with the EPA regulator, developed a final target investigation list for the divers to intrusively investigate. The Navy investigation list contained approximately half of our recommended Dig List targets and about half from our other Target Lists that did not appear on our Dig Lists. The Navy/EPA investigation list emphasized inclusion of smaller targets (independent of our classification scheme) presumably on the assumption that individual ordnance items were likely to be smaller (on the average) than the larger targets that dominated our submitted Dig Lists. The Navy/EPA list also included some targets from all areas of the survey. Our dig lists contained very few targets from the south end of the bay or from the bay north of Erland Point (except for the Railroad Pier).

Figure 11 shows the locations and distribution of targets that were chosen by NAVFAC/EPA for intrusive investigation. The targets appear as red (or yellow) circles overlaying the bathymetric map of the bay. Insets show expanded views of the former Oil Pier, Pier I, the Railroad Pier, and Pier II.

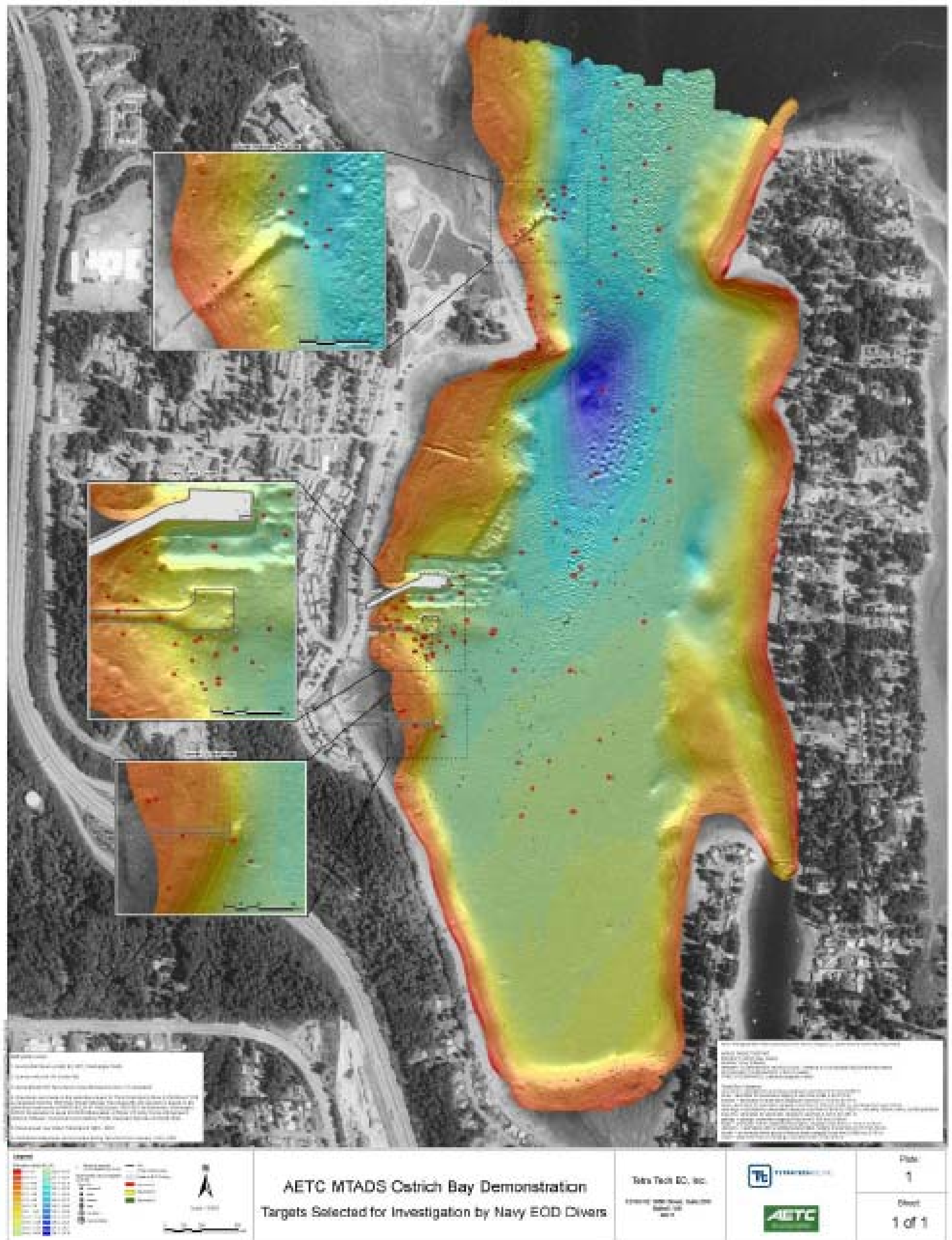

Figure 11. The targets chosen for diver intrusive investigation.

8.0 PERFORMANCE ASSESSMENT

The quantitative and qualitative performance objectives are enumerated in Tables 1 and 2. In Table 1, a specific descriptive response has been entered describing the performance relating to the individual objective statements.

Mobilization issues were complicated because we had to carry out the initial stage of the operation in Seattle (more than 20 miles from the work site) because this was the location of the nearest heavy boat lift to remove the boat, trailer, and sensor platform from the trailer truck that transported it to the West Coast. Fortunately, there was a straightforward (20 mile) access for driving the boat through Puget Sound to the Silverdale public marina where the entire system was assembled, launched, and driven 6 miles (towing the sensor platform) to the work site where it was moored throughout the deployment.

All the equipment component breakdowns during the demonstration (actuator cables, GPS antenna, and marine magnetometer malfunction) were associated with the trip on the truck to the West Coast. Each of these failures was addressed in Silverdale where the sensor platform could be put into the water for testing and pulled from the water for troubleshooting. One actuator cable was replaced with a spare from stock. A GPS antenna replacement was ordered for overnight delivery, and the magnetometer problem was corrected by performing modifications of the data acquisition software. The only other equipment failures during the survey operations were associated with sensor platform collisions with bottom structure, broken off pilings, or other obstructions. These were repaired with new cables or sacrificial “cow catchers” from spare stocks. No significant time was lost to make these repairs.

Overnight processing of the data allowed next day fill-in of missed survey areas or areas where the data quality was inferior. With two exceptions, survey coverage was effectively complete for areas that were surveyed. There were significant missed areas associated with surveying the dredge cuts around Pier II. The MTA system is not designed to abruptly climb into or out of the ditches with 12-15 ft high sheer walls. Additionally, there were a few areas associated with the small region southeast of Erland Point with incomplete survey coverage because the water depths were greater than 40 ft.

One of the primary objective criteria addressed the location accuracy of the MTA system. The two options for evaluating the location accuracy of our target predictions are to compare them to the locations of identified targets in the POS and the ability of the diver investigations to locate and identify the targets in our Dig Lists. In retrospect, each of these approaches is inappropriate. The POS target positioning accuracy goal was claimed to be 1 m. The ability of the EOD divers to reacquire targets in deep water is undetermined, but is likely no better than ±2 m. The historical accuracy of the MTA for determining target positions is accurate to ~25 cm with the magnetometer array and ~35 cm with the EM array. This is effectively independent of water depth.

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9.0 COST ASSESSMENT

9.1 COST MODEL

The cost model for this survey is based on the site preparation, mobilization, demobilization, and survey production costs. Per instruction for the preparation for this report, the breakdown of the approximate capital costs (as detailed in the Demonstration Plan) for developing and fielding the equipment are also included. The cost breakdown is shown in Table 4.

9.1.1 Capital Costs

The capital costs for the development and fielding of the equipment are approximations. They include SAIC labor costs, hydrodynamic and engineering design modeling, equipment component costs, component and system integration costs, and shakedown and testing costs. They do not include project management, project reporting, support facility costs, and other incidentals such as purchase of specialized equipment to support the development, license and permit fees, etc. The approximate capital costs for the development are $1.9 million. We estimate that a copy of the complete MTA system could be reproduced today for $0.8-1.0 million.

As of the writing of this report, the MTA system has supported six large-scale field demonstration surveys at ordnance/ammunition depots and former ordnance training and testing ranges. The repair and maintenance costs for the MTA have averaged about $10,000 per survey.

9.1.2 Site Preparation Costs

Site preparation costs are usually a substantial component of the MTA demonstrations. In this case, NAVFAC Northwest (in conjunction with NEODTD the Bremerton EOD Detachment, and NAVFAC subcontractors) prepared a marine POS and a marine calibration and test site. NAVFAC also resurveyed the GPS base station points and provided onsite office facilities and a secure storage area for our equipment.

Because the MTA survey operations did not directly support any target investigation or recovery operations, the demonstration survey was considered nonintrusive, which significantly reduced the requirements for developing a detailed health and safety work plan that would include MEC operations. An explosives safety submission was not required. The Health and Safety Plan (HASP) that was prepared addressed the typical operation of a vessel in protected waters and emergency diver intervention in case of MTA sensor platform accidents. The Demonstration Plan from the first MTA demonstration (on Currituck Sound) also reduced the development work for these support documents.

9.1.3 Mobilization Costs

Mobilization costs are based on preparation and shipping of all MTA support equipment from Cary, NC, to the Puget Sound demonstration site. Shipping was by means of dedicated trailer motor freight. This mobilization was unique in that it had to take place as a three-step operation. Equipment was motor freighted to Shilshole Marina in downtown Seattle where it was unloaded by a marina operator using heavy equipment (a large canvas strap lift system).

Table 4. Cost breakdown structure for the Ostrich Bay demonstration.

Cost Element	Data Tracked During Demonstration	Estimated Cost ($K)
Capital costs instrumentation	Capital equipment purchase	600.0
	Ancillary equipment purchase	200.0
	Equipment development, in-house	300.0
	Equipment integration/shakedown	400.0
	Software development	200.0
Site preparation	Evaluation trip	4.0
	Establish first-order GPS points	0.0
	Establish POS	0.0
	Establish moorings on site	3.0
	Develop HASP	5.0
	Develop/approve demonstration plan	10.0
Mobilization costs	Airfare	4.0
	Equipment prep and loading	2.8
	Equipment transfer (Cary to Seattle)	8.4
	Equipment unloading & transport to Silverdale	7.0
	Equipment setup/ferry to Ostrich Bay	7.0
Survey operation	**Item Costs**	
	Rental vehicles	3.7
	Chase boat rental	2.5
	Diver support	26.0
	Equipment spares used	6.0
	Misc. logistics costs	3.0
	Daily Costs	
	Daily labor support costs (4 men with per diem)	6.9
	Daily diver costs (boat gas, hardware)	2.5
	Incidental costs	1.6
	Total Survey Cost (19-27 June)	98.6
	Survey cost/hectare	1.1
	Cost/survey hour	1.5
	Number of survey personnel	5 (with diver)
Demobilization costs	Equipment recovery, prep, loading	11.0
	Equipment transfer (Seattle to Cary)	6.8
	Equipment unloading/transport to depot	5.5
	Equipment repair, component replacement	10.0
Survey products	Data processing	11.8
	Onsite meeting support	3.0
	Target analysis	3.0
	Survey graphics products	4.0
	Target investigation, diver support products	3.0
	Diver performance analysis	4.0
	Survey report	25.0

The MTA tow vessel was transported by water (20 miles to Silverdale Marina), and the remainder of the equipment was transported by box truck (with the sensor platform on a boat trailer) to Silverdale (50 miles). The MTA sensor platform and tow vessel were assembled, mated, launched, and tested at this marina and then were ferried about 6 miles to the prepared moorings adjacent to Pier II in Ostrich Bay where the equipment remained until survey operations were completed. The chase boat was used morning and night to transport the crew to another marina where we had access to our vehicles.

9.1.4 The Survey

The survey operation costs are broken out several different ways in Table 4, as required by the instructions. The active surveying took place over a period of 9 days, which included one rest day. Per diem costs were included for the rest day, but other costs were prorated over the 8 actual survey days. Four SAIC employees and one contract diver supported the survey. The diver was associated with the chase boat, except when he was supporting equipment repairs. One person was always on shore in the on-site office facility. He was responsible for processing raw survey data, conducting QC evaluations and running errands, as required, to support the survey vessel. The MTA vessel was operated with either 2 or 3 persons. When 3 persons were on board, two of them took turns driving the vessel, which is tedious, particularly when working in tight areas and on windy days with significant surface chop. The third person, when not driving, was typically involved in oversight, planning operations, monitoring deck conditions and fuel levels, etc. About one-half of the time, the third person (from the MTA vessel) worked on shore in the office carrying out target analyses, preparing presentation materials and graphics for progress reports to NAVFAC and EPA representatives or meeting with other stakeholders or visitors.

9.1.5 Demobilization

These operations took place as the inverse of the Mobilization process. The MTA system was ferried to Silverdale where it was recovered from the water, dismantled, loaded onto the boat trailer and into the box truck and transported to Shilshole Marina in Seattle. The MTA tow vessel was driven through Puget Sound to Shilshole and recovered onto the boat trailer. All equipment was loaded onto a dedicated 45 ft flatbed trailer and returned to Cary, NC where it was dismantled, repaired, and stored for the next operation.

9.1.6 The Survey Products

The cost of the various survey products are detailed in Table 4. The products themselves are described in the text of this report.

9.2 COST DRIVERS

The primary cost drivers for MTA surveys are the labor costs associated with the survey, the mobilization/demobilization costs, and the site preparation costs. In this demonstration, the site preparation costs and facility support costs were borne entirely by NAVFAC. The mobilization costs were substantial for this demonstration because of the complex multi-step deployment requirements. In fact, in all 6 of the MTA demonstrations, there have been no adequate launch/recovery facilities or docking facilities accessible to or near the work site. Our best partial remedy, which we learned in both the Currituck Sound and the Puget Sound demonstrations is that it is most convenient, efficient, and least expensive to moor the complete MTA system on the work site during the entire operation. In some cases, this required us to station security personnel on the vessel overnight, but that is much less expensive and time-consuming than long morning and night ferry trips with the deployed system.

It is our experience that the MTA system must always be deployed with a chase boat and a UXO-certified diver. In many cases, MTA operations take place many miles from a dock (or even the shore), and we have found that some repairs can be done in the water by the diver. We have also concluded that it would be unwise to undertake a survey operation with less than the five person crew who supported this operation. For a very short operation, a survey could be conducted by two persons manning the MTA vessel and one person in the chase boat. However, any operation longer than one day really requires someone on shore to monitor and process the data and a fifth person to think, plan, and provide relief to the vessel driver.

A performance improvement and potential cost efficiency could be realized if the sensor platform were redesigned to reduce weight by 50-60% and to allow it to fold or collapse so that it could be efficiently hoisted onto the deck of the tow vessel. The current system has proven to be impractical to launch from and recover to the deck when the vessel is in the water. If the sensor platform were easily and quickly recoverable, it would allow fast transport (15 knots [kt] rather than 2 kt) to and from the work site. In almost all cases, the marinas or docks that we have tried to work from have channel width or channel depth limitations that make it almost impossible to dock the fully deployed system. Tides or water levels often limit access to certain times of the day or to a limited set of weather conditions.

9.3 COST BENEFIT

It is difficult to evaluate the cost benefit of the MTA in comparison with other marine UXO survey approaches because there are no other comparable platforms available with which to compare. The MTA could be compared with other UXO survey technologies that provide similar quality survey products, e.g., three-dimensional mapped data files that support detailed target analyses; creation of survey graphics and GIS documents; and subsequent target relocation, investigation, and recovery operations.

The information provided in Table 4 for this demonstration shows that the MTA survey operations are less expensive than operating man-portable carts on land surveys (on a per hectare basis) and are similar in cost to operating MTADS-type vehicular towed arrays on land. The MTA and MTADS vehicular towed survey speeds are similar; the man-portable survey speeds are ~50% slower. The MTA array width is typically twice vehicular towed array widths and four times the man-portable cart survey widths.

The helicopter magnetometer arrays are much less expensive on a cost per hectare basis because of the survey speed and array width advantages of the airborne platforms. The MTA detection sensitivity is significantly better than the helicopter array because the sensors in the MTA are typically deployed closer to the land/sediment surface. The detection for the helicopter array is limited in the marine environment because it must remain above the water surface. The magnetometer separations in the MTA are 0.6 m while in the helicopter array the separation is 1.5 m. It should be pointed out that the MTA is still a pre-prototype demonstration platform and the other system costs are based on commercial platforms.

9.4 SURVEY COST COMPARISON

The per hectare and per hour cost for the surveys at Ostrich Bay, Lake Erie, and Blossom Point are shown below in Table 5. The Ostrich Bay demonstration was a total coverage survey, while the Lake Erie and Blossom Point surveys were conducted with relatively widely spaced transects. In blanket coverage surveys, a 4 m wide survey grid is used to guarantee complete coverage. In transect surveys, coverage is calculated based on the full 5 m width of the array.

Table 5. Survey cost summary.

	Ostrich Bay	Lake Erie	Blossom Point
Total survey costs ($K)	98.6	232.1	134.1
Hectares surveyed	86.6	265	187.5
Cost per hectare ($K)	1.1	0.9	0.7
Hours surveyed	66.4	85.7	56.7
Cost per survey hour ($K)	1.5	2.7	2.4
Hectares/hour	1.3	3.1	3.3

Both the Lake Erie and the Blossom Point surveys had a significant amount of work stoppage time because of equipment malfunctions and weather delays. The Ostrich Bay survey was basically trouble-free with only minor breakdowns. The costs per survey hour are based on hours during which surveying actually took place. The survey cost per hectare (which include the total time on the demonstration site) was the highest in the Ostrich Bay survey. Because this was a total coverage survey, a significant amount of time was spent for surveying relatively short lines and for turnarounds. The transect surveys at Lake Erie and Blossom Point were long, straight lines which are more efficient. A better metric for evaluating the productivity is hectares/hour. The two transect surveys were similar in efficiency and both had substantially higher productivity than the Ostrich Bay survey.

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10.0 IMPLEMENTATION ISSUES

The environmental issues associated with this demonstration took place within the ongoing remedial investigation/feasibility study (RI/FS) being conducted by NAVFAC Northwest under CERCLA guidelines. All operations were coordinated with and monitored by EPA Region 10 representatives. The MTA operations associated with this demonstration survey were non-intrusive and did not require permits or explosives safety submissions and were not subject to local environmental constraints.

All our activities were coordinated with NAVFAC Northwest and were conducted within the constraints of the NAVFAC operation plan and the ESTCP Demonstration Plan. Both plans were reviewed and approved by the Washington State Department of Natural Resources, the Suquamish Tribe, and EPA Region 10. All requests for information, site visits, and presentations to site visitors during the MTA operations were overseen and coordinated with Mr. Mark Murphy of NAVFAC Northwest.

The most likely end users of this technology are the commercial UXO service provider firms, in association with regional offices of the Naval Facilities Engineering Commands, the U.S. Army Corps of Engineers (USACE)/Huntsville and the Regional Offices of the Corps and individual DoD installation commanders. Other likely users include the various divisions of Navy and Marine Corps installation managers who are responsible for training ranges with marine UXO contamination problems. The results of this demonstration are being monitored by members of USACE, NAVFAC, the Naval Ordnance Safety and Security Activity (NOSSA) office, and the Engineer Research and Development Center.

The instrumentation used in this demonstration is a custom-built prototype. However, with a few exceptions, it has been constructed with commercial off-the-shelf (COTS) components. The unique components in the MTA are the fiberglass sensor platform, the tow cable and underwater electronics housings, the EM68 sensor, the pilot guidance display and software, and custom-designed printed circuit boards. Each of these components is fully documented and described in various reports and could be purchased from the original manufacturers.

The complete MTA system remains the property of ESTCP. It is housed and maintained by SAIC at our facilities in Cary, NC. It is operational and available to support other demonstration surveys sanctioned by ESTCP.

SAIC independently owns a limited amount of MTA-related equipment and could independently support certain types of limited marine UXO survey operations. SAIC is interested in and would support the creation of a fully capable MTA platform if an end user were identified that could provide enough work to justify the investment costs of fielding a fully capable privately owned system.

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APPENDIX A

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Bill Kelly	Gig Harbor Boat Rentals	253-858-7341	Chase Boat
Gloria Jones	Shilshoal Marina Seattle, WA 98117	206-728-3368 800-426-7817	Ramp to Launch Pontoon Boat
	Golden Gardens Park 8498 Seaview Place Seattle, WA	206-684-4075	Public Boat Launch
	Silverdale Marina Silverdale, WA		Ramp to Launch Sensor Platform
Joey Mills	Overnight Trucking Raleigh, NC	919-232-2200	Lift Pontoon Boat onto Flatbed Trailer
	Flagship Inn 4320 Kitsap Way Bremerton, WA 98312	360-479-6566 800-447-9396	

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