(ESTCP) 200417

Predicting the Mobility and Burial of Underwater Unexploded Ordnance (UXO) Using the UXO Mobility Model

INTERIM FIELD TEST REPORT (FRF Duck, NC)

Reporting Period: June 2005 thru October 2005

Contract N47408-02-D-8319

Task Order TO 0076, CDRL A007

February 2006

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE
February 2006

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
June 2005 – Oct 2005

4. TITLE AND SUBTITLE
Interim Field Test Report (FRF Duck, NC)

5a. CONTRACT NUMBER
N47408-02-D-8319

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Wilson, Jeffrey, V; McKissick, Ian; Daly, William; Jenkins, Scott, A; Devisser, Alexandra; Sugiyama, Barbara, M

5d. PROJECT NUMBER
MM-0417

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

Naval Facilities Engineering Service Center, 1100 23rd Ave Code OP411
Port Hueneme, CA 03043

Sound and Sea Technology, 11931 Maplewood Ave., Edmonds, WA 98026

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Facilities Engineering Service Center
1100 23rd Ave, Code OP411, Port Hueneme, CA 93043

Environmental Security Technology Certification program
901 N Stuart St. Suite 303 Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
NFESC, ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution Statement A: Approved for Public Release, Distribution is Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT The UXO Mobility Model which predicts the movement and burial of UXO in the marine environment is being demonstrated at two sites. The first demonstration is being conducted at the Army Corps of Engineers Field Research Facility in North Carolina. Demonstration design, field deployment, and preliminary results are discussed in this report**.** Although the FRF Duck Field Demonstration data have not yet been used to quantitatively calibrate and validate the UXO Mobility Model, the test to date has been successful. The following conclusions are based upon the data obtained to date: all surrogates were installed as planned and have been tracked for approximately 4 months, measurable movement occurred, generally within the range of initial predictions, test methods were refined and will be used for the remainder of the test period.

15. SUBJECT TERMS
unexploded ordnance, UXO, munitions, mobility, burial, underwater, predictive model

16. SECURITY CLASSIFICATION OF: U			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	U	61	**19b. TELEPHONE NUMBER** *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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LIST OF ABBREVIATIONS and ACRONYMS

Acronym	Definition
0817	Navy Pollution Abatement Ashore R&D Program
ADCP	Acoustic Doppler Current Profiler
ARAMS	Army Risk Assessment Modeling System
ASTM	American Society for Testing and Materials
CATEX	Categorical Exclusion
CFR	U.S. Code of Federal Regulations
CRAB	Coastal Research Amphibious Buggy
DEM/VAL	Demonstration/Validation
Det.	Detachment
DoD	U.S. Department of Defense
DMA	Defense Mapping Agency
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FRF	Field Research Facility
GPS	Global Positioning System
HASP	Health and Safety Plan
LARC	Lighter Amphibious Resupply Cargo
MB	megabyte
MCBH	Marine Corps Base Hawaii
MDT	Mugu Drifter Test
MMFT	Measurement Method Field Test
NAD	Navy Ammunition Depot
NAS	Naval Air Station
NFESC	Naval Facilities Engineering Service Center
NS	Naval Station
NWS	Naval Weapons Station
ONR	Office of Naval Research
NAVFAC Pacific	NAVFAC Pacific Division

QA	Quality Assurance
QAPP	Quality Assurance Plan
QAS	Quality Assurance Specialist
RAC	Risk Assessment Code
SAJ	Dr. Scott A. Jenkins Consulting
SCM	Site Conceptual Model
SEI	Sea Engineering, Inc.
SPAWAR	Space and Naval Warfare Systems Command
SST	Sound & Sea Technology
USACE	U.S. Army Corps of Engineers
USAESCH	U.S. Army Engineering and Support Center
UXO	unexploded ordnance
VSW	Very Shallow Water
VORTEX	Vortex Lattice Model

1. INTRODUCTION

This report is the first in a series documenting the Environmental Security Technology Certification Program (ESTCP) Unexploded Ordnance (UXO) Mobility Model demonstration. The objective of the ESTCP UXO Mobility Model demonstration project is to demonstrate and validate the UXO Mobility Model for two of the most important coastal classifications – Trailing Edge (east coast of the continental United States) and Biogenic Reef (typical of tropical island coastlines). The Trailing Edge environment typically has a very wide, shallow continental shelf area with heavy cover of silicon-based sands and sediments. Biogenic reefs typically have more irregular seafloor shapes crossed by channels with limited cover of carbonate sands.

The ESTCP UXO Mobility Model project is comprised of two field demonstrations. The basic approach is to place a series of surrogate 5”/38 rounds at known locations off the coast and track their movement using acoustic pingers and diver tracking systems, while also recording the local current and wave conditions. The observed movement is then compared to the Model predictions and the Model is thereby first calibrated and then validated.

The first Field Test – a Trailing Edge coast – is in progress at the U.S. Army Corps Of Engineers Engineering, Research & Development Center, Field Research Facility (FRF), Duck, North Carolina. The test was installed on 22 June 2005 and is expected to continue through the winter of 2005-2006. Measurements of the surrogate movements will be made approximately monthly or as weather conditions dictate. The surrogates will be recovered either when there are adequate data or after one year.

The second ESTCP UXO field demonstration will be conducted at a Biogenic Reef site in Hawaii. As of this writing the demonstration site is being moved from Keaau Beach back onto a military installation. Environmental reviews and permitting will extend past the winter season of 2006. Permits for the Pacific Missile Range Facility (PMRF), Kauai, are being pursued as backup. The general schedule now calls for the Hawaii installation to occur in about September 2006. That test will be reported by separate documentation.

This report describes the installation and initial measurements at the FRF Duck site on 22 and 27 June 2005, as well as the second and third round of movement measurements (12 August and 20 October 2005). Model calibration and validation have not occurred using these first measurements because the summer hurricane season produced no useable weather at the FRF Duck site. Despite the extraordinarily high number of extreme hurricanes this year (Katrina, Rita, et al.), they all migrated south of Florida and into the Gulf of Mexico instead of veering up the East Coast. As a result, after a small initial movement, the surrogates were buried by the accretion of the sand and have remained so as of late October 2005.

It is highly likely that the winter season will bring the usual Nor’easter storms. These events typically move south and produce several high-energy events (large waves) during the season and should provide ample data for the Model calibration/validation. In the interim, this report establishes the background for the tests, documents the installation, outlines the measurement process, and provides a preliminary discussion of the first few rounds of measurements.

1.1 Background

Sustainable range management and readiness are vital national security interests, yet are subject to increasingly restrictive regulatory oversight and public concern for safety. In addition to range sustainability interests, the DoD has additional responsibility for human safety and environmental stewardship for coastal ranges and for abandoned ordnance unintentionally left underwater as a result of historic military activities. In an effort to address these concerns, the Navy through its Pollution Abatement Ashore Program (0817) has funded a program to assess the environmental effects of underwater unexploded ordnance (UXO). A site conceptual model (SCM) was developed under this program and is included as Figure 1. This UXO Mobility Model program effort appears on the lower left side of the block diagram. After evaluating the SCM against existing scientific data and models, various data gaps were identified. One of these data gaps was the inability to predict the mobility and burial of UXO underwater. To meet this need, the Naval Facilities Engineering Service Center (NFESC) initiated a project to modify the existing Vortex Lattice model (VORTEX), which is used to predict mine mobility and burial. The new software is called the UXO Mobility Model. Because of the differences in size, shape, and weight from mines, UXO exhibit both variable responses to ambient coastal dynamics and diverse modes of mobility. The mine-movement model was modified to predict UXO mobility and burial in the underwater environment. By using the UXO mobility model, we can resolve the fate of UXO over the broad range of coastal diversity where UXO are known to exist. Additionally, mobility information can be used as part of a risk assessment by identifying the areas and entombment depths likely to contain UXO, thus reducing costs associated with fieldwork focused on physically locating or clearing UXO items. The ultimate goal is to be able to incorporate UXO mobility and burial model output data into a risk assessment model similar to the Army Risk Assessment Modeling System (ARAMS).

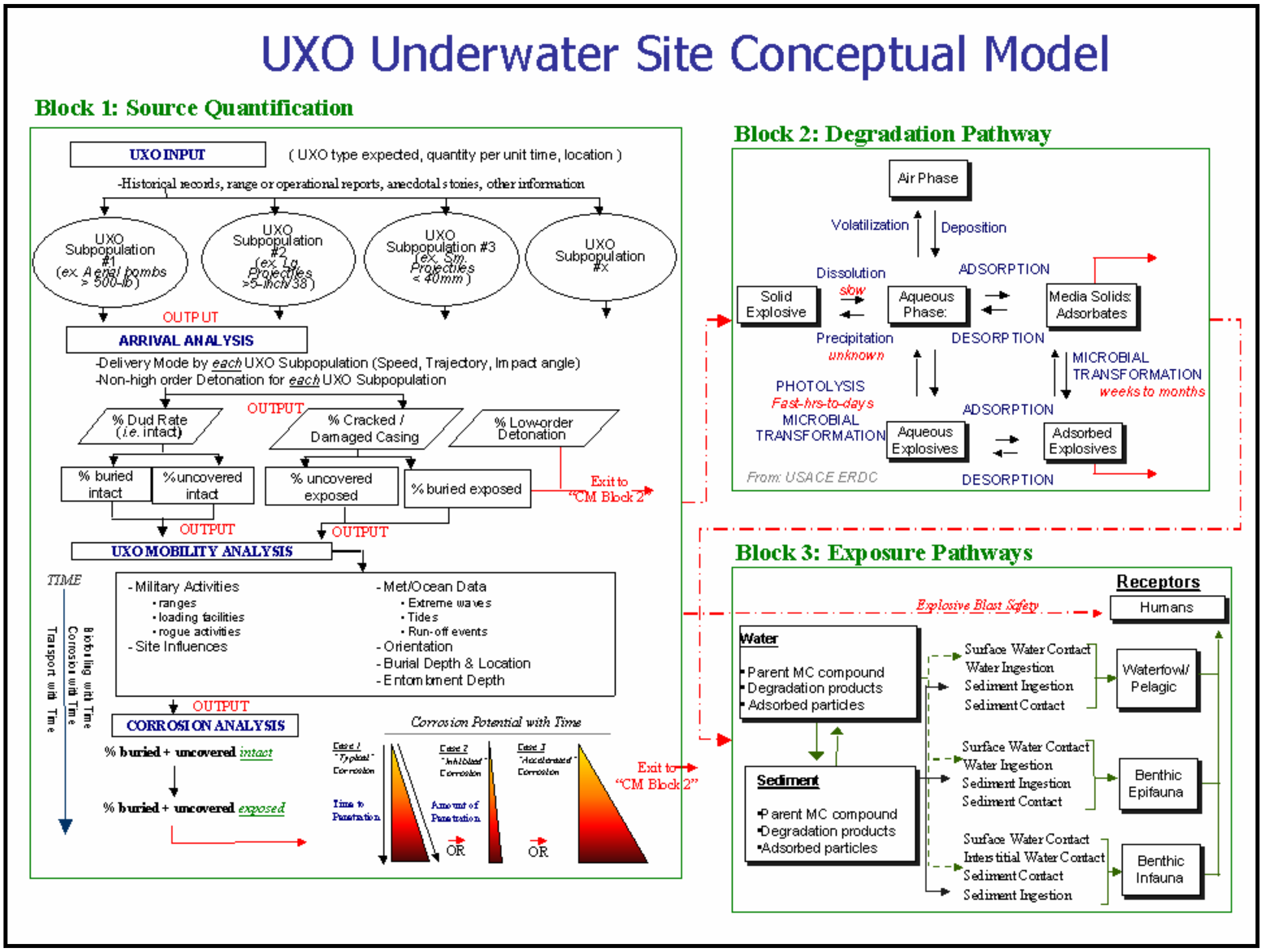


Figure 1. Block diagram of the Site Conceptual Model for UXO.

A preliminary search of significant Navy coastal UXO sites allowed for 23 locations in the United States to be identified as areas in which underwater UXO are highly likely to exist. Using the generic coastal classification system incorporated in the UXO Mobility Model, the sites were categorized with respect to the influence of tectonic plate movement on coastal evolution (Jenkins and Inman, 2002). The sites can be assigned to generic classes of open ocean coastlines characterized by shelf depths, slopes, bottom materials, and dynamic wave environments. There are four coastal categories, which are augmented with sub-category designations: collision (U.S. West Coast), trailing edge (East Coast), biogenic carbonate (Hawaii), and marginal seas (exposed coastlines and embayments). The modified VORTEX model can predict UXO exposure, mobility, and burial with respect to ordnance type and location (i.e., sediment characteristics or coastal classification and local waves/currents) for various marine environments.

The Navy's 0817 Research and Development program developed the UXO Mobility Model software, initiated a limited validation test at a single collision coastal site adjacent to Mugu

Beach, and conducted a series of Measurement Method Field Tests (MMFT 1 and 2) on the coast of Ocean Shores, Washington, in September 2004 and May 2005.

The Mugu Drifter Test (MDT) used only small-diameter UXO (20mm rounds and surrogates). It served as a surrogate for UXO sites belonging to the collision coastline sub-category, one of the eight coastal sub-categories given in the Geomorphic Coastal Classification system (Jenkins and Inman, 2002). It validated the expected movement of small UXO in a large open coastal movement area (the Santa Barbara cell), which tends to move small UXO offshore like sand.

The MMFT at Ocean Shores used only larger UXO (5”/38 inert and surrogate rounds). MMFT was a short-term test intended primarily to validate the effectiveness of two measurement methods for tracking UXO movement (physical tethers and acoustic pingers). The test also provided a calibration for the part of the Model that addresses the high-energy breaking surf zone, again on a collision coastal beach.

The Navy program developed the UXO Mobility Model and completed short term, surf-zone validation for just one coastal type. To be useful to DoD planners, the model must be validated for the remaining major coastal types. The data acquired from such validations will enable users to operate the model either with very limited site data (Mode 1, coastal classification only) or with various levels of site-specific data inputs (Mode 2 or Mode 3). Choosing one of the three modes also depends on the user’s desire to make site-specific adaptations to the model’s configuration.

1.2 Program Performance Objectives

The UXO Mobility Model ESTCP demonstration/validation program has two types of performance objectives (Table 1):

a. The performance objective of the field test program itself is to collect the needed data to validate the UXO Mobility Model at two coastal classifications.
b. The performance objectives of the UXO Mobility Model, are to
    - support the field test planning by using uncalibrated predictions to help design the tests,
    - accept the input data from the field tests, and
    - calibrate and validate with either the skill factor, R, or the coefficient of determination, r^2, > 0.8.

Table 1. Performance Objectives.

Type Of Performance Objective	Primary Performance Criteria	Expected Performance (metric)	Performance Objective Met? (*future*)
Qualitative	Model proves useable by engineers other than software creators.	Review by NFESC – selected panel including Navy, Army, and support contractors concludes software is transferable to other users.	
	Model provides credible predictions of movements in support of test planning.	Predictions check against general engineering theory and observations at similar sites.	
Quantitative	Field Test collect sufficient quality data to allow validation of Model	> 50% of test samples are tracked successfully at each site. Movements are measured within +/- 10%.	
	Model validation shows good match between predictions and measurements, with coefficients correctable to positive match.	Either R or > 0.8, for a given site.	

Qualitative Measures. The organizations that will make up the panel will be defined according to the availability of stakeholders at that time. Given the specialized nature of the UXO Mobility Model, however, it is likely that the most cost-effective way to apply the Model will be for NFESC and support contractors to remain the Center Of Expertise in this area. This schema ensures model continuity beyond the specific engineers who developed the software and yet does not incur the expense of refining the software to a more generalized, user-friendly format. This Center of Expertise will then be available to organizations seeking to use the software to evaluate an operational site.

Quantitative Measures. These measures will be applied by the NFESC/SST team and then reviewed by the beta test panel.

1.3 Field Test Demonstration Method

This ESTCP project encompasses the calibration, demonstration, and validation needed for two geomorphic coastal category/sub-categories. The overall objective of this project is to demonstrate and validate (DEM/VAL) the UXO Mobility Model, which incorporates specific UXO characteristics (e.g., shape, size, weight, and center of gravity), dynamic coupled processes, and seafloor material properties to predict UXO exposure, mobility, and burial. This will be achieved by comparing model predictions to actual movements measured during two field tests.

The first field test site is in a Trailing Edge environment on the East Coast of the United States, at the U.S. Army Corps of Engineers Field Research Facility (FRF) located on the Atlantic Ocean near the town of Duck, North Carolina.

The FRF site is characterized by a long shallow slope to the Continental Shelf and is exposed to Nor'easter storms in the winter and hurricanes in the summer. The environment at this site is well documented and there are excellent support facilities (e.g., pier, crane, instrumentation, etc.). The Army and Navy have both used this site for beach studies and mine movement tests.

The second field test will take place at a site characterized by a limited cover of carbonate sands and, therefore belonging to the Biogenic Reef category. The results of that test will be documented in a separate report.

Together these demonstrations will provide data to calibrate and validate the model for the majority of the identified UXO sites in the U.S., including the highest profile sites. Most of the remaining sites are embayments and harbors such as Mare Island, CA, where energy levels are low. In those areas, UXO rarely moves relative to the coastline. Thus, modeling efforts for UXO located at this type of site would focus on modeling the rate of sedimentation (or excavation) by employing models for sediment transport that already exist.

At each field site, a series of UXO surrogates are placed on the seafloor in various orientations and water depths. Their location, depth of burial, and orientation are then monitored by diver inspections at intervals determined by the occurrence of high-energy environmental events (storms or local big surf). The samples are left in place through the local seasonal cycle, or until they have moved out of the test area, whichever comes first.

The 5"/38 surrogates are installed at pre-planned distances from the shoreline from the closure depth to just seaward of the low tide line. By then plotting the actual movements of each individual surrogate it is possible to look at trends as a function of location with respect to the surf zone, weather forcing function conditions, local sediment properties, etc.

The 20 mm surrogates are initially placed in small groups near the 5”/38 surrogates. The 20 mm surrogates are not individually tracked, but are located and collected when they appear on the beach, or as they are found during the other measurement processes. The 20 mm surrogates are only used at the FRF Duck site.

The location of the 5”/38 surrogates is tracked by a variety of methods. The larger surrogates (5”/38) are equipped with acoustic pingers and have large metal cores. Divers use hand-held receivers, as well as a Benthos fixed acoustic tracking system to track the surrogates. Metal detectors are used to further locate the surrogates in conditions of poor visibility or when they are buried. The location is measured from fixed references by employing acoustical methods, GPS to surface floats, and tape measures, depending on the local conditions at the time.

The primary metric for a successful field test is to collect data on the movement of all or most of the UXO surrogates and to document the environmental conditions that caused those movements (e.g., currents, waves, and seafloor properties). The primary metric for defining a successful UXO Mobility Model validation effort is that the observed movement matches the predicted movement well enough to allow final adjustment of the model parameters to match the observations without changing the basic structure of the model (i.e., assumptions of basic forces and interactions would remain unchanged). The details of the model calibration and validation process will be described in more detail in the ESTCP Final Report, which will be prepared after the final set of measurements are taken and the surrogates are recovered.

1.4 Test Hypotheses (expected outcomes)

This demonstration provides the data required to determine the next steps in the application of this model. Four possible outcomes of the ESTCP Field Tests are listed as follows:

a. Field observations at both sites match predictions within the error bounds of the movement and environmental measurements (i.e., within 10 to 50 percent). Measurements falling within these error bounds signify that the UXO Mobility Model is fully validated for the sites of interest and the theory is sufficiently sound to warrant using the model in all three modes of operation at other coastal classification sites. No further model modifications or dedicated field tests would be required in this instance.
b. Field observations match model predictions well at one site, but not the other. That outcome would imply that the Model is useful for some coastal classifications, but requires further development for others. In that case, extrapolating the model to all coastal classifications would not yet be warranted.
c. Field observations loosely correlate with model predictions for both sites. The data indicate that some of the observed behaviors are not included in the model, which would suggest that the model itself requires additional development and re-testing.
d. There is no clear statistical correlation between field test results and model predictions, thereby leading to the conclusion that the model is not applicable to UXO. In that case, another approach would be required.

The expected outcome for ESTCP field tests is (a) or, possibly, (b). The general success of the early Navy program tests suggests that the negative results of outcomes (c) and (d) are very unlikely. The previous validations of the VORTEX model for mine shapes (including the bomb-shaped versions), the supporting tank test validations from which the theory was derived, and the limited initial validations from the Navy MDT and MMFT all show that the UXO Mobility Model is essentially sound and ready for final field validation.

1.5 Selecting Test Site(s)

The two test sites for the UXO ESTCP demonstration/validation program were selected primarily because each represents a broad class of coastal environments in which underwater UXO is found. The initial phase of the Navy UXO Mobility Model program funded an extensive literature and web search, in addition to gathering information contained in reports by the Environmental Protection Agency (EPA) (2000), Tucker (2003), Jarrah (2001) and the United States Army Engineering and Support Center (USAESCH) (2003), and lists of currently active Naval coastal facilities and closed/transferred facilities (EPA, 2000). This effort identified the sites where underwater resident UXO are highly likely to exist (Hammond et al., 2003). Those sites are enumerated below in Table 2.

Table 2. Potential UXO Sites.

Coastal Ammunition Loading Sites
- NAD Indian Island, WA
- NAD Seal Beach, CA
- NAD Det. Concord, CA
- NAD Det. North Island, CA
- Ex-Naval Ship Yard Mare Island, CA
- NWS Yorktown, VA
- NWS Charleston, SC
- NWS Mayport, FL
- Ex-NAD, Jackson Park, WA (former NAD with continuing UXO problems)

Coastal Live Firing Ranges
- San Clemente, Island, CA (heavy past usage and still active at reduced levels)
- San Nicholas Island, CA (old gunnery range now used for missile testing)

Formerly Used Live Firing Ranges
- Kaho'olawe, HI (heavily used naval gunnery, bombing and ordnance test site)
- Vieques Island, PR (heavily used naval gunnery, bombing and amphibious exercise site)
- Culebra Island, PR (40 years of use as gunnery and bombing range)
- Normans Island, MA (WW II gunnery and bombing)
- Hingham Island, MA (WW II gunnery and bombing)
- Panama Canal Zone (multiple formerly used defense sites)

Salton Sea Test Range, CA (former navy inland sea small caliber firing range)
Ex-Naval Station Adak, AK (extensive UXO of all types)

Operational Bases with Potential Underwater UXO

Marine Corps Base Hawaii, (Kaneohe)
NWS Dahlgren, VA
NS San Diego, CA
NAD Earle, NJ

Furthermore, representatives of the Army Secretariat For The Environment contacted this program in January 2006 to express their interest in using the UXO Mobility Model to assess the stability of a large UXO dumping ground located in 30 to 150 feet of water off Waianae Sewer Outfall.

Though Table 2 is a not an all inclusive list, it is typical of the shallow and very shallow water regions necessary for establishing representative coastal scenarios for comprehensive computer modeling of subsurface UXO movement and burial. This study assumed that ordnance at deeper depths (> 40 ft or the local closure depth, if greater) is permanently and safely entombed. This is probably a reasonable assumption in the absence of oil tanker or other deep draft ship traffic, seabed dredging, marine construction activities – or extreme wave conditions.

As weapons technology moves toward precision-guided munitions, the cost and complexity of each unit increases and a shift from bulk palletization to single weapon packaging has occurred. This change from dumb bombs and large projectiles to sophisticated weapons correlates with a trend from Naval Ammunition Depots (NAD) to Naval Weapons Stations (NWS) and the unit cost translates to more cautious handling with fewer inadvertent losses.

Higher cost and less reliance on large caliber projectiles also translates into less "live firing" and a reduction in new UXO issues on the remaining "Operational Ranges." Most of the underwater UXO on the firing ranges we are concerned with here is therefore older ordnance that has had ample time to move and bury (i.e., WWII through 1970s vintage on the "Formerly Used Live Firing Ranges" given in Table 2).

Combining the 22 potential UXO problem sites with their associated coastal category/sub-category designations provides the basis for the Potential UXO Site Priorities shown in Table 3. These priorities were used as an important criterion in the selection of test sites for the Navy 0817 R&D effort. The Navy program tests that preceded the ESTCP program were used to calibrate the modified VORTEX model and collect supporting model performance data for the Collision Coastal environment (exposed coastal periphery).

Table 3. Navy UXO Sites by Coastal Category and Sub-Category.

Geomorphic Coastal Category	Exposed Coastal Periphery	Sheltered Coastal Bays/Estuaries	TOTAL
Collision Coastal	18%	27%	45%
Trailing Edge Coastal	14%	14%	28%
Biogenic, Carbonate Reef	18%	5%	23%
Marginal Sea	5%	0%	5%

The field test at Duck, North Carolina, validates the model for a Trailing Edge Coastal environment. The field test in Hawaii will validate the model for a Biogenic Reef environment. Along with the Navy tests, these tests validate the model for 50% of all known UXO sites. More importantly, that 50% of the UXO sites includes nearly all the sites of known high energy and expected high rates of UXO movement. In the "sheltered coastal bays/estuaries" sub-categories the energy is much lower and movement is primarily related to sediment transport. The risks are generally lower there. These sites will eventually need to be calibrated, but that can come at a later date.

Both field test sites were also selected because they replicate the typical environments in which UXO is found but are not themselves active UXO sites. Since these field tests require installation of instrumented surrogates from small boats and diver operations on the seafloor, safety dictates that the operations not be conducted around live UXO, if at all possible.

The sites also are attractive because they are either under military control or have very limited civilian access. Navy environmental reviews for the California and Washington state tests have all shown that there is no significant impact from the short-term testing process. That expedited permitting processes (especially at FRF Duck).

Finally, the environments of both sites are already reasonably well documented because of recent offshore test activities there. The FRF at Duck, NC, is an operational Army test facility and has been used in the past for Navy tests of the migration of seafloor mine shapes.

The FRF Duck site general area is shown in Figure 2.

Figure 2. Duck, NC, is approximately 60 miles south of Norfolk, VA.

1.5.1 Pre-Demonstration Testing and Analysis

Prior to the demonstration, the FRF site was analyzed by running the UXO Mobility Model using available parameters inputting historical wave, current, sediment transport, and other seafloor data from the site to determine the expected movement of the UXO as a function of location along and across the coastline profile. At the FRF site that analysis was used to set the final location and initial orientation of each surrogate 5"/38 round. It also was used to determine the details of the locations of reference stakes, approaches for use by divers in conducting surveys, etc.

A preliminary dive was conducted at the FRF site to collect small samples of the seafloor sediment across the test site area. The samples were analyzed for sediment type and a standard grain-size analysis will be performed, since grain size is an important input to the UXO Mobility Model. At FRF there are permanently installed instruments to measure waves and currents at the site. There also is an extensive historical database of meteorological and oceanographic information from which to make predictions.

The preliminary dive also baselined local procedures and logistics processes for the initial installation and follow-on monitoring visits.

2. FIELD TEST ONE (FRF Duck, NC)

2.1 Test Site Description

2.1.1 Characteristics Of Trailing Edge Coastal Classification

The general characteristics of a Trailing Edge site are shown as Row B in Figure 3.

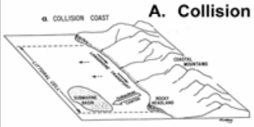
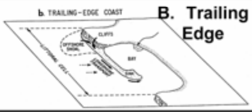
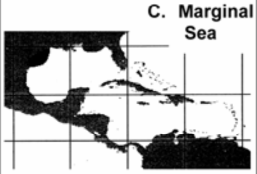
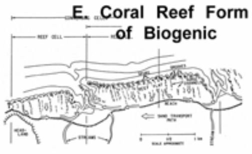
Geomorphic Type	Boundary Conditions					Model Parameters		
	Morphology (Example)	Sediment Source	Sediment Sink	Closure Depth	Littoral Cell Dimensions	Grid Cell	Grain Size	Bed Roughness, η_0
A. Collision 	Narrow-Shelf Mountainous Coastal Bluffs (Cailfornia)	Rivers & Bluff Erosion	Submarine Canyons	15 - 18 m	Longshore: 50 km Cross Shore: 1 - 5 km	Farfield: 70 - 90 m Nearfield: 1 - 4 cm	Beach: 0.2 - 0.3 mm Shelf: 0.06 - 0.10 mm	0.5 - 3 cm
B. Trailing Edge 	Wide-Shelf Plains (Duck, NC)	Headlands & Shelves	Roll-Over Shoals Spit-Extension	10 -13 m	Longshore: 100 km Cross Shore: 30 - 50 km	Farfield: 40 - 80 m Nearfield: 2 - 7 cm	Beach: 0.2 - 0.4 mm Shelf: 0.06 - 0.15 mm	0.8 - 5 cm
C. Marginal Sea 	a) Narrow-Shelf Mountainous (Korea) b) Wide-Shelf Plains (Corpus Christi) c) Deltaic tideless (Mississippi) d) Deltaic tidal (Bangladesh) Wide-Shelf	Rivers & Deltas	a) Canyons b) Beaches & Barriers c) Delta & Shelf d) Delta Islands, flats, canyons	Narrow shelf: 7 - 10 m Wide shelf: 4 - 7 m Delta: 3 m	Longshore: a) 5-10 km b) 100 km c) 5-200 km d) var Cross Shore: a) 1 - 5 km b) 50 km c) 20-80 km d) var	Farfield: 10 - 20 m Nearfield: 1 - 3 cm	Beach: 0.06 - 0.21 mm Shelf: 0.01 - 0.09 mm Delta: .005 - .05 mm	a-d) 0.1 - 1 cm d) sand waves
E. Coral Reef Form of Biogenic 	Coral Reef Island (Hawaii)	Carbonate Reef Material Volcanic Headlands	Pocket Beaches & Awa Channels to the Shelf	Reef Platform	Longshore: ~2 km Cross Shore: 0.5 km	Farfield: 100 - 150 m Nearfield: 1 - 20 cm	Beach: 0.2 - 0.4 mm Shelf: 0.03 - 0.1 mm	Reef Platform ~1 m Offshore 1 - 15 cm

Figure 3. Coastal classification system with geomorphic types and synthesized model input parameters.

2.1.3 Environmental Permitting

The following permits and approvals were obtained:

- NC Department of Environment and Natural Resources – Concurence with Negative Determination, December 13, 2004
- U.S. Army Corps of Engineers Section 10 Permit, November 16, 2004
- Record of Categorical Exclusion

The permits obtained are provided in Appendix A for reference.

2.1.4 Field Test Staff

Table 4. ESTCP UXO FRF Duck Field Test Points Of Contact.

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone/Fax/e-mail	Role In Project
Barbara Sugiyama	NFESC, 1100 23rd Ave., Port Hueneme, CA 93043	805-982-1668/805-982-4304/ barbara.sugiyama@navy.mil	Principal Investigator
Alexandra De Visser	NFESC, 1100 23rd Ave., Port Hueneme, CA 93043	805-982-6070/805-985-1197/ alexandra.devisser@navy.mil	Co PI
Jeff Wilson	Sound & Sea Technology, 11931 Maplewood Ave., Edmonds, WA 98026	425-743-1282/425-742-5643/ jwilson@soundandsea.com	SST Project Manager, Demonstration Design
Bill Daly	Sound & Sea Technology, 11931 Maplewood Ave., Edmonds, WA 98026	425-836-2909/425-742-5643/ wdaly@soundandsea.com	SST Senior Field Test Engineer
Ian McKissick	Sound & Sea Technology, 11931 Maplewood Ave., Edmonds, WA 98026	425-743-1282/425-742-5643/ imckissick@soundandsea.com	SST Field Test Engineer, Surrogates, Instruments
Scott Jenkins	Dr. Scott A. Jenkins Consulting, 14765 Kalapana St., Poway, CA 92064	858-534-6480/858-534-0300/ saj@coast.ucsd.edu	UXO Mobility Model Development, Site Analysis
Carl Miller	USACE-CEERD-HC-F, Field Research Facility, 1261 Duck Road, Kitty Hawk, NC 27949-4472	252-261-3511/252-261-4432 herman.miller@erdc.usace.army.mil	Field Test Planning, Logistic Support, Diving Ops

2.2 Test Plan

The general test approach was to first install the surrogates at pre-planned locations at increasing distance from shore (and depth of water) and then measure their movement from those initial locations.

2.2.1 Test Layout

The general layout of the test for the initial installation is shown in Figure 4. The test hardware details are shown in Appendix B. The positions were established north of the FRF Pier because the expected worst-case movement along the beach was to the south. Because of the scouring effect of the pier pilings there is a trough under the pier that would capture the surrogates in case they should move farther than predicted.

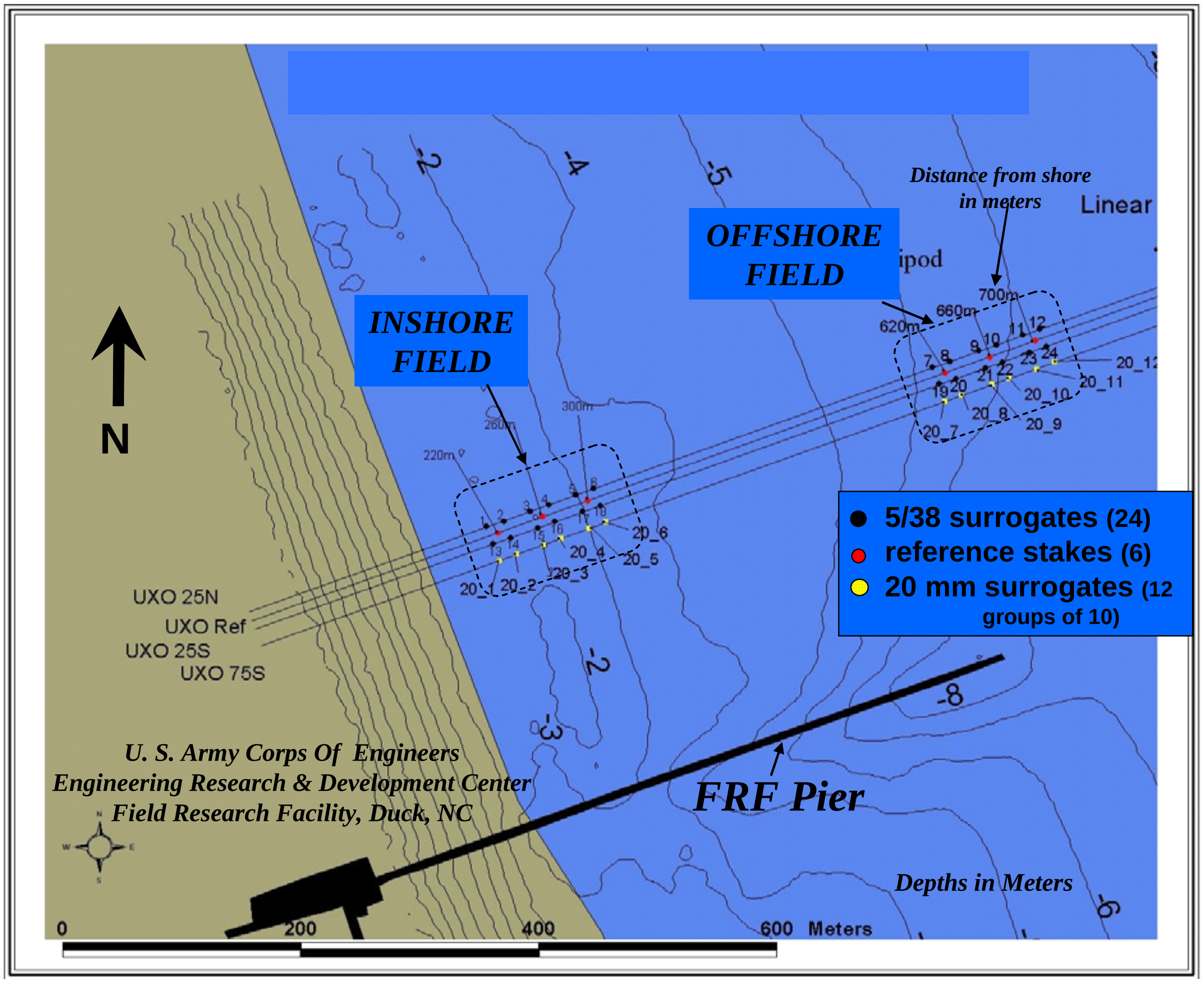


Figure 4. FRF Duck Site Overview.

Figure 5 shows the head of the FRF Duck pier and the Coastal Research Amphibious Buggy (CRAB) wheeled vehicle used to install the surrogates. Note that the slope of the seafloor seaward of the shoreline is even milder than the slope of the exposed beach.

Figure 5. FRF Duck pier, beach, and CRAB vehicle.

2.2.2 Surrogates Used

The two ordnance sizes selected bracket the ends of the general behavior spectrum; the 20 mm rounds behave like small “sand” particles, while the 5”/38 rounds behave like larger “cobbles.” The details of the surrogate designs and fabrication method are described in Appendix B of Reference 2, the Navy UXO program’s Measurement Method Field Test (MMFT1) Test Plan. The two types of surrogates are shown in Figures 6 and 7.

Figure 6. 5”/38 surrogates.

Figure 7. 20 mm surrogates.

2.3 Field Test Installation

The general procedures were as follows:

a. Ensure permits are in place and all personnel are briefed on the test objectives and procedures.
b. Ship surrogates, acoustic pingers, tracking devices, ADCP, tethers and stakes to local mobilization site.
c. Check out acoustic tracking devices, local instrumentation, and installation equipment (e.g., CRAB, LARC, etc.)
d. Move gear by truck to the dive site. Diving was supported by Lighter Amphibious Resupply Cargo (LARC) vehicle at the Duck site.
e. Conduct the initial dive to verify seafloor conditions, check out acoustic tracking devices and collect sand samples for use in Model calibration.
f. Install the surrogate rounds in the planned locations. At Duck, the rounds were lowered from the CRAB vehicle crawling framework.
g. Install reference stakes metal pipes pushed into the sand). Check acoustic tracking devices to determine range of detection for each pinger.
h. Record the initial location of each surrogate. At Duck, the CRAB will be used for direct survey of seafloor bottom points.
i. Record the Global Positioning System (GPS) location of each stake.

Contingencies were as follows:

a. Do not start the test till surf and visibility conditions are acceptable to the divers. At least 5-6 feet of visibility is required, and the surf conditions will likely limit the ability to launch the small boat before they stop diving operations.
b. If any of the acoustic pingers fail, replace the failed pinger. Pingers may be replaced either on deck or on the seafloor.
c. If any surrogate is dropped, mark the location with a float and conduct a search to recover it.
d. Follow all required diver safety procedures. If a diving accident of any kind occurs, abort the installation.

2.3.1 Installation Notes

The installation occurred on 22 June 2005. The CRAB was stable enough and the current offset small enough that the survey coordinates were used as the initial measurement of surrogate as-installed position. The CRAB installation process is shown in Figure 8.

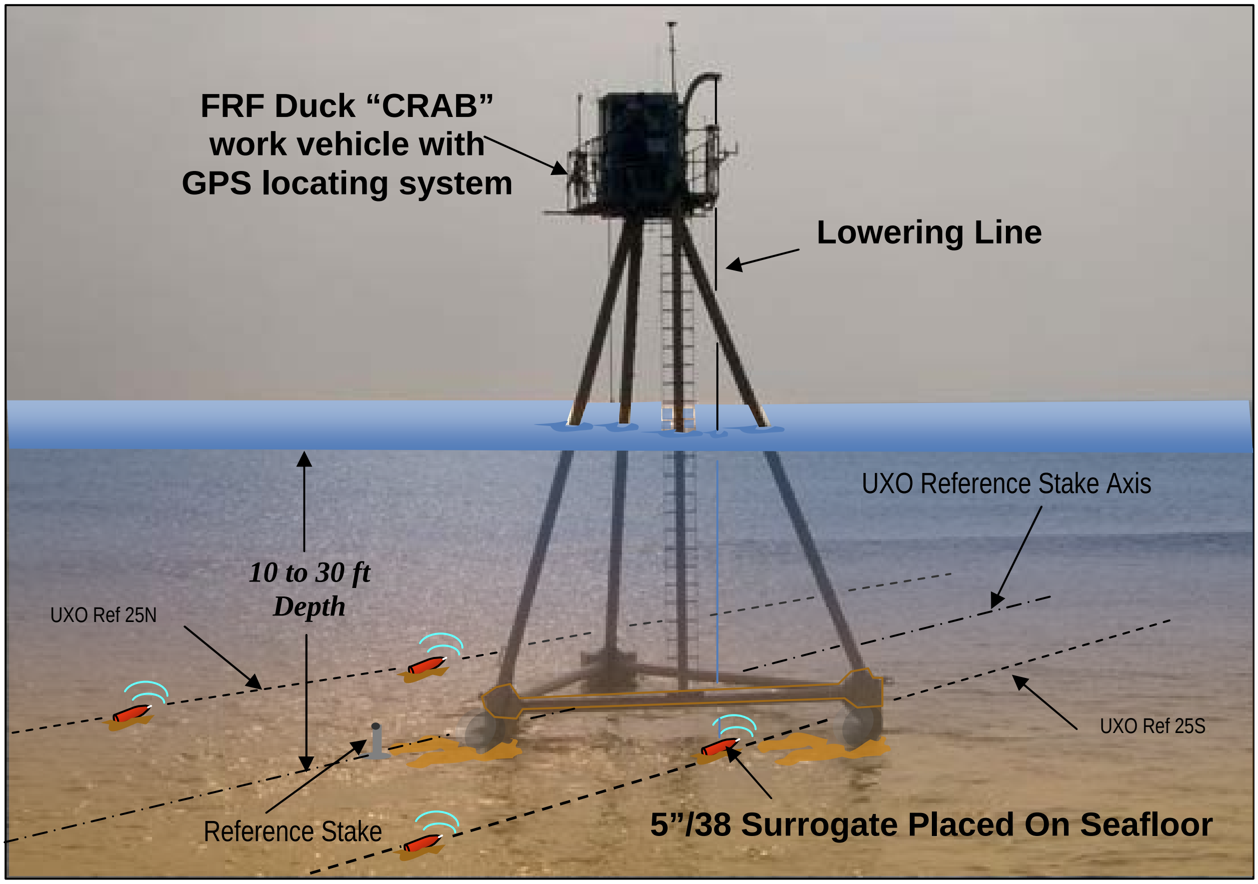


Figure 8. FRF Duck CRAB installing UXO surrogates.

The reference stake pipes were jetted in and their height above the bottom was recorded as a cross-check on the routine bottom surveys of bottom bathymetry that are performed weekly by the FRF Duck staff. Since the pipes were jetted in much deeper than the surface layer of sand, they provide a set of 6 direct observation points through the main axis of both surrogate fields from which to measure any accretion or erosion of the sand level.

2.3.2 Diving Operations During Installation And First Round Of Measurements

Bad weather caused the initial dive to be postponed for 5 days until 27 June 2005. The divers used that down time to learn to use the hand-held acoustic-tracking units and were able to locate all 24 surrogates during the first dive. All pingers functioned and the surrogates were trackable.

The divers were able to record the ping interval and pinger code without a problem. Close proximity frequency duplication was not an issue.

Although some of the surrogates had moved as much as several feet from their initial location and all had become buried in the 5 days since they were installed, the divers were able to complete an initial set of movement data ("Round 1") on 27 June 2005. The divers measured each surrogate's position by swimming to its location following the signal from the pinger with their hand-held acoustic tracker. Since the surrogates were buried the divers located the hand-held tracker over the surrogate burial site within a meter or so. The Benthos receiver was then used to record the distance (range) from each of two or three of the Benthos transmitters, which were located on the adjacent reference stakes. The resolution of those ranges is typically a meter or better.

Future measurements will include use of a metal detector for locating the rounds when the location using the pinger finder becomes unclear. When the rounds are located with the metal detector, a probe will be used to make contact with the round. Then the location of the hand-held receiver will be horizontally within a few inches of the actual surrogate site.

For some of the surrogates, the acoustic measurements were checked by using tape measurements of the distance from the surrogate location to the reference stakes. The tape measurement method proved to be very time consuming when compared to the Benthos transponder unit. However, the tape is much more accurate than the Benthos even with a 3ft drift on a 40ft measurement (measurement will read ~ 0.5ft further than actual). Fortunately, in each case, the tape-measured position turned out to be exactly in the middle of the estimated position using the acoustic tracking system, which suggests that the actual errors in the acoustic tracking system may be less than advertised. Because the tape measurements are more time consuming, they will not be repeated until the surrogates can be physically located, either by unburial or by a probe.

The pingers were not as reliable as advertised. During installation preparations, several had stopped pinging well before they should have. Additionally two of the pingers were alternating from working to not working. Sufficient spares had been procured so all pingers were operational when installed and they have continued to work to date. The test layout incorporated sufficient redundancy (two surrogates at every depth) so that even if several more pingers fail there will be sufficient data recorded for a successful test.

The divers were unsuccessful when they tried to dig for Surrogate #19 by hand in the loose sandy seafloor. This noteworthy incident will aid in planning future recovery or unburial efforts to confirm surrogate location. Thus, it probably will be necessary to use a diver-held eductor system (a "gold dredge") during those operations.

The contract divers supporting FRF Duck will continue to handle the on-site work and proceed to take measurements when directed. That will minimize the cost associated with travel. It also will allow for more timely measurements to be recorded because weather changes so rapidly on the Duck coast.

2.4. Measurement Data From Installation Phase (Round One Data)

2.4.1 Measurement Method Used

The basic approach for measuring 5”/38 surrogate locations is shown in Figure 9. The sequence is as described in the discussion of diving operations above (Section 2.3.2).

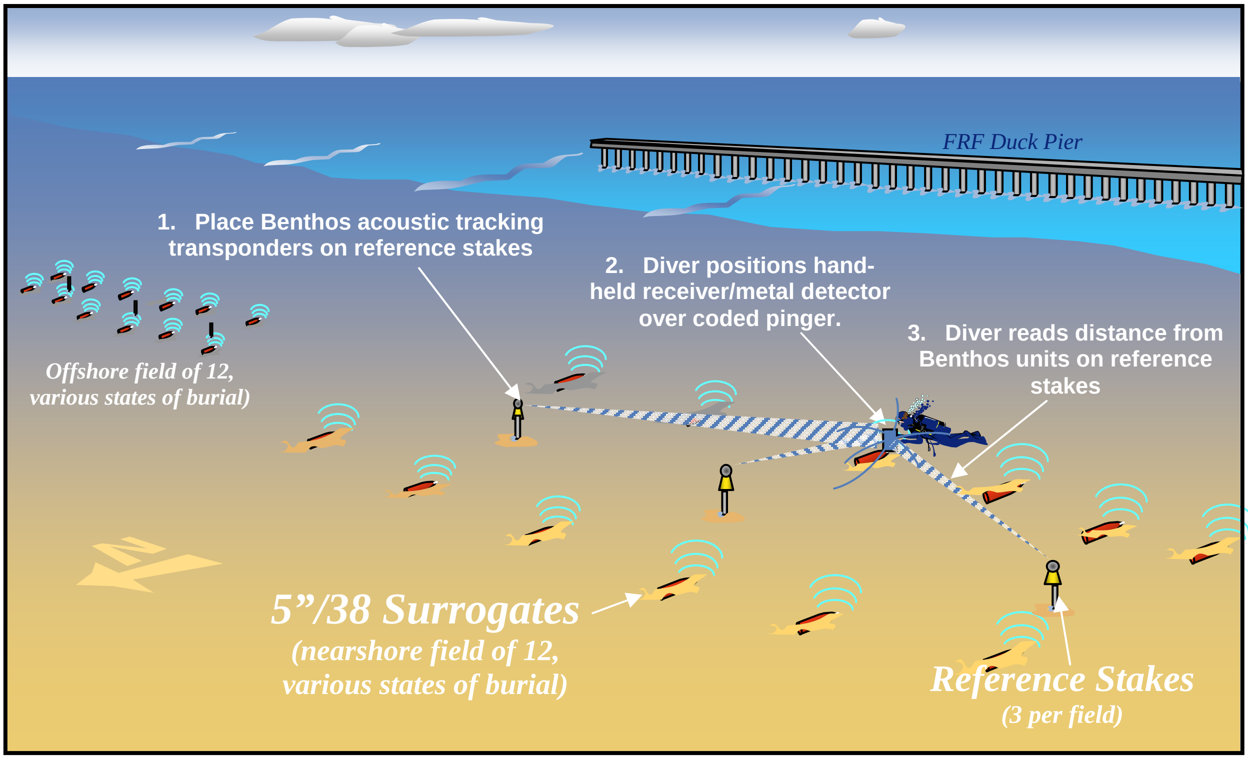


Figure 9. The FRF Duck measurement method.

The details of the conversion of the Benthos range measurements to surrogate location are shown in Figure 10.

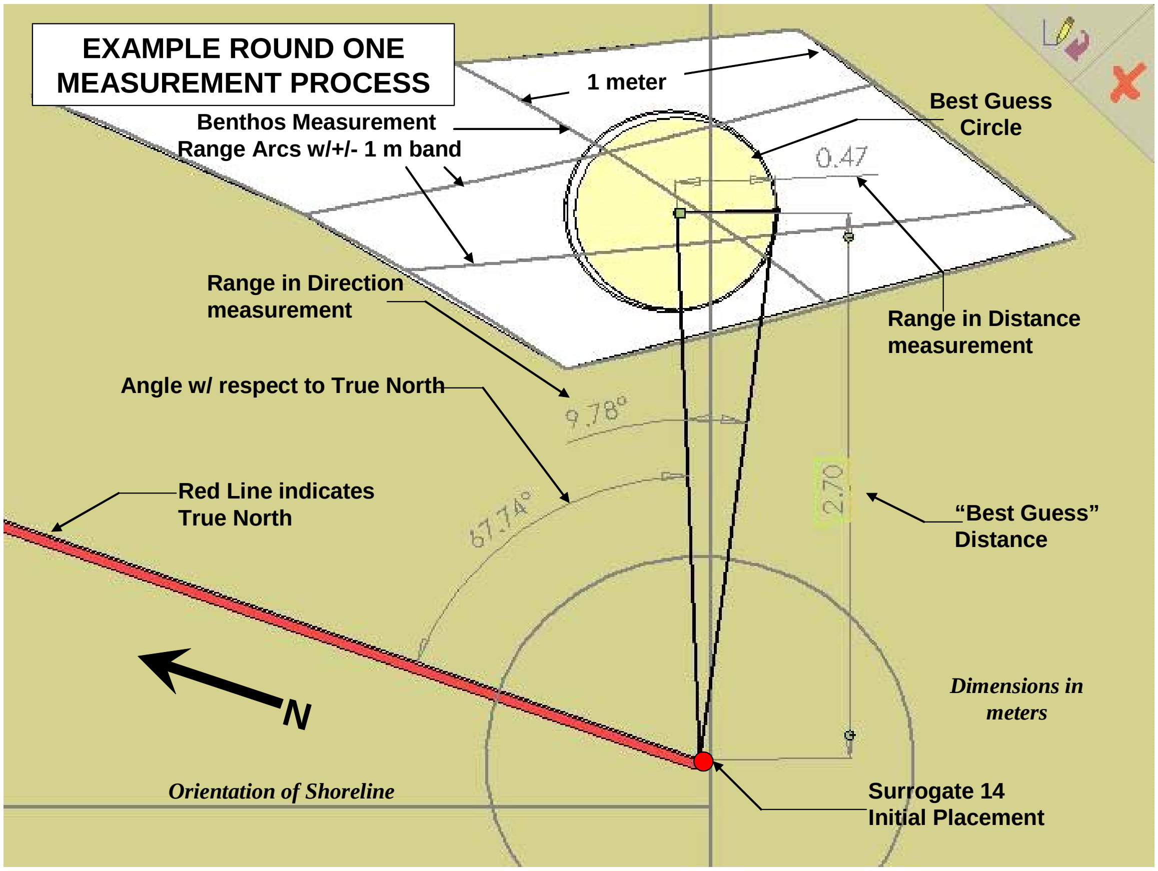


Figure 10. Converting Benthos range measurements to surrogate location.

The 20 mm surrogates will be measured by using the same method, except that only metal detectors will be used to determine their location.

The sample size of twenty-four large surrogates provides confidence there will be at least two sets of ten data points from each measurement cycle. There is little value in having a much larger data set than ten because the accuracy of meteorological/oceanographic measurements such as waves, currents, etc., is typically not much better than 10% or so, and the standard deviation of the statistics of forcing functions (weather) is quite large. Even the *in situ* measurements of UXO surrogate movement by divers will only be accurate to within a few percent. Thus, the results will be sufficient for conducting a credible engineering analysis of risks. The 120 Lagrangian Drifters are required because even with pingers in some of them, they will be quick to bury and easy to lose. However, a ten percent recovery rate should be possible when conducting inspections on a regular basis.

The 5"/38 surrogates are being acoustically, magnetically, or visually tracked as conditions allow. The 20mm surrogate rounds will be allowed to move as Lagrangian drifters and, therefore, provide a useful and direct description of oceanic transport and dispersal. Their location will be noted as they wash up on shore, or as they are visually or magnetically identified during monitoring dives for the larger surrogates.

Relative movement of the surrogates on the order of as little as one meter is measurable by divers. “Significant” movement occurs when the surrogates begin to move beyond the normal visibility at the site, which at Duck is on the order of (a few feet. Should this be the case, the reference stakes will be moved as needed.

2.4.2 Round One Measurement Data

The first round of measurements was made 5 days after the original installation. All the 5”/38 surrogates were located and their positions measured. All were buried. The divers estimated the burial depth to be greater than approximately 12 inches because the surrogates were beyond the reach of manual probing with a dive knife.

Most of the surrogates had measurably moved from their installed location, but none had moved so far they could not be easily found with the acoustic pingers.

Figure 11 is a graphical representation of the original location and the measurement arcs for the inshore field obtained during Round One. Figure 12 shows the surrogates in the offshore field.

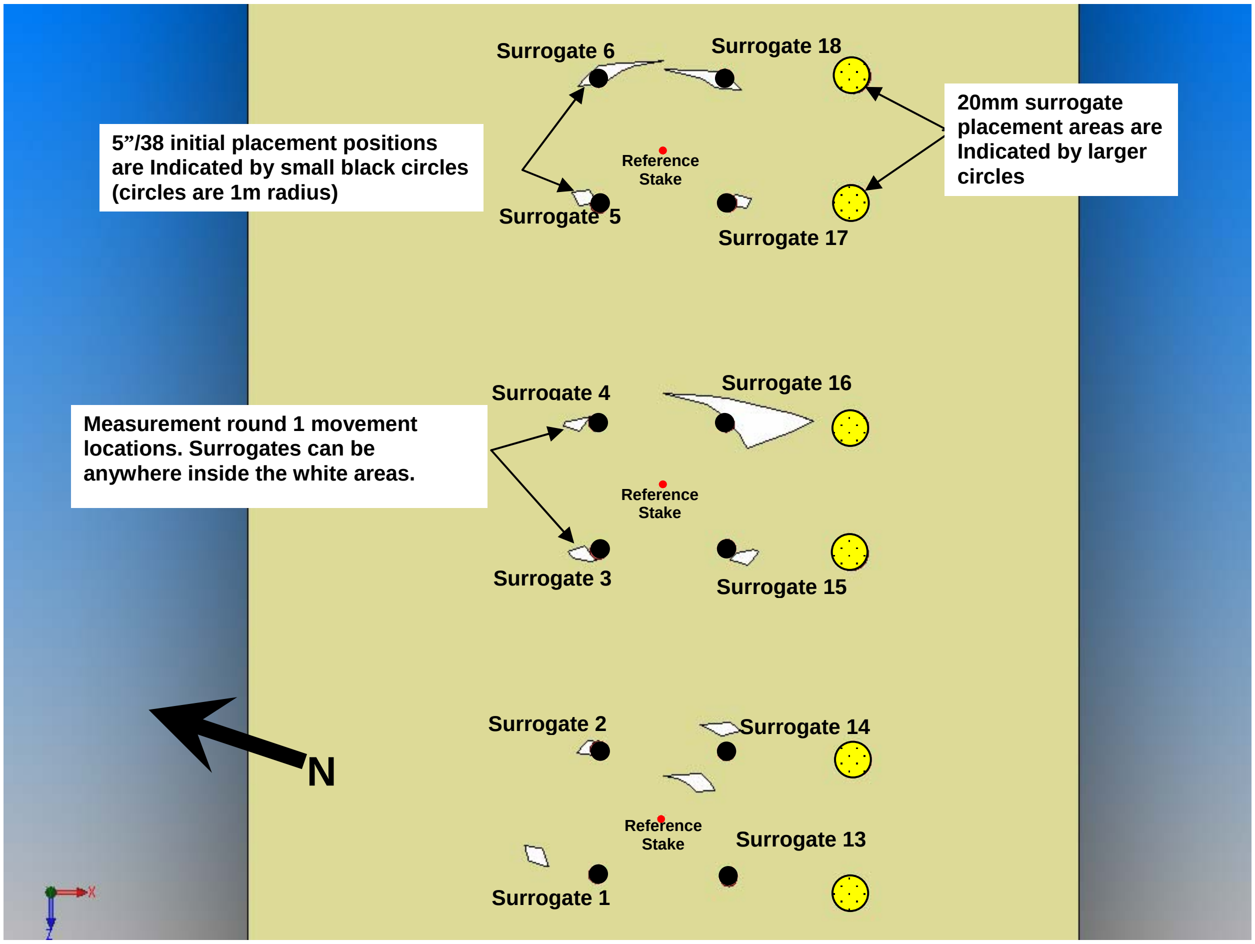


Figure 11. Inshore Field Round One Measurements.

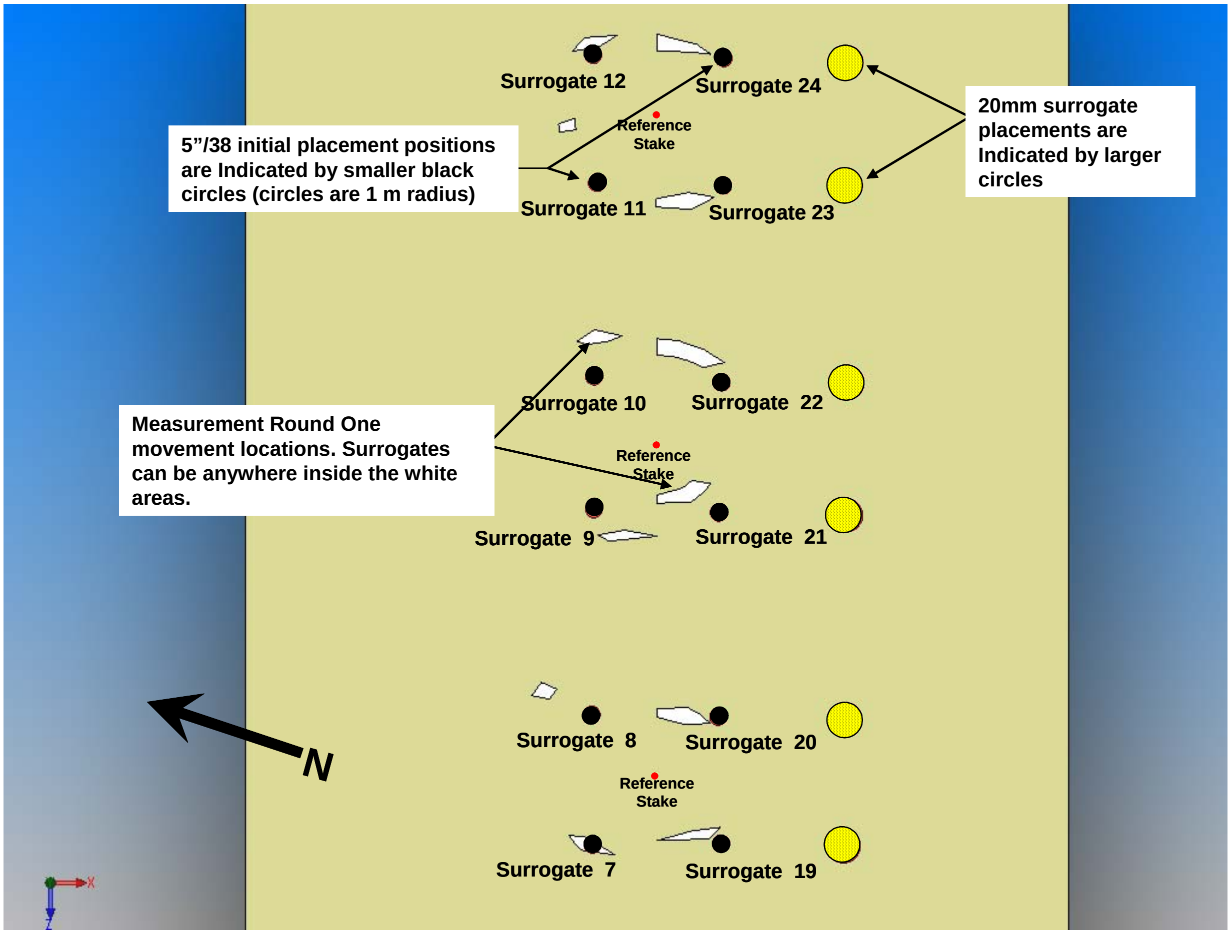


Figure 12. Offshore Field Round One Measurements.

Figures 12 and 13 show detailed views of example Round One measurements. The white area of uncertainty is constructed using the three arcs showing the range to each of the three Benthos units. Each arc representing an area of uncertainty shows an accuracy range of ±1 meter range. The size and shape varies considerably from surrogate to surrogate, primarily due to the relative position of the reference stakes. Triangulating the fixes on a position is always better when the range arcs intersect at wide angles.

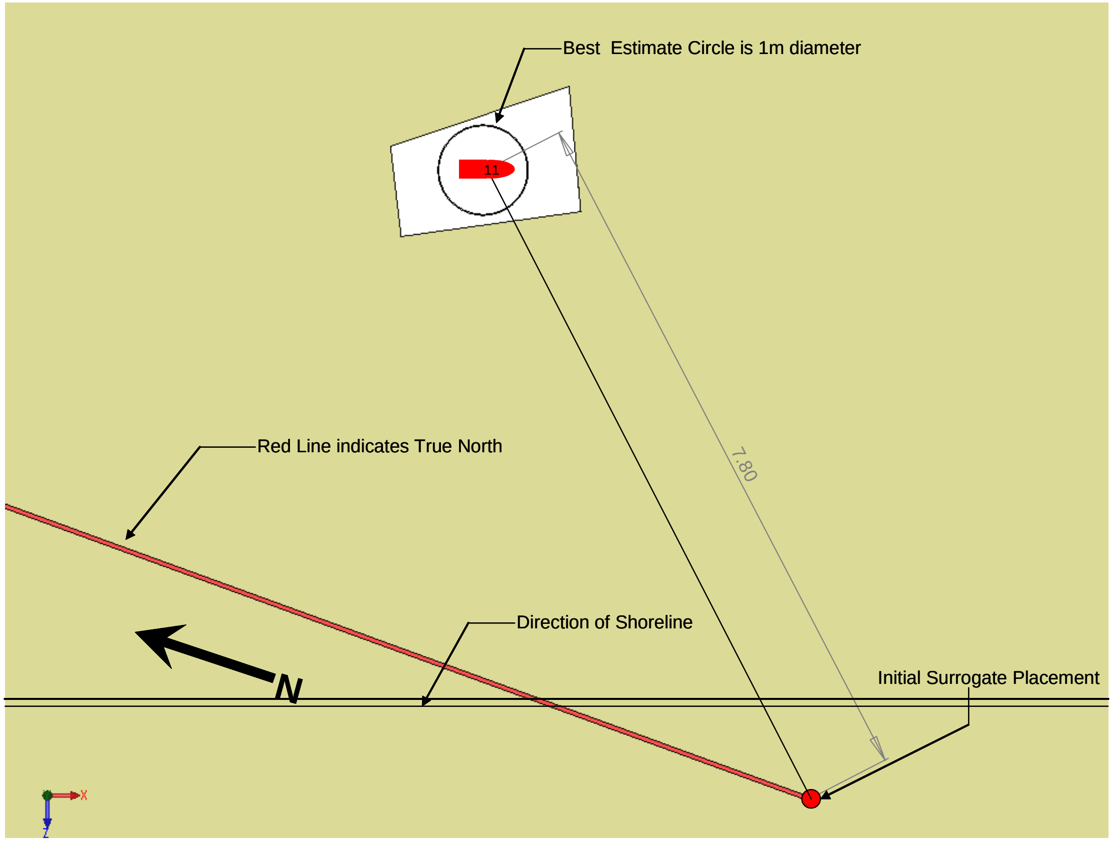


Figure 13. Round One measurement data for Surrogate #11.

Figure 13 shows a surrogate with one of the largest movements with respect to the installation point, but also one of the best acoustic fixes (smallest area of uncertainty). The surrogate moved approximately 7.8 meters in a direction of approximately 040 degrees True, which is north along the coast and slightly seaward of its original position.

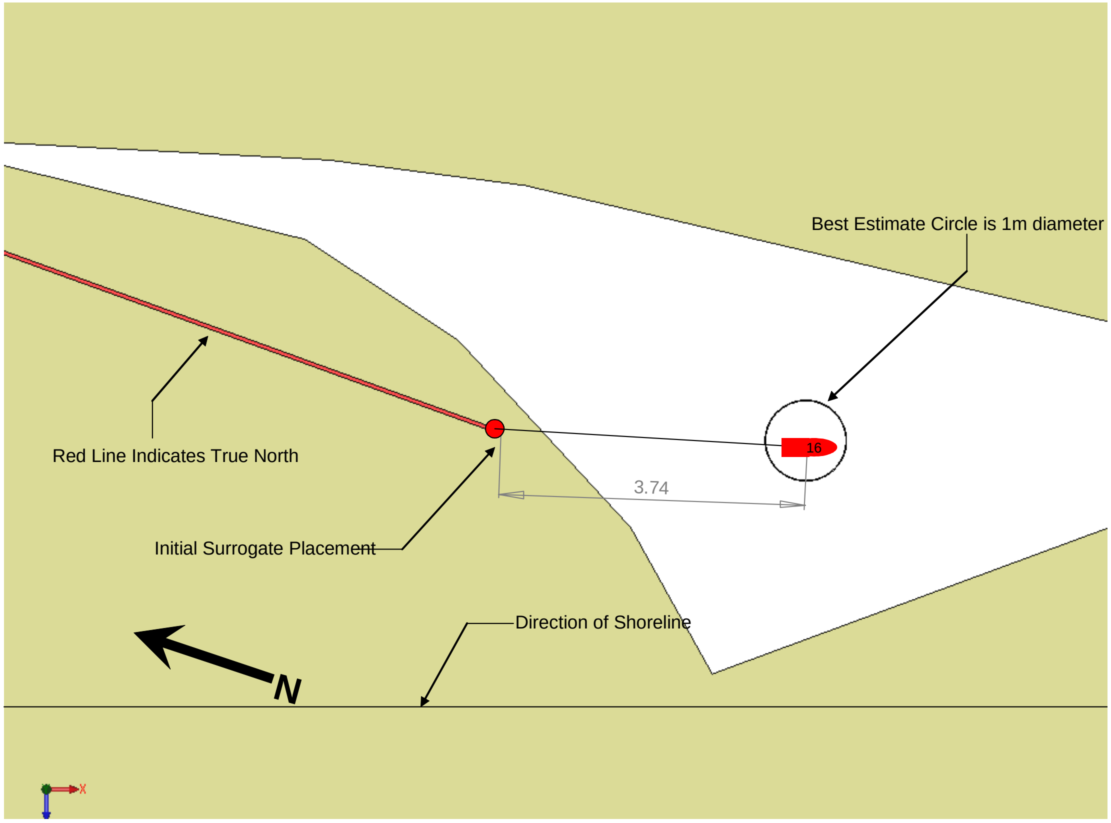


Figure 14. Round One measurement for Surrogate #16.

Figure 14 shows a surrogate with what is best described as moderate movement, but with a very large area of uncertainty. The surrogate has probably moved approximately 3 to 4 meters, in a direction almost due south (parallel to the shoreline).

Table 6 shows the Round One measured movement with respect to the initial installation location of all of the 5”/38 surrogates (distance measured in meters and direction in degrees True).

Table 6. Round One Surrogate Movement (22-27 June 2005).

Surrogate	"Best Estimate" Distance (m)	Accuracy of Distance (+/- m)	Angle w/ Respect to True North (in deg)	Angle w/ Respect to Shoreline (in deg)	Accuracy of Angle (+/- deg)
1	7.7	0.2	358	18	2
2	0.9	0.3	353	13	19
3	2.0	0.4	331	-9	10
4	2.4	0.4	336	-4	10
5	2.0	0.3	7	27	7
6	0.8	0.5	125	145	34
7	0.7	0.4	348	8	29
8	6.3	0.3	6	26	3
9	4.7	0.5	201	-139	5
10	4.8	0.3	72	92	4
11	7.8	0.5	43	63	4
12	1.6	0.6	66	85	21
13	11.9	0.3	53	73	1
14	2.7	0.5	68	87	10
15	2.6	0.4	189	-151	8
16	3.7	2.2	162	182	30
17	1.4	0.4	152	182	14
18	0.7	0.3	308	-32	27
19	3.0	0.6	359	19	10
20	3.9	0.5	342	2	8
21	4.1	0.8	341	1	10
22	3.7	0.3	34	54	5
23	4.3	0.9	316	-24	12
24	5.4	0.7	357	17	7
AVERAGES	3.7	0.5	356	16	12
Std Dev	*2.7*	*0.4*	*90.6*		*9.5*
AVERAGE Nearshore	3.5		337.1	-2.9	
AVERAGE Offshore	4.0		14.2	34.2	

The data are plotted in Figure 15.

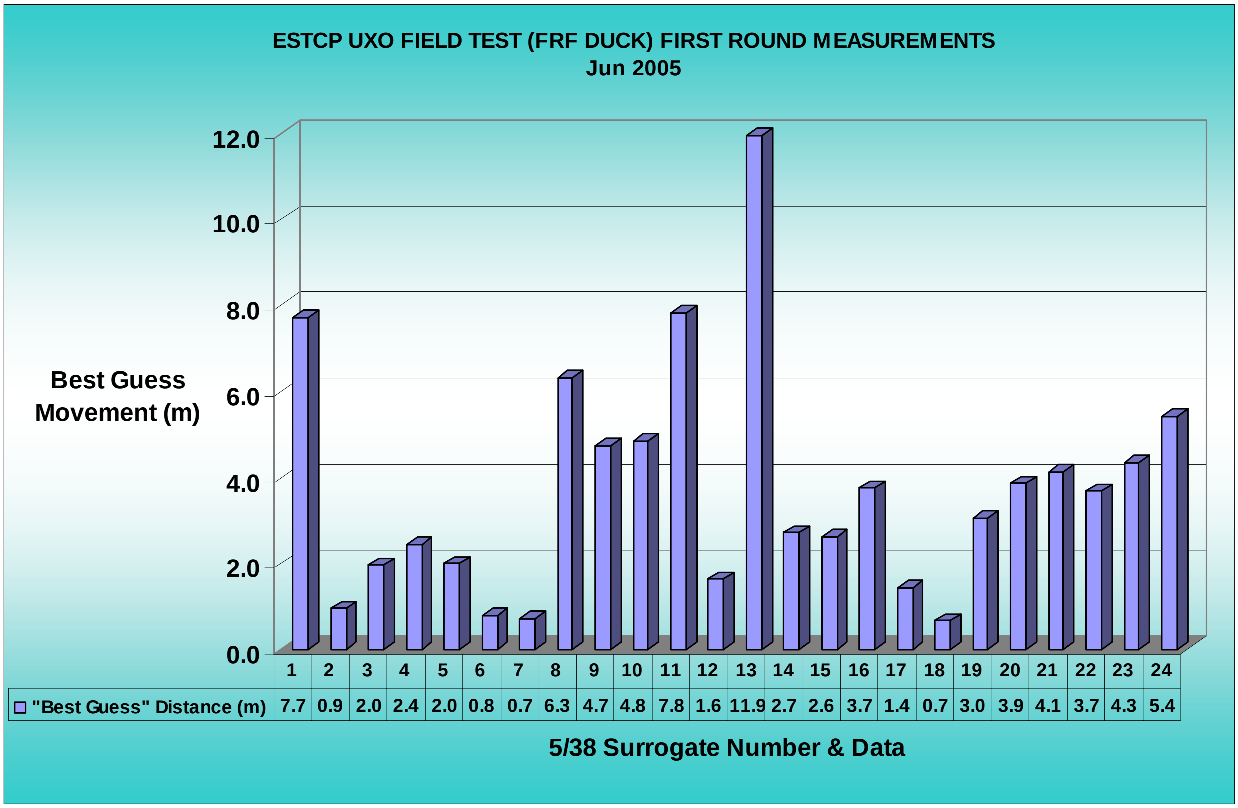


Figure 15. Round One surrogate movement measurements.

2.4.3 Round One Preliminary Results

The data indicates a rather wide range of movement. Some of the surrogates rolled several meters before becoming buried, while others moved only slightly at all. Any movement of 1 meter or less is well inside the resolution of the measurement process. The fact that there are several cases of almost imperceptible movement also tends to confirm the accuracy of the original installation position estimates.

The average amount of measured movement was approximately 3.5-4.0 meters to the north. All but five of the surrogate measurements show net movement to the north. Surrogates 5, 15, 16, and 17 indicate movement to the south, but most of those migrations are within the noise of their particular measurements and do not substantially impact the averages.

The two largest movements were recorded for the two surrogates closest to shore (Surrogate #s 1 and 13, located in the shallowest water). However, all but one of the ten most seaward surrogates also moved substantially. Surrogate #s 8-11 and 20-24 all moved 3 to 5 meters.

There was essentially no net movement toward or away from the shore, although the inshore surrogates tended to move slightly toward shore while the offshore field tended to move slightly away from shore.

The northward movement tends to contradict the original general prediction about a long-term southerly current, but given the small amount of movement and the short time before burial it will require a specific analysis of the weather (e.g., currents and waves) in those critical first few days after deployment to determine if the behavior matches the Model results.

2.5 Round Two Measurement Data

On 12 August 2005, the FRF Duck team conducted a second round of measurements. Once again, all the surrogates were located acoustically and their positions measured with respect to the reference stakes.

All the surrogates were buried, at least as deeply as during the Round One measurements made about six weeks earlier. The divers used a 3-foot probe but were unable to locate them, so the surrogates must be buried beyond that depth. The small 5-pound buoy anchors near shore were buried approximately 3 feet deep.

The team checked the changed in seafloor depth by inspecting the exposed length of the driven reference stakes. The reference stakes were installed with approximately 4 feet of pipe exposed above the seabed.

At the time of Round Two, the reference stake nearest to shore was completely buried, which indicates a four-foot accretion of sand. The next reference stake exposed 2 feet of pipe, which correlates to 2 feet of accretion, and the next pipe had 6 feet of pipe showing, which was equivalent to 2 feet of erosion at that location. The reference stakes in the offshore field exposed 4.5, 4, and 4 feet of pipe, respectively, thereby indicating that no net change in sand accretion occurred with respect to the initial installation condition. This state suggests that a degree of net accretion of sand occurred nearshore, but no net change in accretion was recorded at the locations further offshore. Long-shore sand movement likely explains this combination of conditions.

Given the minimal net change in seafloor depth and the consistently good ability to hear the surrogate pinger, it may well be that the units are not as deep as the divers believe them to be. Estimating the depth of buried objects in the seafloor can be a challenging task unless powered units are available to actually unbury the objects. Also, the Round Two data show that some of the surrogates have moved several meters since Round One, which indicates that they did not remain buried throughout the interval between measurements – yet another point suggesting that the burial may be less than estimated.

It is known that there are migrating sand waves in the Duck area and on most of the Continental Shelf which may explain the movement observed. After receiving the detailed survey data from FRF Duck, this pattern of sand dispersal can be studied in more detail. The data clearly indicate that there are energetic processes affecting surrogate movement.

For this round of measurements, there were two items of interest: the incremental movement since the Round One measurement and the total movement since installation. While the actual Round Two diver measurements only show the cumulative movement, since they are made with respect to the same reference stakes and in Round One, the incremental movement in terms of distance and direction is calculated by triangulation. Table 7 shows actual Round Two diver measurements of the surrogate locations with respect to the reference stakes.

Table 7. Round Two measurements from reference stakes (cumulative from installation point).

12 AUG 05 UXO Surrogate Location Measurements at FRF Duck, NC

				Benthos Transducer Measurement (m)		
Surrogate	freq (kHz)	Code	Interval	stake 220m	stake 260m	stake 300m
1	70			10	47	83
2	81			12	32	72
3	78			24	14	52
4	72			49	12	33
5	69			72	44	12
6	82			86	48	10
Date:	Time:		Recorder:	**Hand Measurement with Tape (ft.)**		
Surrogate	Notes (Burial depth, Orientation):			stake 220m	stake 260m	stake 300m
1						
2						
3						
4						
5						
6						
				Benthos Transducer Measurement (m)		
Surrogate	freq (kHz)	Code	Interval	stake 620m	stake 660m	stake 700m
7	71			11	47	87
8	75			14	35	74
9	72			33	13	49
10	74			48	13	33
11	71			73	36	11
12	79			85	48	7
Date:	Time:		Recorder:	**Hand Measurement with Tape (ft.)**		
Surrogate	Notes (Burial depth, Orientation):			stake 220m	stake 260m	stake 300m
7						
8						
9						
10						
11						
12						
				Benthos Transducer Measurement (m)		
Surrogate	freq (kHz)	Code	Interval	stake 220m	stake 260m	stake 300m
13	77			6	42	81
14	78			9	38	74
15	77			22	11	48
16	79			52	13	26
17	77			69	29	9
18	78			86	46	9
Date:	Time:		Recorder:	**Hand Measurement with Tape (ft.)**		
Surrogate	Notes (Burial depth, Orientation):			stake 220m	stake 260m	stake 300m
13						
14						
15						
16						
17						
18						
				Benthos Transducer Measurement (m)		
Surrogate	freq (kHz)	Code	Interval	stake 620m	stake 660m	stake 700m
19	79			11	51	90
20	70			9	42	77
21	76			37	10	50
22	81			50	16	33
23	73			77	10	9
24	69			89	51	12
Date:	Time:		Recorder:	**Hand Measurement with Tape (ft.)**		
Surrogate	Notes (Burial depth, Orientation):			stake 220m	stake 260m	stake 300m
19						
20						
21						
22						

Table 8 shows the calculated Round Two movement (distance and direction) from initial installation. Table 9 shows the incremental movement (distance and direction) from Round One position).

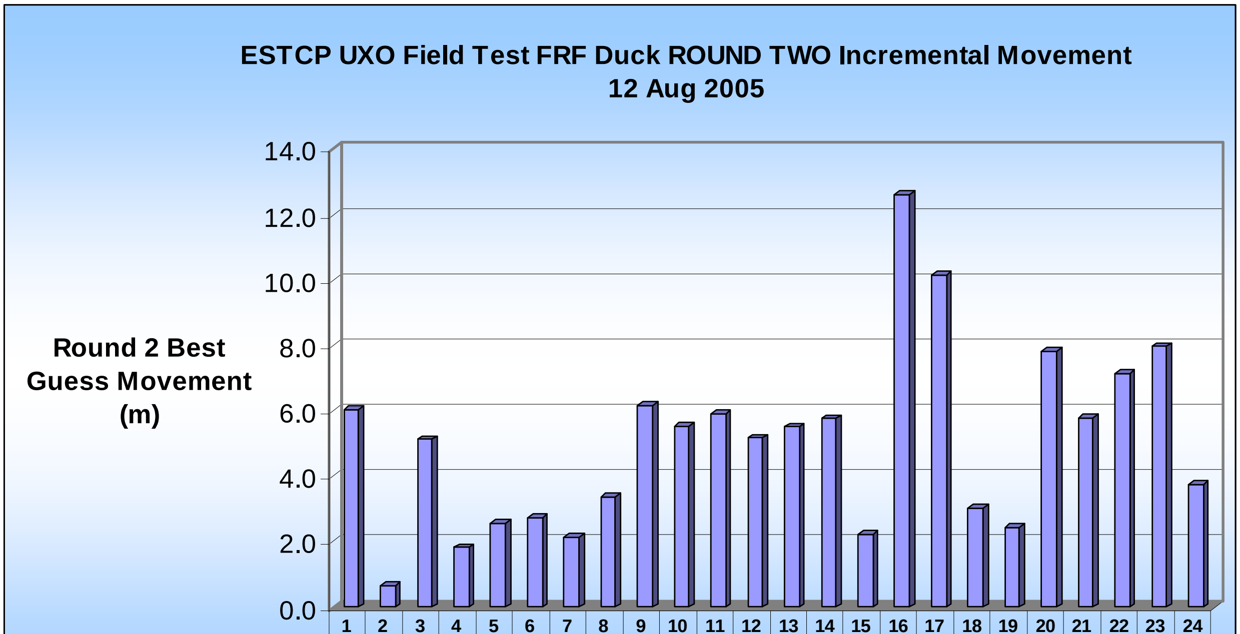
Table 8. Round Two calculated incremental movement since installation.

Total Surrogate Movement (from initial placement and rounds 1 and 2 movement)		
Surrogate	**Movement Distance (m)**	**Movement Angle w/ Respect to True North**
1T	3.7	48
2T	0.7	38
3T	4.2	222
4T	1.1	22
5*T	4.5	16
6T	2.3	241
7T	2.5	43
8T	4.2	336
9T	2.1	328
10T	1.5	419
11T	1.9	31
12T	4.3	180
13T	6.4	53
14T	3.1	248
15T	0.8	134
16T	9.4	17
17T	8.8	314
18T	3.4	255
19T	3.2	313
20T	5.8	236
21T*	2.8	133
22T	5.3	138
23T	5.0	74
24T	3.6	41
AVERAGE	**3.8**	**162**

Table 9. Round Two incremental movement since Round One measurements.

Round 2 Surrogate Movement		
Surrogate	Movement Distance (m)	Movement Angle w/ Respect to True North (deg)
1	6.1	149
2	0.7	122
3	5.1	201
4	1.8	129
5*	2.6	23
6	2.7	256
7	2.1	58
8	3.4	224
9	6.2	6
10	5.5	266
11	5.9	226
12	5.2	197
13	5.5	233
14	5.8	248
15	2.2	25
16	12.6	7
17	10.2	317
18	3.0	245
19	2.5	248
20	7.8	208
21*	5.8	173
22	7.2	168
23	8.0	102
24	3.8	136
AVERAGE	**5.1**	**165**

The average movement was 5.1 meters just slightly east of south (parallel to the beach). Figure 16 shows the distance moved as a bar chart. The average error in the measurement was 1.5 to 1.9 meters, although some of the surrogates did show considerably larger error bands because of their location with respect to the reference stakes.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Movement Distance (m)	6.1	0.7	5.1	1.8	2.6	2.7	2.1	3.4	6.2	5.5	5.9	5.2	5.5	5.8	2.2	12.6	10.2	3.0	2.5	7.8	5.8	7.2	8.0	3.8

Figure 16. Round Two incremental movement.

The two surrogates nearest the shore (Surrogate #s 1 and 13) moved substantially and all the seaward surrogates (#s 9-12 and 20-24) exhibited distinctive migration distances of 4 to 8 meters. This data set shows that the largest recorded movements were for two of the surrogates located on the seaward end of the inshore field (Surrogate #s 16 and 17).

The other important observation is that the average incremental movement was to the south, which was originally predicted by the general nature of the coastal currents.

Note that the Round One and Round Two “average” movements of 3.7 m north and 5.1 m to the south east do not form a closed triangle with the average cumulative vector of 3.8 m to the south east, though they are within the error of the overall measurements.

Figure 17 shows an example of the Round One movement plus the incremental movement derived from the Round Two measurements.

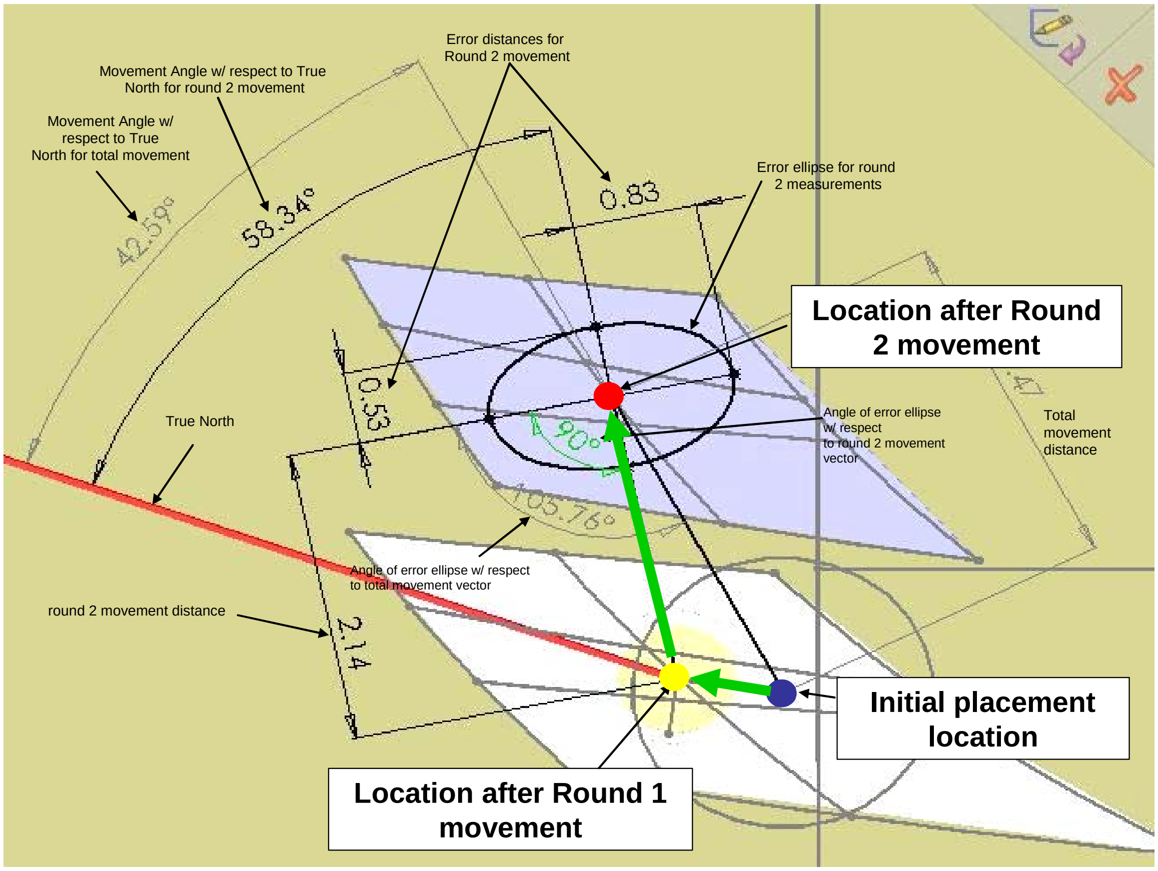


Figure 17. Surrogate #7 movement from installation to Round One to Round Two.

Figure 18 shows the two rounds of movement for the Inshore Field and Figure 19 shows the two rounds of movement for the Offshore Field. Details of the movement are shown in Appendix B.

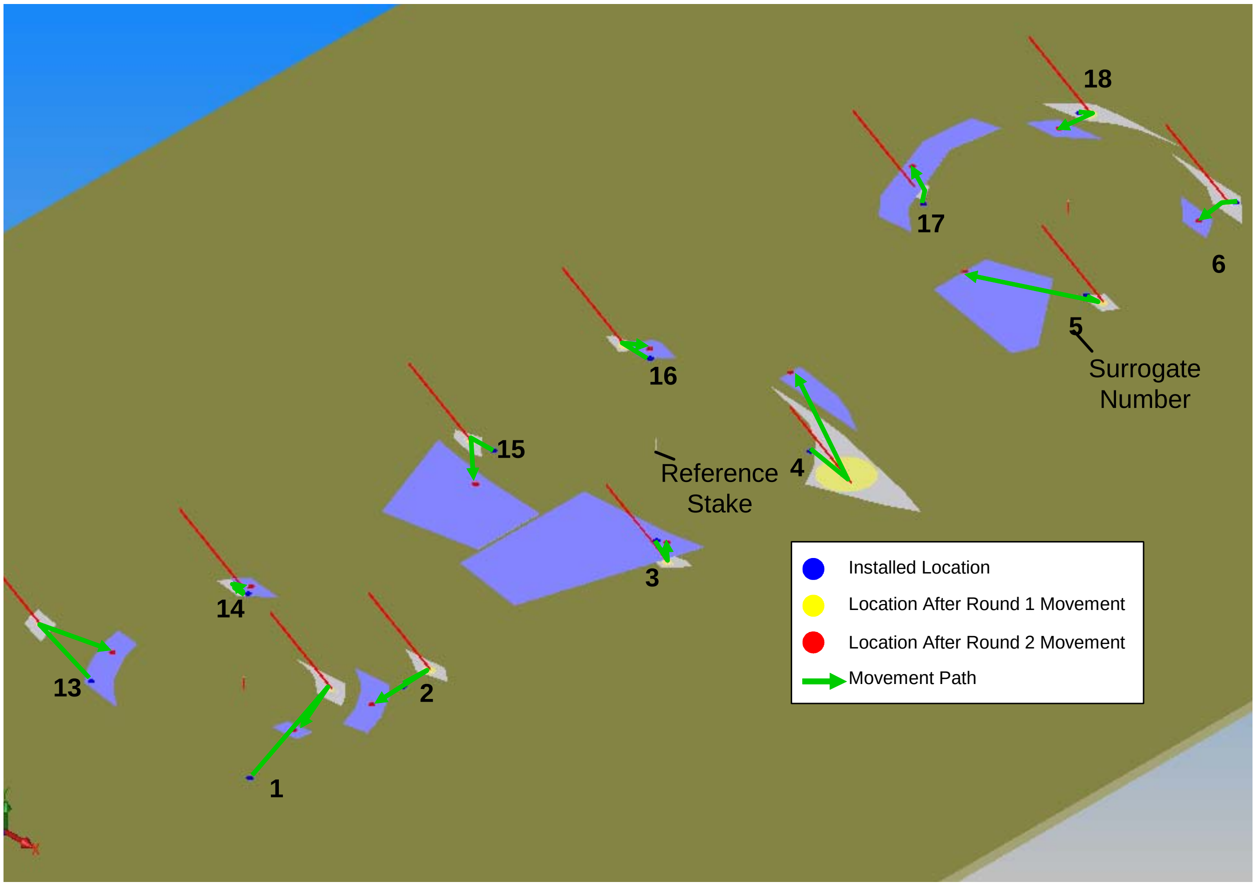


Figure 18. Inshore surrogate field Round One and Round Two movement.

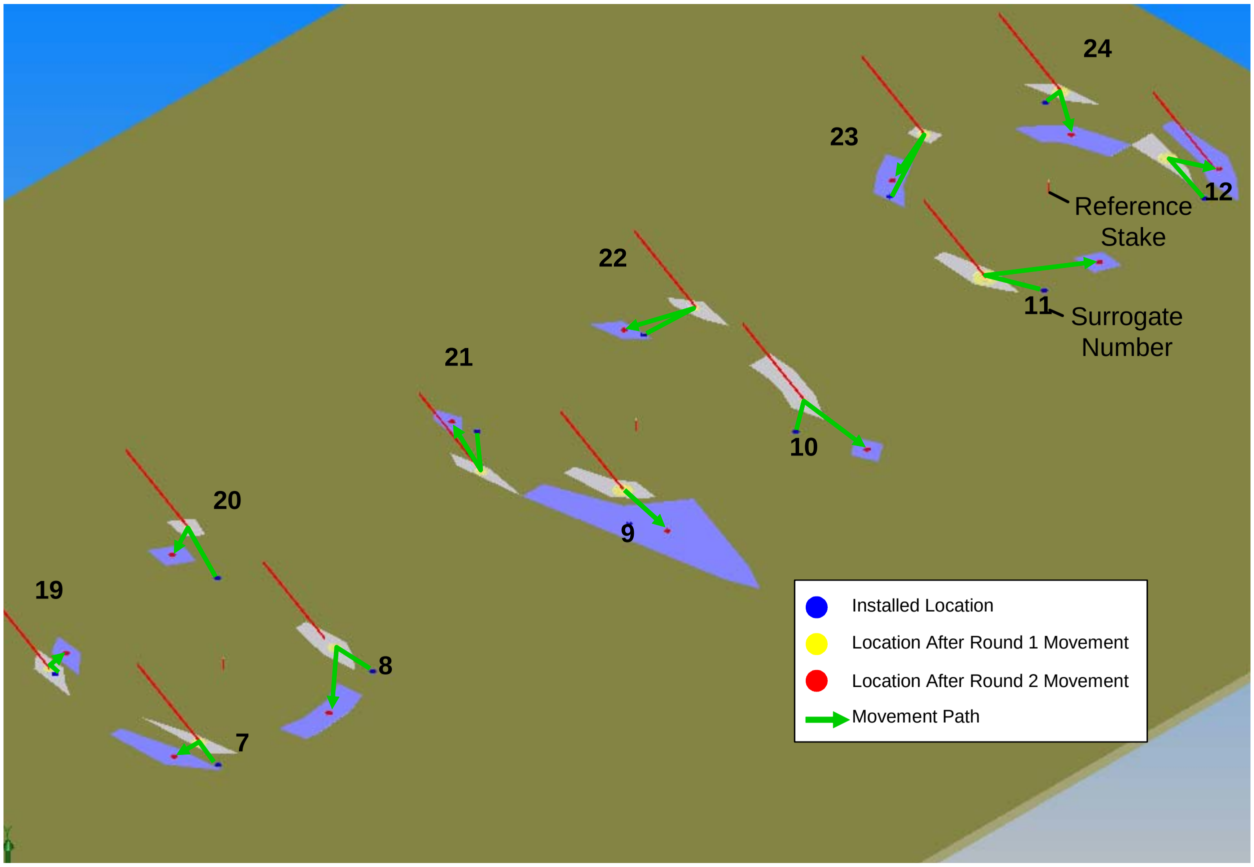


Figure 19. Offshore surrogate field Round One and Round Two Movement.

It is noted that although most of the Round One surrogates moved North, most of Round Two's surrogates tended to move South.

In some instances, the Round Two data are not as consistent and accurate as the Round One data. The primary complication is that some of the rounds have moved far enough that they are no longer in a favorable position to be triangulated from the three reference stakes. This is particularly true for the surrogates that have moved close to the centerline of the fields (in line with all the reference stakes). In following rounds of measurement, additional reference stakes will be used and the transponders will be placed as needed to obtain better fixes on surrogate locations.

3.0 FUTURE PLANS

The testing at FRF Duck will continue into 2006. The duration of testing and the dates of measurements will be dictated by the weather patterns at the site and the time and cost required for the divers to make each set of measurements. It is anticipated six to eight more rounds of measurements will be conducted.

Measurement cycles will continue till either:

a. There are three data sets during which the surrogates were unburied and movement was measured on a full suite of samples (20 or more) and the movement is within an order of magnitude of the predicted movement, or
b. The observed movement is more than an order of magnitude outside the predicted range (model clearly requires rework), or
c. The test permits elapse (about one year), or
d. Allocated field test funds are expended.

The measured movements will be compared to the predictions from the UXO mobility model for each site and ordnance type. Model internal parameters will be adjusted and code updated to consider UXO mobility and burial. For each measurement cycle and the location of 24 x 5”/38 surrogates and as many 20 mm surrogates that can be re-located, the data set will be bifurcated. The first half of the data will be used to calibrate the model and the second half will be used to validate it. Each measurement set of test data will enhance and further calibrate the existing and partially validated model.

Offshore wind, wave, and bottom current data will be collected at regular intervals using the existing monitoring systems at FRF Duck. These instruments typically collect data every few minutes, which is well inside the rate of change of weather. FRF Duck has a full-time environmental monitoring system in place that will provide appropriate input data for the model. Divers manually unburying appropriate surrogates will monitor entombment depths; the divers will then replace the sediment. This inspection is not expected to alter the UXO movement cycle because the seafloor sediments in this environment remain essentially unconsolidated; disturbance will not change the engineering properties significantly.

3.1 Data Quality Indicators.

The data quality will be determined by statistical analysis of the scatter in the measurements between fixed stakes and by the scatter in the movement of the multiple UXO samples. The R and r^2 measurements discussed previously apply.

For each data set the Model will be run in all three modes. That will not only calibrate and validate the Model in each mode, but will also allow for the relative accuracy between modes to be determined. Among the three modes, Mode 1 is the simplest. It requires the least data input but makes the most assumptions about environmental conditions. Mode 2 and Mode 3 will be used to determine the errors introduced by using the simplified Mode 1 analysis. Mode 1 is less expensive to employ because it does not require site-specific data collection; however, it does introduce risk because it is less accurate.

3.2 Instrument Calibration Procedures, Quality Control Checks, and Corrective Action.

FRF Duck regularly calibrates their depth soundings, ADCP, and other instruments. The Benthos system will be checked against tape measurements occasionally to ensure accuracy.

3.3 Demobilization

Divers will remove all UXO surrogates, with assistance from lift bags or the CRAB. Lagrangian drifters that are found will be recovered by the divers. Any UXO that migrates to the beach will be recovered by hand. All seafloor stakes will be removed.

There are no restoration steps required for the seafloor area because it is a high-energy coastal zone. Any disturbances of the seafloor will be erased by wave action.

If any of the larger surrogates are irretrievable, it is likely that they have become permanently entombed below the depth under the seafloor at which they can be found (i.e., on the order of several feet). They will therefore pose no further risk to the environment or personnel – especially since the surrogates are inert.

3.4 Final Report

The ESTCP Final Report will be prepared after the measurements have been completed using the criteria of Section 3.0 above, the surrogates have been recovered, and the calibration and validation of the UXO Mobility Model against those data has been conducted. This report will be prepared towards the middle of 2006.

4.0 CONCLUSIONS

Although the FRF Duck Field Test data have not yet been used to quantitatively calibrate and validate the UXO Mobility Model, the test to date has been successful. The following conclusions are based upon the data obtained to date.

- All the surrogates were installed as planned and have been tracked for approximately 4 months, despite the fact that they were all found buried at each round of measurements.
- Measurable movement occurred, generally within the range of initial predictions.
- The test methods were refined and will be used for the remainder of the test period.

5.0 REFERENCES

1. Inman and Jenkins (2002). "*Scour and Burial of Bottom Mines: A Primer for Fleet Use*", Scripps Institution of Oceanography, SIO Reference Series 02-2, 42 pp.

2. Wilson, J., McKissick, I., and Meggitt, D, (2004). "*UXO Mobility Measurement Method Field Test Plan,*" Sound and Sea Technology Report, 29 March 2004.

Appendix A

FRF Duck Field Test Site Permits

NCDENR
North Carolina Department of Environment and Natural Resources
Division of Coastal Management
Michael F. Easley, Governor **Charles S. Jones, Director** William G. Ross Jr., Secretary

December 13, 2004

W. Coleman Long
Chief, Planning and Environmental Branch
Wilmington District, U.S. Army Corps of Engineers
P.O. Box 1890
Wilmington, NC 28402-1890

SUBJECT: Concurrence with Negative Determination for Tracking Inert Ordnance

Dear Mr. Long:

The Division of Coastal Management received (on December 2, 2004) a Negative Determination from the U.S Army Corps of Engineers (Corps) demonstrating that the proposal of the Naval Facilities Engineering Service Center at its facility in Duck in Dare County to track inert ordnance would not have coastal effects. It is the objective of the Division of Coastal Management to manage the State's coastal resources to ensure that proposed Federal activities would be compatible with safeguarding and perpetuating the biological, social, economic, and aesthetic values of the State's coastal waters.

The Division of Coastal Management (DCM) has reviewed the submitted information pursuant to the management objectives of the State's coastal program. DCM concurs that the proposed Federal activity is consistent, to the maximum extent practicable, with the enforceable policies of North Carolina's coastal management program.

Should the proposed activity be modified, a revised consistency certification could be necessary. Likewise, if further project assessments reveal environmental effects not previously considered by the proposed development, a revised consistency certification could be required. This might take the form of either a supplemental consistency determination pursuant to 15 CFR 930.46, or a new consistency determination pursuant to 15 CFR 930.36. If you have any questions, please contact Stephen Rynas at 252-808-2808. Thank you for your consideration of the North Carolina Coastal Management Program.

Sincerely,

Doug Huggett
Manager, Major Permits and Consistency Unit

cc: Ted Sampson, Division of Coastal Management

151-B Hwy. 24, Hestron Plaza II, Morehead City, North Carolina 28557-2518
Phone: 252-808-2808 \ FAX: 252-247-3330 \ Internet: www.nccoastalmanagement.net

DEPARTMENT OF THE ARMY
WILMINGTON DISTRICT, CORPS OF ENGINEERS
PO BOX 1890
WILMINGTON NC 28402-1890

CESAW-RG (1145-b) 10 February 2005

MEMORANDUM FOR Ms. Barbara Sugiyama, Principal Investigator, Naval Facilities Engineering Service Center, ESC411, 1100 23rd Avenue, Port Hueneme, California 93043

SUBJECT: Action ID 200510367, Department of the Army Permit for Naval Facilities Engineering Service Center

1. Enclosed is a Department of the Army (DA) permit to place unexploded ordnance models on the floor of the Atlantic Ocean, adjacent to the U.S. Army Corps of Engineers Field Research Facility and Pier, located at 1261 Duck Road, in Duck, Dare County, North Carolina, in accordance with your written request received 8 December 2004 and the ensuing administrative record.

2. If you require any change in the authorized work because of unforeseen or altered conditions or for any other reason, please revise the plans and send to this office promptly. Such action is necessary, as we must review and modify the permit for revised plans.

3. Carefully read your permit. The general and special conditions are important. Your failure to comply with these conditions could result in a violation of Federal law. Certain significant general conditions require that:

a. You must complete construction before 31 December 2008.

b. You must allow representatives from this office to make periodic visits to your worksite as deemed necessary to assure compliance with permit plans and conditions.

4. You must notify this office in advance as to when you intend to commence and complete work.

5. Please contact Mr. Raleigh W. Bland at the Washington Regulatory Field Office, at (252) 975-1616, extension 23, if you have questions.

Encls

CHARLES R. ALEXANDER, JR.
Colonel, EN
Commanding

CF(with encls):

Chief, Source Data Unit
NOAA/National Ocean Service
ATTN: Sharon Tear N/CS261
1315 East-west Hwy., Rm 7316
Silver Spring, MD 20910-3282

CF (w/special conditions and plans):

U.S. Fish and Wildlife Service
Fish and Wildlife Enhancement
Post Office Box 33726
Raleigh, North Carolina 27636-3726

Mr. Ron Sechler
National Marine Fisheries Service
Pivers Island
Beaufort, North Carolina 28516

Mr. Ronald J. Mikulak, Chief
Wetlands Protection Section - Region IV
Water Management Division
U.S. Environmental Protection Agency
61 Forsyth Street
Atlanta, Georgia 30303

Mr. Doug Huggett
Division of Coastal Management
North Carolina Department of
Environment and Natural Resources
151-B NC Hwy, Hestron Plaza II
Morehead City, North Carolina 28557

Mr. David Rackley
National Marine Fisheries Service
219 Fort Johnson Road
Charleston, South Carolina 29412-9110

DEPARTMENT OF THE ARMY PERMIT

RECEIVED
FEB 7 - 2005
REGULATORY
WILM. FLD. OFC.

Permittee **Naval Facilities Engineering Service Center**
Permit No. **200510367**
Issuing Office **CESAW-RG**

NOTE: The term "you" and its derivatives, as used in this permit, means the permittee or any future transferee. The term "this office" refers to the appropriate district or division office of the Corps of Engineers having jurisdiction over the permitted activity or the appropriate official of that office acting under the authority of the commanding officer.

You are authorized to perform work in accordance with the terms and conditions specified below.

Project Description: **Place inert unexploded ordinance models on the floor of the Atlantic Ocean.**

Project Location: **Adjacent to the U.S. Army Corps of Engineers Field Research Facility and Pier, located at 1261 Duck Road, in Duck, Dare County, North Carolina.**

Permit Conditions:

General Conditions:

1. The time limit for completing the work authorized ends on **December 31, 2008** If you find that you need more time to complete the authorized activity, submit your request for a time extension to this office for consideration at least one month before the above date is reached.

2. You must maintain the activity authorized by this permit in good condition and in conformance with the terms and conditions of this permit. You are not relieved of this requirement if you abandon the permitted activity, although you may make a good faith transfer to a third party in compliance with General Condition 4 below. Should you wish to cease to maintain the authorized activity or should you desire to abandon it without a good faith transfer, you must obtain a modification of this permit from this office, which may require restoration of the area.

3. If you discover any previously unknown historic or archeological remains while accomplishing the activity authorized by this permit, you must immediately notify this office of what you have found. We will initiate the Federal and state coordination required to determine if the remains warrant a recovery effort or if the site is eligible for listing in the National Register of Historic Places.

ENG FORM 1721, Nov 86 EDITION OF SEP 82 IS OBSOLETE. *(33 CFR 325 (Appendix A))*

4. If you sell the property associated with this permit, you must obtain the signature of the new owner in the space provided and forward a copy of the permit to this office to validate the transfer of this authorization.

5. If a conditioned water quality certification has been issued for your project, you must comply with the conditions specified in the certification as special conditions to this permit. For your convenience, a copy of the certification is attached if it contains such conditions.

6. You must allow representatives from this office to inspect the authorized activity at any time deemed necessary to ensure that it is being or has been accomplished in accordance with the terms and conditions of your permit,

Special Conditions:

SEE ATTACHED SPECIAL CONDITIONS

Further Information:

1. Congressional Authorities: You have been authorized to undertake the activity described above pursuant to:

(X) Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403).

( ) Section 404 of the Clean Water Act (33 U.S.C. 1344).

( ) Section 103 of the Marine Protection, Research and Sanctuaries Act of 1972 (33 U.S.C. 1413).

2. Limits of this authorization.

a. This permit does not obviate the need to obtain other Federal, state, or local authorizations required by law.

b. This permit does not grant any property rights or exclusive privileges.

c. This permit does not authorize any injury to the property or rights of others.

d. This permit does not authorize interference with any existing or proposed Federal project.

3. Limits of Federal Liability. In issuing this permit, the Federal Government does not assume any liability for the following:

a. Damages to the permitted project or uses thereof as a result of other permitted or unpermitted activities or from natural causes.

b. Damages to the permitted project or uses thereof as a result of current or future activities undertaken by or on behalf of the United States in the public interest.

c. Damages to persons, property, or to other permitted or unpermitted activities or structures caused by the activity authorized by this permit.

d. Design or construction deficiencies associated with the permitted work.

e. Damage claims associated with any future modification, suspension, or revocation of this permit.

4. Reliance on Applicant's Data: The determination of this office that issuance of this permit is not contrary to the public interest was made in reliance on the information you provided.

5. Reevaluation of Permit Decision. This office may reevaluate its decision on this permit at any time the circumstances warrant. Circumstances that could require a reevaluation include, but are not limited to, the following:

a. You fail to comply with the terms and conditions of this permit.

b. The information provided by you in support of your permit application proves to have been false, incomplete, or inaccurate (See 4 above).

c. Significant new information surfaces which this office did not consider in reaching the original public interest decision.

Such a reevaluation may result in a determination that it is appropriate to use the suspension, modification, and revocation procedures contained in 33 CFR 325.7 or enforcement procedures such as those contained in 33 CFR 326.4 and 326.5. The referenced enforcement procedures provide for the issuance of an administrative order requiring you to comply with the terms and conditions of your permit and for the initiation of legal action where appropriate. You will be required to pay for any corrective measures ordered by this office, and if you fail to comply with such directive, this office may in certain situations (such as those specified in 33 CFR 209.170) accomplish the corrective measures by contract or otherwise and bill you for the cost.

6. Extensions. General condition 1 establishes a time limit for the completion of the activity authorized by this permit, Unless there are circumstances requiring either a prompt completion of the authorized activity or a reevaluation of the public interest decision, the Corps will normally give favorable consideration to a request for an extension of this time limit.

Your signature below, as permittee, indicates that you accept and agree to comply with the terms and conditions of this permit.

Barbara M Sugiya — Jan 31, '05

(PERMITTEE) **NAVAL FACILITIES ENGINEERING SERVICE CENTER** *(DATE)*

This permit becomes effective when the Federal official, designated to act for the Secretary of the Army, has signed below.

Charles R Alexander — 11 Feb 05

(DISTRICT ENGINEER) **CHARLES R. ALEXANDER, JR., COLONEL** *(DATE)*

When the structures or work authorized by this permit are still in existence at the time the property is transferred, the terms and conditions of this permit will continue to be binding on the new owner(s) of the property. To validate the transfer of this permit and the associated liabilities associated with compliance with its terms and conditions, have the transferee sign and date below.

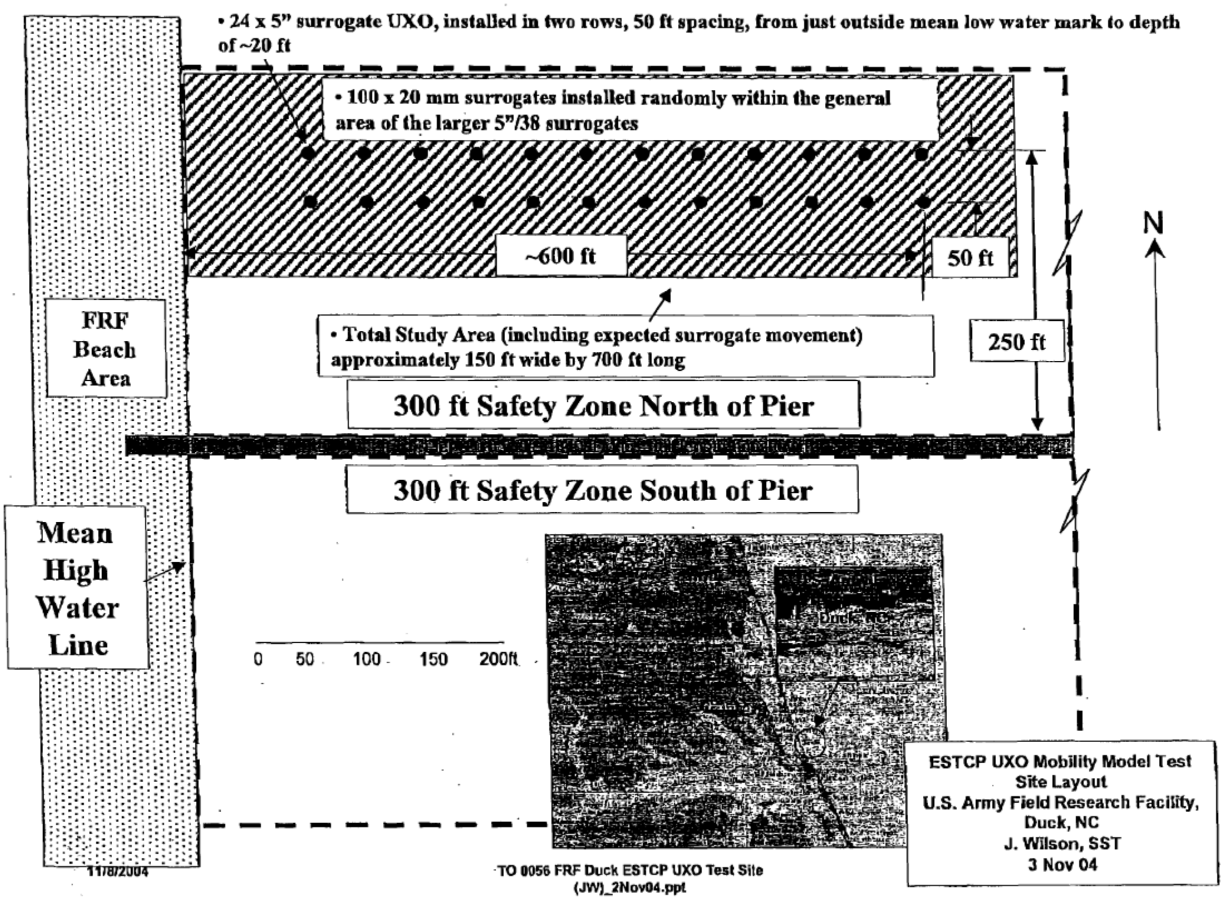
(TRANSFEREE) *(DATE)*

*U.S. GOVERNMENT PRINTING OFFICE: 1986 - 717-425

SPECIAL CONDITIONS

a. If, in the opinion of the Secretary of the Army or his authorized representative, said structure or work shall cause unreasonable obstruction to the free navigation of the navigable waters, the Permittee will be required, upon due notice from the Corps of Engineers, to remove, relocate, or alter the structural work or obstructions caused thereby.

b. The Permittee must place the tethering devices in such a manner so as not to create a risk of entanglement by sea turtles feeding or foraging in the vicinity of the pier.



NOTIFICATION OF ADMINISTRATIVE APPEAL OPTIONS AND PROCESS AND REQUEST FOR APPEAL

Applicant: **Naval Facilities Engineering Service Center**		File Number: **200510367**	Date: **JAN. 19, 2005**
Attached is:			See Section below
X	INITIAL PROFFERED PERMIT (Standard Permit or Letter of permission)		A
	PROFFERED PERMIT (Standard Permit or Letter of permission)		B
	PERMIT DENIAL		C
	APPROVED JURISDICTIONAL DETERMINATION		D
	PRELIMINARY JURISDICTIONAL DETERMINATION		E

SECTION I – The following identifies your rights and options regarding an administrative appeal of the above decision. Additional information may be found at http://usace.army.mil/inet/functions/cw/cecwo/reg or Corps regulations at 33 CFR Part 331.

A: INITIAL PROFFERED PERMIT: You may accept or object to the permit.

- ACCEPT: If you received a Standard Permit, you may sign the permit document and return it to the district engineer for final authorization. If you received a Letter of Permission (LOP), you may accept the LOP and your work is authorized. Your signature on the Standard Permit or acceptance of the LOP means that you accept the permit in its entirety, and waive all rights to appeal the permit, including its terms and conditions, and approved jurisdictional determinations associated with the permit.
- OBJECT: If you object to the permit (Standard or LOP) because of certain terms and conditions therein, you may request that the permit be modified accordingly. You must complete Section II of this form and return the form to the district engineer. Your objections must be received by the district engineer within 60 days of the date of this notice, or you will forfeit your right to appeal the permit in the future. Upon receipt of your letter, the district engineer will evaluate your objections and may: (a) modify the permit to address all of your concerns, (b) modify the permit to address some of your objections, or (c) not modify the permit having determined that the permit should be issued as previously written. After evaluating your objections, the district engineer will send you a proffered permit for your reconsideration, as indicated in Section B below.

B: PROFFERED PERMIT: You may accept or appeal the permit

- ACCEPT: If you received a Standard Permit, you may sign the permit document and return it to the district engineer for final authorization. If you received a Letter of Permission (LOP), you may accept the LOP and your work is authorized. Your signature on the Standard Permit or acceptance of the LOP means that you accept the permit in its entirety, and waive all rights to appeal the permit, including its terms and conditions, and approved jurisdictional determinations associated with the permit.
- APPEAL: If you choose to decline the proffered permit (Standard or LOP) because of certain terms and conditions therein, you may appeal the declined permit under the Corps of Engineers Administrative Appeal Process by completing Section II of this form and sending the form to the division engineer. This form must be received by the division engineer within 60 days of the date of this notice.

C: PERMIT DENIAL: You may appeal the denial of a permit under the Corps of Engineers Administrative Appeal Process by completing Section II of this form and sending the form to the division engineer. This form must be received by the division engineer within 60 days of the date of this notice.

D: APPROVED JURISDICTIONAL DETERMINATION: You may accept or appeal the approved JD or provide new information.

- ACCEPT: You do not need to notify the Corps to accept an approved JD. Failure to notify the Corps within 60 days of the date of this notice means that you accept the approved JD in its entirety, and waive all rights to appeal the approved JD.
- APPEAL: If you disagree with the approved JD, you may appeal the approved JD under the Corps of Engineers Administrative Appeal Process by completing Section II of this form and sending the form to the division engineer. This form must be received by the division engineer within 60 days of the date of this notice.

E: PRELIMINARY JURISDICTIONAL DETERMINATION: You do not need to respond to the Corps regarding the preliminary JD. The Preliminary JD is not appealable. If you wish, you may request an approved JD (which may be appealed), by contacting the Corps district for further instruction. Also you may provide new information for further consideration by the Corps to reevaluate the JD.

SECTION II - REQUEST FOR APPEAL or OBJECTIONS TO AN INITIAL PROFFERED PERMIT

REASONS FOR APPEAL OR OBJECTIONS: (Describe your reasons for appealing the decision or your objections to an initial proffered permit in clear concise statements. You may attach additional information to this form to clarify where your reasons or objections are addressed in the administrative record.)

ADDITIONAL INFORMATION: The appeal is limited to a review of the administrative record, the Corps memorandum for the record of the appeal conference or meeting, and any supplemental information that the review officer has determined is needed to clarify the administrative record. Neither the appellant nor the Corps may add new information or analyses to the record. However, you may provide additional information to clarify the location of information that is already in the administrative record.

POINT OF CONTACT FOR QUESTIONS OR INFORMATION:

If you have questions regarding this decision and/or the appeal process you may contact: Mr. Raleigh Bland Washington Regulatory Field Office P.O. Box 1000 Washington, North Carolina 27889-1000	If you only have questions regarding the appeal process you may also contact: Mr. Arthur Middleton, Administrative Appeal Review Officer CESAD-ET-CO-R U.S. Army Corps of Engineers, South Atlantic Division 60 Forsyth Street, Room 9M15 Atlanta, Georgia 30303-8801

RIGHT OF ENTRY: Your signature below grants the right of entry to Corps of Engineers personnel, and any government consultants, to conduct investigations of the project site during the course of the appeal process. You will be provided a 15-day notice of any site investigation, and will have the opportunity to participate in all site investigations.

_______________________ Signature of appellant or agent	Date:	Telephone number:

DIVISION ENGINEER:
Commander
U.S. Army Engineer Division, South Atlantic
60 Forsyth Street, Room 9M15
Atlanta, Georgia 30303-3490

Appendix B

Test Hardware

NOTE: This discussion of Test Hardware - with accompanying photographs - appears in the UXO Measurement Method Field Test Plan of 29 March 2004 (reference 2 of this report).

Preliminary brainstorming for materials to be used in construction of surrogate UXO called for the use of concrete, lead, rebar, and tin. This design was appealing on a cost basis but required a lot of steps. Using a concrete matrix with an SG (specific gravity) of 2.3 the design would have to incorporate lead to reach the desired overall SG and CG (center of gravity). Concrete is also prone to water erosion and requires strength members to make it strong. These strength members combined with use of lead and tin (for the cylindrical portion of the UXO) make a very complicated modeling process. With some research it was found that there exists a resin type moldable plastic that is machineable and has a high SG. This plastic is also very strong and resistant to water absorption. The strength enables the design to be much simpler allowing modeling to be much more accurate. The high SG permits the avoidance of lead use for the core. (See Figure13 for typical plastic properties.)

Hapco, Inc., Hapcast 3738/60 Properties

Viscosity @ 25° C	9,000 cps
Hardness Shore D	85-90
Ultimate Compressive Strength	16-18,000 psi
Linear Shrinkage inch/inch	.001
Specific Gravity	2.5
Color	Black
Machinability	Very good

Properties of HapCast 3738/60
Courtesy of Hapco, Inc. <http://www.hapcoweb.com>

2.5 pound cast iron weight-plates (identical to ones used for fitness) were selected as the SG equalizer because of their diameter, cost, and high density (7.0 g/cm^3). The center rod is a standard weight lifting handle with nutlike screwing weight-locks to hold the weight-plates in place. This cast iron core facilitates the correct specific gravity and center of mass. Placement of the cast iron weight-plates must be 1.65 inches from the base of the rod and rod end must be flush the end of the mold to reach ideal center of mass. Pouring the Hapcast 3738/60 into the mold with correct placement of the cast iron core will result in properties listed.

Mass properties of Assembly UXO
Output coordinate System: -- default -- Density = .18 pounds per cubic inch Mass = 54.22 pounds Volume = 302.7 cubic inches
Center of mass: (Inches) X=0.00 Y-7.72 (19.61 cm) Z=0.00

USR-96 Narrow Band Scanning Receiver:

The USR-96 offers wide tuning range and narrow band reception ideal for use in noisy environments. Additionally, the USR-96 may be set to scan 10 preset frequencies to reduce the labor in manual tracking. The two line LCD displays both frequency and interval. The USR-96 is available as a part of the **MANTRAK Kit**, bringing all of the tools together necessary for manual tracking.

FREQUENCY: 30 - 90 kHz, 250 Hz steps.
BANDWIDTH: 500 Hz, 7 pole response.
OUTPUT: Headphone jack, RS-232 output.
POWER: Internal rechargeable batteries with charger.
SIZE: 6.3 in. x 6.3 in. x 4.5 in. deep
INPUT: BNC connector
SENSITIVITY: 1 uVolts for 30 dB (S+N)/N ratio.
DISPLAY: 2 x 16 LCD

Model DH-4 directional hydrophone:

This unit provides the greatest range and precision in locating tags in lakes and oceans, and permits rejection of local noise caused by dams or pumping stations in rivers and streams. The DH-4 is the primary hydrophone for both fixed stations and manual tracking.

SENSITIVITY: -84 dBV ref 1 uBar.
BEAM WIDTH: +/-6 degrees at half power points.
SHAFT LENGTH: User supplies mounting shaft (1 inch PVC).
OUTPUT: BNC connector on 10-foot coaxial cable (other lengths available).
CABLE: *Replaceable* RG-58 C/U.

UDR Underwater Diver Receiver:
The UDR allows a diver to approach an object or target marked with a pinger, even in low visibility environments. The UDR comes with waterproof headphones. The unit has variable gain control to maintain good signal strength and directionality during approach to the target. It also has a volume control and a backlit display. The unit is user programmable for frequency selection and gain range.

Length: (From Display to outer rim) 16cm
Width: (At outer rim) 11cm
Height: (Bottom of Handle to top of unit) 20cm
Weight (Air): UDR: 900g, Headphones: 415g
Sensitivity: 20uV, (S+N)/N = 30dB
Frequencies: 30 to 90 kHz
Controls: Gain control, volume control, and frequency control. User can preprogram the unit before the dive for a variety of applications.

EMT-01-2 Acoustic Pingers:

The EMT transmitters are a set of standard models packaged and configured for equipment marking applications.

The EMT series transmitters come standard with flat ends and 3/16" mounting holes on each end. Other custom packaging options are possible.

Each EMT pinger is individually numbered, with different frequencies and pinger intervals so that differentiation can take place in the “in field” environment.

FREQUENCY RANGE: 77-83kHz
RANGE: Up to 3km
SOURCE LEVEL: 146dB re 1µPa at 1 meter (14dB below NMFS 160dB standard for impact on marine mammals)
SIZE: 104x18mm
WEIGHT: 15g
BATTERY LIFE: 18 months

Appendix C

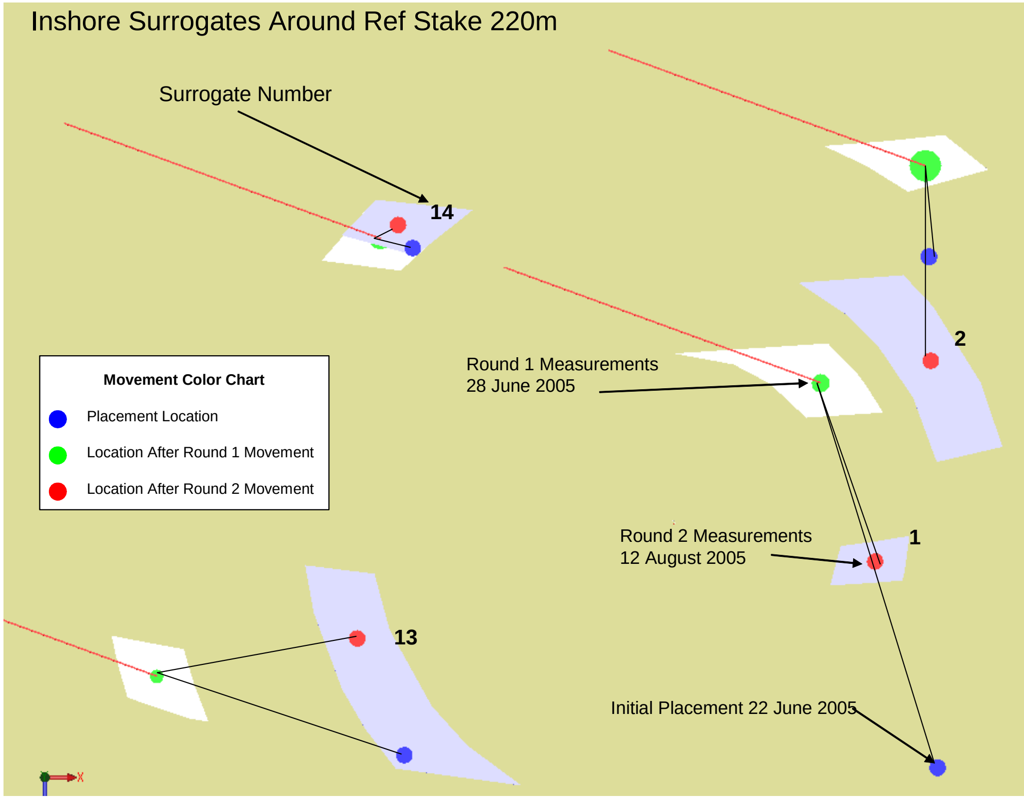
Round One and Round Two Movement Details

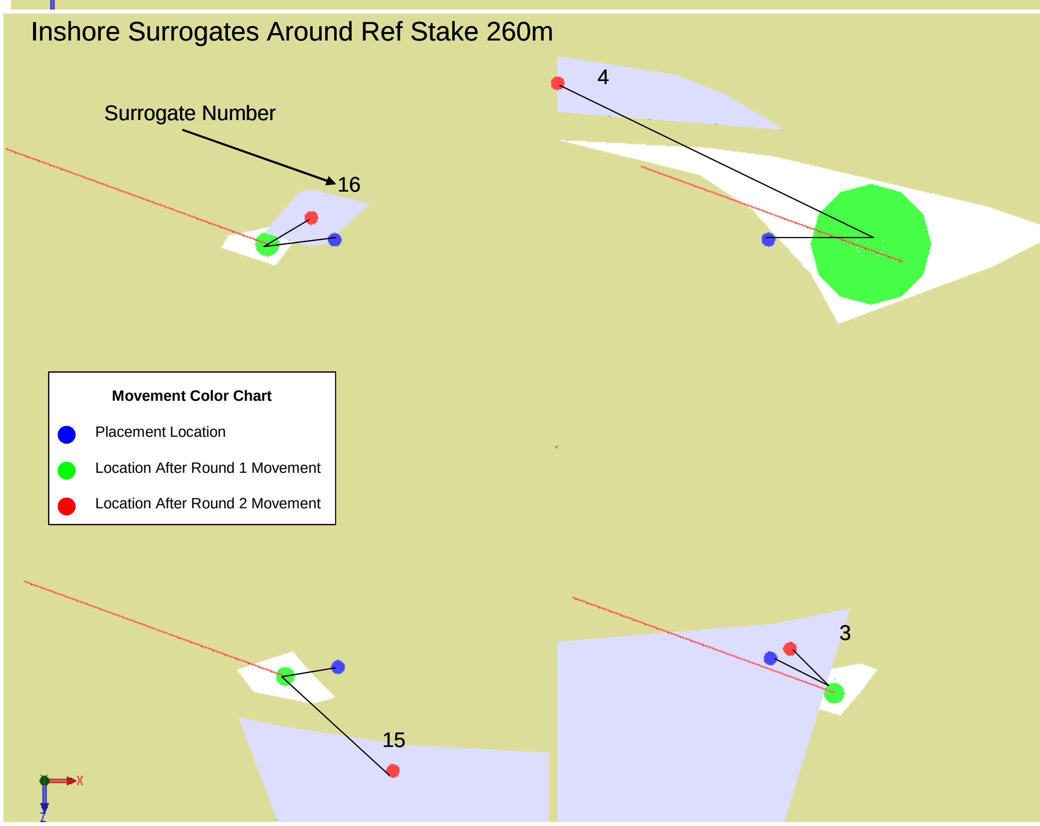
Total Surrogate Movement FRF Duck, NC (Net movement from: initial placement 22 June 05, Round 1 Movement 28 June 05, and Round 2 Movement 12 Aug 05)								
Total Surrogate Movement (from initial placement and rounds 1 and 2 movement)			Error 1			Error 2		
Surrogate	**Movement Distance (m)**	**Movement Angle w/ Respect to True North**	Distance (m)	Angle 1 (deg) w/respect to movement vector	Angle 2 (deg) w/respect to movement vector	Distance (m)	Angle 1 w/respect to movement vector	Angle 2 w/respect to movement vector
1T	3.7	48	2.6	11	191	1.0	101	281
2T	0.7	38	0.4	180	360	0.5	90	270
3T	4.2	222	1.2	41	221	4.2	131	311
4T	1.1	22	0.3	90	270	0.3	180	360
5*T	4.5	16	1.2	123	303	7.4	33	213
6T	2.3	241	1.5	90	270	0.7	180	360
7T	2.5	43	0.8	106	286	0.5	16	196
8T	4.2	336	0.6	90	270	0.6	180	360
9T	2.1	328	0.9	12	192	0.3	102	282
10T	1.5	419	0.8	96	276	1.2	6	186
11T	1.9	31	2.7	4	184	1.2	94	274
12T	4.3	180	1.1	25	205	3.0	115	295
13T	6.4	53	0.7	180	360	1.1	90	270
14T	3.1	248	1.0	49	229	3.3	139	319
15T	0.8	134	2.7	171	351	1.2	81	261
16T	9.4	17	1.1	53	233	1.5	143	323
17T	8.8	314	1.3	26	206	2.5	116	296
18T	3.4	255	0.9	112	292	0.4	23	203
19T	3.2	313	2.4	20	200	1.1	110	290
20T	5.8	236	3.3	14	194	1.1	104	284
21T*	2.8	133	4.0	117	297	9.2	27	207
22T	5.3	138	0.9	90	270	0.9	180	360
23T	5.0	74	1.0	52	232	0.8	142	322
24T	3.6	41	3.9	145	325	1.1	55	235
AVERAGE	**3.8**	**162**	**1.5**	79	259	**1.9**	102	282

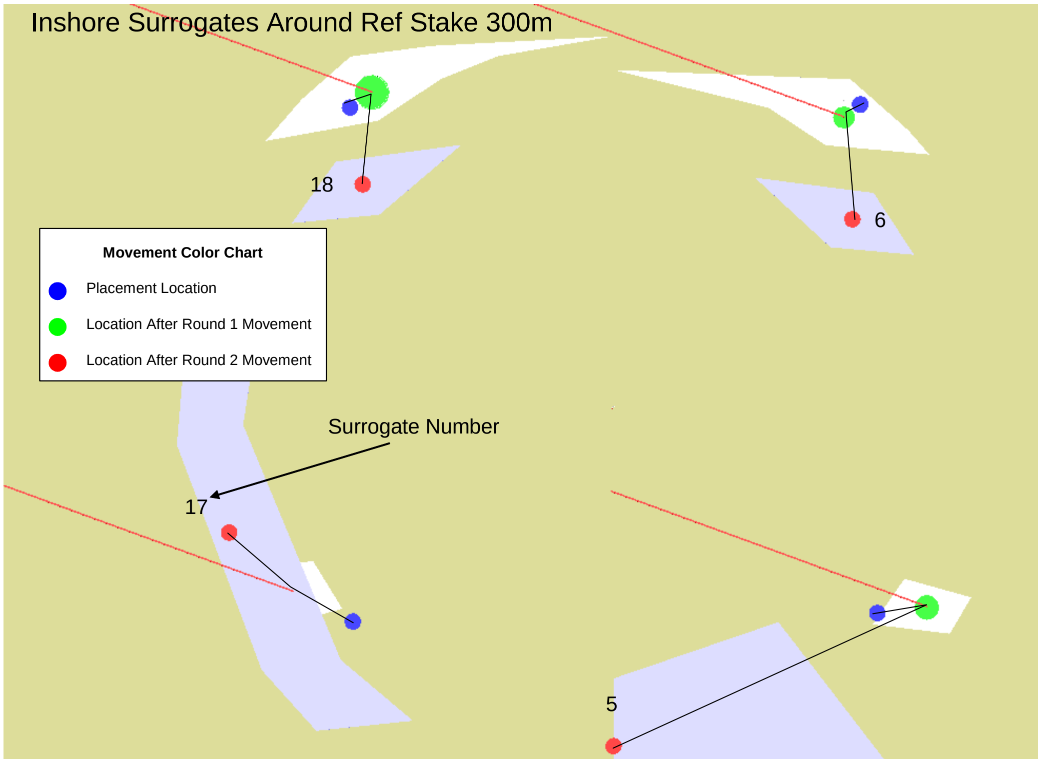
		Explanation of Cell Title
Round 2 Surrogate Movement	Surrogate	Surrogate number with respect to placement field. The "T" indicates total movement. The "*" indicates very poor data for the corresponding surrogate.
	Movement Distance (m)	The distance moved in meters from the initial placement location 22 June 05 to the round 2 diver measured locations of 12 Aug 05.
	Movement Angle w/ Respect to True North	The angle of the movement vector, in degrees, with respect to true North. This is the angle of surrogates movement between the initial placement location and the movement measurements of round 2 (12 Aug 2005).
Error 1	Distance +/- (m)	The Benthos triangulation process has some degree of error, with some of the diver's measurements being far more accurate than others. Some of the diver's measurements were also most of the time more accurate along one axis than another (see figure 1 for a visual). For this reason we chose to use an elliptical error region. The "Error 1 Distance" is one of the radii of the calculated error ellipses in a +/- factor.
	Angle 1 (deg) w/respect to movement vector	The error ellipse, to maintain a minimum error, had to have a unique orientation for each surrogate movement measurement. "Angle 1, in degrees, with respect to the movement vector" is the angle the radius from "Distance 1" creates with respect to the movement vector. (See Figure 1 for a visual.)
	Angle 2 (deg) w/respect to movement vector	Because an ellipse has two unique radii each with a +/- factor, the is a second angle made with respect to the movement vector which is 180 degree translation of the first angle
Error 2	Distance +/- (m)	The second radius of the error ellipse.
	Angle 1 (deg) w/respect to movement vector	The angle that the "Error 2" distance radius makes with respect to the movement vector.
	Angle 2 (deg) w/respect to movement vector	A 180 degree translation of the first "Error 2" angle.

Round 2 Surrogate Movement FRF Duck, NC Taken 12 Aug 2005								
Round 2 Surrogate Movement			Error 1			Error 2		
Surrogate	Movement Distance (m)	Movement Angle w/ Respect to True North (deg)	Distance +/- (m)	Angle 1 (deg) w/respect to movement vector	Angle 2 (deg) w/respect to movement vector	Distance +/- (m)	Angle 1 w/respect to movement vector	Angle 2 w/respect to movement vector
1	6.1	149	2.6	90	270	1.0	180	360
2	0.7	122	0.4	96	276	0.5	6	186
3	5.1	201	1.2	62	242	4.2	152	332
4	1.8	129	0.3	90	270	0.3	180	360
5*	2.6	23	1.2	116	296	7.4	26	206
6	2.7	256	1.5	75	255	0.7	155	335
7	2.1	58	0.8	90	270	0.5	180	360
8	3.4	224	0.6	90	270	0.6	180	360
9	6.2	6	0.9	154	334	0.3	64	244
10	5.5	266	0.8	148	328	1.2	58	238
11	5.9	226	2.7	168	348	1.2	78	258
12	5.2	197	1.1	9	189	3.0	99	279
13	5.5	233	0.7	180	360	1.1	90	270
14	5.8	248	1.0	49	229	3.3	139	319
15	2.2	25	2.7	100	280	1.2	10	190
16	12.6	7	1.1	63	243	1.5	153	333
17	10.2	317	1.3	24	204	2.5	114	294
18	3.0	245	0.9	122	302	0.4	32	212
19	2.5	248	2.4	84	264	1.1	174	354
20	7.8	208	3.3	42	222	1.1	132	312
21*	5.8	173	4.0	77	257	9.2	167	347
22	7.2	168	0.9	90	270	0.9	180	360
23	8.0	102	1.0	24	204	0.8	114	294
24	3.8	136	3.9	50	230	1.1	140	320
AVERAGE	**5.1**	**165**	**1.5**	87	267	**1.9**	117	297

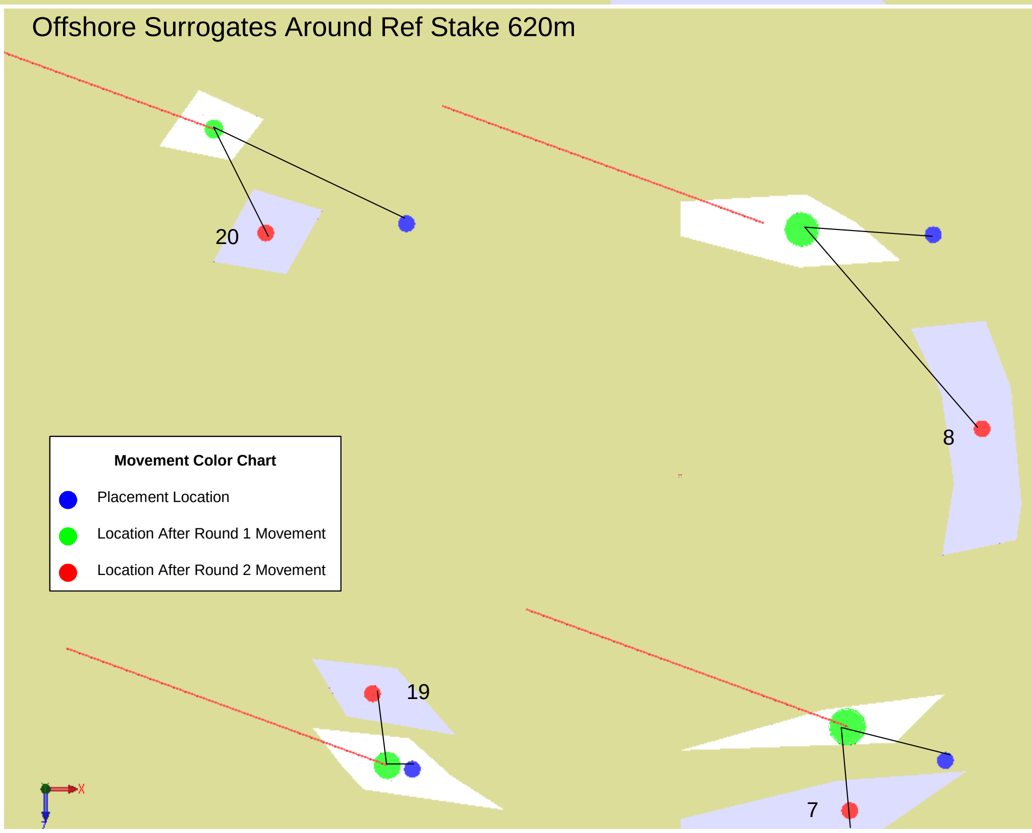
		Explanation of Cell Title
Round 2 Surrogate Movement	Surrogate	Surrogate number with respect to placement field. The "*" indicates very poor data for the corresponding surrogate.
	Movement Distance (m)	The distance moved in meters from the center of the round 1 measurement data (collected on 28 June 2005).
	Movement Angle w/ Respect to True North	The angle of the movement vector, in degrees, with respect to true North. This is the angle the surrogates moved between the round 1 movement measurements (28 June 2005) and the round 2 movement measurements (12 Aug 2005).
Error 1	Distance +/- (m)	The Benthos triangulation process has some degree of error, with some of the diver's measurements being far more accurate than
	Angle 1 (deg) w/respect to movement vector	The error ellipse, to maintain a minimum error, had to have a unique orientation for each surrogate movement measurement. "Angle 1, in degrees, with respect to the movement vector" is the angle the radius from "Distance 1" creates with respect to the movement vector. (See Figure 1 for a visual.)
	Angle 2 (deg) w/respect to movement vector	Because an ellipse has two unique radii each with a +/- factor, the is a second angle made with respect to the movement vector which is 180 degree translation of the first angle
Error 2	Distance +/- (m)	The second radius of the error ellipse.
	Angle 1 (deg) w/respect to movement vector	The angle that the "Error 2" distance radius makes with respect to the movement vector.
	Angle 2 (deg) w/respect to movement vector	A 180 degree translation of the first "Error 2" angle.


Inshore Surrogates Around Ref Stake 220m
Surrogate Number
14
2
Round 1 Measurements
28 June 2005
Movement Color Chart
Placement Location
Location After Round 1 Movement
Location After Round 2 Movement
Round 2 Measurements
12 August 2005
1
13
Initial Placement 22 June 2005
X

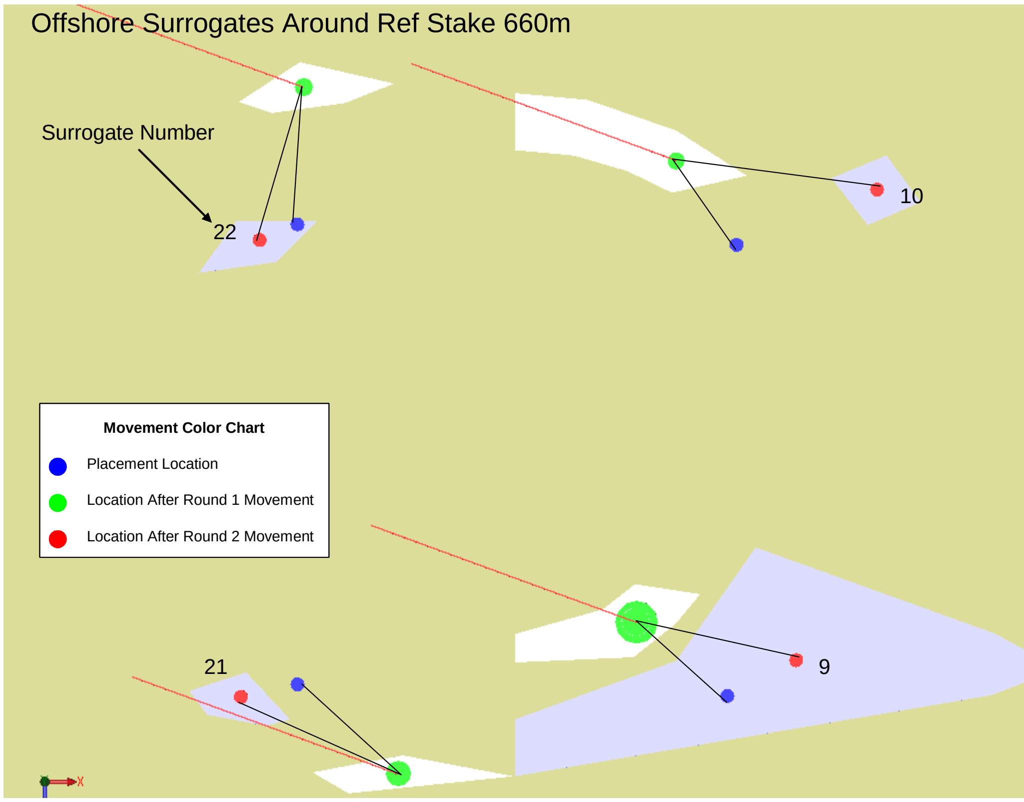

Inshore Surrogates Around Ref Stake 260m
4
Surrogate Number
16
Movement Color Chart
Placement Location
Location After Round 1 Movement
Location After Round 2 Movement
3
15
X
Z

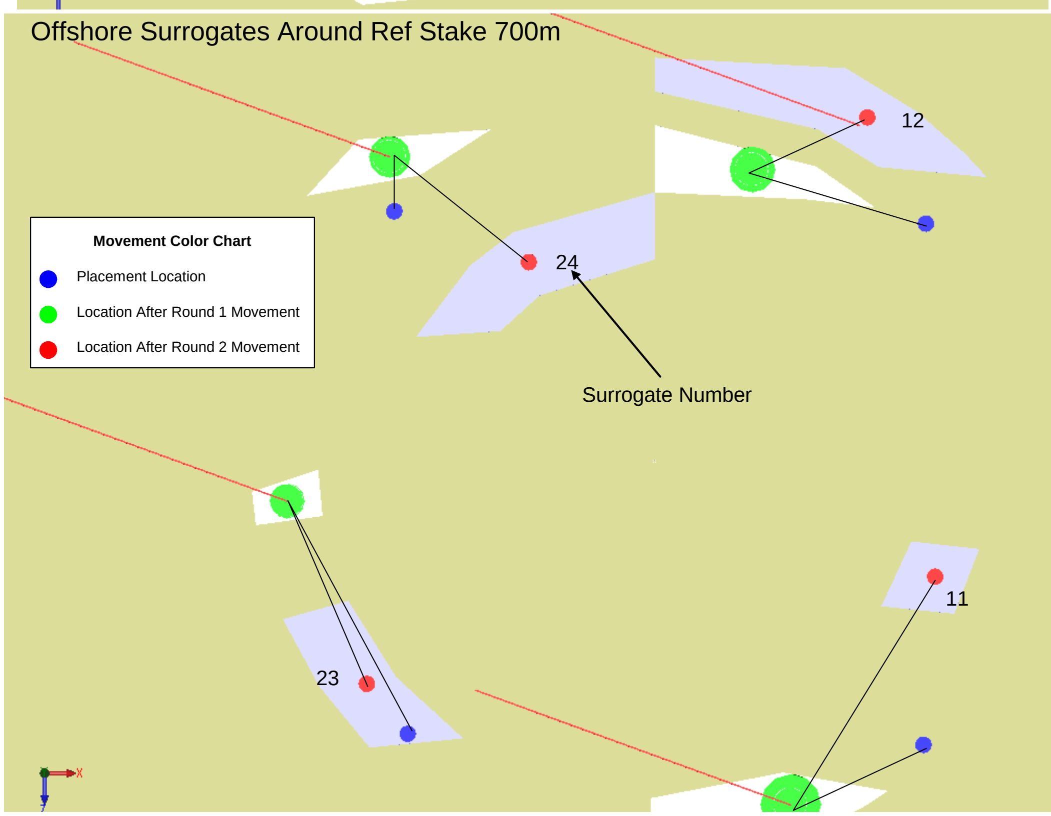


Inshore Surrogates Around Ref Stake 300m
18
6
Movement Color Chart
Placement Location
Location After Round 1 Movement
Location After Round 2 Movement
Surrogate Number
17
5



Offshore Surrogates Around Ref Stake 620m
20
8
Movement Color Chart
Placement Location
Location After Round 1 Movement
Location After Round 2 Movement
19
7


Offshore Surrogates Around Ref Stake 660m
Surrogate Number
22
10
Movement Color Chart
Placement Location
Location After Round 1 Movement
Location After Round 2 Movement
21
9


Offshore Surrogates Around Ref Stake 700m
12
Movement Color Chart
Placement Location
Location After Round 1 Movement
Location After Round 2 Movement
24
Surrogate Number
11
23