FINAL REPORT

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

ESTCP Project MM-0417

MAY 2008

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Environmental Security Technology Certification Program

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List of Abbreviations and Acronyms

Acronym	Definition
ADCP	Acoustic Doppler Current Profiler
AGD	Applications Guidance Document
ARAMS	Adaptive Risk Assessment Modeling System
ASTM	American Society for Testing and Materials
BPR	bottom measure recorders
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
DRI	Dive Ranger Interrogator
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
LIDAR	Light Detection and Ranging
MB	megabyte
MCBH	Marine Corps Base Hawaii
MDT	Mugu Drifter Test
MMFT	Measurement Method Field Test
MSL	Mean Sea Level
NAD	Navy Ammunition Depot
NAS	Naval Air Station
NAVFAC	Naval Facilities Engineering Command
NAVFAC ESC	Naval Facilities Engineering Command Engineering Service Center
NAVFAC Pacific	NAVFAC Pacific Division
NESDI	Navy Environmental Sustainability Development to Integration

NGDC	National Geophysical Data Center
NOS	National Ocean Service
NS	Naval Station
NWS	Naval Weapons Station
ONR	Office of Naval Research
PMRF	Pacific Missile Range Facility
QA	Quality Assurance
QAPP	Quality Assurance Project 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
UDR	Underwater Diver Receiver
USACE	U.S. Army Corps of Engineers
USAESCH	U.S. Army Engineering and Support Center
USGS	United States Geological Survey
UXO	unexploded ordnance
VSW	Very Shallow Water
VORTEX	Vortex Lattice Model

Acknowledgements

The UXO Mobility Model Demonstration/Validation program was funded by the Environmental Security Technology Certification Program (ESTCP). It was conducted by the Naval Facilities Engineering Command Engineering Service Center (NAVFAC ESC), with support from Sound & Sea Technology, Inc. (SST). Ms. Barbara Sugiyama and Ms. Alexandra DeVisser, with NAVFAC ESC, were the Co-Principal Investigators for this effort. The SST program was led by Mr. Jeffrey Wilson. The UXO Mobility Model was developed by Dr. Scott Jenkins and Mr. Joe Wasyl of Scott A. Jenkins Consulting. The Model was tested and evaluated by Mr. Dennis Garrood, Mrs. Chanda Daly, and Mr. Eugene Keam of SST. The field work was directed by Mr. William Daly and Mr. Ian McKissick of SST. On-site field test demonstration support was provided by Mr. Dan Momohara and the staff of the Pacific Missile Range Facility (PMRF) at Barking Sands, Kauai, Hawaii. This report was prepared by the combined NAVFAC ESC/SST/SAJ staff.

The original UXO Mobility Model was developed under the Chief of Naval Operation's (CNO) Navy Environmental Sustainability Development to Integration (NESDI) program. The NESDI program is managed for CNO-N45 by the Naval Facilities Engineering Command (NAVFAC). The model upgrades and the field demonstration and validation field test efforts were funded by ESTCP.

Executive Summary

A process-based underwater unexploded ordinance (UXO) Mobility Model (MM)was developed and exercised with field measurements obtained at two separate offshore sites in a biogenic reef environment off the west coast of the island of Kauai, HI, at the Pacific Missile Range Facility (PMRF), Barking Sands. The MM was used to generate hydrodynamic forcing, UXO migration, and UXO burial simulations that were in general agreement with the ensemble results from 24 inert surrogate 5”/38 projectiles that were monitored between 13 February and 27 June 2007. The following conclusions are derived from the demonstration results and the following MM calibration and validation analysis:

- The biogenic reef environment is the most challenging UXO modeling problem encountered to date due to the presence of complex micro-bathymetry associated with meandering channels that cut through the fringing reef; in the Hawaiian language, these channels are called **“**awa**”**. The complexities of the awa side walls influence the nearfield flow dynamics, presenting a tedious challenge when defining the grid spacing of the model. Meeting this challenge did not require generating new MM code, but did necessitate using high resolution bathymetry data obtained with Light Detection and Ranging (LIDAR) optical remote sensing technology and considerable computer memory to permit adequate high density grid computing to be performed. The channels introduce both curvature and roughness effects that affect the flow of wave surges and wave-induced streaming. These flow disturbances produce vertical divergence in the flow over the UXO body and introduce large-scale eddies in the nearfield of the UXO that induce localized scour, which adds vectorally to the component already excited directly by the UXO’s shape.

- The reef channels confine a sediment cover of complex composition that alters parameters of the granular transport equations in the model. The components of this sediment cover vary considerably between the windward and leeward sides of biogenic reef environments, requiring a separate set of granular parameters for the opposing sides of the reef. Typically, 70% of awa sediments are composed of carbonate deposits which are primarily biological in origin, and largely consist of the skeletal remains of marine organisms (e.g., coral). The carbonate sediments comprise the majority of the coarser size bins, while the finer fractions are predominately sediments of terrigenous origin and generally make up about 27% of the channel sediments, while 3% are organic material, a major portion of which is also derived from the erosion of rocks on land. These terrigenous sediments and organics are carried to the sea’s reef environment by rivers and local intermittent streams. Generally, the mean grain sizes of sand, mud, and silt from streams and rivers draining the leeward sides are smaller than those of streams draining the windward sides and their composition is usually related to their source rocks.

- Model predictions and measurements are presented in this report for 24 surrogates of a 5”/38 projectile half of which were deployed at a shallow water inshore site at 8.3 m local

depth and the other half at a deeper offshore site at 16.6 m local depth. Both sites occupied the same awa that takes several turns and bends between the two locations. The average threshold of migration for the 5”/38 UXO surrogates at the shallow site appears to occur at a significant wave height, *Ho*, of approximately 1.3 m. From this threshold, migration rates increase rapidly with increasing wave height, roughly tripling with an increase of only 0.3m in wave height. As this happens, burial rates increase at first slowly from being negligibly small at threshold of migration wave heights, to rapidly increasing rates as burial lock-down is approached at significant wave heights of approximately 1.6 m. Maximum migration rates are approximately 0.0028 cm/min. Beyond burial lock-down, the burial rate continues to accelerate until total burial is achieved. At that point, the scour burial mechanism vanishes and only farfield burial induced by bottom profile change can effect any subsequent burial. Scour burial maxima for the inshore site occur at $Ho \approx 2$ m at a rate of 0.003% per minute; although this result is somewhat controlled by the particular sidewall effects of the channel at the inshore site. The threshold wave height for migration of the UXO surrogates at the offshore array is substantially higher and increased to $Ho = 1.7$ m, primarily due to depth attenuation of the wave orbital velocity in the deeper waters of the offshore site. For the same reason, there are fewer numbers of wave events that induce migration at the deeper offshore site. However, once the UXO surrogates at the offshore site began to move, their migration rate increased rapidly with wave height, reaching a maximum migration rate 0.0015 cm/min at $Ho > 1.8$ m. This maximum migration rate is approximately one half that of the surrogates at the inshore site and occurs at a substantially higher significant wave height (i.e., 1.8 m versus 1.6 m), again because of depth attenuation in orbital wave velocities. At their maximum migration rate, surrogates in the offshore array are burying at 0.0019% per minute while surrogates in the inshore array are burying at approximately one-third that rate, or 0.0005% per minute. Thus, surrogates in the offshore array reach burial lock-down sooner, and therefore have less time to migrate from their previous location. Maximum burial rates of surrogates in the offshore array are 0.0045% per minute at a $Ho = 2$ m, or about 50% faster than for surrogates in the inshore array; this is not a counter-intuitive result when considering that burial rates tend to increase with orbital velocity while orbital velocity decreases with increasing depth; when waves move into shallow water, the height and orbital velocity increase as the wavelength decrease while the wave period remains invariant. Our interpretation of this specific and somewhat paradoxical result is that the large scale eddies induced by the awa sidewalls are more active and well developed at the offshore site, and this action increases scour burial rates induced by relatively smaller orbital velocities.

- Two approaches were applied to assess the quantitative model’s skill in predicting the magnitude of migration and burial of UXO surrogates at PMRF. In the first approach, probability density functions of migration and burial magnitudes predicted by the model were constructed and compared with the probability density functions assembled from the observed outcomes of the experiment. As the second approach, a predictive skill factor, *R,* was computed from the mean squared error between the predicted and measured outcomes. The peak, spread, and shape of the predicted and measured

probability density functions of migration are quite similar to each other. Both distributions yield a mean migration distance of approximately 1 m and a maximum migration of greater than 3 m. In both the predicted and observed outcomes, migration was almost exclusively along the axis of the awa channel. The peak of the measured burial probability distribution, its breadth, and shape all closely resemble the modeled distribution. Mean burial depths are approximately 20 cm, while maximum burial depths are slightly over 40 cm. These burial depths are greater than what was observed during the brief deployment at Ocean Shores, Washington, but are on a par with the burial depths of the inshore surrogates at Duck, NC. The skill factor for migration, R_ξ at PMRF was calculated at $R_\xi =$ 0.88 and $R_h =$ 0.90 for burial. For coastal processes modeling and mine burial prediction in particular, it is noted that a skill factor in excess of 0.8 is considered to be a good result (Gallagher et al. (1998) [1], Jenkins and Inman (2006) [2]).

1.0 INTRODUCTION

This report documents the second of two Environmental Security Technology Certification Program (ESTCP) UXO Mobility Model demonstrations. The objective of the ESTCP UXO Mobility Model project is to demonstrate and validate the UXO Mobility Model (MM) 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, such as Hawaii).

The Trailing Edge environment typically is characterized by areas located on a very wide, shallow continental shelf area with heavy bottom sediment cover composed of silicon-based sands and sediments. Biogenic reefs typically exhibit more irregular seafloor shapes crossed by channels and limited sediment covers of detrital carbonate sands. The first ESTCP UXO field demonstration was conducted at a Trailing Edge site off the coast of North Carolina at the Field Research Facility (FRF) Duck, NC); the results of that demonstration are reported under separate cover [3].

The ESTCP UXO Mobility Model project is divided into three main parts which address the following areas:

- Refine and update the Navy-developed UXO Mobility Model
- Conduct two field demonstrations to provide calibration/validation data
- Calibrate/validate the MM using field demonstration data.

Section 1 provides the project's background, demonstration hypotheses, program performance objectives, a description of the field demonstration method, and a description of the demonstration site selection process. Section 2 of this report documents the data collected during the field demonstration at the Pacific Missile Range Facility (PMRF), Barking Sands,

located on the west side of the island of Kauai, Hawaii, a Biogenic Reef environment. Section 3 of the report discusses the validation process for the Mobility Model.

The field demonstration data collection method consisted of deploying a series of surrogate 5”/38 rounds at known locations off the coast and tracking their movement using acoustic pingers and diver tracking systems, while also recording the local current and wave conditions. Once the observed movement was compared to MM predictions for the given environmental conditions, the MM was first calibrated, and then validated.

Taken together, these demonstrations provide data to calibrate and validate the MM for the majority of the identified underwater UXO sites in the U.S., including the highest profile sites which may present underwater environmental hazards. Most of the remaining sites are embayments and harbors such as Mare Island, CA, where current and wave energy levels are much lower than those on the open and unobstructed nearshore waters. In those confined 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 existing models for sediment transport and deposition.

For this second field demonstration, Sea Engineering, Inc. (SEI) was contracted by Sound & Sea Technology, Inc., (SST) to install, track, and, following the demonstration’s conclusion, recover inert surrogate projectiles representing standard naval 5-inch 38 caliber (5”/38) rounds deployed in a narrow, meandering awa, or sand channel, that cuts through the fringing coral reef at PMRF. The demonstration was conducted at this site, an area representative of a complex biogenic reef environment, from February 2007 through June 2007.

The deployment area selected for the Hawaii field demonstration is an awa channel oriented in an approximately east-west direction that bisects a limestone and coral reef bottom off the Pacific Missile Range Facility on the west coast of the island of Kauai (Figure 1). The awa extends from approximately the 5.5 m to the 24.5 m water depth, where it opens up into a larger offshore sand deposit. The distance from the 9.25 m depth to the 18.5 m depth is approximately 600 m. At the 15 m water depth there are vessel remnants in the middle of the awa that appear to be the remains of a small sail boat. At the 13 m water depth the sand channel narrows to a width of only approximately 3 m, but it is at least 18.5 m wide between the 6.2 m to 12.5 m depths and the 15 m to 25 m depths. This entire awa is bounded by reef and/or limestone on three sides. It ends abruptly inshore at a 1.5m reef escarpment in 4m of water. The escarpment walls on the north and south sides of the channel are typically 0.6 to 3m high. The awa’s sand thickness at the 13m depth (the location of the narrow bottleneck) is 0.7m, but the thickness throughout the remaining channel varies between 1.1 to 1.6m. All surrogates were installed in the sandy part of the awa, rather than on the coral sides, to (a) ensure minimal chance of actual loss of the surrogates and (b) to minimize any possible damage to the coral reefs.

The demonstration was installed on 13 February 2007 and continued through the spring and early summer of 2007. The surrogates were recovered on 27 June 2007. The coastal Kauai climate during the four-month deployment was relatively benign and no extreme weather events were

recorded. Measurements of the surrogate movements were conducted every month, as weather permitted. It is noted that the measurement system did reveal movements that were consistent with MM predictions.

This report describes the installation at the PMRF Kauai site on 13 February 2007 and seven sets of location measurements taken over the following 3.5 months (Table 1.). Section 2 of the report summarizes the data collected.

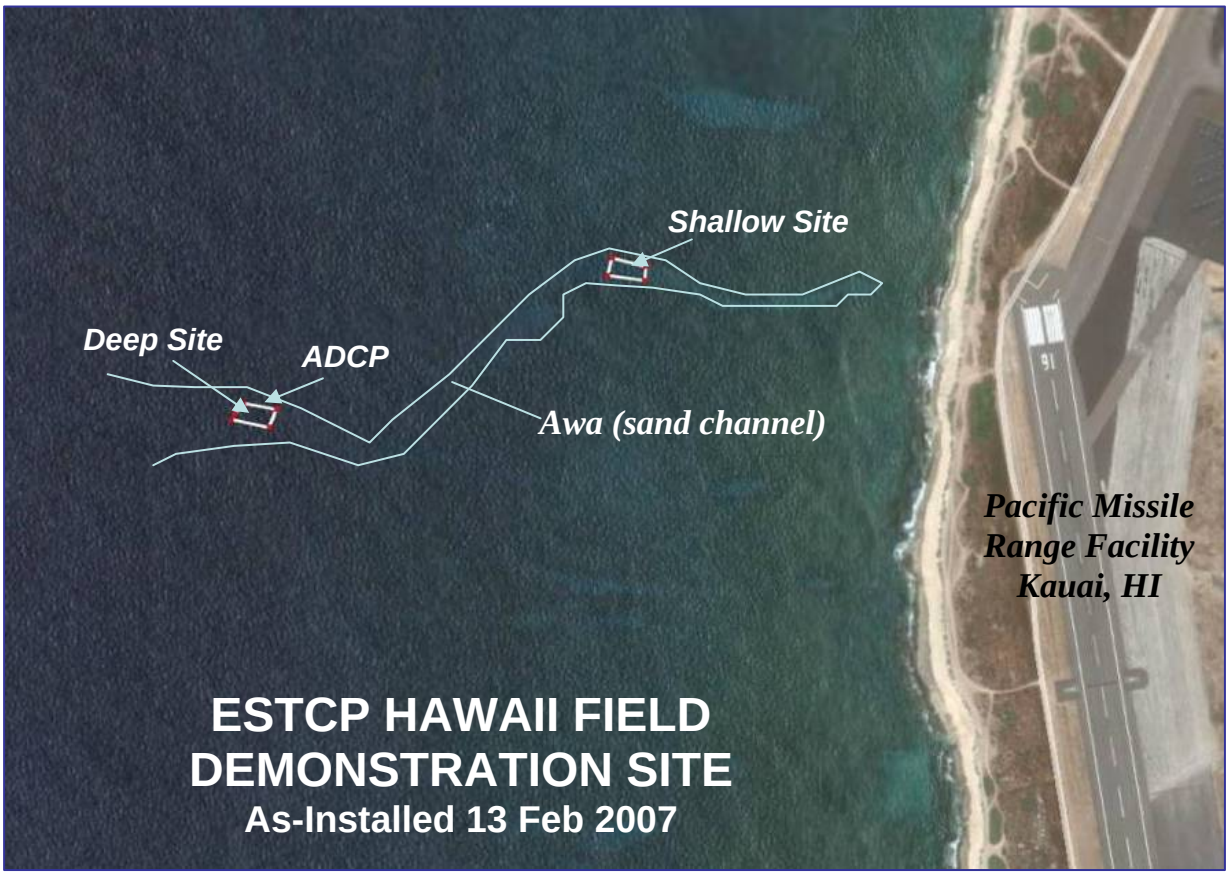


Figure 1. PMRF, Barking Sands, is located on the west coast of Kauai, Hawaii.

Table 1. Kauai, HI, UXO Mobility Model Field Demonstration Schedule.

Operation	Date
Deployment	13 February 2007
Round One	22 February 2007
Round Two	02 March 2007
Round Three	21 March 2007
Round Four	13 April 2007
Round Five	09 May 2007
Round Six	31 May 2007
Round Seven (recovery)	27 June 2007

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 Department of Defense (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 Navy Environmental Sustainability Development to Implementation (NESDI) Program funded a program to assess the environmental effects of underwater unexploded ordnance (UXO) in 2002. A site conceptual model (SCM) was developed under this program and is included as
Figure 2. This UXO Mobility Model program effort appears on the lower left side of the block diagram.

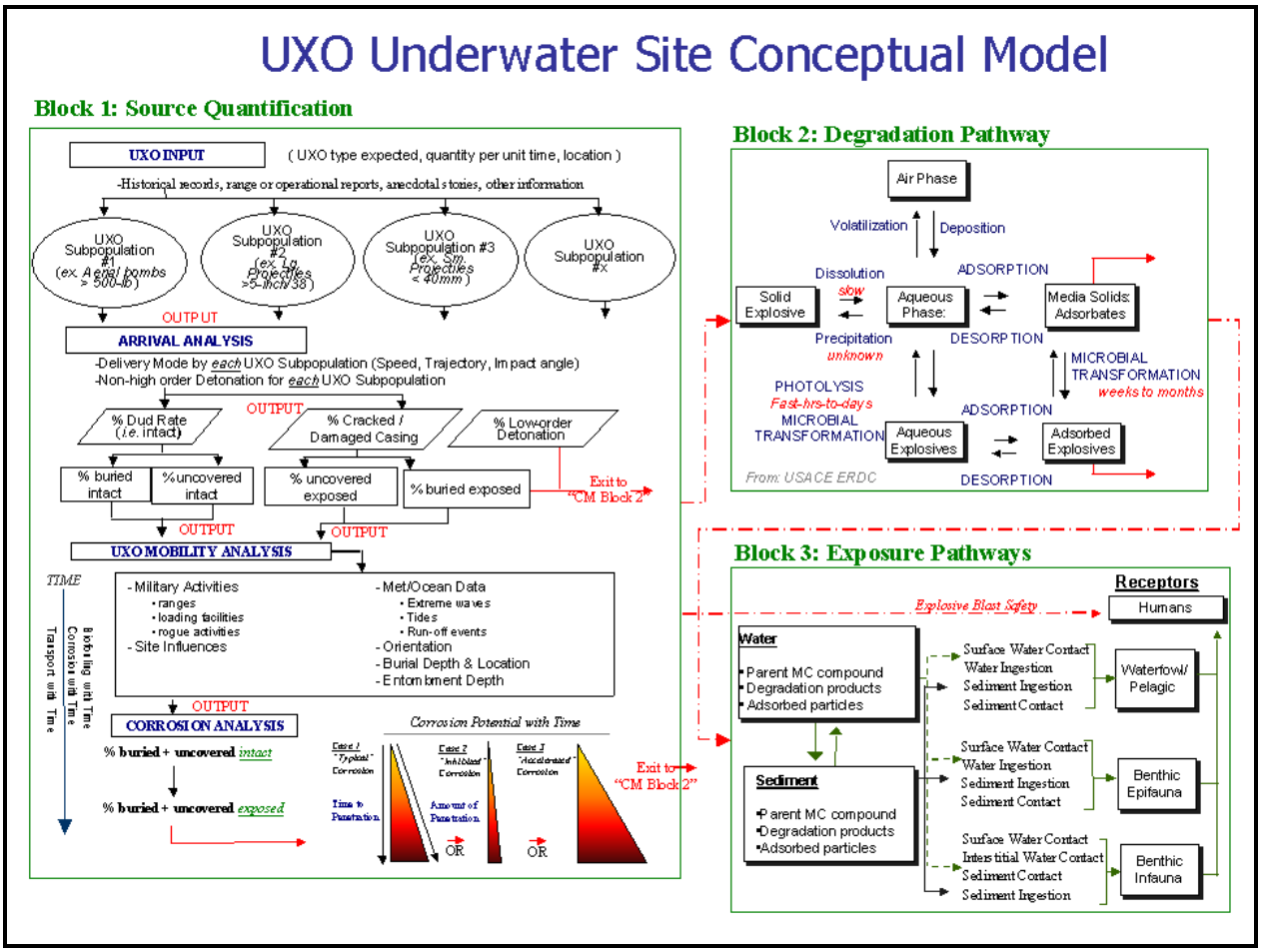


Figure 2. Site Conceptual Model for UXO showing the UXO Mobility Analysis as part of Source Quantification [4].

After evaluating the SCM at the beginning of this effort 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* (VORTEX) *Scour and Burial* model, which is used to predict mine mobility and burial (Jenkins and Inman, 2002 [5]); the new software is named 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.

Figure 3 shows a plot illustrating the model of the near-field flow over a partially buried UXO (5”/38 round) and the scour associated with the flow.

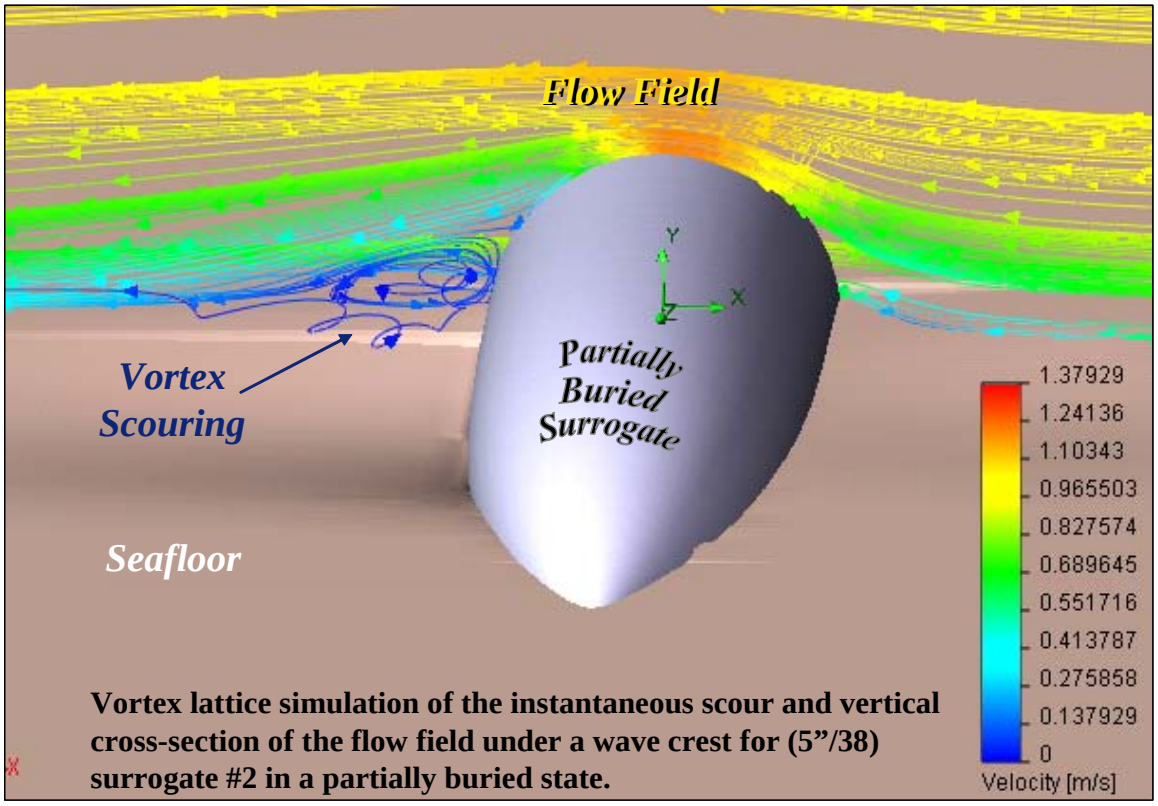


Figure 3. UXO Mobility Model output of flow and scour over a 5”/38 projectile surrogate.

By using the UXO Mobility Model, the fate of UXO over the broad range of coastal diversity where UXO are known to exist can be resolved. Additionally, mobility information can be used as part of a risk assessment by using this data to identify 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 Adaptive Risk Assessment Modeling System (ARAMS) developed by the U.S. Army Corps of Engineers (USACE). As an interim step and as a supplement to the overall Model development effort, an “Application Guidance Document (AGD)” is being developed. The AGD outlines a process by which UXO site managers and others can (a) identify the areas of present UXO risk within or adjacent to their geographic areas of responsibility and (b) use the Model to predict the areas in which UXO will remain entombed and which are at risk of having UXO moving into them.

The NESDI Research and Development program supported the MM software development and a limited validation effort at a single collision coastal site adjacent to Mugu Beach, CA [6], and a series of Measurement Method Field Tests (MMFT 1 and 2) on the coast of Ocean Shores, Washington, in September 2004 and May 2005[7].

The Mugu Drifter Test (MDT) was run with only small-diameter UXO (i.e., 20mm inert and surrogate rounds). This location was representative of 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 [8]). Data obtained from this test was used to validate the expected movement of small UXO in the Santa Barbara littoral cell, a large open coastal movement area which tends to move small UXO offshore like sand.

The MMFT at Ocean Shores used only larger UXO (i.e., 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 MM that addresses movement in the high-energy breaking surf zone, again on a collision coastal beach.

The Navy program supported MM development and allowed for short term, surf-zone validation for the collision coastal type. To be useful to DoD planners, the model needed to be validated for the remaining major coastal types. The data acquired from such validations would enable users to operate the model as a function of three distinct modes for input data. Thus, the MM can be run with either very limited site data (i.e., Mode 1, using only the coastal classification as input) or with more detailed configurations using various levels of site-specific data inputs (i.e., 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 MM’s configuration.

1.2 Demonstration Hypotheses (expected outcomes)

One of the following four possible outcomes results from comparing ESTCP Field Demonstration data to site-specific UXO Mobility Model predictions:

a. Field observations 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 that site and the theory is sufficiently sound to warrant using the Model in all three modes of operation at other sites with similar coastal classification. No further Model modifications or dedicated field efforts would be required in this instance.
b. Field observations loosely correlate with Model predictions (i.e., > 50%). The data therefore 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.
c. There is no clear statistical correlation between field demonstration 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.
d. Data collected were inadequate to provide statistically-significant conclusions.

The expected outcome for the ESTCP field demonstration was (a) or, possibly, (b). The general success of the early Navy program tests suggested that the negative results of outcomes (c) or (d) were 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 indicate that the UXO Mobility Model was essentially sound and ready for final field validation.

1.3 Program Performance Objectives

The UXO Mobility Model ESTCP demonstration/validation program is characterized by two types of performance objectives (Table 2):

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

Qualitative Measures. Given the specialized nature of the UXO Mobility Model, however, it is likely that the most cost-effective way to apply the MM 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. It also decreases the possibility of incorrectly using the MM.

Table 2. Performance Objectives.

Type Of Performance Objective	Primary Performance Criteria	Expected Performance (metric)	Performance Objective Met?
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.	Yes. Both NFESC and SST staff have been able to use the software (run the Model). However, there is still value from the Model developer (Scott A. Jenkins Consulting) as new applications arise.
	Model provides credible prediction of movement in support of demonstration planning.	Predictions check against general engineering theory and observations at similar sites.	At both the PMRF and FRF Duck sites, the Model predictions generally agree with complex movements observed for multiple surrogates.
Quantitative	Field Demonstration collects sufficient quality data to allow MM validation.	> 50% of surrogates are tracked successfully at each site. Movements are measured within ± 10%.	At Hawaii, 73% of the possible 168 data points collected during the 6 rounds of measurements were successfully tracked. 100% of the final 3 measurement sets were successfully tracked. Measurements were accurate within 1-2 m (<7% of range).
	Model validation shows good match between predictions and measurements, with coefficients correctable to positive match.	R > 0.8, for a given site.	Model validation by visual match to measurements is very good. $R_{movement} = 0.88$, $R_{burial} = 0.90$ for burial.

1.4 Field Demonstration Method

This ESTCP project encompasses the calibration, demonstration, and validation efforts needed for two geomorphic coastal categories/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. The details of that analysis are provided in the ESTCP UXO Mobility Model Final Report [9]. It compares MM predictions to actual movements measured during both of the field demonstrations.

The first field demonstration site was located in a Trailing Edge environment on the East Coast of the United States, at the U.S. Army Corps of Engineers (USACE) Field Research Facility (FRF) located on the Atlantic Ocean near the town of Duck, North Carolina [3]. The second field demonstration, reported herein, was conducted in a Biogenic Reef environment off the Pacific Missile Range Facility (PMRF), Barking Sands, on the west side of the island of Kauai, Hawaii.

The PMRF site is situated in a narrow, meandering sand channel (***awa***) that bisects a limestone and coral reef bottom (Figure 1). This awa extends from approximately the 18-foot to the 80-foot water depth, where it opens up into a larger offshore sand deposit. The distance from the 30-foot depth to the 60-foot depth is approximately 1,900 feet, a slope of less than 1:600. The sand channel varies in width from10 feet to more than 60 feet. The entire channel is bounded by reef and/or limestone on both sides and bottom. The channel ends abruptly inshore at a five foot reef escarpment at the 12-foot water depth. The escarpment walls on the north and south sides of the channel are typically 2 to 10 feet high.

At PMRF, a series of UXO surrogates were placed on the seafloor in various water depths. Their location and depth of burial (whenever possible) were then monitored by diver inspections at intervals determined by the occurrence of high-energy environmental events (e.g., storms or large, local wave events). The surrogates were left in place through the 2007 spring season, with some overlap into winter and summer at the end of each measurement round.

The 5”/38 surrogates were 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 was possible to examine trends as a function of location with respect to such meteorological/oceanographic parameters as surf zone characteristics, weather forcing function conditions, local sediment properties, etc. Only the 5”/38 surrogates were used during the field efforts at the PMRF site.

The locations of the 5”/38 surrogates were tracked by a variety of methods. The surrogates were each composed of a large metal core and equipped with an acoustic pinger. Divers used hand-held receivers, as well as a Benthos fixed acoustic tracking system to track the surrogates. Metal detectors were used to further locate the surrogates in conditions of poor visibility or when they

were buried. Each location was measured with respect to fixed references by employing acoustical methods, Global Positioning System (GPS) to surface floats, and tape measures, depending on the local conditions at the time. Those range data were then intersected to obtain fixes on surrogate locations by using the method of triangulation.

The primary metric for a successful field demonstration 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, tides, waves, and seafloor properties). The primary metric for defining a successful UXO MM 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 [9].

1.5 Demonstration Site Selection

Both the FRF Duck and PMRF Kauai field demonstration sites were selected because they represent broad classes of coastal environments in which underwater UXO is found. The demonstration sites were also chosen because they are 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, which, in turn, supported the PMRF permitting processes. Finally, the environments of both sites were already reasonably well documented due to recent offshore test activities there.

1.5.1 Pre-Demonstration Testing and Analysis

Prior to the demonstration, the PMRF, Barking Sands, site was analyzed by running the UXO Mobility Model in Mode 1using available input parameters such as historical wave, current, sediment transport, general bathymetry 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. This analysis was then used to set the deployment location and initial orientation of each 5”/38 surrogate.

To characterize the bottom sediment characteristics, a preliminary dive was conducted at the PMRF site to collect small samples of the seafloor sediment across the demonstration site area. The samples were analyzed for sediment type and a standard grain-size analysis was performed, since grain size is an important input to the UXO Mobility Model. At PMRF there are no permanently installed instruments to measure waves and currents at the site. A network of bottom pressure recorders (BPRs) was installed to provide accurate wave measurements during the demonstration.

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

2.0 FIELD DEMONSTRATION TWO (PMRF Barking Sands, HI)

2.1 Demonstration Site Description

2.1.1 Characteristics of Biogenic/Coral Reef Coastal Classification

The following boundary conditions and synthesized model parameters for a Biogenic/Coral Reef site are shown as Row D of Figure 4.

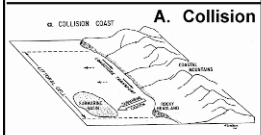
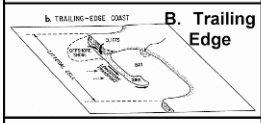
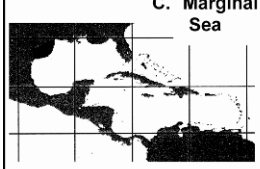
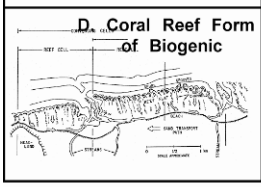
Geomorphic Type	Boundary Conditions					Model Parameters		
	Morphology (Example)	Sediment Source	Sediment Sink	Closure Depth	Littoral Cell Dimensions	Grid Cell	Grain Size	Bed Roughness, η_0
 A. Collision	Narrow-Shelf Mountainous Coastal Bluffs (Cailfornia)	Rivers & Bluff Erosion	Submarine Canyons	15 - 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
 D. 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 4. Coastal classification system shows geomorphic types and synthesized model input parameters; the PMRF Demonstration Site is a Type D (Biogenic/Coral Reef) site.

Accordingly, the biogenic morphology characteristic of Hawaii ocean sediments consists of carbonate reef material and volcanic sediments that migrate onto pocket beaches and awa channels stretching to the continental shelf. The depth beyond which active beach dynamics occurs is the closure depth or the reef platform, as is the case in reef regimes. The littoral cell dimensions and synthesized model parameters for this coastal classification are as indicated above.

2.1.2 Environmental Permitting

The environmental permits obtained prior to conducting the PMRF field demonstration are provided in Appendix A.

2.1.3 Field Demonstration Staff

Table 3. ESTCP UXO PMRF Barking Sands Field Demonstration Points of Contact.

POINT OF CONTACT	ORGANIZATION	E-mail Address	Role In Project
Barbara Sugiyama	NAVFAC ESC	barbara.sugiyama@navy.mil	Principal Investigator
Alexandra DeVisser	NAVFAC ESC	alexandra.devisser@navy.mil	Co PI
Jeff Wilson	Sound & Sea Technology	jwilson@soundandsea.com	SST Project Manager, Demonstration Design
Bill Daly	Sound & Sea Technology	wdaly@soundandsea.com	SST Senior Field Operations Engineer
Ian McKissick	Sound & Sea Technology	imckissick@soundandsea.com	SST Field Operations Engineer, Surrogates, Instruments
Dr. Scott Jenkins	Dr. Scott A. Jenkins Consulting	sjenkins@ucsd.edu	UXO Mobility Model Development, Site Analysis
Robert Rocheleau	Sea Engineering, Inc.	bobr@seaengineering.com	Field Operations Planning, Logistic Support, Diving Ops
Dan Momohara	NAVFAC PMRF	dan.momohara@navy.mil	Field Operations Planning

2.2 Demonstration Plan

The general approach for the PMRF field demonstration was to first install the surrogates at pre-planned locations at increasing distance from shore and at increasing water depths, and then measure their movement relative to those initial locations.

2.2.1 Demonstration Layout

The general layout of the demonstration for the initial installation is shown in Figure 1. The demonstration hardware details are provided in Appendix B. The following paragraphs summarize deployment details as they occurred.

February 13, 2007 - Deployment

The surrogates were installed in two groups of twelve each. The surrogates labeled 1 through 12 were installed in the offshore field in approximately 60 ft of water (Deep Field) (Figure 1). The surrogates labeled 13 through 24 were deployed along the inshore field in approximately 30 feet of water (Shallow Field). An RDI Workhorse Acoustic Doppler Current Profiler (ADCP) wave gauge was anchored to the seafloor on the northern side of the deep field at the 55 foot water depth (Figure 5).

The surrogates were positioned in the configuration shown in Figure 6. In each field, two rows of six surrogates each were oriented approximately east-west and parallel to the major axis of the crooked sand channel. The distance between each deployed row and the distance between surrogates within each row was approximately 9m.

Figure 5. Wave gauge installed in the Deep Field.

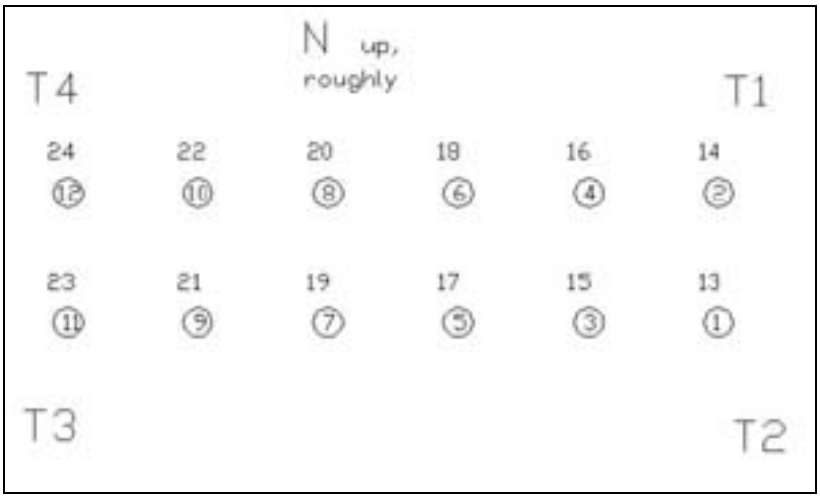


Figure 6. Benthos transponder (T1-T4) and surrogate installation configuration for deep (1-12) and shallow (13-24) fields.

After installing the surrogates, permanent stations were established for four Benthos acoustic tracking transponders. The transponder sites were selected by identifying unique bottom features on the surrounding limestone bottom that had suitable angles of intersection with the demonstration fields. These were marked by light line and/or surveyors' tape so that they could be easily located and reoccupied during each site visit. A Benthos transponder was then temporarily installed at each station. A Benthos Dive Ranger Interrogator (DRI) was used to measure the distance from each surrogate's initial location to each of the four stations. The installed locations for the Deep and Shallow Field surrogates are summarized below in Table 4 and Table 5.

Table 4. Deep Field – Installed Surrogate Positions.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
1	16	16	46	48
2	7	25	47	45
3	17	20	37	39
4	10	28	39	36
5	22	26	28	31
6	17	33	32	27
7	28	34	20	23
8	25	37	24	20
9	36	42	13	17
10	33	45	19	12
11	44	51	12	13
12	42	53	19	6

Table 5. Shallow Field – Installed Surrogate Positions.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	18	9	37	39
14	10	18	40	35
15	23	16	29	32
16	17	23	32	26
17	29	25	20	26
18	25	30	25	18
19	36	34	13	21
20	34	38	20	12
21	44	43	9	20
22	43	46	19	10
23	52	52	13	22
24	51	55	21	15

During the installation, GPS coordinates of the transponder locations for the deep and shallow fields were also obtained, and are shown in Table 6 and Table 7.

Table 6. Deep Field – Transponder Coordinates.

Surrogate	Latitude	Longitude
T1	22° 1.778' N	159° 47.723' W
T2	22° 1.761' N	159° 47.725' W
T3	22° 1.771' N	159° 47.750' W
T4	22° 1.784' N	159° 47.747' W

Table 7. Shallow Field – Transponder Coordinates.

Surrogate	Latitude	Longitude
T1	22° 1.877' N	159° 47.463' W
T2	22° 1.864' N	159° 47.455' W
T3	22° 1.864' N	159° 47.488' W
T4	22° 1.879' N	159° 47.485' W

2.3 Site Visits

As shown previously in Table 1. , six rounds of measurements were taken between February to May 2007. Given below are summaries of the measurement operations that took place during each site visit subsequent to the initial deployment.

February 22, 2007

The first post-installation site visit was conducted on 22 February 2007, following the first large wave event after surrogate installation. Due to problems with the Sonotronics Underwater Diver Receivers (UDRs), SEI was unable to locate any surrogates in the deep wave field. During the shallow field work SEI was able to obtain positions for eight of the twelve surrogates. Estimated accuracy for the positions obtained on this visit is ± 2 to 3 meters. At high gain settings, the UDRs have demonstrated poor or no directional discrimination capability, probably due to the proximity of the surrogates to the diver. Even at very low gain (a setting of 1 out of a possible 100), divers were not able to precisely pinpoint surrogate locations. The shallow field data for this visit is shown in Table 8.

Table 8. Shallow Field – Surrogate Positions on 22 February 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	16	11	37	43
14				
15	22	16	28	33
16				
17	22	20	29	35
18	25	31	25	17
19				
20	32	43	21	10
21	41	40	9	20
22	43	48	17	12
23				
24	51	63	22	17

March 2, 2007

Based on the experience of the 22 February site visit, two J.W. Fisher Pulse 8X metal detectors were added to the instrument suite to aid in locating the surrogates. However, even with use of metal detectors, SEI was unable to locate any surrogates in the deep field on this date. Eight of the twelve surrogates in the shallow field were located using a combination of the UDRs and the metal detectors. Surrogate #s 17 and 21 were located using only the UDRs, due to difficulties with the metal detectors. Estimated positional accuracy with the metal detectors is better than one meter, which is approximately equivalent to the length of each surrogate.

Table 9. Shallow Field – Surrogate Positions on 2 March 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	17	10	37	41
14				
15	22	16	28	31
16				
17*	22	20	29	35
18	25	31	25	15
19				
20	34	38	20	10
21*	41	40	9	20
22	43	46	18	10
23				
24	52	56	21	16

* Surrogates located with UDR only.

March 21, 2007

During the 21 March visit, the wave gauge located at the deep field was serviced. The memory card was replaced and the wave gauge reinstalled at the same location from which it had been retrieved. All twenty-four surrogates were located using the metal detectors for primary contact and the UDRs for surrogate identification. No UDR signals were received for shallow surrogates 14 and 22, even though the metal detectors indicated a contact; the pingers had apparently failed on these two surrogates. The results of the 21 March site visit are summarized in Table 10 and Table 11.

Table 10. Deep Field – Surrogate Positions on 21 March 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
1	16	16	45	49
2	7	25	47	43
3	17	19	36	40
4	10	28	38	35
5	22	26	28	30
6	18	32	31	27
7	28	33	20	23
8	25	34	24	21
9	36	42	14	17
10	32	42	19	13
11	43	50	12	12
12	41	53	18	5

Table 11. Shallow Field – Surrogate Positions on 21 March 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	18	6	44	45
14	11	17	38	33
15	16	9	36	38
16	17	23	30	24
17	23	16	28	31
18	25	30	24	17
19	29	24	19	25
20	34	38	19	10
21	39	35	10	21
22	42	45	18	10
23	46	44	11	17
24	51	54	20	16

The shallow field data indicated that the southern row of surrogates (surrogate #s 13, 15, 17, 19, 21, and 23) had all moved approximately 9m inshore of their original positions. At the time, this apparent extreme movement was thought to be unusual, but sand waves with a height of approximately 0.3 meters were noted only in the southern half of the channel, so there was some evidence that supported the movement of only one row of the surrogates. However, subsequent site visits indicated that the same surrogates appeared to have moved back almost exactly to their original positions.

This migration behavior can be interpreted in two ways. Either all six surrogates moved 9 m shoreward and then migrated back to their starting points, or an erroneous measurement was

recorded. Based upon the body of data collected that shows almost no movement for any other surrogates, we believe that a spurious metal detector signal, possibly from another buried object, was obtained inshore of the shallow field and was incorrectly interpreted as surrogate #13. All other metal detector signals were therefore offset by one surrogate, indicating that the farthest offshore surrogate, #23, was never located on 21 March.

Although the UDRs were used to identify a surrogate after initial location measurements were made with the metal detectors, subsequent experimentation with the UDRs continued to indicate a lack of consistent repeatability with the instruments, even when they were directly positioned over a surrogate. Subsequent location data were therefore based primarily on metal detector or tape measured locations.

April 13, 2007

During the April 2007 site visit, the wave gauge was retrieved and the battery and memory card replaced. From this date on, the metal detectors were the primary means of determining surrogate location, and the UDRs were only used occasionally. After the deep field was located, the positions were measured using the DRI. Measurements were also obtained with tape measures for comparison. Wave conditions at the shallow site were too rough to allow for any field measurements to be taken. The results of the deep field for the DRI and tape measurements are shown in Table 12 and Table 13.

Table 12. Deep Field – Surrogate Positions on 13 April 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
1	15	16	45	47
2	7	24	47	43
3	17	18	36	39
4	9	27	38	34
5	21	25	28	31
6	17	32	30	26
7	28	33	19	23
8	25	36	23	20
9	35	41	13	16
10	32	42	19	12
11	43	50	12	12
12	41	53	19	5

Table 13. Deep Field – Taped Measurements for Surrogates on 13 April 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
1	15.4	16.2	46.1	47.8
2	6.6	24.6	47.4	44.3
3	16.6	19.1	37.2	39.4
4	9.4	27.1	39.3	35.5
5	21.5	25.7	28.3	31.3
6	17.3	32.3	31.3	26.9
7	28.3	33.6	20.0	23.7
8	25.0	36.6	24.1	20.5
9	35.6	42.2	13.9	16.6
10	32.4	44.0	19.9	12.8
11	43.1	50.8	12.6	12.2
12	42.2	54.1	19.3	5.3

May 9, 2007

During the 9 May 2007 site visit, all surrogates in the deep and shallow fields were located using the metal detectors. An attempt was made to identify the surrogates using the UDRs, but the results were inconsistent. The positions for the deep field were obtained with the Benthos DRI while the positions for the shallow field were obtained with the DRI and then verified with a tape measure. The divers were unable to acquire pinger signals for surrogate #s 14, 15, 17, 18, 21, and 22, and the identification readings for the other surrogates were not repeatable. The results of the 9 May site visit are shown in Table 14, Table 15, and below.

Table 14. Deep Field – Surrogate Positions on 9 May 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
1	15	16	45	47
2	7	24	46	44
3	17	19	36	41
4	10	27	39	35
5	22	25	28	31
6	17	32	31	26
7	28	33	19	24
8	25	35	23	19
9	35	41	14	16
10	32	43	19	13
11	43	50	12	12
12	42	53	18	5

Table 15. Shallow Field – Surrogate Positions on 9 May 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	16	10	36	42
14	11	16	37	33
15	23	16	28	30
16	18	22	31	26
17	28	26	20	25
18	25	29	24	18
19	37	34	12	20
20	34	39	19	11
21	45	41	8	19
22	42	45	19	10
23	55	51	11	22
24	51	54	21	16

Table 16. Shallow Field – Taped Measurements on 9 May 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	16.8	9.6	37.5	38.3
14	11	16.7	38.4	33.8
15	22.6	16.6	28.1	31.5
16	17.6	22.6	31.2	25.6
17	29	25.2	19.8	25.1
18	25.6	30.4	24.7	17.2
19	37	34.5	11.9	20.8
20	34.2	38.6	20.3	10.7
21	44.7	43	8.4	20
22	42.8	46.9	19	9.9
23	53	52	12.4	22.8
24	51.8	55	21.1	16.1

May 31, 2007

All surrogates were located using the metal detectors and positions were measured using the Benthos DRI. SEI also probed for the surrogates to determine burial depth using a 1/8" diameter fiberglass instrument. The search process was carefully conducted, so no surrogates were displaced or disturbed during the probing activities. The results of the 31 May site visit are summarized below.

Table 17. Deep Field –Measurements on 31 May 2007.

Surrogate	Distance from Transponder (m)				Probe Depth
	T1	T2	T3	T4	(Inches)
1	15	16	45	46	6
2	7	25	46	43	7
3	16	19	36	40	8
4	9	27	39	35	7
5	22	25	27	30	7
6	17	32	30	26	8
7	28	32	19	23	7
8	25	35	23	20	4
9	34	42	15	15	8
10	31	43	18	12	8
11	42	49	12	12	3
12	42	53	18	5	8

Table 18. Shallow Field –Measurements on 31 May 2007.

Surrogate	Distance from Transponder (m)				Probe Depth
	T1	T2	T3	T4	(Inches)
13	16	9	37	42	11
14	11	16	37	32	12
15	23	16	27	30	12
16	18	22	31	25	9
17	28	25	19	25	12
18	25	30	24	18	10
19	37	33	12	20	14
20	34	39	19	11	7
21	45	40	8	20	16
22	41	46	19	10	8
23	54	51	11	22	15
24	51	54	20	16	7

June 27, 2007

SEI located the deep and shallow fields using the metal detector and retrieved the Acoustic Doppler Current Profiler (ADCP) for maintenance and redeployment. Surrogate positions were measured using the Benthos DRI. The ADCP data appeared to stop recording data on 6 June 2007 due to a full memory card. The results of the 27 June site visit are summarized below (Table 19 and Table 20).

Table 19. Deep Field –Measurements on 27 June 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
1	16	16	45	47
2	7	25	46	43
3	17	19	37	39
4	10	27	39	34
5	22	25	28	31
6	18	33	31	27
7	28	33	20	24
8	25	36	24	20
9	35	42	15	17
10	32	43	19	12
11	43	49	13	12
12	42	53	18	5

Table 20. Shallow Field –Measurements on 27 June 2007.

Surrogate	Distance from Transponder (m)			
	T1	T2	T3	T4
13	17	9	37	38
14	11	17	38	33
15	22	17	27	30
16	18	22	30	24
17	28	24	18	24
18	25	30	24	17
19	37	33	11	20
20	34	38	19	10
21	44	42	7	20
22	42	45	18	10
23	54	51	13	23
24	51	55	20	15

2.4 Field Demonstration Results

Figure 7 and
Figure 8 graphically represent the installed positions of the transponders and surrogates. Figure 7 shows the deep field with the installed layout and the surrogate positions as they were measured on 27 June 2007.
Figure 8 shows the shallow field with the installed layout, the questionable layout of 21 March, and the final layout as measured on 27 June 2007.

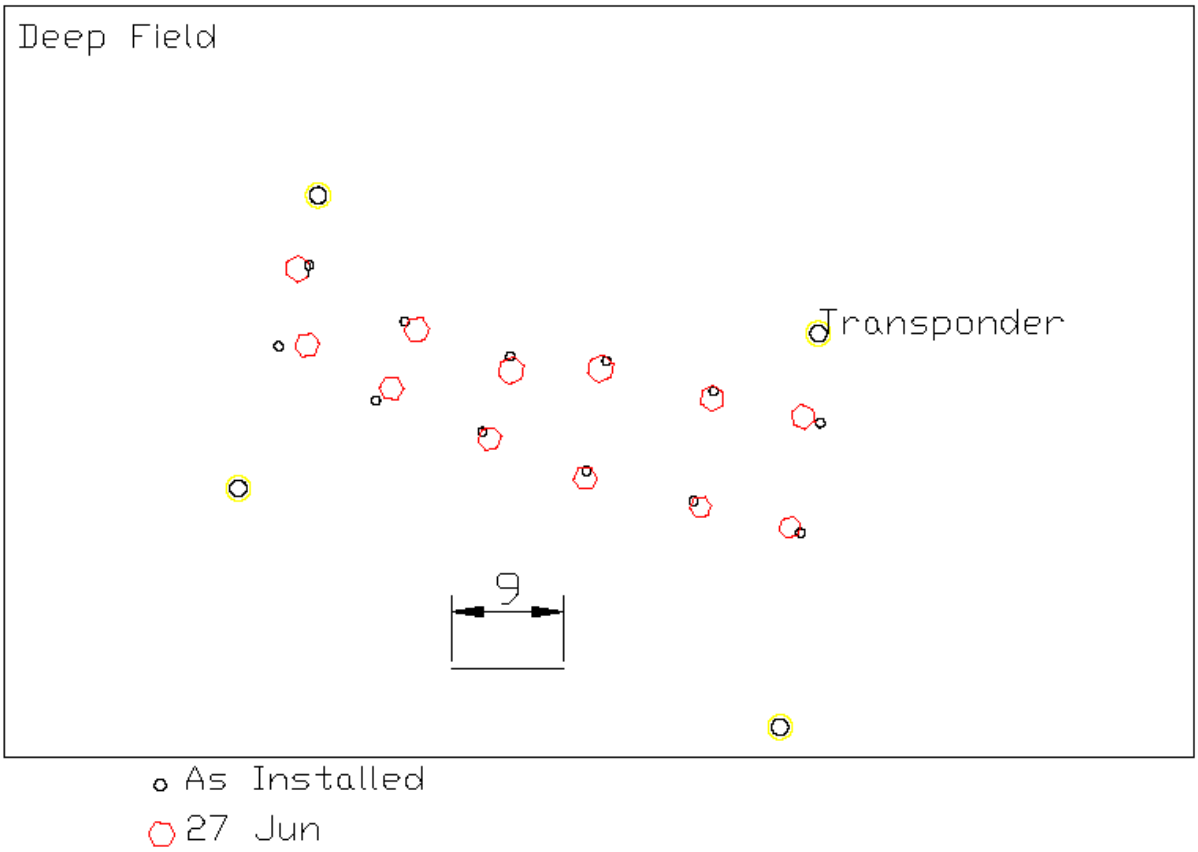


Figure 7. The Offshore (Deep) Field shows the very limited movement (meters) that occurred in the 17 weeks of exposure between 13 February till 27 June 2007.

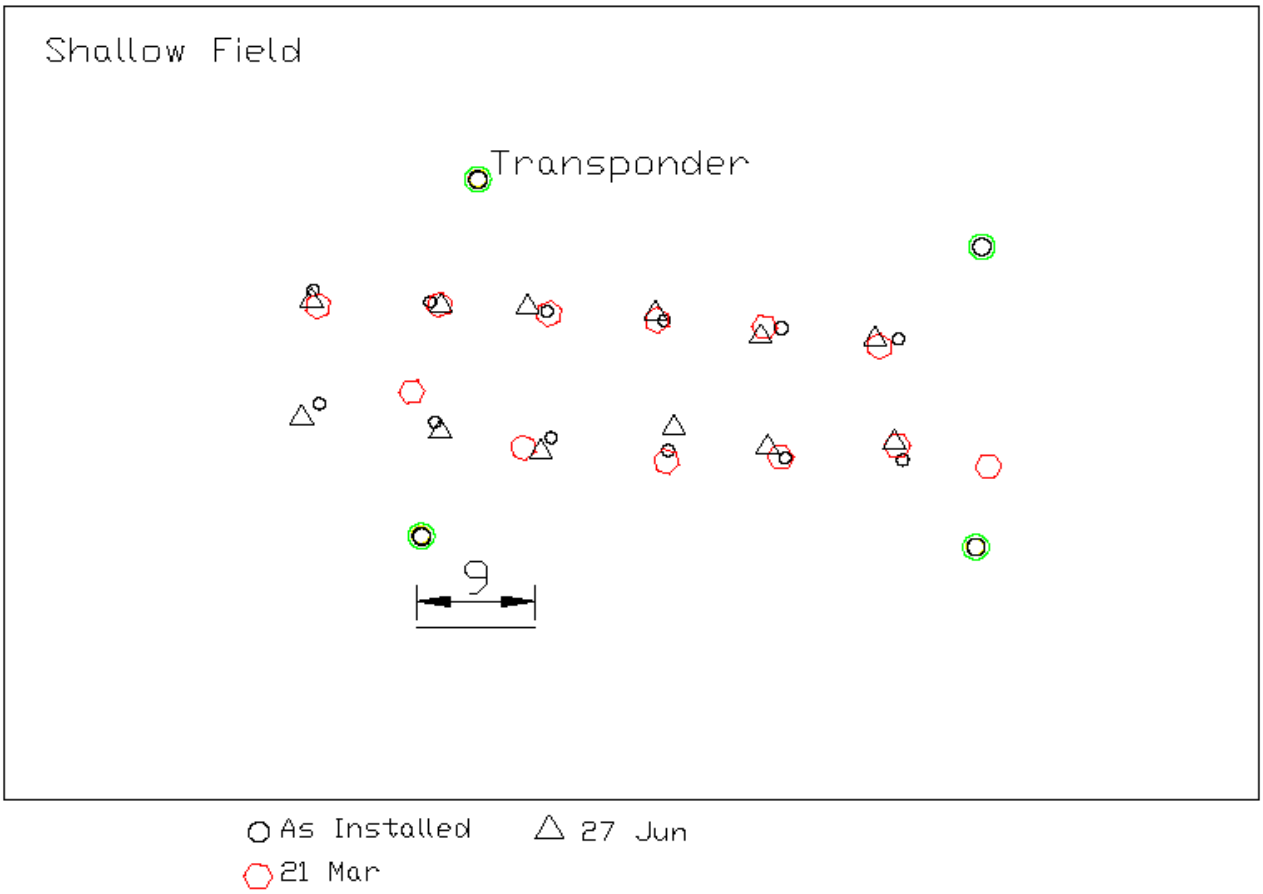


Figure 8. For the Inshore (Shallow) Field, note the offset measurements (meters) on 21 March 2007 caused by the false measurement at the lower right (red hexagon).

3.0 MODEL VALIDATION

3.1 Technical Approach

The MM was used to predict migration and burial behavior of UXO surrogates of 5”/38 projectiles (Figure 9) when grounded on the seafloor in the near shore of a biogenic reef environment. The reef environment selected for this experiment was the Pacific Missile Range Facility (PMRF) located off the west coast of the island of Kauai, HI.

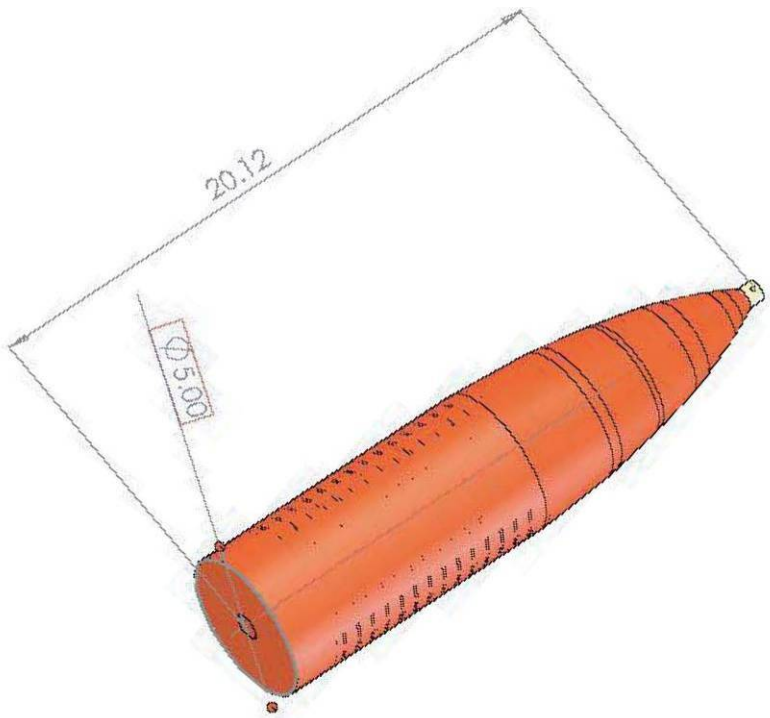


Figure 9. 5”/38 projectile surrogate used in the PMRF Field Demonstration.

3.2 Process Model Architecture

Migration and burial processes consist of two distinct types: nearfield (local) and farfield (regional) [8]. These operate on significantly different length and time scales. Nearfield processes occur over length scales on the order of the body dimensions and on time scales of a wave period, a few seconds to hours in length are primarily governed by scour mechanics. In contrast, farfield processes involve changes in the elevation of the seabed with cross-shore distances of hundreds of meters that may extend along the coast for kilometers. Farfield time scales are typically seasonal in nature and are characterized by longer periods due to variations in climate and travel time of longshore sediment fluxes associated with accretion/erosion waves. These processes are coupled together with the component code modules in an architecture diagrammed in Figure 10 and referred to as the *Vortex Lattice (VORTEX) Scour and Burial Model.* The farfield processes and inputs are found above the orange line in Figure 10 while the nearfield processes and inputs are below the green line.

As with any boundary value problem, the solution follows from specifying initial conditions, forcing functions, and the boundary conditions from which the response is computed using a set of process-based algorithms. This computational sequence proceeds in Figure 10 from the top of the diagram down, with the set of forcing functions and initial conditions bundled together in a *module* shown by the pink shaded box at the top of the flow chart, while boundary conditions (beige box) and response (blue box) modules of the farfield are found in the pathways below it.

The farfield response modules are upstream of the nearfield modules in the computational flow chart because the farfield processes determine the fluid forcing and elevation of the sand bed around the object, which is essential to specifying the nearfield boundary value problem.

The forcing function module (shown in the pink box) provides time series of waves (code module #2), currents (code module #3) and sediment flux (code module #4). Waves and currents are derived from direct observations by means of Datawell directional wave buoys and ADCPs, to validate model velocity algorithms (Appendix B). Fluxes of river sediment are neglected as explicit boundary conditions, but the presence of those sediments are accounted for in the grain size distributions of the offshore sediments. The wave and current forcing provides excitation applied to the deep water boundary of the farfield computational domain. These boundaries are specified in the boundary conditions module (beige box) in Figure 10, where the farfield computational domain is assembled from the following: (1) a series of boundary-conforming control cells (Figure 11), using a combination of bathymetric data obtained from National Ocean Service (NOS) and United States Geological Survey (USGS) [10] as compiled by the National Geophysical Data Center (NGDC) [11] to assemble the gross morphology of the fringing reef, and LIDAR data to construct bathymetric details of local awa channels at 1m grid cell resolution to characterize the areas in which the UXO fields were placed.

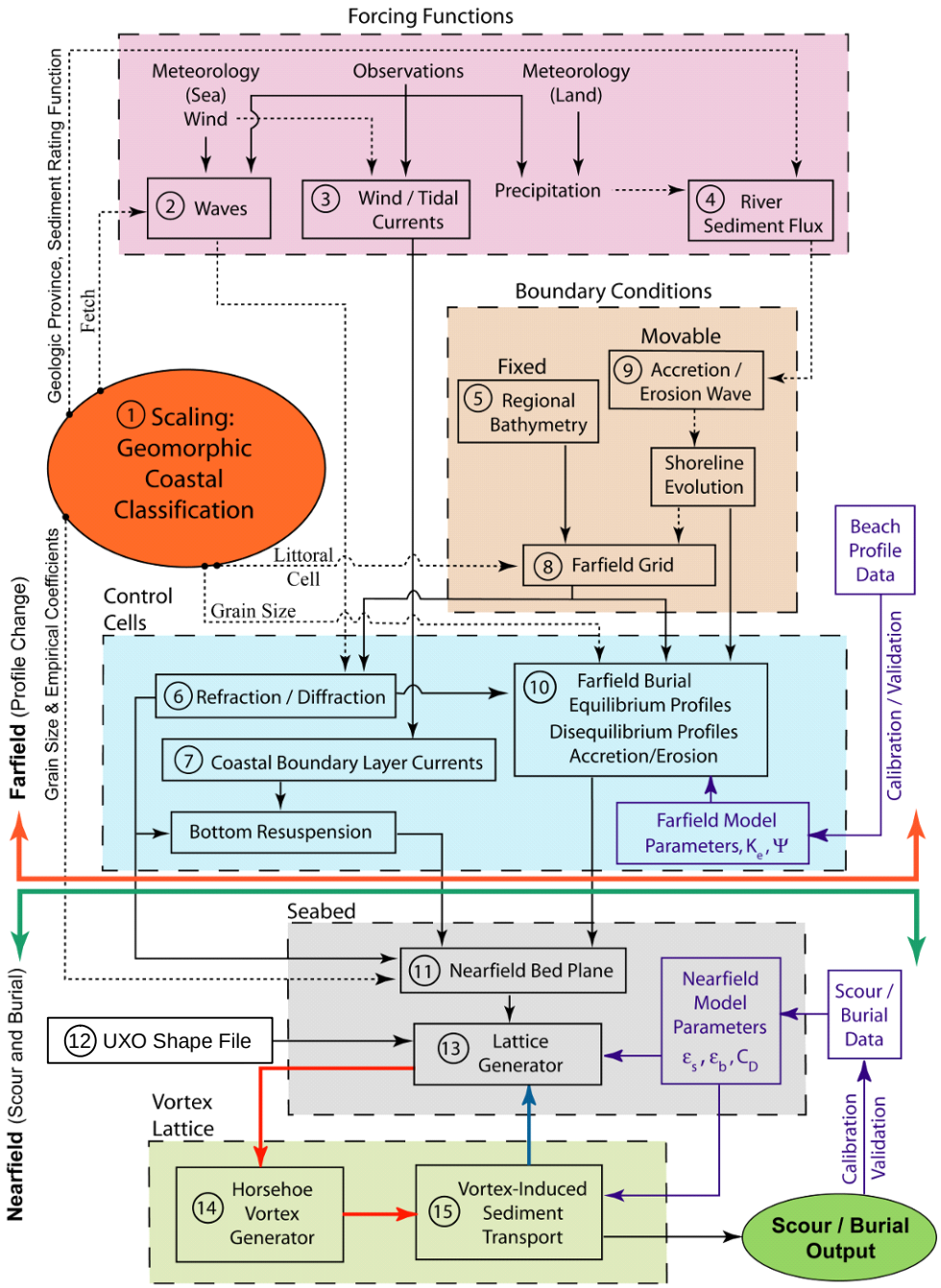


Figure 10. Vortex Lattice Scour Burial Model.

With these forcing functions and boundary conditions, the farfield response module (blue box) computes the spatial and temporal evolution of the fluid forcing and bottom elevation along cross-shore profiles of a control cell representing the gross morphology of a fringing reef system (Figure 11). At the PMRF site, these control cells are bounded in the cross shore by the walls of

sand and awa channels cut cross-shore through the lithified reef structures. Predominately carbonate sediments accumulate in these channels along bottom gradients that can be specified by profiles having three matching segments: 1) the stationary profile that extends from the deep water boundary inshore to closure depth, h_c, where profile changes become vanishingly small; 2) the shorerise profile that continues from closure depth to the wave break point; and, 3) the bar-berm profile that begins at the break point and ends at the berm crest. The stationary profile is invariant with time and is given by the regional bathymetry. Bottom elevation changes along the non-stationary profiles of the shorerise and bar-berm (Figure 12a) are computed by (code module #10) in the farfield response module (blue box) using equilibrium profile algorithms after several researchers ([12], [13], [14], [15], and [16]). The stationary and non-stationary profiles are interpolated to create a Cartesian depth grid within each control cell on which simultaneous refraction and diffraction patterns are computed by (code module #6) using algorithms from Kirby [17] and Dalrymple et al. [18] to specify fluid forcing by shoaling waves.

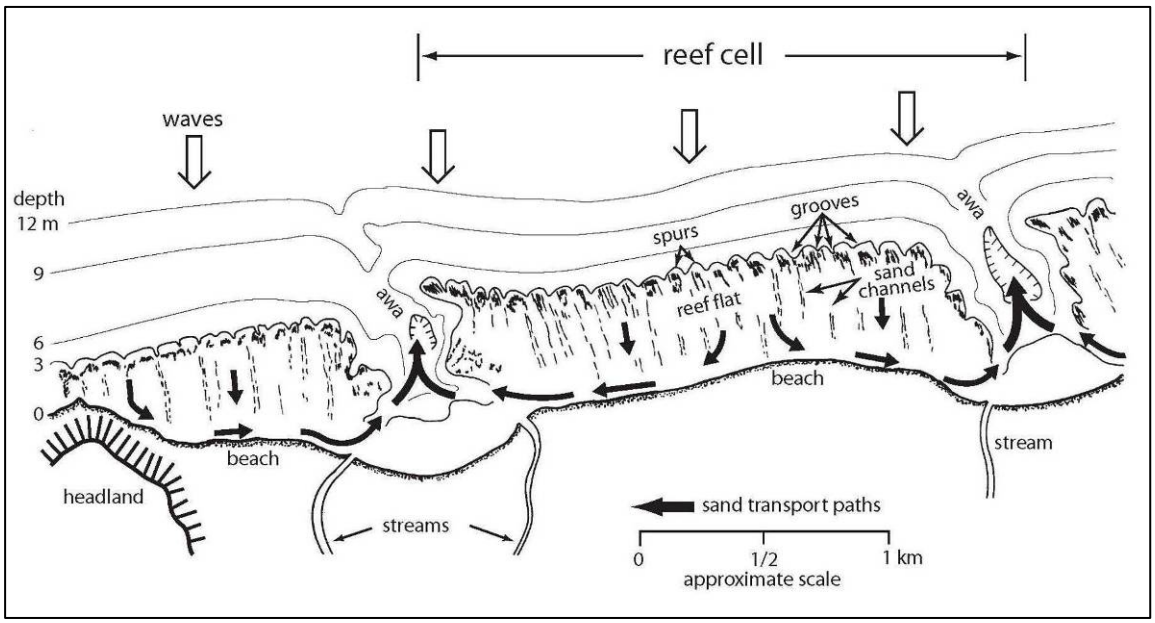


Figure 11. Schematic diagram of control cells along a fringing reef coast.

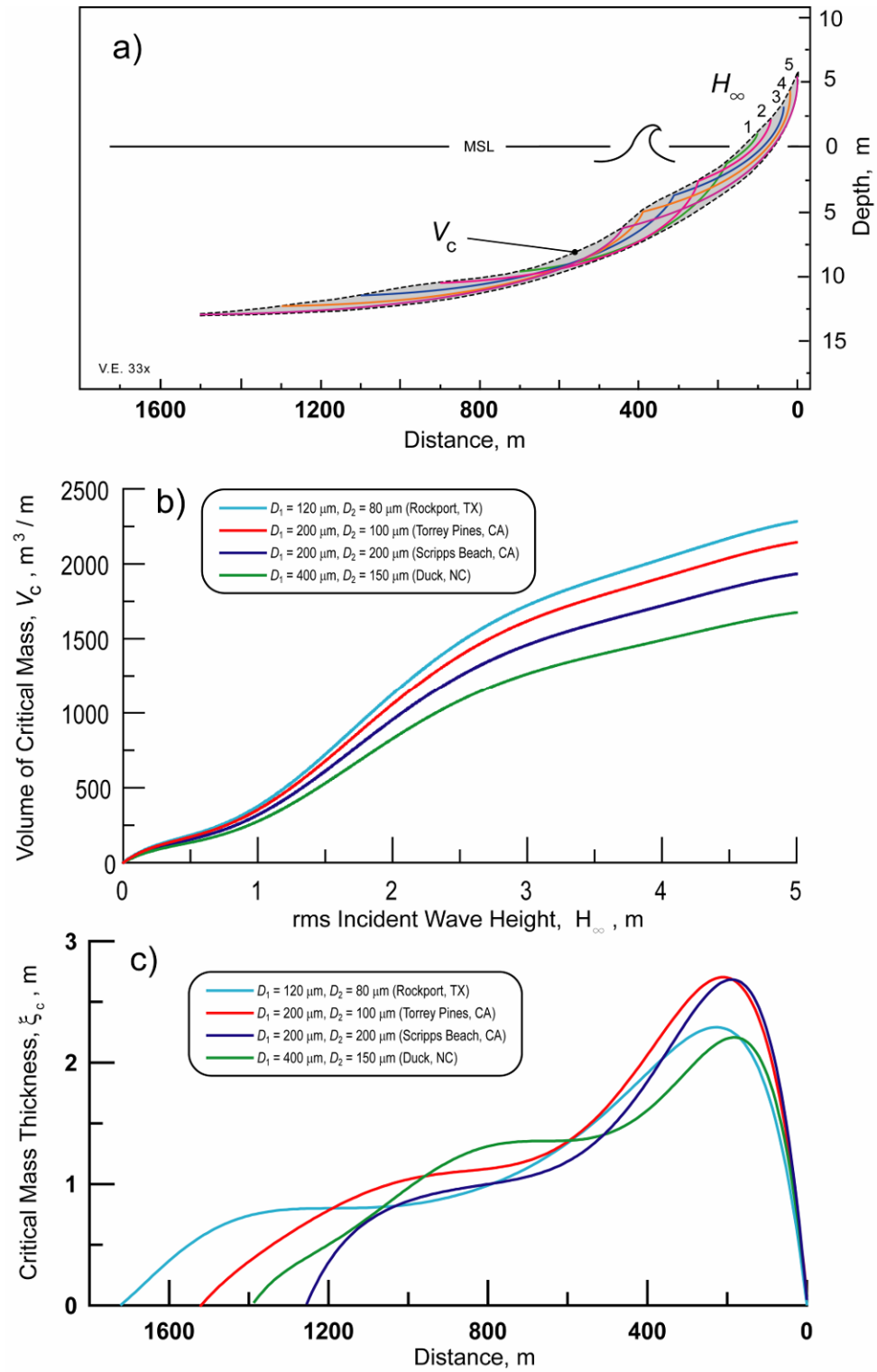
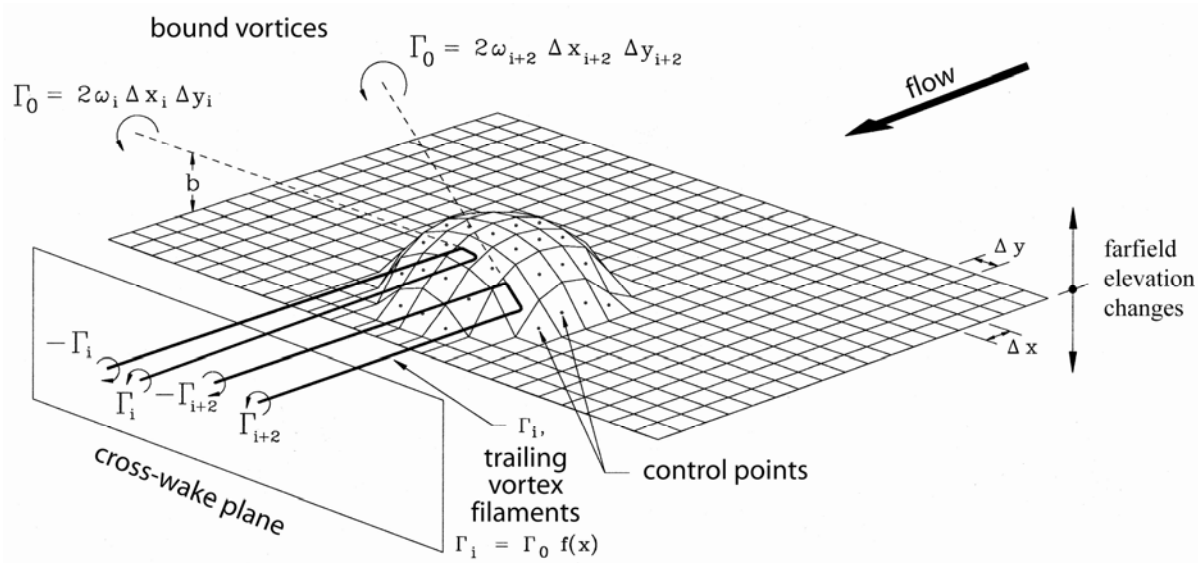


Figure 12. Mechanics of farfield burial: (a) envelope of profile change (critical mass), (b) volume of critical mass from elliptic cycloids, and (c) cross-shore variation in thickness.

Fluid forcing by currents in the farfield are computed in (code module #7) where wave induced streaming and mass transport are based on algorithms after [19], [29], [21] and shallow water tidal currents follow from algorithms after [22]. Fluid forcing time series and bottom elevations computed in the farfield response module are through-put to the nearfield response modules shown below the green line in Figure 10. The farfield throughput is applied to the local seabed boundary conditions module (gray box). These local boundary conditions include two types: 1) the slope and elevation of the seabed plane around the object base derived by (code module #11) from location in the farfield control cell; and 2) the shape file of the body in question (#12). These two local boundary conditions are used to generate lattice panels (code module #13) that define the object and bedform of the surrounding seabed (Figure 13a). The lattice is the computational domain of the nearfield scour-burial processes in which the method of embedded vortex singularities (vortex lattice method) is applied in (code module #14) using algorithms after [23], [24], [25]. This method employs horseshoe vortices embedded in the near-bottom potential wave oscillation to drive local sediment transport in (code module #15) based on ideal granular bed load and suspended load equations after [26], [27], [28]. A horseshoe vortex is specified by (code module #14) for each lattice panel during every half-cycle of the wave oscillation as shown schematically in Figure 13a. The horseshoe vortices release trailing pairs of vortex filaments into the local potential flow field that induce downwash on the neighboring seabed (Figure 13b), causing scour with associated bed and suspended load transport as computed by (code module #15). This scour action by trailing vortex filaments can be seen occurring in nature ((Figure 13b).

The lattice generation in code module #13, horseshoe vortex generation in (code module #14) and sediment transport computations in code module #15 are implemented as a leap-frog iteration in a time-stepped loop shown by the red and blue pathway arrows at the bottom of Figure 10. The leading time step (delineated by the red arrow pointing from code module #s 13 to 14) computes the strength of the horseshoe vortex filaments generated by the pressure gradients and shear setup over the lattice panels of the combined body-bedform geometry of the previous (lagging) time step. The bed and suspended load transport induced by these filaments results in an erosion flux from certain neighboring lattice panels on the seabed and a deposition flux on others, based on image lifting line theory (Figure 14a) as first applied by Jenkins and Wasyl [29] to a mobile sedimentary boundary. The erosion and deposition fluxes of the leading time step are returned in the computational loop to the lattice generator (blue arrow in Figure 10) where those fluxes are superimposed on the lattice geometry of the lagging time step. That superposition produces a new lattice geometry for implementing the next leading time step. With this leap-frog iterative technique, an interactive bedform response is achieved whereby the flow field of the leading time step modifies the bedform of the lagging time step; and that modified bedform in turn alters the flow field of the next leading time step. This lead and lag arrangement is based on the fact that the inertial forces of granular bed near incipient motion are large compared to those of the fluid [26], hence the flow field responds faster to a change in bedform than the bedform can respond to a change in flow field.

a)



b)

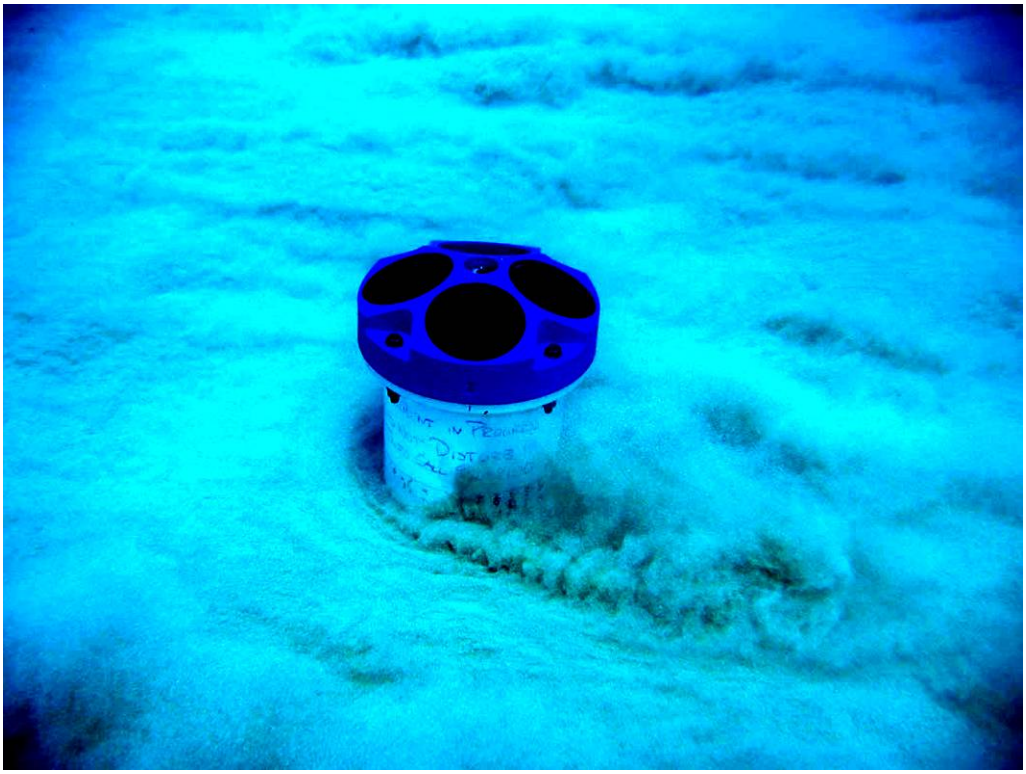


Figure 13. Vortex lattice method shows a) lattice and horseshoe vortex system and b) horseshoe vortices inducing sediment transport in nature (photo courtesy of K. Millikan).

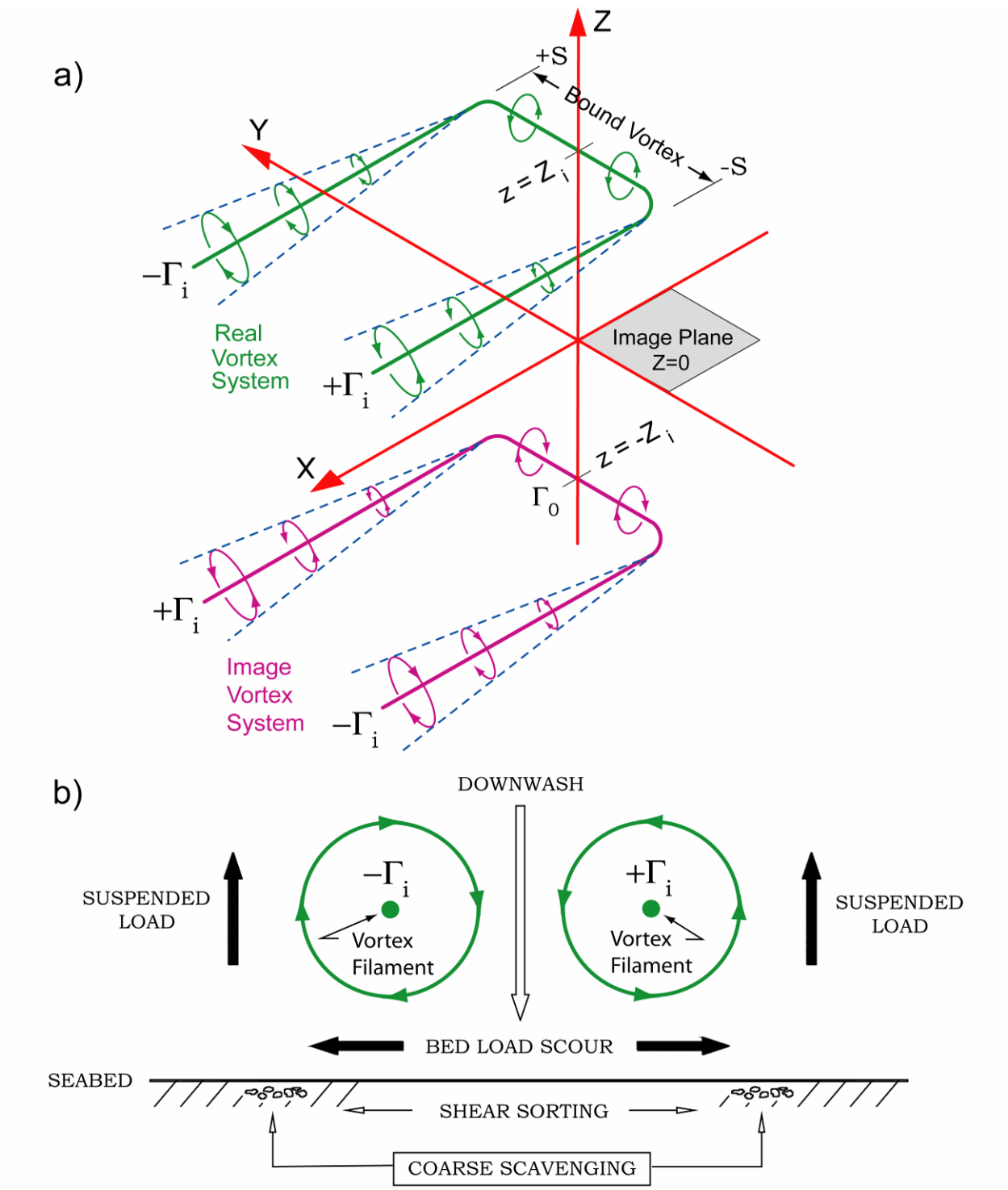


Figure 14. Vortex induced velocity at any point near the bed: a) image plane due to the horseshoe vortex system of an imaginary lattice plane, b) schematic in the vertical plane.

3.3 Model Initialization

3.3.1 Farfield Initialization

Farfield initialization involves data base constructions and model parameterizations for model inputs above the orange line in Figure 10. A detailed listing of these inputs can be found in [3]. They are reviewed here in context specific or unique to the PMRF site.

3.3.1.1 Bathymetry

The stationary farfield bathymetry was derived from the National Ocean Service (NOS) digital database as contoured in Figure 15 seaward of the 0 m mean sea level (MSL) depth contour. This coarse-scale bathymetry defines the basic morphology of the fringing reef system at PMRF along the west coast of Kauai. The mesh is defined by latitude and longitude with a 3 x 3 arc second grid cell resolution yielding a computational domain of 15.4 km x 18.5 km. Grid cell dimensions along the x-axis (longitude) are 77.2 m and 92.6 m along the y-axis (latitude). This small amount of grid distortion is converted internally to Cartesian coordinates, using a Mercator projection of the latitude-longitude grid centered on PMRF air field. The convention for Cartesian coordinates uses x-grid spacings for longitude and y-grid spacings for latitude. For the non-stationary bathymetry data inshore of closure depth (<12m MSL) Jenkins and Inman's [16] equilibrium beach algorithms were used. Depth contours generated from these algorithms vary with wave height, period, and grain size and are plotted in Figure 14 landward of the 12m depth contour for the typical seasonal range of wave parameters of the PMRF site during the time frame of February through June 2007.

While Figure 15 defines the gross morphology of the reef platform, the micro-bathymetry of the specific awa in which the UXO were placed was resolved with high resolution LIDAR data. Figure 16 gives a co-registration of the LIDAR data with the coarse-scale NOS bathymetry, and shows the sample density of the LIDAR data over that portion of the PMRF reef where the UXO fields were placed. Sample density of the LIDAR data was typically on the order of 1m, allowing for considerable detail of the awa to be resolved around the offshore and inshore UXO sites (Figure 17). Coordinates for the offshore and inshore UXO sites are given in Figure 17a. The inshore site is located in local water depths of 25 ft -30 ft (~8.3m MSL), while the offshore site is at depths of 52 ft - 57 ft (~16.6m MSL). The channel takes several bends and curves in the cross shore direction between the offshore and inshore sites, resulting in vertical convergence and divergence of surge currents flowing over the reef top as is apparent in Figure 17b where the instantaneous current magnitude ranges from 0.9 to 1.1 m/sec; the current forcing is computed by using the Coastal Boundary Layer Currents given in code module #7 (Figure 10). This reef-induced divergence tends to make UXO mobility and more sensitive to specific location than is otherwise found on the planar beaches of collision and trailing edge coastlines [3].

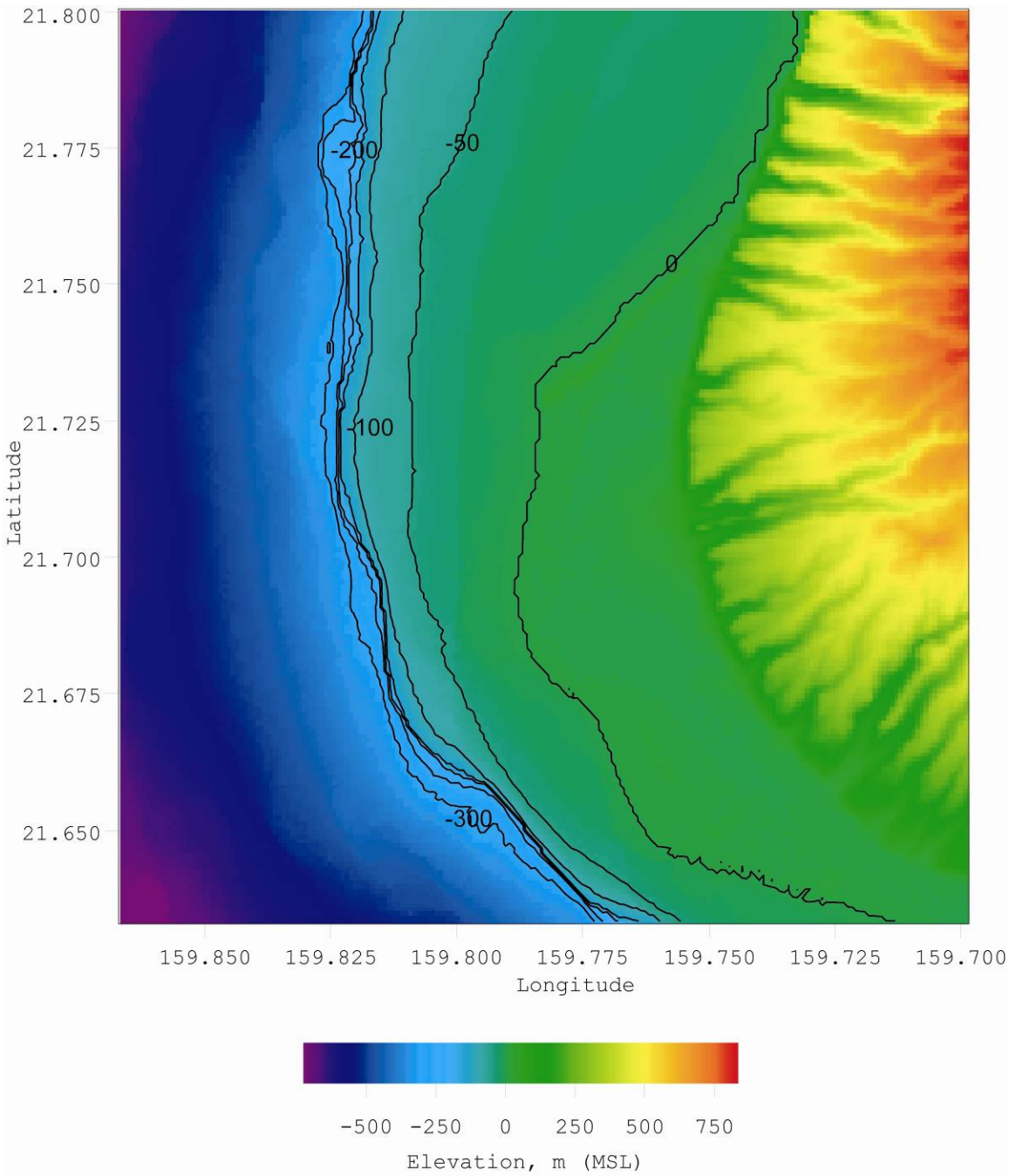


Figure 15. Composite bathymetry (meters below MSL) derived from NOS database and equilibrium profiles ([16]Jenkins and Inman, 2006) for February–May 2007 wave conditions.

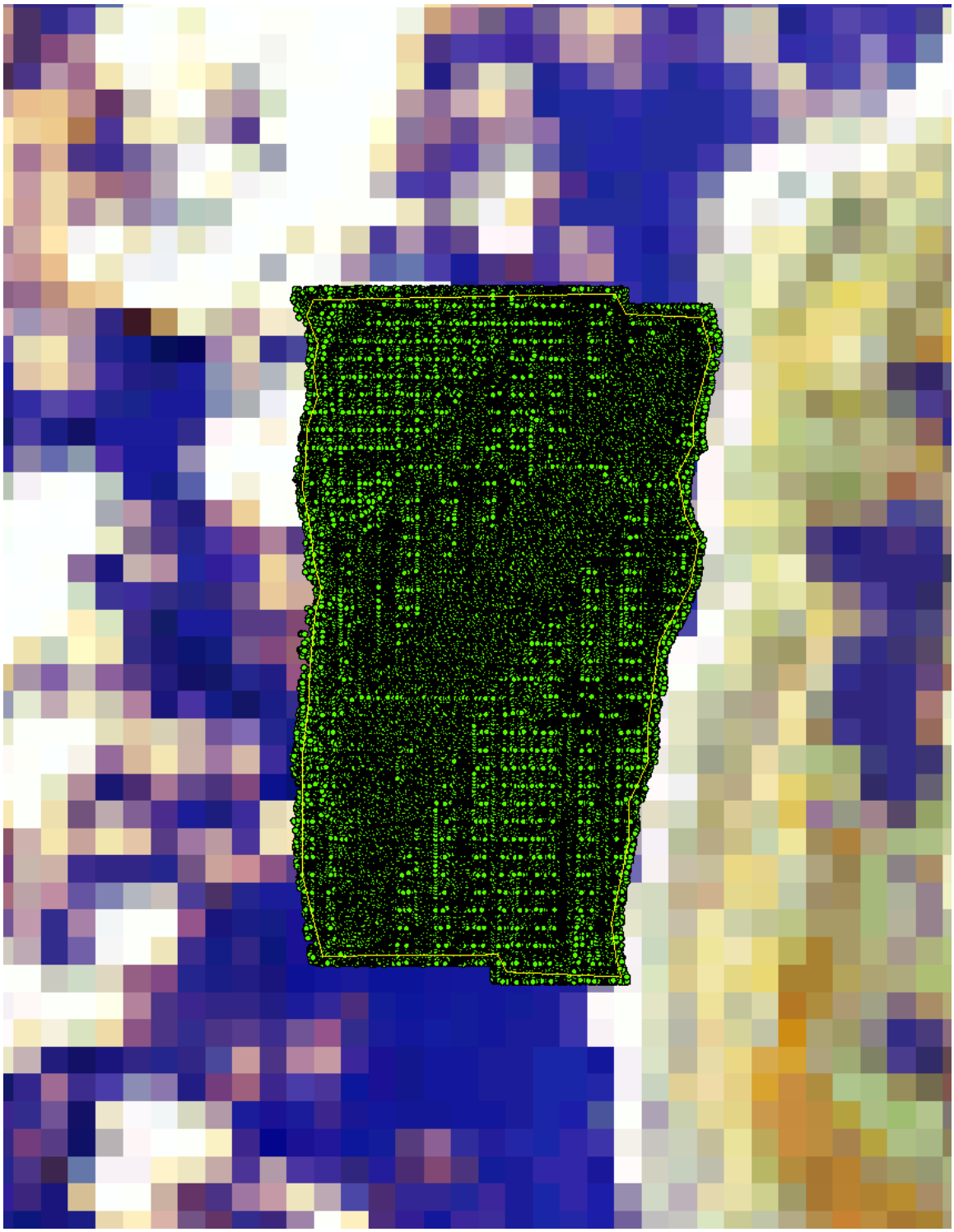
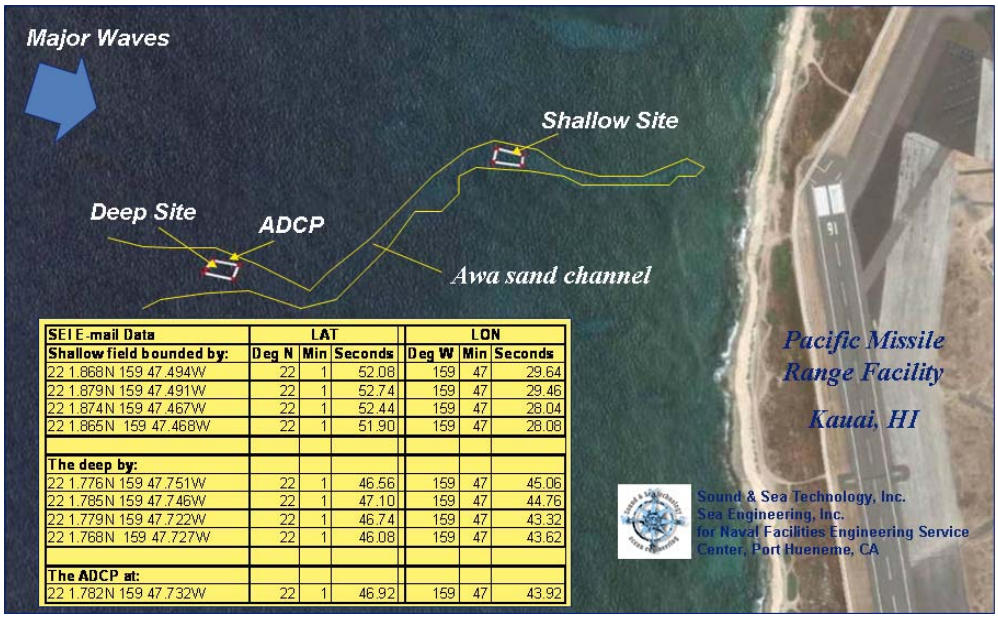


Figure 16. Sample density of LIDAR high resolution bathymetry data (green dots) over the PMRF demonstration site, including a fringing reef section.

a)



SEI E-mail Data	LAT			LON		
Shallow field bounded by:	Deg N	Min	Seconds	Deg W	Min	Seconds
22 1.868N 159 47.494W	22	1	52.08	159	47	29.64
22 1.879N 159 47.491W	22	1	52.74	159	47	29.46
22 1.874N 159 47.467W	22	1	52.44	159	47	28.04
22 1.865N 159 47.468W	22	1	51.90	159	47	28.08
The deep by:						
22 1.776N 159 47.751W	22	1	46.56	159	47	45.06
22 1.785N 159 47.746W	22	1	47.10	159	47	44.76
22 1.779N 159 47.722W	22	1	46.74	159	47	43.32
22 1.768N 159 47.727W	22	1	46.08	159	47	43.62
The ADCP at:						
22 1.782N 159 47.732W	22	1	46.92	159	47	43.92

b)

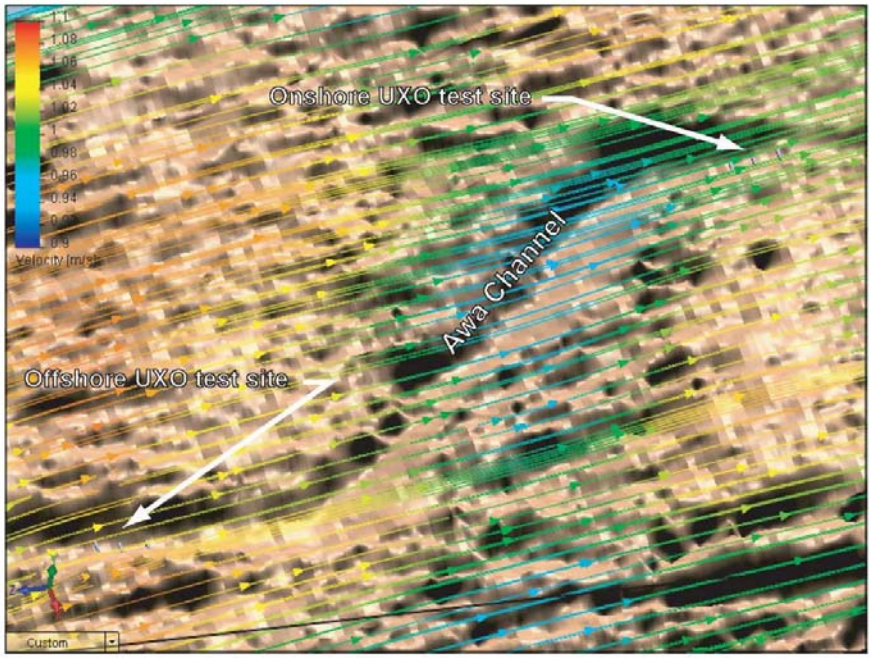


Figure 17. a) PMRF Demonstration Site and b) LIDAR-derived, high-resolution bathymetry of awa channel with current magnitude scaled to color (upper left corner).

3.3.1.2 Wave and Current Forcing

Spatial variation in wave forcing over the reef platform and channel system is derived from refraction/diffraction analysis of directional wave measurements interpolated from an RD Instruments ADCP (Appendix B) installation at 22° 1.782'N; 159° 47.732'W near the offshore (deep) UXO site. The ADCP data were back refracted to deep water and forward refracted over the PMRF site (Figure 18). The broad-scale refraction/diffraction plot in Figure 18 was computed for the largest waves measured by the ADCP during the duration of the demonstration, February through May 2007, with a deep water wave height of 3m, a 12 sec period, and approaching the coast from 270°, which is indicative of a swell from the post-frontal side of a distant cold front dropping south from the Gulf of Alaska. Considering that 10m high waves are not uncommon in winter months along the windward coast of Kauai, the measured wave climate at 22° 1.782'N; 159° 47.732'W near the offshore (deep) site at a depth of 16.6 m MSL must be considered unusually benign (Figure 19). This observation is enforced by the fact that the summer portion of the wave record in Figure 19 produced wave heights comparable to all but the first few weeks of winter waves. The benign wave climate during the experiment combined with the vertical divergence in the flow field over the awa (Figure 17b) produced fluid forcing that was generally insufficient to cause large displacements in the 5"/38 UXO surrogates.

While the reef produces bright spots in the refraction pattern along the west coast of Kauai at several locations north of the PMRF demonstration (Figure 18), the refracted waves display small alongshore variation around the UXO sites. The absence of local alongshore gradients in shoaling wave heights indicate very small longshore currents produced from the current prediction algorithms of the model. That assures that the predominant motion over the UXO fields will be up/down channel along the cross-shore axis of the awa. This observation is confirmed by the measured current directions given in Figure 20, which on a daily basis are from the west and south west, directed onshore along the axis of the awa (cf. Figure 17b); these currents were measured at a location of 22° 1.782'N; 159° 47.732'W near the offshore site at a depth of 16.6 m MSL),

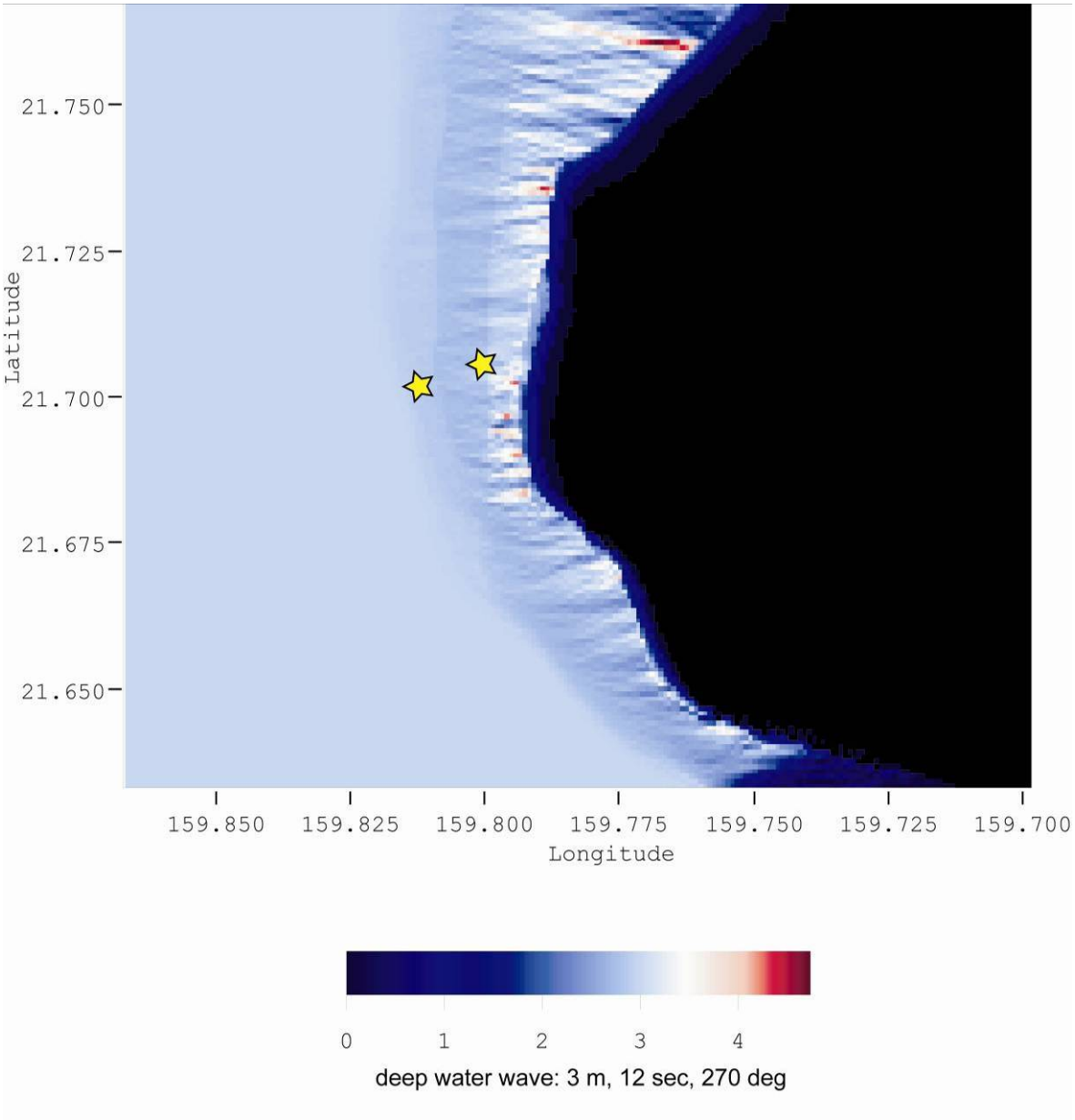


Figure 18. Refraction/Diffraction pattern at PMRF site for highest waves occurring during the duration of the demonstration; yellow stars indicate the inshore and offshore fields.

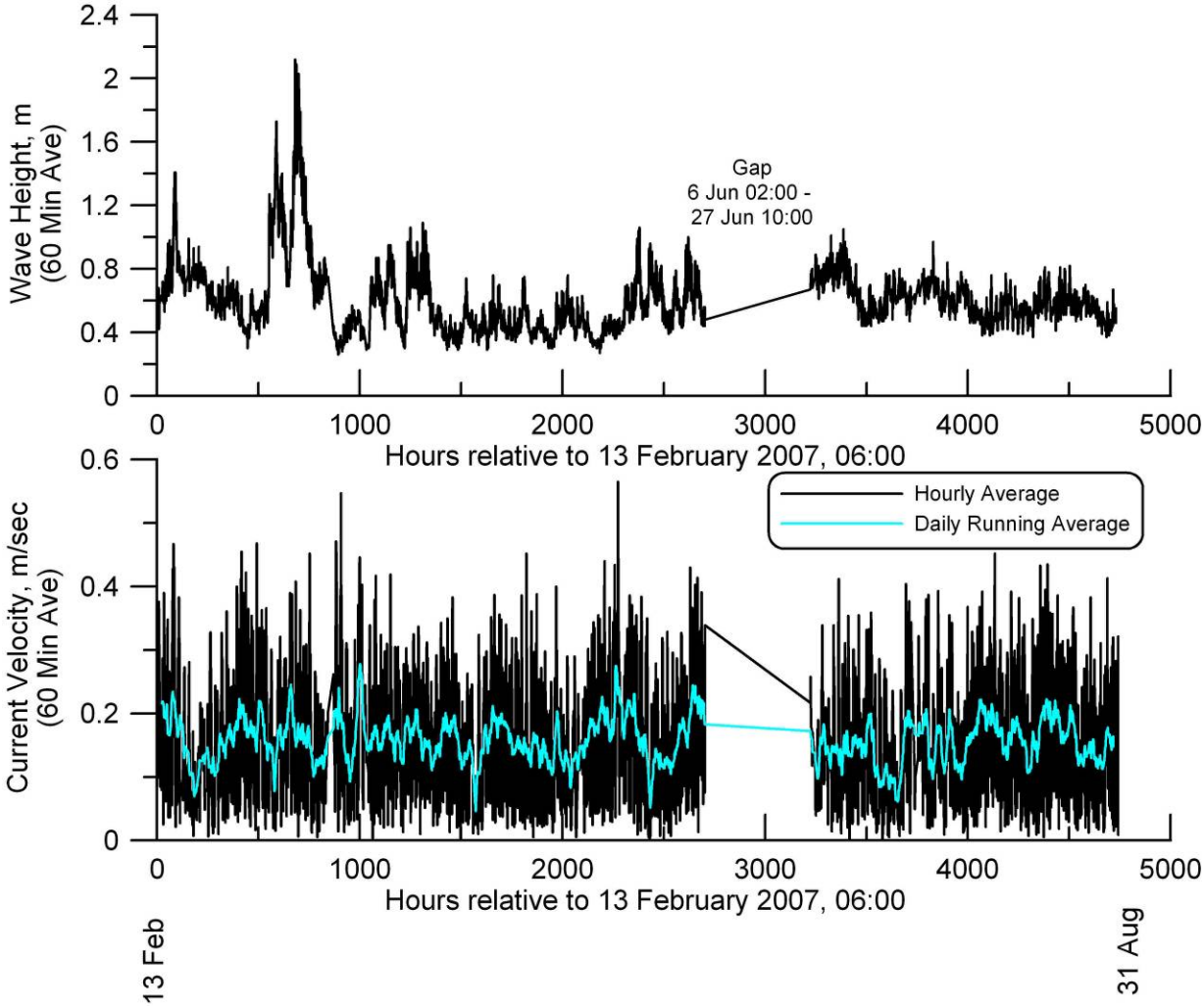


Figure 19. Wave height (upper) and current magnitude (lower) measured with an RD Instruments wave gauge and current profiling ADCP during the demonstration.

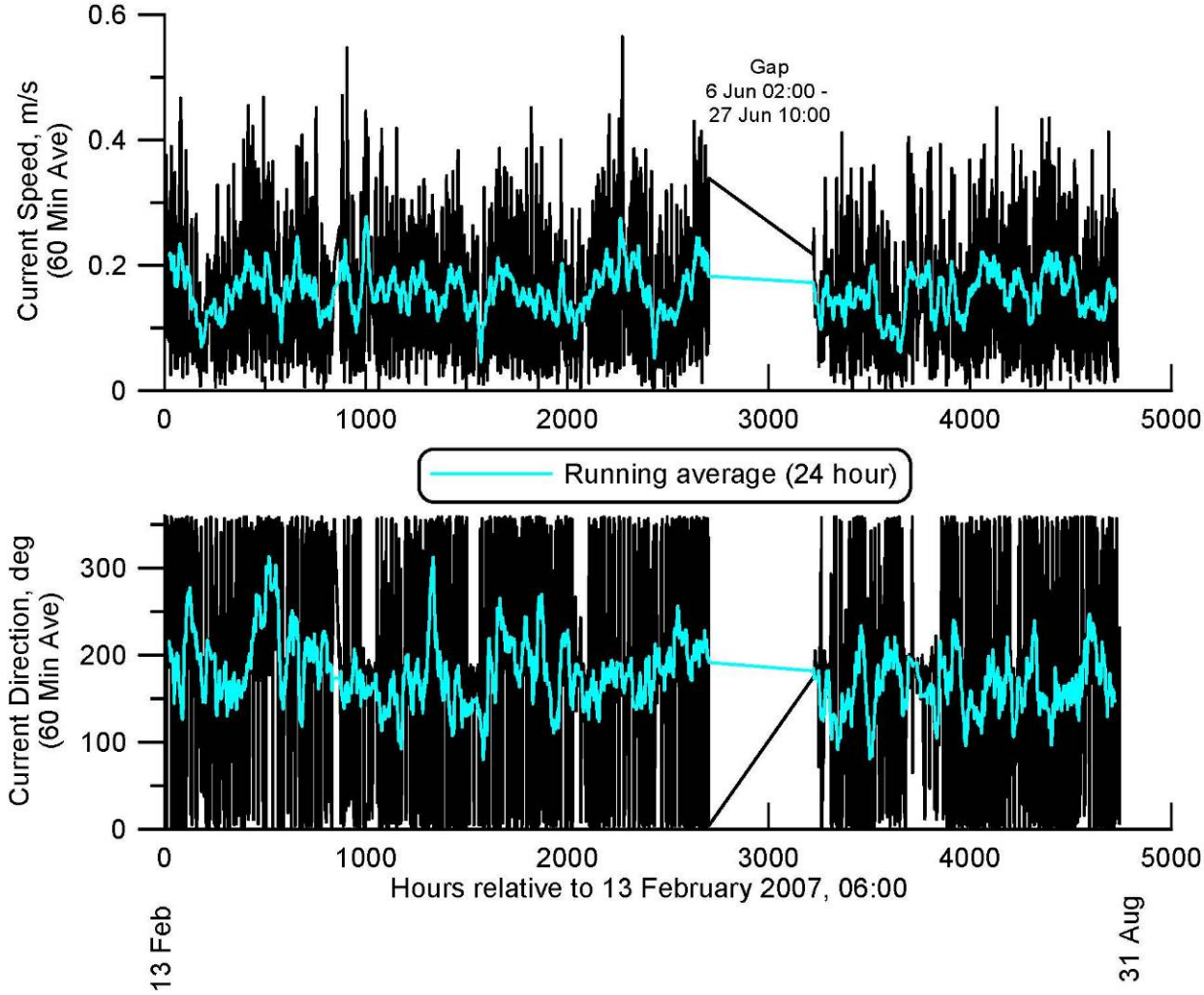


Figure 20. Current speed (upper) and current direction (lower) measured with an RD Instruments wave gauge and current profiling ADCP during the demonstration.

3.3.2 Nearfield Initialization

Nearfield initialization involves data base constructions and model parameterizations for model inputs below the green line shown in Figure 10. A detailed listing of these inputs can be found in [3] and are reviewed here with respect to those that are either in context specific or unique to the PMRF site.

3.3.2.1 Sediment Parameters

The model's nearfield grid was defined as described in Section 1.1 for a coarse sand bottom in the awa channel defined by 14 grain size bins according to the grain size distribution shown in

Figure 21. The pie chart reveals that 70% of these channel sediments are carbonate, derived from biogenic processes and reef fragments. The carbonate sediments comprise the majority of the coarser size bins shown. The finer fractions are predominately sediments of terrigenous origin and make up about 27% of the awa sediments. Generally, mean grain sizes of sandy sediments from streams draining the leeward sides of Kauai are smaller than those of streams draining the windward sides [30], and the PMRF site is a leeward location. Most of the terrigenous sands along the PMRF beaches, stretching from the Napali Coast, south through Polihale State Park to Barking Sands, are composed of material eroded from the Kokee Highlands, remnant of a shield volcano that is dissected on its western side by numerous small intermittent streams and outwash areas. Drainage basins under erosion on the leeward side drain older geomorphic surfaces, which when combined with smaller amounts of leeward rainfall, results in a longer duration of weathering, predominantly chemical in nature, with greater fining and rounding of eroded sand-sized fractions. The small percentage of organics in the PMRF sand sample is another characteristic of the terrigenous sediment yield of the lee-side watersheds. Conversely, the sediments discharged from drainage basins on the windward side are eroded from younger, more vegetated geomorphic surfaces having steeper gradients exposed to higher rainfall, which result in larger sand-sized fractions with higher organic content. Therefore, a windward/leeward segregation of grain size parameters is probably necessary when initializing the model for generic biogenic reef environments.

Of course for this particular demonstration season, which covers the time period of late winter through spring, the dominant winds and waves are from the west, so the hydrodynamic forcing functions are typical of a windward shore.

In general, the sediment properties of biogenic reef environments as represented by Kauai are distinctly different from those of previously studied UXO MM test and demonstration sites along collision and trailing edge coastlines [3]. The MMFT and FRF sites on the coasts of Washington and North Carolina, respectively, were comprised almost entirely of well-sorted, fine-grained quartz sediments of terrigenous origin. In contrast, the Kauai site presents a composite of coarse-grained carbonate and fine-grained volcanic sediments that is less well sorted and contains a higher percentage of organics (although not enough to produce granular cohesion). The lithified side walls of the channels in the biogenic reef also introduce longshore barriers to sediment transport, analogous to what is found in densely packed groin fields along well developed coastlines [31]. These obstructions to longshore transport tend to compartmentalize the sediment transport to the along channel axis of the awas (Section 3.3.1.2, Figure 19 discussion).

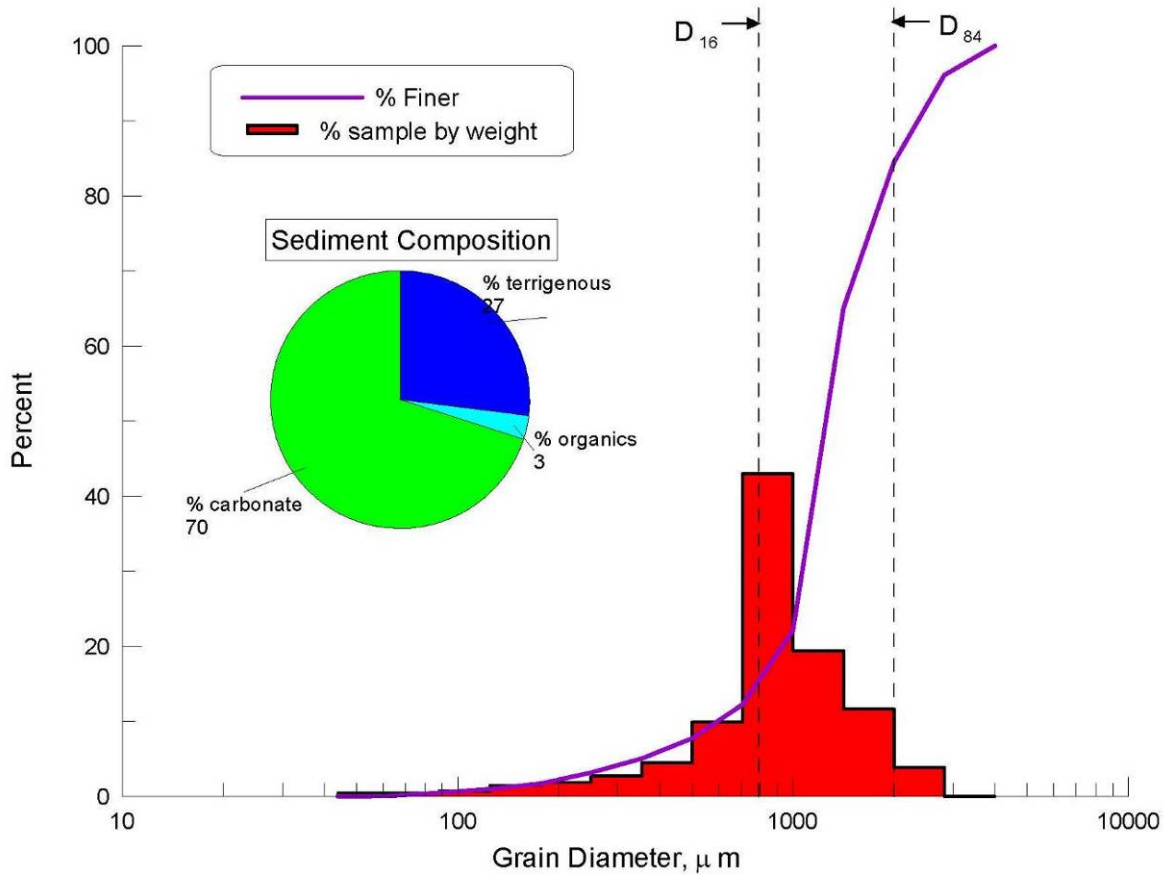


Figure 21. Grain size distribution of sediment, PMRF Field Demonstration Site, Kauai, May 2007; data provided by Sea Engineering, Inc.

3.3.2.2 UXO Shape Lattice

To provide a systematic and manageable set of inputs for shape specific calibration parameters we concentrated our model simulations on the 5”/38 projectile shown in Figure 9. These rounds were approximated by an elliptic frustrum revolved about the major axis (y-axis) of the round and transverse to the mean flow (Figure 13). For this orientation, the generalized shape of the round can be represented by the analytic expression:

$$R(y) = a - a\left(\frac{y}{S}\right)^{\beta} \qquad (1)$$

where $a = D/2$ is the basal radius and D is the basal diameter of the round, $R(y)$ is the local radius at any arbitrary location y along the major axis of the round, S is the total length of the round as measured along the y-axis, and β is a constant that adjusts the pointedness of the round. A best fit of equation (1) to the 5”/38 round using the dimensions shown in Figure 9

found that $\beta = 3.5$. To accommodate these dimensions and the small radius curves of the shape, the VORTEX shape lattice file was gridded for 3mm grid cells.

3.3.2.3 Burial and Migration on Planar Carbonate Sediment Beds

Prior to considering the nearfield influence of the channel walls on the burial migration response of the UXO at PMRF, we test the performance of the shape lattice files using the coarse-grained carbonate sediment distribution from Figure 21 on a planar bed, (with no extraneous irregularities in either the stream-wise or cross stream directions). Figure 22 presents the modeled instantaneous vortex and scour field produced from an initially planar bed with the surrogate's major axis aligned transverse to a train of monochromatic waves with 12 sec period propagating from right to left. The wave oscillatory velocity amplitude at the top of the bottom boundary layer is 96 cm/sec, which corresponds to the super-critical transport regime for the grain size distribution in Figure 21. In this regime, flow separation with a basal vortex is observed on the down-wave (shoreward) side of the round, inducing formation of a scour hole. As the scour hole deepens, the round slips or rolls into the hole, resulting in migration and burial through what is known either as a *scour and slip* or *scour and roll* burial sequence. At the instant the flow field in Figure 22 was calculated, the burial/ migration progression of the UXO had advanced to a state of 55% burial.

At an advanced stage in the burial/migration progression referred to as *lock-down,* burial becomes sufficiently extensive that migration is no longer possible [32], [33], [34]. For excitation by monochromatic waves of various periods and heights, the distance a UXO migrates before lock-down sets up has a monotonic dependence on a parameter of dynamic similitude referred to as the Shield's parameter. This parameter, which combined with the grain Reynolds number, is now recognized as a reliable predictor of whether or not a grain will erode, is a measure of the intensity of environmental forcing relative to the inertia of the UXO. Explicitly, the Shields parameter, Θ, or dimensionless shear stress, represents a ratio between the hydrodynamic forces (i.e., drag and lift) acting to move the UXO and the gravitational forces acting to restrain and bury the UXO:

$$\Theta = \frac{u^2}{g'D} \qquad (2)$$

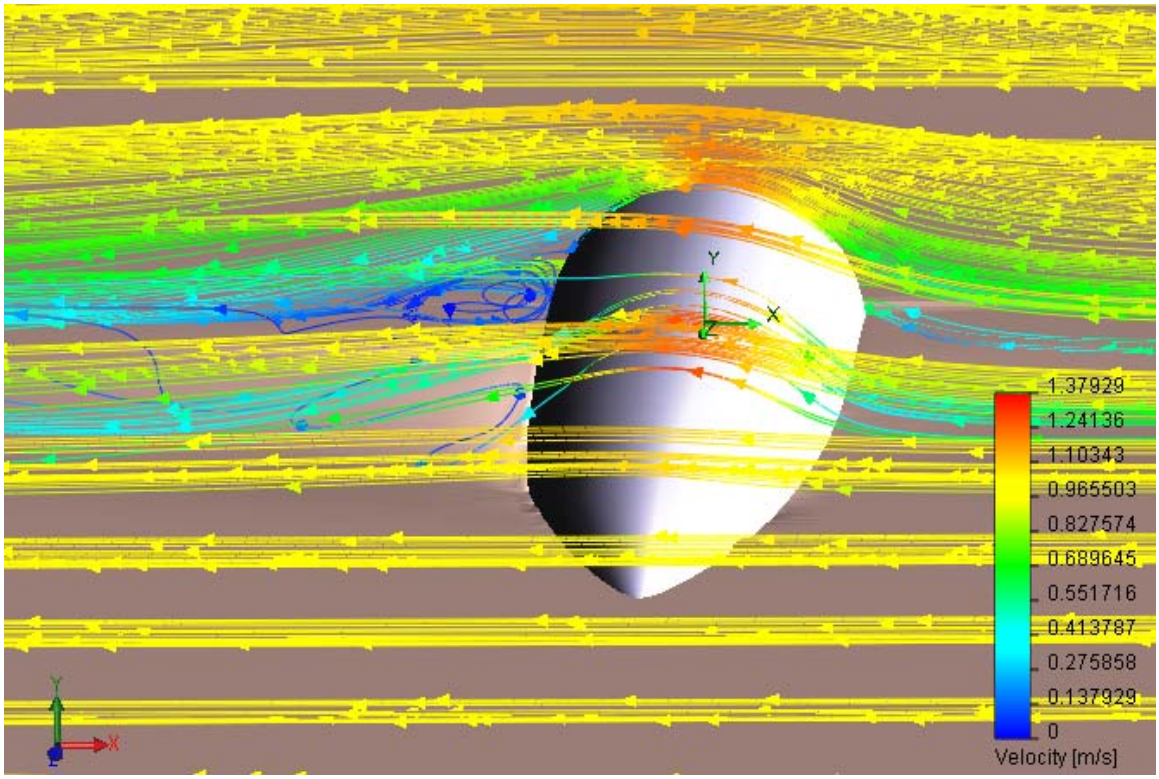


Figure 22. A simulation of the vortex and scour field in the nearfield grid shows 55% of the 5”/38 UXO surrogate buried in a coarse sand bottom.

where u is the oscillatory wave velocity amplitude at the top of the bottom boundary layer, D is the basal diameter of the UXO, g is the acceleration of gravity, $g' = g * \Delta\rho / \rho$ is the reduced gravity, and $\Delta\rho$ is the density difference between the UXO and seawater density, ρ. Planar bed simulations of the type shown in Figure 22 indicate that UXO mobility increases with increasing wave velocity (proportional to wave height and inversely proportional to wave period), with decreasing caliber of the UXO, or with decreasing density (specific gravity) of the UXO. Planar bed simulations using the wave velocities measured at PMRF (Figure 20) reveal that with the exception of a few storms early in the deployment, the Shields parameter was predominantly in the sub-critical range of $\Theta \leq 7$; see [32, 33,34] for more detailed references on sub- and super-critical transport regimes. As an indicator of the stability of a particle, sub-critical values of the Shield’s parameter indicate that very little movement of the UXO occurs because hydrodynamic moments associated with drag and lift are insufficient to overcome the restraining moments due to gravity. The reasons this condition occurred during the PMRF experiment are due to a combination of benign wave climate and vertical divergence of the wave induced surges and streaming over the reef channels (cf. Section 3.3.1.2).

3.3.2.4 Eddies and Secondary Flows from Awa Channel Sidewalls

Awa side wall influence on the nearfield flow dynamics are one of the most unique features of the biogenic reef environments that was not previously encountered at the other UXO MM field test and demonstration sites that took place on collision and trailing edge coasts. Both the gridded LIDAR data in Figure 17b and underwater photos of the demonstration site (Figure 23) reveal that the channels introduce both curvature effects and roughness effects on the flow of wave surges and wave induced streaming.

These flow disturbances undoubtedly produce eddies that could induce additional vortex scour to the nearfield of the UXO beyond that induced directly by the UXO shape. This increases the modeling challenge by forcing us to expand the nearfield grid to include the prominent features of awa side walls in the immediate vicinity of the UXO site. It is neither practical nor computationally efficient to extend the 3mm resolution of the shape lattice of the UXO across tens of meters of adjacent awa channel sidewalls. A coarser-scale lattice of the awa wall geometry was nested around the UXO shape lattice and embedded it inside the farfield grid of the reef platform. This merely required replication of existing code to create a secondary nested grid inside code module #13 of the model architecture (Figure 10). Grid resolution was set at 0.5 m for the secondary nested grid of the sidewall geometry around the UXO field.

Figure 24 shows a VORTEX model simulation of the curvature effects of the awa in the neighborhood of the offshore UXO field. Vertical divergence of the flow field between the top of the reef and the bottom of the channel is accentuated over the UXO field because it is sited on the inside of the channel bend for onshore directed surges and wave-induced streaming. There is also a tendency for the near channel bottom flow to develop secondary meanders that can introduce cross-flow components over the UXO surrogates. The primary consequence of these secondary flows and vertical divergence phenomena is to promote sub-critical flow conditions over the UXO that retard migration while promoting burial.

The second major influence of the awa sidewalls comes from the encroaching shoulders of the sidewalls into the sand channel. These shoulders cause large scale disturbances along the major axis of the primary flow channel. These disturbances in turn can generate rather large scale eddies, much larger than those shed by the relatively small body radius of the UXO. In Figure 25, the nested secondary grid of the VORTEX model was used to simulate these large-scale channel vortices near two of the twelve UXO in the offshore field. This simulation is representative of the sub-critical channel surges recorded by the ADCP shown in Figure 19 for which $u \approx 0.4$ m/sec. In spite of the low velocities in the bottom of the channel, the encroaching sidewall is able to excite a large channel eddy with a high vertical velocity component, $w \approx 0.2$ m/sec.

Vertical velocities of this magnitude in the nearfield of the UXO are capable of excavating large scour depressions into which the UXO can readily roll. Thus, large external channel eddies can facilitate UXO migration even when the Shields parameter remains sub-critical.

Figure 23. The awa channel's sidewall intersects the carbonate seabed at the PMRF site; note the wall surface roughness and curvature of the lithified reef structures (photo: SEI).

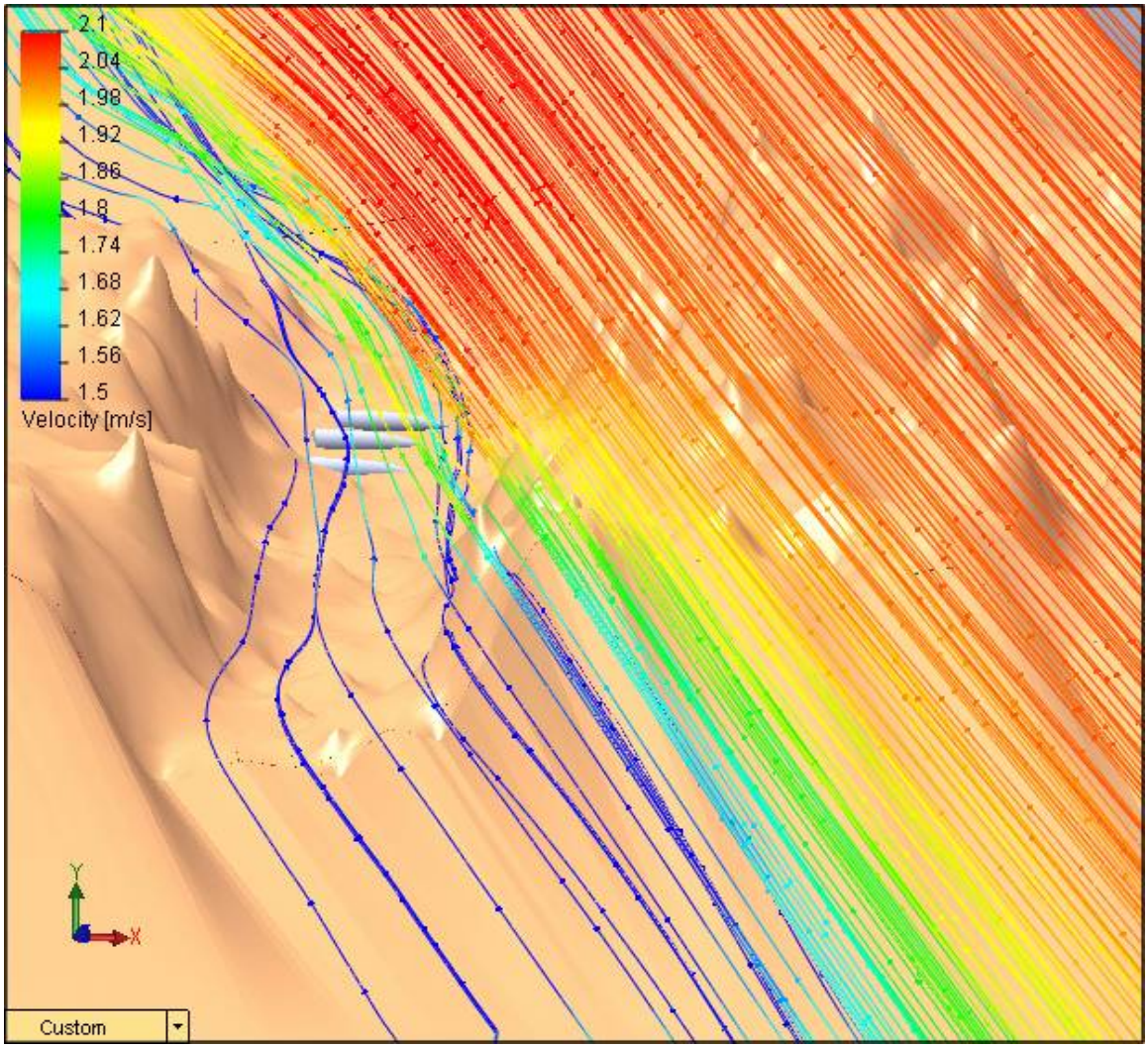


Figure 24. A simulation of vertical divergence and secondary flows induced by the curvature of the awa axis in the vicinity of the demonstration site at PMRF, Kauai.

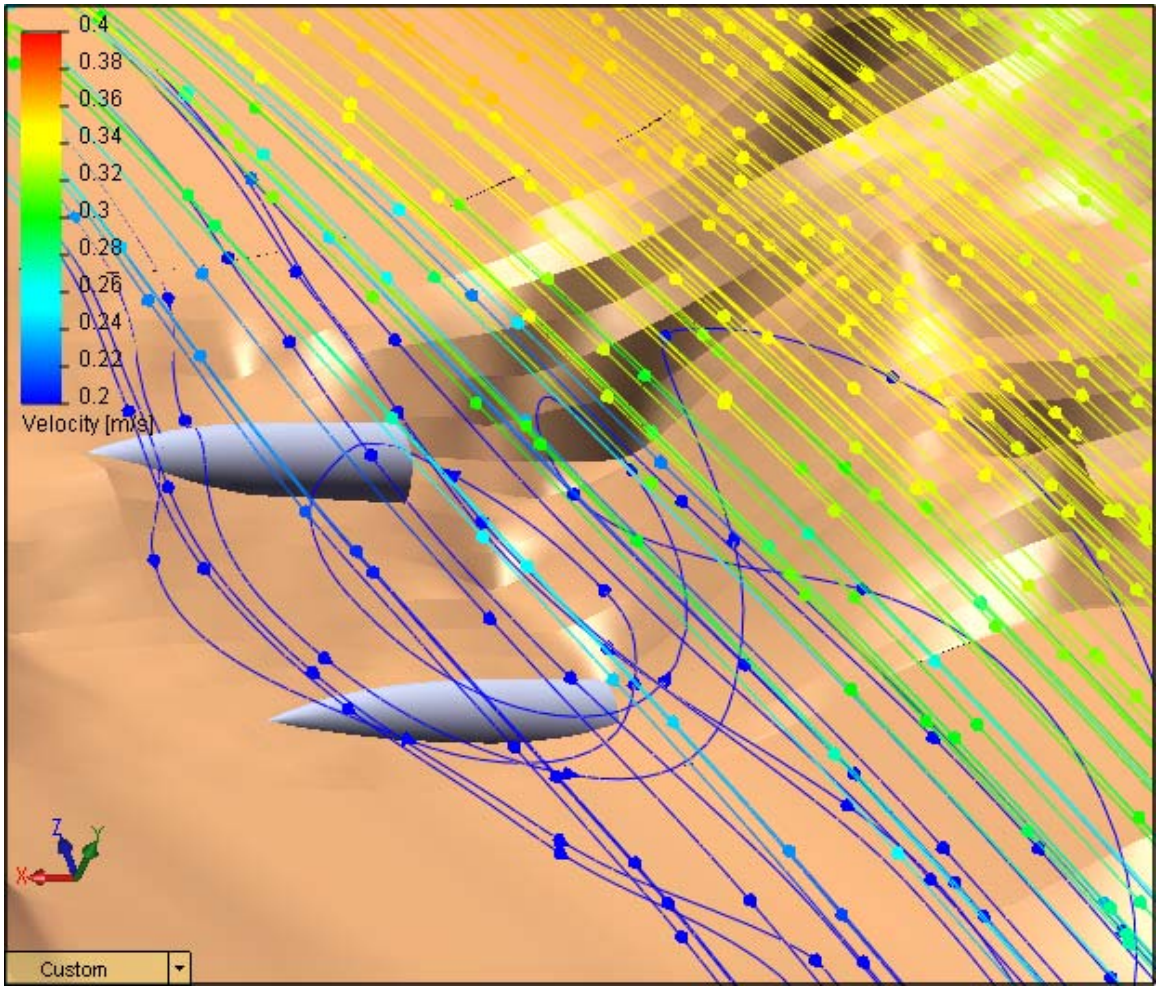


Figure 25. A simulation of the large-scale eddies induced over UXO by the encroaching shoulders of the awa sidewalls in the vicinity of the demonstration site at PMRF, Kauai.

3.4 UXO Migration/Burial Model Performance at PMRF Experiment

The model performance was compared against data from two separate UXO sites deployed in an awa in the nearshore of PMRF, Kauai, HI between 13 February 2007 and 27 June 2007. Figure 17a gives the bounding coordinates of the two sites and the micro-bathymetry of the channel. Figure 26 shows the lay-down pattern of the shallow and deep deployment sites, each containing 12 UXO surrogates of 5”/38 naval rounds. At both the offshore and inshore sites, surrogates were laid in two along-channel rows 30 ft apart at 30 ft spacing with six surrogates in each row. The surrogates were laid on 13 February 2007 and the position and burial depths of some or all of the surrogates were measured during subsequent visits: 22 February, 2 March, 21 March, 13 April, 9 May, 31 May, and 27 June 2007.

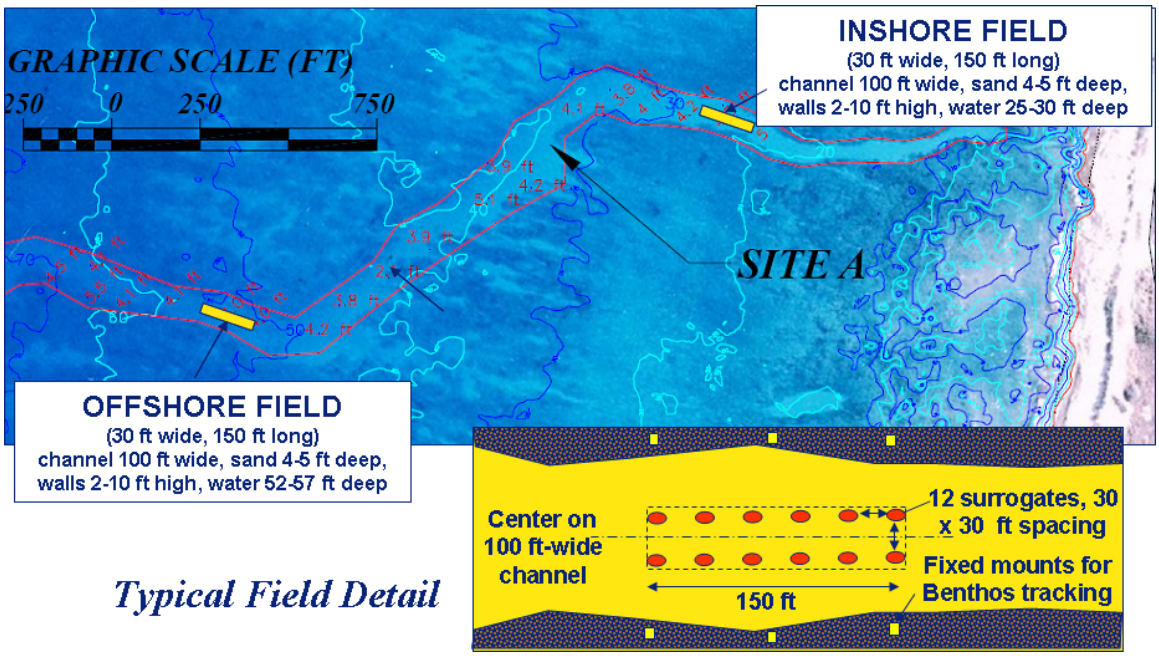


Figure 26. Lay-down pattern for the inshore and offshore fields at PMRF.

Because the surrogates all became buried during the experiment, the primary method for locating the surrogates was an acoustic ranging technique that used embedded pingers and four transponders mounted around the perimeter of each demonstration site. Figure 27 gives a schematic of the technique that was perfected at earlier UXO experiments at Ocean Shores, Washington, and Duck, North Carolina. Because of reverberation concerns from the awa sidewalls at PMRF, the accuracy of this acoustic ranging technique was verified during the 13 April 2007 survey, when the acoustic range data were compared against tape measurements between each of the four transponders and the UXO specimens. The acoustic measurements showed a consistent underestimation of the range to the surrogates, with an error that averaged 0.6 m and a standard deviation of 0.4 m; the acoustic range data was subsequently corrected for this systematic error.

Burial depths were measured using penetration probes that were inserted into the sand bed at the surrogate locations indicated by the acoustic range data. Probes were hand driven by divers and refusal depths recorded manually. All refusal depths were substantially less than the known thickness of the sediment cover in the awa, which averaged 4-5 ft (≈140 cm). Consequently, refusal depth, the depth at which the probe encountered a hard surface and could not be driven any further by the diver's hammer blows, was taken to be equivalent to burial depth.

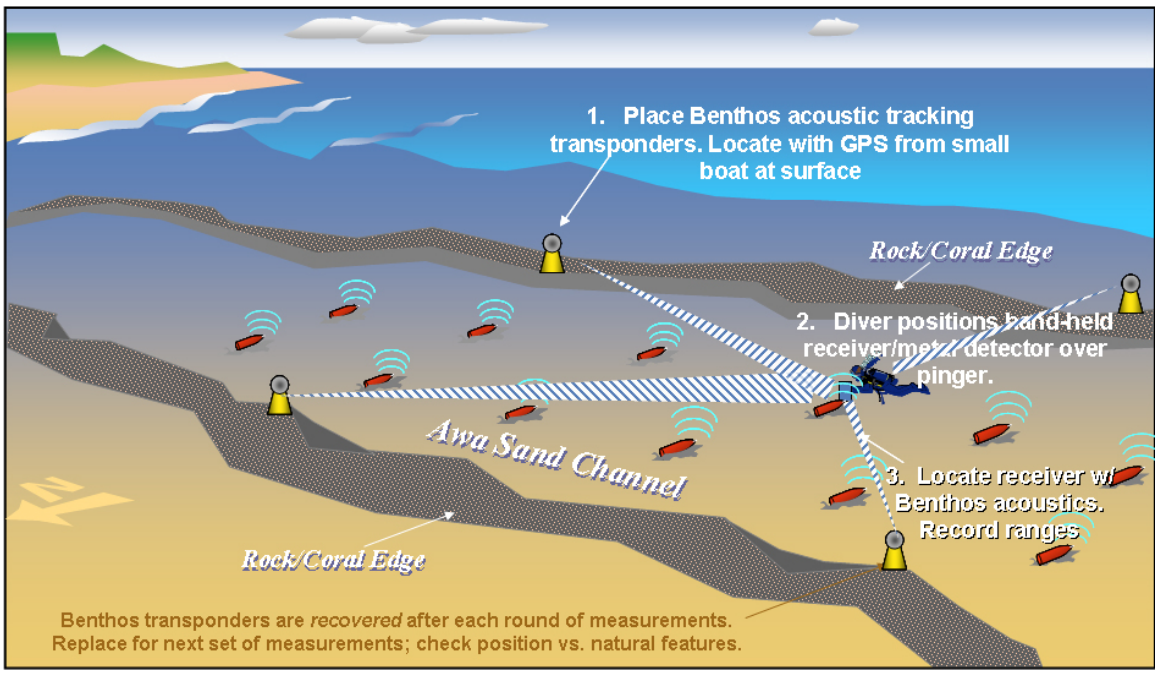


Figure 27. Schematic of the acoustic transponder ranging technique for locating UXO surrogate positions during the demonstration at PMRF.

3.4.1 Model Predictions of UXO Migration and Burial Rates

Migration and burial of each of the 24 UXO in the inshore and offshore demonstration sites at PMRF (Figure 26) were simulated by the VORTEX model for the wave and current forcing measured by the ADCP (Figure 19), and the grain size distribution in Figure 20. Wave forcing measured at the offshore site by the ADCP was corrected to the inshore site using refraction/diffraction analysis like that shown in Figure 18. The vertical divergence and large scale eddies induced by the awa side wall geometry was computed separately for the offshore and inshore sites. These simulations were based on the high resolution bathymetry (Figure 16) applied to nested secondary gridding of the channel as demonstrated in Figure 24 and Figure 25.

Figure 28 gives the VORTEX model simulated migration and burial rates during the entirety of the PMRF experiment averaged over the 12 surrogates in the inshore site; blue crosses indicate the individual simulations of migration for each wave measurement recorded in Figure 19 that caused an increment of migration to occur.

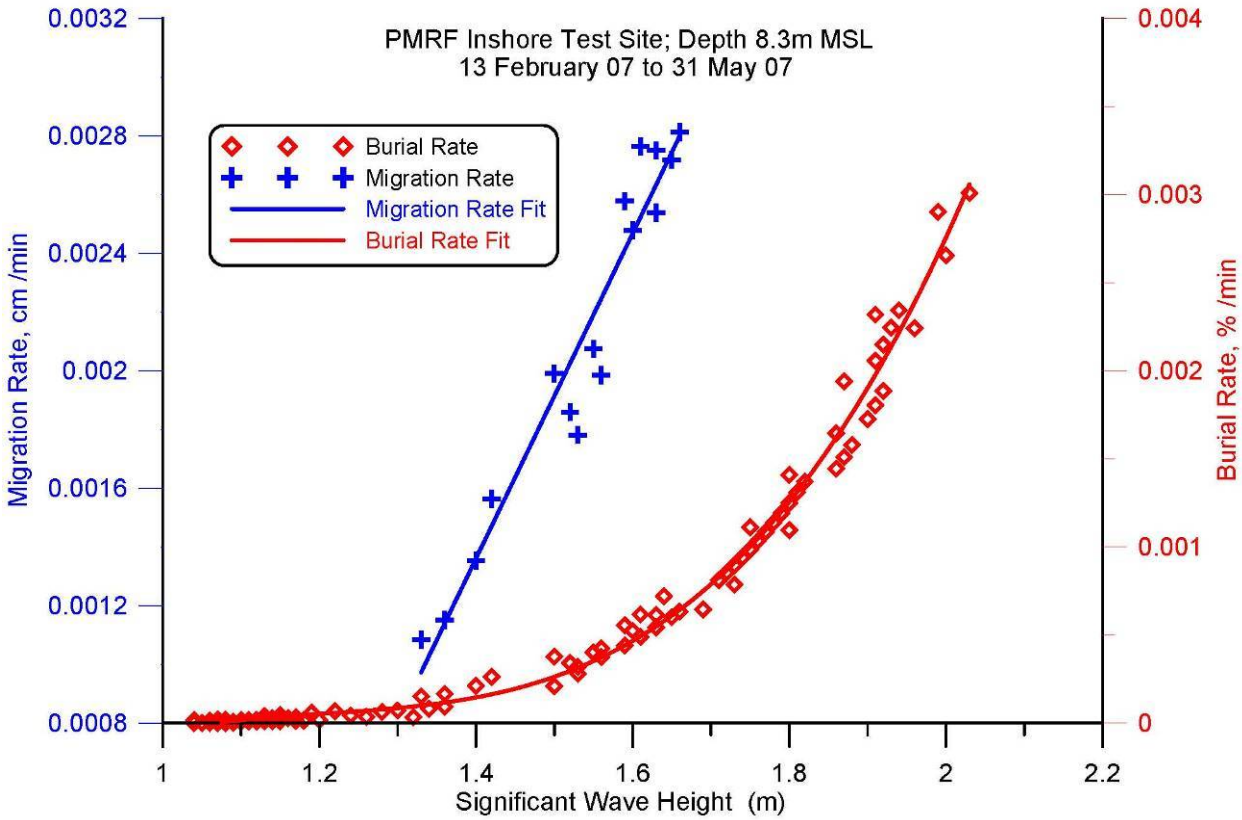


Figure 28. VORTEX model simulation of migration and burial rates of 5”/38 UXO surrogates at the inshore site at 8.3 depth as a function of measured wave heights.

Similarly, the red diamonds in Figure 28 give simulations of burial for each wave measurement in Figure 19 that caused some increment of burial to occur. Here burial is expressed in terms of burial depth as a % of the diameter (caliber) of the round. The obvious difference in the numbers of blue crosses versus red diamonds indicates that relatively few wave events caused the rounds to actually move. This reflects the fact that the surrogates became completely buried under many centimeters (20-50 cm) of overburden, whereas migration is halted by lock-down that sets up while the surrogates are still only partially buried. The solid blue and red lines in Figure 28 are best-fit polynomials to the simulated points generated by the individual wave events. No model realizations are shown for waves heights less than 1m because smaller waves produce bottom velocities at 8.3 m depth that are less than the threshold of motion of the median grain size of sediment in Figure 20.

The scatter about each of the best-fit lines in Figure 28 is due to the wave period dependence of migration and burial rate, which for these shallow water conditions is second order relative to wave height dependence. From this outcome, the average threshold of migration for the 5”/38

UXO surrogates appears to be at about a significant wave height of 1.3 m at water depths of 8.3 meters. From this threshold, migration rates increase rapidly with increasing wave height, roughly tripling with an increase of only 0.3 m in wave height. While this is happening, burial rates increase at first slowly from negligibly small rates at threshold of migration wave heights to rapidly increasing rates as burial lock-down is approached, at $Ho \approx 1.6$ m. Maximum migration rates are approximately equal to 0.0028 cm per minute. Beyond burial lock-down, the burial rate continues to accelerate until total burial is achieved, whence the scour burial mechanism vanishes and only farfield burial from bottom profile change can effect any subsequent burial. Scour burial maximums for the 5”/38 surrogates occur at significant wave heights of about 2 m at a rate of 0.003 % per minute, although this result is somewhat controlled by the particular sidewall effects of the awa at the inshore site.

Figure 29 provides the average simulated migration and burial rates for the 12 surrogates in the offshore site at PMRF at 16.6 m mean depth (Figure 26). As in Figure 28, blue crosses indicate the simulations of migration for each wave measurement that caused some increment

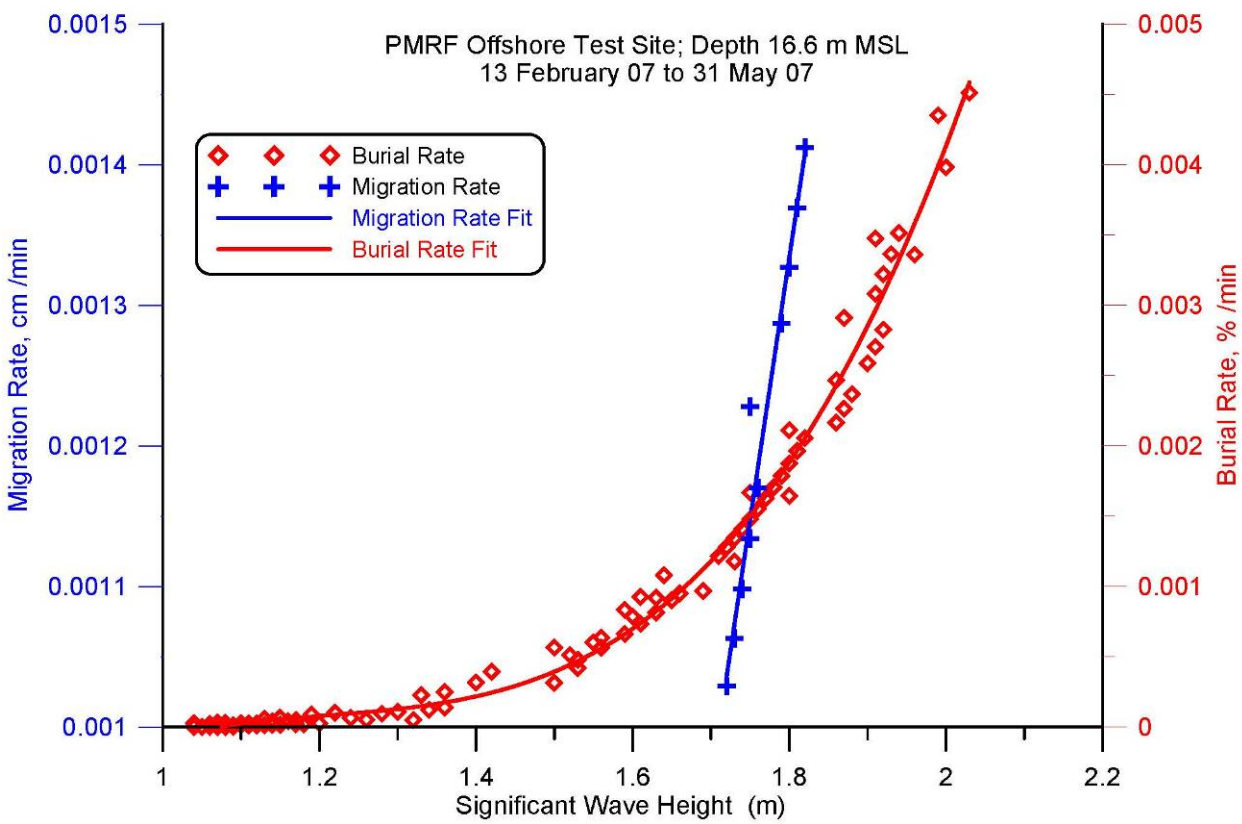


Figure 29. VORTEX Model simulation of migration and burial rates of 5”/38 UXO surrogates at the offshore site at 16.6m depth as a function of measured wave heights.

of migration to occur; and, red diamonds give simulations of burial for each wave measurement that caused some increment of burial to occur; where burial is expressed in terms of burial depth as a % of the diameter of the round. For clarity the axes in Figure 29 have been re-scaled for the differences in dynamic range. Comparing Figure 29 with Figure 28 it is apparent that the threshold wave height for migration of the UXO surrogates in the offshore array is substantially higher (increasing to a significant wave height of 1.7m), primarily due to depth attenuation of the wave orbital velocity in the deeper waters of the offshore site. For the same reason, there are fewer numbers of wave events that induce migration at the deeper offshore site; (compare numbers of blue crosses in Figure 29 with those in Figure 28). However, once the UXO surrogates in the offshore array begin to move, their migration rate increases rapidly, it increases 140% with a 0.1m increase in wave height above threshold of migration and reaches a maximum migration rate 0.0015 cm per minute at significant wave heights greater than 1.8m. This maximum migration rate is approximately one half that of the surrogates in the inshore array and occurs at a substantially higher significant wave height (1.8 m vs. 1.6 m), again due to the depth attenuation in orbital wave velocities. At their maximum migration rate, surrogates in the offshore array are burying at 0.0019 % per minute while surrogates in the inshore array are burying at about 1/3 that rate, or 0.0005 % per minute. Thus, surrogates in the offshore array reach burial lock-down sooner, and thereby have less time to migrate off-station. Maximum burial rates of surrogates in the offshore array equal 0.0045 % per minute at a significant wave height of 2m, or approximately 50% faster than for surrogates in the inshore array. While this may be partly understood in terms of slower migration rates occurring simultaneously with higher burial rates, it is not intuitive when considering that burial rates tend to increase with orbital velocity while orbital velocity decreases with increasing depth. Our interpretation of this specific and somewhat paradoxical result is that the large scale eddies induced by the awa sidewalls are more active and well developed at the offshore site (cf. Figure 25), which increases scour burial rates induced by relatively smaller orbital velocities.

3.4.2 Predictive Skill of Model Predictions

Two approaches are applied to assess the predictive skill of the quantitative model predictions of the magnitude of migration and burial of UXO surrogates at PMRF. With the first approach, probability density functions are produced for migration and burial magnitudes predicted by the Mobility Model. Those are then compared with the probability density functions assembled from the observed outcomes of the experiment. Because the experimental outcomes involve small ensemble statistics, we merge the results of all 24 surrogates from the inshore and offshore demonstration sites (cf. Figure 26) into a single set of probability density functions. By the second approach, we a compute predictive skill factor, *R,* is computed from the mean squared error between the predicted and measured outcomes.

To generate predictions of migration and burial magnitudes from the rates in Figure 28 and Figure 29, we integrate those rates (as computed for each surrogate) over the duration of each migration or burial rate-inducing wave event. Figure 30a presents the probability density function (histogram) of the predicted UXO migration distances for all 24 surrogates at PMRF.

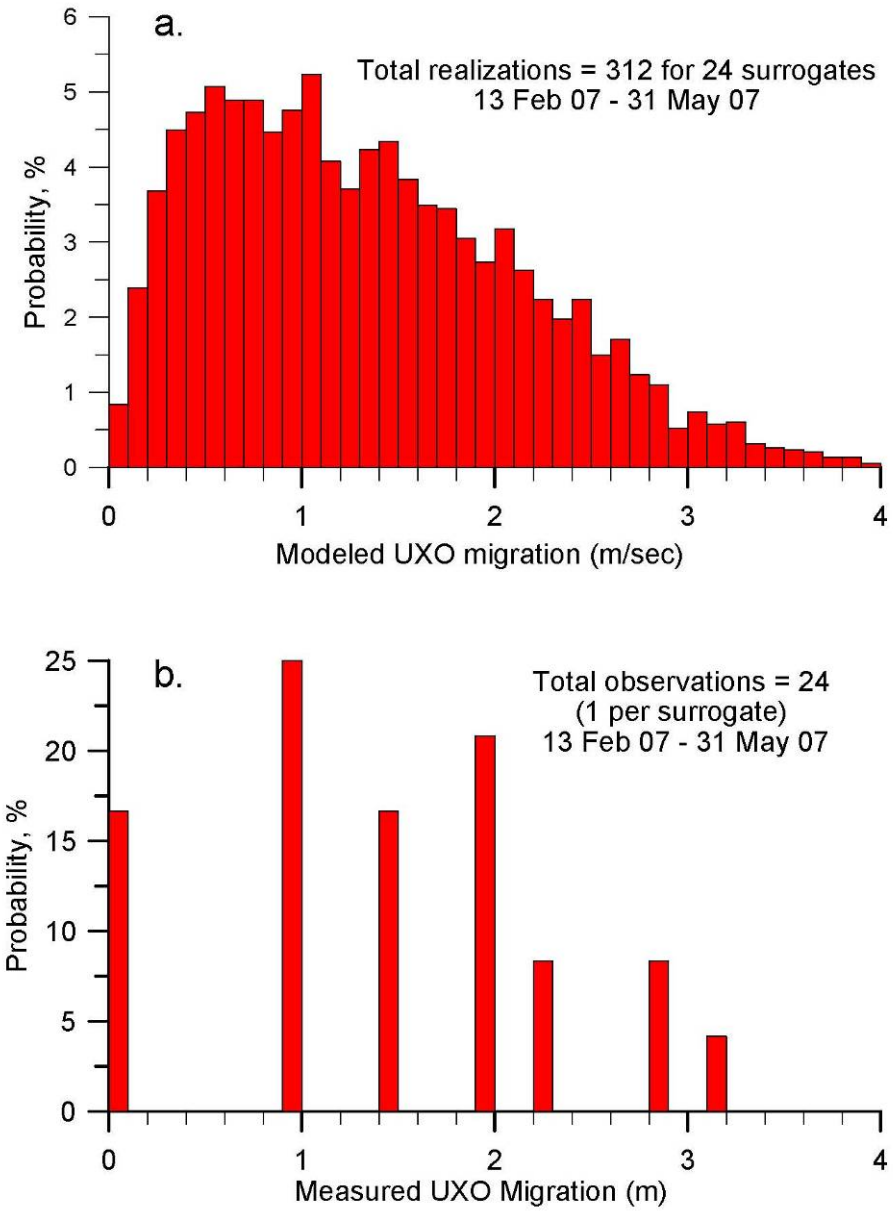


Figure 30. Modeled probability density functions for UXO migration versus (a) the measured probability density function and (b) all surrogates during the demonstration.

A total of 312 migration distance outcomes were constructed from the rates (blue crosses) in Figure 28 and Figure 29. These are contrasted with the 24 measured outcomes of migration distance that make up the measured probability density function in Figure 30b. The peak, spread and shape of the predicted and measured probability density functions of migration in Figure 30 are quite similar, although the granularity of the measured distribution is much coarser owing to the relatively small numbers of observations. Both distributions give a mean migration distance

of approximately 1 m and a maximum migration of slightly greater than 3 m. In both the predicted and observed outcomes, migration almost exclusively occurred along the major axis of the awa channel.

Migration at PMRF was approximately double the values measured for the same type of surrogates deployed on a collision coast at Ocean Shores, Washington. Although the Pacific Northwest deployment took place over the span of only 1 to 2 days – very brief by comparison to PMRF – the surrogates were placed directly in the surfzone instead of fully submerged offshore. Similarly, migration magnitudes at PMRF were on average approximately 1/3 of what was observed for similar surrogates deployed on a trailing edge coast at Duck, NC. The length of the FRF Duck deployment was approximately seven times the duration of the PMRF experiment. None of the three UXO experiments experienced effects from any extreme event storms. With these gross comparisons, it is evident that a certain degree of monotonic migration behavior exists over the time underwater UXO spend in the environment in the absence of extreme events.

Figure 31 compares the predicted versus measured probability density functions for UXO burial at PMRF. The larger numbers of burial-inducing wave events in Figure 28 and Figure 29 produced nearly 10 times more instances (3,806) of predicted burial in Figure 31a. The comparison with measured probability density function for burial in Figure 30b is quite satisfying, despite the small ensemble of measured statistics. Again, the peak of the measured distribution, its breadth and shape all closely resemble the modeled distribution in Figure 31a. Mean burial depths are approximately 20 cm while maximum burial depths are slightly over 40 cm. These burial depths are greater than what was observed during the brief deployment at Ocean Shores, Washington, and on a par with the inshore surrogates deployed at Duck, NC.

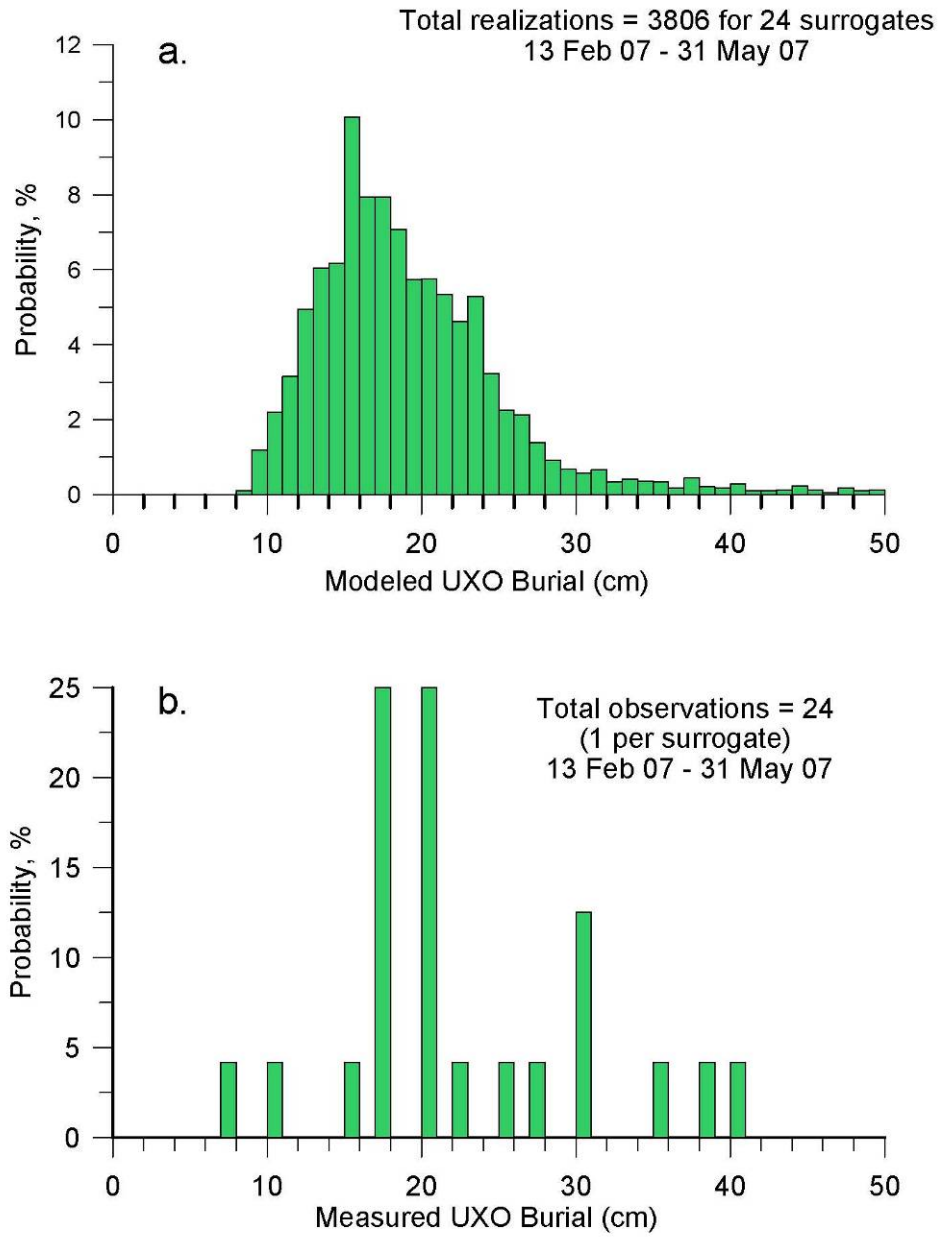


Figure 31. Comparing modeled probability density functions for UXO burial versus (a) the measured probability density function and (b) for all surrogates during the demonstration.

Using the analytical statistical approach to error assessment, we compute the predictive skill factor, *R,* of the UXO migration distance, ξ, and burial depth, *h,* as quantified by an estimator adapted from the mean squared error. For burial depth the skill factor, R_h is of the following form adapted from Jenkins and Inman [35]:

$$R_h = 1 - \frac{1}{N\hat{\sigma}_i}\left\{\sum_{1}^{i=N}\left[\hat{h}(i) - h(i)\right]^2\right\}^{1/2} \tag{3}$$

where $\hat{h}(i)$ is the measured burial depth for $i = 1, 2...N$ observations, $h(i)$ is the predicted burial depth for the ith observation, and σ_i is the standard deviation of all observations over the period of record. For migration distance, the skill factor, R_{ξ},, would have the form:

$$R_{\xi} = 1 - \frac{1}{N\hat{\sigma}_i}\left\{\sum_{1}^{i=N}\left[\hat{\xi}(i) - \xi(i)\right]^2\right\}^{1/2} \tag{4}$$

where $\hat{\xi}(i)$ is the measured migration distance for $i = 1, 2...N$ observations, $\xi(i)$ is the predicted migration distance for the ith observation. Based on these formulations and the predicted versus measured outcomes in Figure 30 and Figure 31 the skill factor for migration at PMRF was calculated at $R_{\xi} =$ 0.88 and $R_h =$ 0.90 for burial. For coastal processes modeling and mine burial prediction in particular, any skill factor in excess of 0.8 is considered to be a good result [36].

4.0 CONCLUSIONS

A process-based UXO model has been developed and exercised during the winter-spring season at two separate offshore sites on the leeward side of a biogenic reef environment off the west coast of the island of Kauai, HI, at the PMRF. The model generated simulations of hydrodynamic forcing, UXO migration and burial that were in general agreement with the ensemble results from 24 inert surrogates of a 5”/38 projectile that were monitored between 13 February and 27 June 2007.

The field demonstration met all objectives, except that no “extreme” weather event occurred during this effort. All the required data were collected and all field demonstration surrogates and associated instruments were successfully recovered.

The following conclusions are derived from the demonstration results and the following Model calibration and validation analysis:

- The biogenic reef environment is the most challenging UXO modeling problem encountered to date because of the complex micro-bathymetry associated with the awa that cut through the fringing reef. Awa side walls influence the nearfield flow dynamics, presenting a tedious challenge to the requirement for a regular gridding of the model

domain. Meeting this challenge did not necessitate generating new model code, but did require the availability of high resolution LIDAR bathymetry data and considerable computer memory for operating on the resulting dense grids. Reef channels introduce both curvature effects and roughness effects to the flow of wave surges and wave induced streaming. These flow disturbances produce vertical divergence in the flow over UXO and introduce large scale eddies to the nearfield of the UXO that induce additional scour to that excited directly by the UXO shape.

- Awa channels confine a sediment cover of complex composition that alters parameters of the granular transport equations in the model. The composition of this sediment cover varies considerably between the windward and leeward sides of these biogenic reef environments, requiring a separate set of granular parameters for the opposing sides of the reef environment. Typically 70 % of awa sediments are carbonates, derived from biogenic processes and reef fragments. The carbonate sediments comprise the majority of the coarser size bins. The finer fractions are predominately sediments of terrigenous origin and generally make up approximately 27 % of reef channel sediments, while 3 % are organics, a major portion of which is also of terrigenous origin. These terrigenous sediments and organics are delivered to the reef environment by small local intermittent streams and headward erosion of sea cliffs. Generally, mean grain sizes of sediments from streams draining the leeward sides are smaller than those of streams draining the windward sides.

- Model predictions and measurements were presented for 24 surrogates of a 5”/38 projectile divided equally between a shallow water inshore site in 8.3 m local depth and a deeper offshore site in 16.6 m local depth. Both sites occupied the same awa that made several turns and bends between the two sites. The average threshold of migration for the 5”/38 UXO surrogates at the shallow site appears to be at a $Ho \approx$ 1.3 m. From this threshold, migration rates increase rapidly with increasing wave height, roughly tripling with an increase of only 0.3 m in wave height. While this occurs, burial rates increase at first slowly from negligibly small rates at threshold of migration wave heights to rapidly increasing rates as burial entombment is approached, for $Ho \approx 1.6$ m. Maximum migration rates are approximately 0.0028 cm per minute. Beyond burial entombment, the burial rate continues to accelerate until total burial is achieved, whence the scour burial mechanism vanishes and only farfield burial from bottom profile change can effect any subsequent burial. Scour burial maximums for the inshore site occur at significant wave heights of about 2m at a rate of 0.003 % per minute (although this result is somewhat controlled by the particular sidewall effects of the channel at the inshore site). The threshold wave height for migration of the UXO surrogates at the offshore array is substantially higher and increases to $Ho \approx 1.7$m), primarily due to depth attenuation of the wave orbital velocity in the deeper waters of the offshore site. For the same reason, there are fewer numbers of wave events that induce migration at the deeper offshore site. However, once the UXO surrogates at the offshore site begin to move, their migration rate increases rapidly with wave height, reaching a maximum migration rate 0.0015 cm per minute at $Ho > 1.8$m. This maximum migration rate is approximately one half that of

the surrogates at the inshore site and occurs at a substantially higher significant wave height (1.8 m vs. 1.6 m), again because of depth attenuation in orbital wave velocities. At their maximum migration rate, surrogates in the offshore array are burying at 0.0019 % per minute while surrogates in the inshore array are burying at about 1/3 that rate, or 0.0005 % per minute. Thus, surrogates in the offshore array reach burial lock-down sooner, and thereby have less time to migrate off-station. Maximum burial rates of surrogates in the offshore array are 0.0045 % per minute at a *Ho* =2m, or approximately 50% faster than for surrogates in the inshore array. Though not an intuitive result when considering that burial rates tend to increase with orbital velocity while orbital velocity decreases with increasing depth. Our interpretation of this specific and somewhat paradoxical result is that the large scale eddies induced by the awa sidewalls are more active and well developed at the offshore site, thereby increasing the scour burial rates induced by relatively smaller orbital velocities.

- Two approaches were applied to assessing the predictive skill of the quantitative model predictions of the magnitude of migration and burial of UXO surrogates at PMRF. The first approach was to construct probability density functions of migration and burial magnitudes predicted by the model and compare them with the probability density functions assembled from the observed outcomes of the experiment. The second approach computed predictive skill factor, *R,* from the mean squared error between the predicted and measured outcomes. The peak, spread and shape of the predicted and measured probability density functions of migration are quite similar. Both distributions give a mean migration distance of approximately 1 m and a maximum migration of slightly greater than 3 m. In both the predicted and observed outcomes, migration was almost exclusively along the major axis of the awa. The peak of the measured burial probability distribution, its breadth and shape all closely resemble the modeled distribution. Mean burial depths are approximately 20 cm while maximum burial depths are a slightly greater than 40 cm. These burial depths are greater than what was observed during the brief deployment at Ocean Shores, Washington, but are on a par with the inshore surrogates deployed at Duck, NC. The skill factor for migration at PMRF was calculated at $R_\xi =$ 0.88 and $R_h =$ 0.90 for burial. For coastal processes modeling and mine burial prediction in particular, it is noted that a skill factor greater than 0.8 is considered to be a good result.

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Appendix A: PMRF Barking Sands Field Demonstration Site Permits

DEPARTMENT OF THE NAVY

NAVAL FACILITIES ENGINEERING SERVICE CENTER
1100 23RD AVE
PORT HUENEME CA 93043-4370

IN REPLY REFER TO:

5090
20 Feb 2007

From: Commanding Officer, Naval Facilities Engineering Service Center, Port Hueneme
To: Commander, Fourteenth Coast Guard District, Prince Kuhio Federal Building, 300 Ala Moana Boulevard, Honolulu, HI 96858-4982

Subj: DEPARTMENT OF THE ARMY PERMIT APPLICATION FOR AN UNEXPLODED ORDNANCE MOBILITY TEST AT THE PACIFIC MISSILE RANGE FACILTIY (PMRF), KAUAI, HAWAII

Encl: (1) Location of Underwater Surrogates

1. We are providing you with the information below as required in the Department of the Army permit obtained to conduct an unexploded ordnance mobility test at PMFR.

   a. Location of the unexploded ordnance surrogates. The locations are included in enclosure (1).

   b. Data of planned removal. The surrogates will be removed by February 14, 2008.

   c. Any special request of the maritime public. There are no special requests.

2. Please direct any questions to Ms. Barbara Sugiyama at (805) 982-1668, or e-mail barbara.sugiyama@navy.mil.

Rebecca L. Biggers

R. L. BIGGERS
By direction

NFESC UXO MOBILITY MODEL FIELD DEMONSTRATION PLAN HAWAII

Oct 2005

1.0 INTRODUCTION

The Department of Defense is ultimately responsible for human safety and environmental stewardship for abandoned ordnance unintentionally left underwater as a result of historic military activities or past utilization of coastal test ranges. A Navy-funded program is supporting the Naval Facilities Engineering Service Center (NFESC) in its development of an Unexploded Ordnance (UXO) Mobility Model to predict underwater UXO movement and burial. The model can predict UXO exposure, mobility, and burial with respect to ordnance type and location for various marine environments (e.g., sediment characteristics and local wave and current regime).

The Hawaii field test plan is one of several filed tests around the country that have the overall objective of calibrating and validating the UXO mobility model. This will be achieved by comparing model predictions to actual movements measured during field tests undertaken in varying geomorphic environments and wave conditions. Coastal UXO sites throughout the United States can be categorized into four categories; collision (U.S. West Coast), trailing edge (East Coast), biogenic carbonate (Hawaii) and marginal seas (exposed coastlines and embayments).

Full realization of the model's capabilities requires calibration at sites representing each of the four categories. At each site, a series of UXO surrogates will be placed on the seafloor in various conditions of burial and water depth. Their location and orientation will then be monitored at intervals determined by the occurrence of high-energy environmental events (storms or high surf). Together the field tests will provide data to calibrate and validate the model for future application to the majority of the identified UXO sites in the U.S., including the highest profile sites. The primary metric for success of each field test is the collection of data on the movement of all or most of the UXO surrogates and documentation of the environmental conditions that caused those movements. The primary metric for success of the 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.

Field calibration work completed to date includes a limited validation study at a site adjacent to Mugu Beach and two tests on the coast of Ocean Shores, Washington in September 2004 and May 2005. The Mugu Drifter Test used only small-diameter UXO (20mm rounds and surrogates). It serves as a representative for the collision coastline sub-category. 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 tests at Ocean Shores used primarily larger UXO (5" surrogate rounds) and also provided calibration for the part of the model that addresses the high-energy breaking surf zone, again on a Collision Coastal beach. These were short-term tests intended to validate the effectiveness of two measurement methods for tracking UXO movement (physical tethers and acoustic pingers). Because of the demonstrated effectiveness of the acoustic location system, and because of the substantial demonstrated effect of the tethers on surrogate movement, no tethers will be used in the Hawaii field test.

The first relatively long term field test is being conducted 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 Duck Field Test was installed in June 2005 and three rounds of measurement have been conducted. Data analysis is in progress and preliminary indications are that the movement is within the range of the model predictions.

The candidate Biogenic Reef site is in Hawaii. It is particularly important to conduct the Biogenic Reef field test because that environment is representative of a large fraction of the known UXO sites in the world. The different structure of the sand, different wave patterns and generally different distribution of fluid energy on the seafloor are important variables in the Model.

2.0 HAWAII FIELD TEST

2.1 Objectives

The Hawaii effort seeks to obtain field test data in a biogenic environment where coral reefs and other biogenic sediments (degrades shells, reefs and carbonate sand) are an important component of the general sediment supply. A test site in Hawaii offers a unique combination of carbonate sands and a high wave energy environment.

2.2 Approach

The Hawaii field test is planned for the winter season of 2005-2006. Twenty-four surrogates, representing 5-inch UXO rounds will be placed on a sandy bottom in water depths ranging from 20 to 50 feet. The ideal site will have high-energy wave events through the winter, but at discrete intervals so that diving operations can take place between wave events in order to measure the surrogate movement. By selecting a site on Oahu, the dive team will be able to respond within 1 or 2 days after an event so that monitoring will occur as soon after major weather as practical. The monitoring will occur approximately six times over the winter season, after which the surrogates will be removed. The general configuration of the field test will be as shown in Figure 1 below.

The surrogates will be placed on the bottom and the exact position noted. There will be no other activity during placement – the surrogates will simply be placed on the ocean bottom. Past history has shown that the surrogates tend to self bury after placement. The surrogates then cycle through episodes of burial and exposure, and during the process are moved along the ocean floor. Movement of the surrogates during typical conditions is predicted to be on the order of a few meters; during extreme wave events, movement on the order of tens of meters is expected.

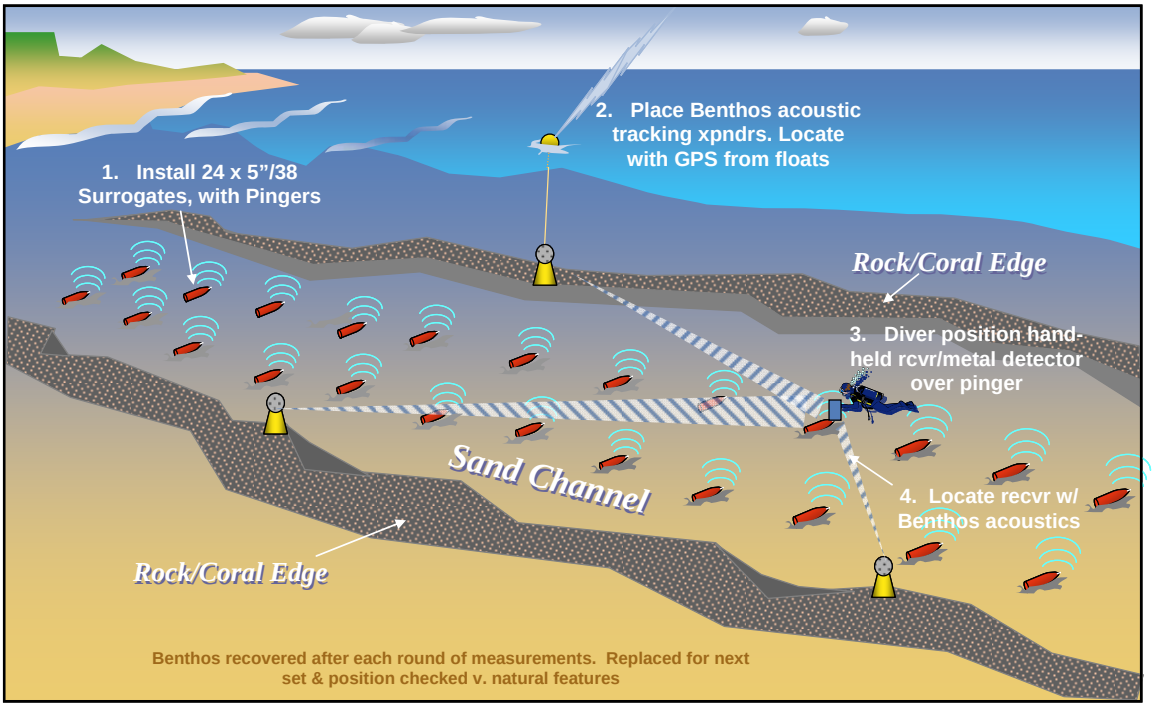


Figure 1. Hawaii UXO Field Test Hawaii Schematic View
(Total area utilized is approximately 200 x 700 feet)

The surrogates are readily visible if exposed on the seafloor. To facilitate finding buried surrogates, each one will house an acoustic pinger. Each surrogate will have its own discrete frequency. The pingers provide a range of at least several hundred meters. The diver will home in on the surrogates using a hand held receiver. Once in the general vicinity of the surrogate, the exact location will be determined using hand held metal detectors.

The location of each surrogate will be carefully measured during the monitoring visits. As each surrogate is found, three range measurements will be made from known geographic references using a Benthos underwater positioning system. In addition, the divers will make backup tape measurements from reference marks.

An acoustic Doppler current/wave profiler (ADCP) will be installed on the bottom seaward of the surrogates at approximately the 60 to 70-foot depth. The position will be selected to be as close as possible to the line of the surrogates. The ADCP will measure waves and currents throughout the test period. During each round of measurements the data will be recovered and batteries replaced (if required).

3.0 HAWAII FIELD TEST

The ideal test site would have the following characteristics:

- Sand channel extending through a coral or limestone bottom, at least 60 feet wide and several hundred feet long.
- Vertical ledge bounding the inshore border of the sand channel, eliminating the possibility of the surrogates ending up on shore.
- Water depths of 20 to 60 feet.
- Discrete periods of significant wave events with relatively calm period in between.
- Not subject to heavy recreational or commercial use.
- Not off a popular recreational beach.

Given the above characteristics, the search area was limited to the leeward cost of Oahu. While suitable bottom conditions could probably be found on the north shore, the severe wave events on that coastline are frequently too closely spaced to allow suitable monitoring visits. A search of the available literature and aerial photographs identified six potential sites located between the fish haven off Maile Beach and Yokohama Beach. Several of these were discarded after consideration of their current usage. Pokai Bay is heavily used for recreation, and the sand channel extends all the way to the shoreline; the Yokohama and Makaha Beach areas both have numerous fiber optic cables crossing the nearshore areas; and Makua Beach is used for recreational dolphin watching tours.

Diving investigations were conducted at three locations, and an ideal site was located off Keaau, approximately 4.5 miles northwest of the Waianae Small Boat Harbor and 1.5 miles northwest of Makaha Beach Park. The selected site is a sand channel extending from the 15 foot water depth to well beyond the 70 foot depth. Figure 2 shows the general site location. Figure 3 shows the bathymetry of the general area and the boundaries of the sand channel. The inshore limit of the sand channel is bounded by a 2 to 3 foot high limestone ledge (Photo 1). The ledge is located about 60 feet off the shoreline. This ledge should act as an inshore boundary for surrogate movement.

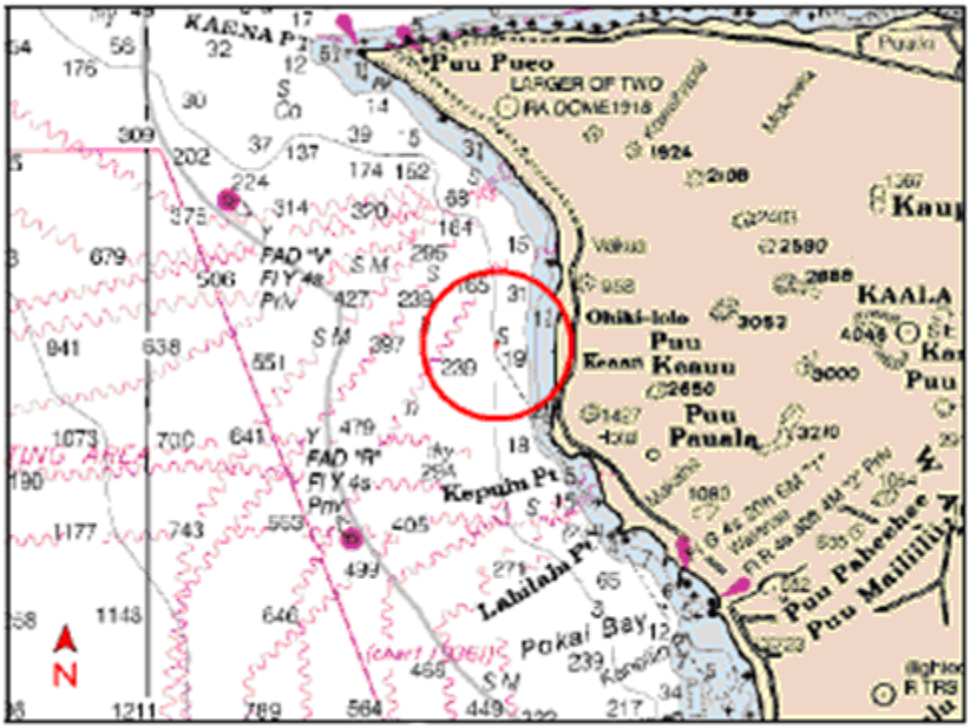


Figure 2. General Site Location

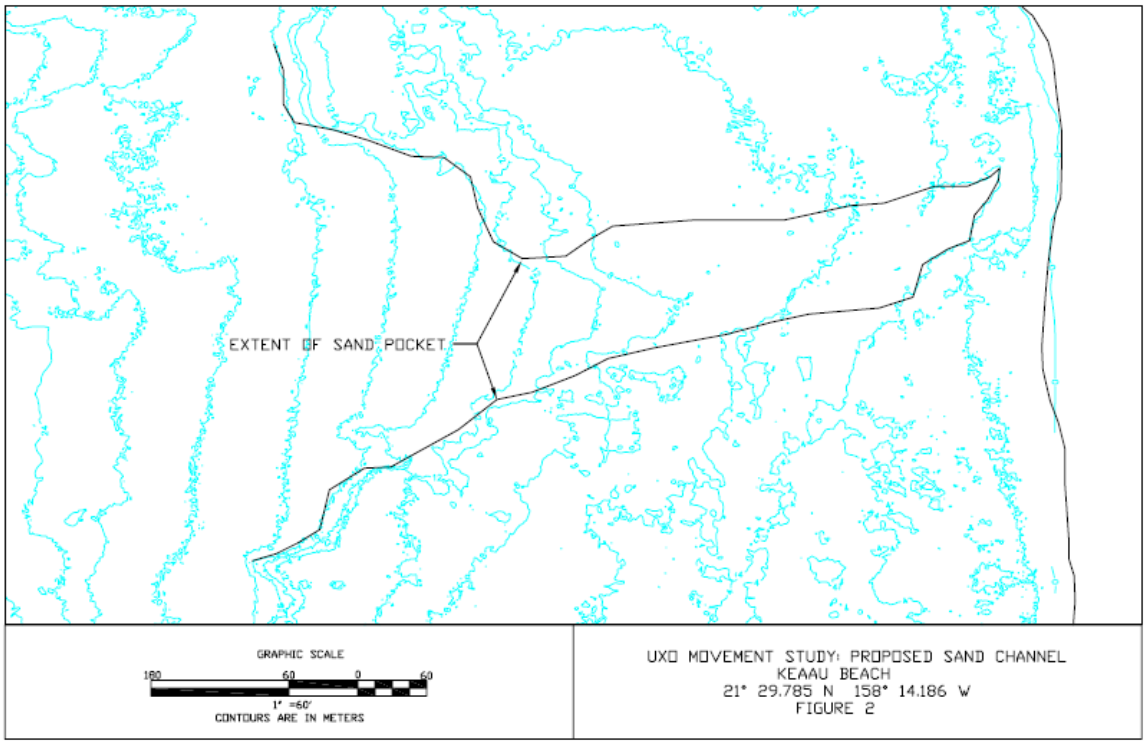


Figure 3. Sand Channel Outline and Bathymetry

Photo 1. Ledge Bordering the Inshore Edge of the Sand Channel.

Sand thickness was probed at several locations in the channel using an air jet probe, with the following results:

Water Depth (ft)	Sand Thickness (ft)
16	6+ (+ indicates no refusal)
20	4+
25	5+
35	5+
50	4 (hit refusal)
55	5+

4.0 ANTICIPATED IMPACTS

The beneficial impacts of this project are obvious. A successful field test will provide important calibration data for the UXO Mobility Model. A validated model will in turn improve the military's capability to evaluate potential UXO hazards.

Negative impacts include:

Possibility of loss of surrogates – to date, no 5" surrogates have been lost in any of the field tests. A total of 150 surrogates have been placed and recovered at Ocean Shores, Washington and Duck, North Carolina. While it cannot be guaranteed that all surrogates will be recovered, the reliability of the tracking methods, the generally contained shape of the test site, the planned monitoring visits and the favorable diving conditions (excellent

visibility) make it highly likely that all will be recovered. If any are lost, they are chemically inert, and pose no threat to the environment or to the local populace. Each surrogate is tagged and marked.

Possibility of surrogates on the beach – the site was selected to minimize this possibility, and the inshore ledge should be an obstacle to any movement beyond that point. If a surrogate should end up on the beach, it is inert and is clearly marked as a test item.

Acoustic interference with marine mammals – the pulse signals from the pingers are much weaker than the acoustic signals from bathymetric sonars, which are commonly used on most fishing recreational fishing boats that transit through the area. Marine mammal communications should not be masked by the relatively low power output of the pingers.

APPLICATION FOR DEPARTMENT OF THE ARMY PERMIT (33 CFR 325)	OMB APPROVAL NO. 0710-003

Public reporting burden for this collection of information is estimated to average 5 hours per response, including the time for reviewing instructions, Searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Service Directorate of Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302; and to the Office of Management and Budget, Paperwork Reduction Project (0710-003), Washington, DC 20503. Please DO NOT RETURN your form to either of those addresses. Completed applications must be submitted to the District Engineer having jurisdiction over the location of the proposed activity.

NOV - 1

PRIVACY ACT STATEMENT

Authority: 33 USC 401, Section 10; 1413, Section 404. Principal Purpose: These laws require permits authorizing activities in or affecting navigable waters of the United States; the discharge of dredged or fill material into waters of the United States, and the transportation of dredged material for the purpose of dumping it into ocean waters. Routine uses: Information provided on this form will be used in evaluating the application for a permit. Disclosure: Disclosure of requested information is voluntary. If information is not provided, however, the permit application cannot be processed nor can a permit be issued.

One set of original drawings or good reproducible copies which show the location and character of the proposed activity must be attached to this application (see sample drawings and instructions) and be submitted to the District Engineer having jurisdiction over the proposed activity. An application that is not completed in full will be returned.

(ITEMS 1 THRU 4 TO BE FILLED BY THE CORPS)

1. APPLICATION NO.	2. FIELD OFFICE CODE	3. DATE RECEIVED	4. DATE APPLICATION COMPLETED
POH-2005-600			

(ITEMS BELOW TO BE FILLED BY APPLICANT)

5. APPLICANT'S NAME	8. AUTHORIZED AGENT'S NAME & TITLE (an agent is not required)
Sound and Sea Technology	Robert Y. Rocheleau, Sea Engineering, Inc.
6. APPLICANT'S ADDRESS 11931 Maplewood Ave. Edmonds, Wa. 98026	9. AGENT'S ADDRESS Makai Research Pier Waimanalo, HI. 96795
7. APPLICANT'S PHONE NUMBERS WITH AREA CODE a. Residence b. Business (425) 879-3820	10. AGENT'S PHONE NUMBERS WITH AREA CODE a. Residence b. Business (808) 259-7968

11. STATEMENT OF AUTHORIZATION

I hereby authorize Sea Engineering, Inc. to act in my behalf as my agent in the processing of this application and to furnish, upon request, supplemental information in support of this permit application.

x [signature] October 31, 2005

APPLICANT'S SIGNATURE DATE

NAME, LOCATION, AND DESCRIPTION OF PROJECT OR ACTIVITY

12. PROJECT NAME OR TITLE (see instructions)

UXO Movement Study. Keaau Beach, Oahu

13. NAME OF WATERBODY, IF KNOWN (if applicable)	14. PROJECT STREET ADDRESS (if applicable)
Pacific Ocean, Keaau Beach	N/A
15. LOCATION OF PROJECT Honolulu — COUNTY Hi — STATE	

16. OTHER LOCATION DESCRIPTIONS, IF KNOWN (see instructions)

Sand channel at Keaau Beach park, located at 21 30.222 N 158 14.714 W, between the depths of 60ft and 15ft. (See attached)

17. DIRECTIONS TO THE SITE

Keaau Beach Park is located along HWY 93 (Farrington HWY) around the 600 block in the district of Makaha on the island of Oahu. The inshore boundary of the sand channel in 15ft water depth approximately 50 yards from the shoreline. The offshore boundary of the sand channel is in 60ft water depth, and the width of the channel varies from 50ft to several hundred feet. (See attached)

ENG FORM 4345 – ONLINE CESPK-CO-R

18. NATURE OF ACTIVITY (Description of project, include all features)

Twenty four inert surrogates simulating 5" ordnance will be placed on the bottom of the sand channel and their movements will be monitored before and after large swell events during the winter of 2005/2006. All surrogates will be removed by April 2006. (See attached)

19. PROJECT PURPOSE (Describe the reason or purpose of the project, see instructions)

Calibration of a U.S. Navy model that will predict the movement of underwater unexploded ordnance. (See attached)

USE BLOCKS 20-22 IF DREDGED AND/OR FILL MATERIAL IS TO BE DISCHARGED

20. REASON(S) FOR DISCHARGE

N/A

21. TYPE(S) OF MATERIAL BEING DISCHARGED AND THE AMOUNT OF EACH TYPE IN CUBIC YARDS

N/A

22. SURFACE AREA IN ACRES OF WETLANDS OR OTHER WATERS FILLED (see instructions)

N/A

23. IS ANY PORTION OF THE WORK ALREADY COMPLETE? YES ○ NO ◉ IF YES, DESCRIBE THE WORK

24. ADDRESSES OF ADJOINING PROPERTY OWNERS, LESSEES, ETC. WHOSE PROPERTY ADJOINS THE WATERBODY (If more than can be entered here, please attach a supplemental list)

N/A

25. LIST OF OTHER CERTIFICATIONS OR APPROVALS/DENIALS RECEIVED FROM OTHER FEDERAL, STATE, OR LOCAL AGENCIES FOR WORK DESCRIBED IN THIS APPLICATION

AGENCY	TYPE APPROVAL*	IDENTIFICATION NUMBER	DATE APPLIED	DATE APPROVED	DATE DENIED
DLNR	- Submitted application for Site Plan Approval (Section 13-5-38) on October 31, 2005				

* Would include but is not restricted to zoning, building and flood plain permits.

26. Application is hereby made for a permit or permits to authorize the work described in this application. I certify that the information in this application is complete and accurate. I further certify that I possess the authority to undertake the work described herein or am acting as the duty authorized agent of the applicant.

SIGNATURE OF APPLICANT	DATE	SIGNATURE OF AGENT	DATE
	October 31, 2005	Robert Y. Rodeleau	October 31, 2005

The application must be signed by the person who desires to undertake the proposed activity (applicant) or it may be signed by a duly authorized agent if the statement in block 11 has been filled out and signed.

18 U.S.C. Section 1001 provides that: Whoever, in any manner within the jurisdiction of any department or agency of the United States knowingly and will fully falsifies, conceals, or covers up any trick, scheme, or disguises a material fact or makes any false, facticious, or fraudulent statements or representations or makes or uses any false writing or document knowing same to contain any false, fictitious or fraudulent statements or entry, shall be fined not more than $10,000 or imprisoned not more than five years or both.

ENG FORM 4345 – ONLINE CESPK-CO-R

DEPARTMENT OF THE ARMY
U. S. ARMY ENGINEER DISTRICT, HONOLULU
FT. SHAFTER, HAWAII 96858-5440

REPLY TO
ATTENTION OF

CEPOH-EC-R (1145b)

21 NOV 2006

MEMORANDUM FOR Commander, Naval Facilities Engineering Command, Pacific, (NAVFAC Pacific EV21/Mr. Leighton Wong), Environmental Business Line Manager, 258 Makalapa Drive, Suite 100, Pearl Harbor, Hawaii 96860-3134

SUBJECT: Department of the Army (DA) Permit Application for an Unexploded Ordinance (UXO) mobility test at the Pacific Missile Range Facility (PMRF), Kauai, Hawaii

1. This is to inform you that your application for a Department of Army (DA) Nationwide Permit to perform work within navigable waters of the PMRF is hereby verified under the Corps Nationwide Permit (NWP) authority at 33 CFR 330 Appendix A, Paragraph B.5 (NWP#5, Scientific Measuring Devices), pursuant to Section 10 of the Rivers and Harbors Act of 1899.

2. Work shall be performed in conformance with the General Conditions (Enclosure 1) of the NWP authorization, and the Special Conditions listed in Enclosure 2. Upon completion of the work please sign and return the enclosed Compliance Certification form (Enclosure 3).

3. This authorization to perform the work will take effect from the above issuance date and will remain valid until the nationwide permit program is modified, reissued, or revoked on 19 March 2007. If during this period the NWP authorization is reissued without modification or if the activity complies with any subsequent modification of the NWP authorization, this authorization will continue to remain valid for the period. However, if during this period, the NWP authorization expires, is suspended, or revoked, or is modified that the activity would no longer comply with the terms and conditions of the NWP, the provisions of 33 CFR Part 330, Section 330.6(b) (Enclosure 4) will apply.

4. A copy of this correspondence will be forwarded to: the U.S. Environmental Protection Agency; NOAA Fisheries; U.S. Fish and Wildlife Service; State of Hawaii, Department of Land and Natural Resources; and the State of Hawaii Historic Preservation Division.

5. POC: Ms. Connie Ramsey at 808-438-2039 (FAX 808-438-4060). File No. **POH-2006-449** is assigned to this project. Please refer to this number in any correspondence with us.

4 Encls

CHARLES H. KLINGE
Lieutenant Colonel, U.S. Army
Commanding

Enclosure 1

Nationwide Permit General Conditions

The following general conditions must be followed in order for any authorization by an NWP to be valid:

1. Navigation. No activity may cause more than a minimal adverse effect on navigation.

2. Proper Maintenance. Any structure or fill authorized shall be properly maintained, including maintenance to ensure public safety.

3. Soil Erosion and Sediment Controls. Appropriate soil erosion and sediment controls must be used and maintained in effective operating condition during construction, and all exposed soil and other fills, as well as any work below the ordinary high water mark or high tide line, must be permanently stabilized at the earliest practicable date.

4. Aquatic Life Movements. No activity may substantially disrupt the movement of those species of aquatic life indigenous to the waterbody, including those species which normally migrate through the area, unless the activity's primary purpose is to impound water. Culverts placed in streams must be installed to maintain low flow conditions.

5. Equipment. Heavy equipment working in wetlands must be placed on mats, or other measures must be taken to minimize soil disturbance.

6. Regional and Case-By-Case Conditions. The activity must comply with any regional conditions which may have been added by the division engineer (see 33 CFR 330.4(e)) and with any case specific conditions added by the Corps or by the State or tribe in its Section 401 water quality certification and Coastal Zone Management Act consistency determination.

7. Wild and Scenic Rivers. No activity may occur in a component of the National Wild and Scenic River System; or in a river officially designated by Congress as a "study river" for possible inclusion in the system, while the river is in an official study status; unless the appropriate Federal agency, with direct management responsibility for such river, has determined in writing that the proposed activity will not adversely affect the Wild and Scenic River designation, or study status. Information on Wild and Scenic Rivers may be obtained from the appropriate Federal land management agency in the area (e.g., National Park Service, U.S. Forest Service, Bureau of Land Management, U.S. Fish and Wildlife Service).

8. Tribal Rights. No activity or its operation may impair reserved tribal rights, including, but not limited to, reserved water rights and treaty fishing and hunting rights.

9. Water Quality. (a) In certain States and tribal lands an individual 401 water quality certification must be obtained or waived (See 33 CFR 330.4(c)). (b) For NWPs 12, 14, 17, 18, 32, 39, 40, 42, 43, and 44, where the State or tribal 401 certification (either generically or

individually) does not require or approve a water quality management plan, the permittee must include design criteria and techniques that will ensure that the authorized work does not result in more than minimal degradation of water quality. An important component of a water quality management plan includes stormwater management that minimizes degradation of the downstream aquatic system, including water quality. Refer to General Condition 21 for stormwater management requirements. Another important component of a water quality management plan is the establishment and maintenance of vegetated buffers next to open waters, including streams. Refer to General Condition 19 for vegetated buffer requirements for the NWPs.

10. Coastal Zone Management. In certain states, an individual state coastal zone management consistency concurrence must be obtained or waived (see Section 330.4(d)).

11. Endangered Species. (a) No activity is authorized under any NWP which is likely to jeopardize the continued existence of a threatened or endangered species or a species proposed for such designation, as identified under the Federal Endangered Species Act, or which will destroy or adversely modify the critical habitat of such species. Non-federal permittees shall notify the District Engineer if any listed species or designated critical habitat might be affected or is in the vicinity of the project, or is located in the designated critical habitat and shall not begin work on the activity until notified by the District Engineer that the requirements of the Endangered Species Act have been satisfied and that the activity is authorized. For activities that may affect Federally-listed endangered or threatened species or designated critical habitat, the notification must include the name(s) of the endangered or threatened species that may be affected by the proposed work or that utilize the designated critical habitat that may be affected by the proposed work. As a result of formal or informal consultation with the FWS or NMFS, the District Engineer may add species-specific regional endangered species conditions to the NWPs.
(b) Authorization of an activity by a nationwide permit does not authorize the "take" of a threatened or endangered species as defined under the Federal Endangered Species Act. In the absence of separate authorization (e.g., an ESA Section 10 Permit, a Biological Opinion with "incidental take" provisions, etc.) from the U.S. Fish and Wildlife Service or the National Marine Fisheries Service, both lethal and non-lethal "takes" of protected species are in violation of the Endangered Species Act. Information on the location of threatened and endangered species and their critical habitat can be obtained directly from the offices of the U.S. Fish and Wildlife Service and National Marine Fisheries Service or their world wide web pages at http://www.fws.gov/r9endspp/endspp.html and http://www.nfms.gov/prot_res/esahome.html, respectively.

12. Historic Properties. No activity which may affect historic properties listed, or eligible for listing, in the National Register of Historic Places is authorized, until the DE has complied with the provisions of 33 CFR Part 325, Appendix C. The prospective permittee must notify the District Engineer if the authorized activity may affect any historic properties listed, determined to be eligible, or which the prospective permittee has reason to believe may be eligible for listing on the National Register of Historic Places, and shall not begin the activity until notified by the District Engineer that the requirements of the National Historic Preservation Act have been satisfied and that the activity is authorized. Information on the location and existence of historic

resources can be obtained from the State Historic Preservation Office and the National Register of Historic Places (see 33 CFR 330.4(g)). For activities that may affect historic properties listed in, or eligible for listing in, the National Register of Historic Places, the notification must state which historic property may be affected by the proposed work or include a vicinity map indicating the location of the historic property.

13. Notification. (a) Timing: Where required by the terms of the NWP, the prospective permittee must notify the District Engineer with a preconstruction notification (PCN) as early as possible. The District Engineer must determine if the PCN is complete within 30 days of the date of receipt and can request the additional information necessary to make the PCN complete only once. However, if the prospective permittee does not provide all of the requested information, then the District Engineer will notify the prospective permittee that the PCN is still incomplete and the PCN review process will not commence until all of the requested information has been received by the District Engineer. The prospective permittee shall not begin the activity:

(1) Until notified in writing by the District Engineer that the activity may proceed under the NWP with any special conditions imposed by the District or Division Engineer; or,

(2) If notified in writing by the District or Division Engineer that an individual permit is required; or,

(3) Unless 45 days have passed from the District Engineer's receipt of the complete notification and the prospective permittee has not received written notice from the District or Division Engineer. Subsequently, the permittee's right to proceed under the NWP may be modified, suspended, or revoked only in accordance with the procedure set forth in 33 CFR 330.5(d)(2).

(b) Contents of Notification: The notification must be in writing and include the following information:

(1) Name, address, and telephone numbers of the prospective permittee;

(2) Location of the proposed project;

(3) Brief description of the proposed project; the project's purpose; direct and indirect adverse environmental effects the project would cause; any other NWP(s), regional general permit(s), or individual permit(s) used or intended to be used to authorize any part of the proposed project or any related activity; and

(4) For NWPs 7, 12, 14, 18, 21, 34, 38, 39, 40, 42, and 43, the PCN must also include a delineation of affected special aquatic sites, including wetlands, vegetated shallows (e.g., submerged aquatic vegetation, seagrass beds), and riffle and pool complexes (see paragraph 13(f));

(5) For NWP 7, Outfall Structures and Maintenance, the PCN must include information regarding the original design capacities and configurations of those areas of the facility where maintenance dredging or excavation is proposed.

(6) For NWP 14, Linear Transportation Crossings, the PCN must include a compensatory mitigation proposal to offset permanent losses of waters of the United States and a statement describing how temporary losses of waters of the United States will be minimized to the maximum extent practicable.

(7) For NWP 21, Surface Coal Mining Activities, the PCN must include an Office of Surface Mining (OSM) or state-approved mitigation plan.

(8) For NWP 27, Stream and Wetland Restoration, the PCN must include documentation of the prior condition of the site that will be reverted by the permittee.

(9) For NWP 29, Single-Family Housing, the PCN must also include:

(i) Any past use of this NWP by the individual permittee and/or the permittee's spouse;

(ii) A statement that the single-family housing activity is for a personal residence of the permittee;

(iii) A description of the entire parcel, including its size, and a delineation of wetlands. For the purpose of this NWP, parcels of land measuring 1/4 acre or less will not require a formal on-site delineation. However, the applicant shall provide an indication of where the wetlands are and the amount of wetlands that exists on the property. For parcels greater than 1/4 acre in size, a formal wetland delineation must be prepared in accordance with the current method required by the Corps. (See paragraph 13(f));

(iv) A written description of all land (including, if available, legal descriptions) owned by the prospective permittee and/or the prospective permittee's spouse, within a one mile radius of the parcel, in any form of ownership (including any land owned as a partner, corporation, joint tenant, co-tenant, or as a tenant-by-the-entirety) and any land on which a purchase and sale agreement or other contract for sale or purchase has been executed;

(10) For NWP 31, Maintenance of Existing Flood Control Projects, the prospective permittee must either notify the District Engineer with a PCN prior to each maintenance activity or submit a five year (or less) maintenance plan. In addition, the PCN must include all of the following:

(i) Sufficient baseline information so as to identify the approved channel depths and configurations and existing facilities. Minor deviations are authorized, provided the approved flood control protection or drainage is not increased;

(ii) A delineation of any affected special aquatic sites, including wetlands; and,

(iii) Location of the dredged material disposal site.

(11) For NWP 33, Temporary Construction, Access, and Dewatering, the PCN must also include a restoration plan of reasonable measures to avoid and minimize adverse effects to aquatic resources.

(12) For NWPs 39, 43, and 44, the PCN must also include a written statement to the District Engineer explaining how avoidance and minimization of losses of waters of the United States were achieved on the project site.

(13) For NWP 39, Residential, Commercial, and Institutional Developments, the PCN must include a compensatory mitigation proposal that offsets unavoidable losses of waters of the United States or justification explaining why compensatory mitigation should not be required.

(14) For NWP 40, Agricultural Activities, the PCN must include a compensatory mitigation proposal to offset losses of waters of the United States.

(15) For NWP 43, Stormwater Management Facilities, the PCN must include, for the construction of new stormwater management facilities, a maintenance plan (in accordance with State and local requirements, if applicable) and a compensatory mitigation proposal to offset losses of waters of the United States.

(16) For NWP 44, Mining Activities, the PCN must include a description of all waters of the United States adversely affected by the project, a description of measures taken to minimize adverse effects to waters of the United States, a description of measures taken to comply with the criteria of the NWP, and a reclamation plan (for aggregate mining activities in isolated waters and non-tidal wetlands adjacent to headwaters and any hard rock/mineral mining activities).

(17) For activities that may adversely affect Federally-listed endangered or threatened species, the PCN must include the name(s) of those endangered or threatened species that may be affected by the proposed work or utilize the designated critical habitat that may be affected by the proposed work.

(18) For activities that may affect historic properties listed in, or eligible for listing in, the National Register of Historic Places, the PCN must state which historic property may be affected by the proposed work or include a vicinity map indicating the location of the historic property.

(19) For NWPs 12, 14, 29, 39, 40, 42, 43, and 44, where the proposed work involves discharges of dredged or fill material into waters of the United States resulting in permanent, above-grade fills within 100-year floodplains (as identified on FEMA's Flood Insurance Rate Maps or FEMA-approved local floodplain maps), the notification must include documentation demonstrating that the proposed work complies with the appropriate FEMA or FEMA-approved local floodplain construction requirements.

(c) Form of Notification: The standard individual permit application form (Form ENG 4345) may be used as the notification but must clearly indicate that it is a PCN and must include all of the information required in (b) (1)-(19) of General Condition 13. A letter containing the requisite information may also be used.

(d) District Engineer's Decision: In reviewing the PCN for the proposed activity, the District Engineer will determine whether the activity authorized by the NWP will result in more than minimal individual or cumulative adverse environmental effects or may be contrary to the public interest. The prospective permittee may, optionally, submit a proposed mitigation plan with the PCN to expedite the process and the District Engineer will consider any proposed compensatory mitigation the applicant has included in the proposal in determining whether the net adverse environmental effects to the aquatic environment of the proposed work are minimal. If the District Engineer determines that the activity complies with the terms and conditions of the NWP and that the adverse effects on the aquatic environment are minimal, the District Engineer will notify the permittee and include any conditions the District Engineer deems necessary.

Any compensatory mitigation proposal must be approved by the District Engineer prior to commencing work. If the prospective permittee is required to submit a compensatory mitigation proposal with the PCN, the proposal may be either conceptual or detailed. If the prospective permittee elects to submit a

compensatory mitigation plan with the PCN, the District Engineer will expeditiously review the proposed compensatory mitigation plan. The District Engineer must review the plan within 45 days of receiving a complete PCN and determine whether the conceptual or specific proposed mitigation would ensure no more than minimal adverse effects on the aquatic environment. If the net adverse effects of the project on the aquatic environment (after consideration of the compensatory mitigation proposal) are determined by the District Engineer to be minimal, the District Engineer will provide a timely written response to the applicant stating that the project can proceed under the terms and conditions of the nationwide permit.

If the District Engineer determines that the adverse effects of the proposed work are more than minimal, then he will notify the applicant either: (1) that the project does not qualify for authorization under the NWP and instruct the applicant on the procedures to seek authorization under an individual permit; (2) that the project is authorized under the NWP subject to the applicant's submission of a mitigation proposal that would reduce the adverse effects on the aquatic environment to the minimal level; or (3) that the project is authorized under the NWP with specific modifications or conditions. Where the District Engineer determines that mitigation is required in order to ensure no more than minimal adverse effects on the aquatic environment, the activity will be authorized within the 45-day PCN period, including the necessary conceptual or specific mitigation or a requirement that the applicant submit a mitigation proposal that would reduce the adverse effects on the aquatic environment to the minimal level. When conceptual mitigation is included, or a mitigation plan is required under item (2) above, no work in waters of the United States will occur until the District Engineer has approved a specific mitigation plan.

(e) Agency Coordination: The District Engineer will consider any comments from Federal and State agencies concerning the proposed activity's compliance with the terms and conditions of the NWPs and the need for mitigation to reduce the project's adverse effects on the aquatic environment to a minimal level.

For activities requiring notification to the District Engineer that result in the loss of greater than 1/2 acre of waters of the United States, the District Engineer will, upon receipt of a notification, provide immediately (e.g., via facsimile transmission, overnight mail, or other expeditious manner), a copy to the appropriate offices of the Fish and Wildlife Service, State natural resource or water quality agency, EPA, State Historic Preservation Officer (SHPO), and, if appropriate, the National Marine Fisheries Service. With the exception of NWP 37, these agencies will then have 10 calendar days from the date the material is transmitted to telephone or fax the District Engineer notice that they intend to provide substantive, site-specific comments. If so contacted by an agency, the District Engineer will wait an additional 15 calendar days before making a decision on the notification. The District Engineer will fully consider agency comments received within the specified time frame, but will provide no response to the resource agency, except as provided below. The District Engineer will indicate in the administrative record associated with each notification that the resource agencies' concerns were considered. As required by Section

305(b)(4)(B) of the Magnuson-Stevens Fishery Conservation and Management Act, the District Engineer will provide a response to National Marine Fisheries Service within 30 days of receipt of any Essential Fish Habitat conservation recommendations. Applicants are encouraged to provide the Corps multiple copies of notifications to expedite agency notification.

(f) Wetlands Delineations: Wetland delineations must be prepared in accordance with the current method required by the Corps. For NWP 29 see paragraph (b)(9)(iii) for parcels less than 1/4 acre in size. The permittee may ask the Corps to delineate the special aquatic site. There may be some delay if the Corps does the delineation. Furthermore, the 45-day period will not start until the wetland delineation has been completed and submitted to the Corps, where appropriate.

14. Compliance Certification. Every permittee who has received a Nationwide permit verification from the Corps will submit a signed certification regarding the completed work and any required mitigation. The certification will be forwarded by the Corps with the authorization letter. The certification will include: a.) A statement that the authorized work was done in accordance with the Corps authorization, including any general or specific conditions; b.) A statement that any required mitigation was completed in accordance with the permit conditions; and c.) The signature of the permittee certifying the completion of the work and mitigation.

15. Use of Multiple Nationwide Permits. The use of more than one NWP for a single and complete project is prohibited, except when the acreage loss of waters of the United States authorized by the NWPs does not exceed the acreage limit of the NWP with the highest specified acreage limit. For example, if a road crossing over tidal waters is constructed under NWP 14, with associated bank stabilization authorized by NWP 13, the maximum acreage loss of waters of the United States for the total project cannot exceed 1/3 acre.

16. Water Supply Intakes. No activity, including structures and work in navigable waters of the United States or discharges of dredged or fill material, may occur in the proximity of a public water supply intake except where the activity is for repair of the public water supply intake structures or adjacent bank stabilization.

17. Shellfish Beds. No activity, including structures and work in navigable waters of the United States or discharges of dredged or fill material, may occur in areas of concentrated shellfish populations, unless the activity is directly related to a shellfish harvesting activity authorized by NWP 4.

18. Suitable Material. No activity, including structures and work in navigable waters of the United States or discharges of dredged or fill material, may consist of unsuitable material (e.g., trash, debris, car bodies, asphalt, etc.) and material used for construction or discharged must be free from toxic pollutants in toxic amounts (see Section 307 of the Clean Water Act).

19. Mitigation. The project must be designed and constructed to avoid and minimize adverse effects to waters of the United States to the maximum extent practicable at the project site (i.e., on site). Mitigation will be required when necessary to ensure that the adverse effects to the aquatic environment are minimal. The District Engineer will consider the factors discussed

below when determining the acceptability of appropriate and practicable mitigation necessary to offset adverse effects on the aquatic environment that are more than minimal.

(a) To be practicable, the mitigation must be available and capable of being done considering costs, existing technology, and logistics in light of the overall project purposes. Examples of mitigation that may be appropriate and practicable include, but are not limited to: reducing the size of the project; establishing and maintaining wetland or upland vegetated buffers to protect open waters such as streams; and replacing losses of aquatic resource functions and values by creating, restoring, enhancing, or preserving similar functions and values, preferably in the same watershed;

(b) The District Engineer will require restoration, creation, enhancement, or preservation of other aquatic resources in order to offset the authorized impacts to the extent necessary to ensure that the adverse effects on the aquatic environment are minimal. An important element of any compensatory mitigation plan for projects in or near streams or other open waters is the establishment and maintenance, to the maximum extent practicable, of vegetated buffers next to open waters on the project site. The vegetated buffer should consist of native species. The District Engineer will determine the appropriate width of the vegetated buffer and in which cases it will be required. Normally, the vegetated buffer will be 25 to 50 feet wide on each side of the stream, but the District Engineer may require wider vegetated buffers to address documented water quality concerns. If there are open waters on the project site and the District Engineer requires compensatory mitigation for wetland impacts to ensure that the net adverse effects on the aquatic environment are minimal, any vegetated buffer will comprise no more than 1/3 of the remaining compensatory mitigation acreage after the permanently filled wetlands have been replaced on a one-to-one acreage basis. In addition, compensatory mitigation must address adverse effects on wetland functions and values and cannot be used to offset the acreage of wetland losses that would occur in order to meet the acreage limits of some of the NWPs (e.g., for NWP 39, 1/4 acre of wetlands cannot be created to change a 1/2 acre loss of wetlands to a 1/4 acre loss; however, 1/2 acre of created wetlands can be used to reduce the impacts of a 1/3 acre loss of wetlands). If the prospective permittee is required to submit a compensatory mitigation proposal with the PCN, the proposal may be either conceptual or detailed.

(c) To the extent appropriate, permittees should consider mitigation banking and other appropriate forms of compensatory mitigation. If the District Engineer determines that compensatory mitigation is necessary to offset losses of waters of the United States and ensure that the net adverse effects of the authorized work on the aquatic environment are minimal, consolidated mitigation approaches, such as mitigation banks, will be the preferred method of providing compensatory mitigation, unless the District Engineer determines that activity-specific compensatory mitigation is more appropriate, based on which is best for the aquatic environment. These types of mitigation are preferred because they involve larger blocks of protected aquatic environment, are more likely to meet the mitigation goals, and are more easily checked for compliance. If a mitigation bank or other consolidated mitigation approach is not available in the watershed, the District Engineer will consider other appropriate forms of compensatory mitigation to offset the losses of waters of the United States to ensure that the net adverse effects of the authorized work on the aquatic environment are minimal.

20. Spawning Areas. Activities, including structures and work in navigable waters of the United States or discharges of dredged or fill material, in spawning areas during spawning seasons must be avoided to the maximum extent practicable. Activities that result in the physical destruction

(e.g., excavate, fill, or smother downstream by substantial turbidity) of an important spawning area are not authorized.

21. Management of Water Flows. To the maximum extent practicable, the activity must be designed to maintain preconstruction downstream flow conditions (e.g., location, capacity, and flow rates). Furthermore, the activity must not permanently restrict or impede the passage of normal or expected high flows (unless the primary purpose of the fill is to impound waters) and the structure or discharge of dredged or fill material must withstand expected high flows. The activity must, to the maximum extent practicable, provide for retaining excess flows from the site, provide for maintaining surface flow rates from the site similar to preconstruction conditions, and must not increase water flows from the project site, relocate water, or redirect water flow beyond preconstruction conditions. In addition, the activity must, to the maximum extent practicable, reduce adverse effects such as flooding or erosion downstream and upstream of the project site, unless the activity is part of a larger system designed to manage water flows.

22. Adverse Effects From Impoundments. If the activity, including structures and work in navigable waters of the United States or discharge of dredged or fill material, creates an impoundment of water, adverse effects on the aquatic system caused by the accelerated passage of water and/or the restriction of its flow shall be minimized to the maximum extent practicable.

23. Waterfowl Breeding Areas. Activities, including structures and work in navigable waters of the United States or discharges of dredged or fill material, into breeding areas for migratory waterfowl must be avoided to the maximum extent practicable.

24. Removal of Temporary Fills. Any temporary fills must be removed in their entirety and the affected areas returned to their preexisting elevation.

25. Designated Critical Resource Waters. Critical resource waters include, NOAA-designated marine sanctuaries, National Estuarine Research Reserves, National Wild and Scenic Rivers, critical habitat for Federally listed threatened and endangered species, coral reefs, State natural heritage sites, and outstanding national resource waters or other waters officially designated by a State as having particular environmental or ecological significance and identified by the District Engineer after notice and opportunity for public comment. The District Engineer may also designate additional critical resource waters after notice and opportunity for comment.

(a) Except as noted below, discharges of dredged or fill material into waters of the United States are not authorized by NWPs 7, 12, 14, 16, 17, 21, 29, 31, 35, 39, 40, 42, 43, and 44 for any activity within, or directly affecting, critical resource waters, including wetlands adjacent to such waters. Discharges of dredged or fill materials into waters of the United States may be authorized by the above NWPs in National Wild and Scenic Rivers if the activity complies with General Condition 7. Further, such discharges may be authorized in designated critical habitat for Federally listed threatened or endangered species if the activity complies with General Condition 11 and the U.S. Fish and Wildlife Service or the National Marine Fisheries Service has concurred in a determination of compliance with this condition.

(b) For NWPs 3, 8, 10, 13, 15, 18, 19, 22, 23, 25, 27, 28, 30, 33, 34, 36, 37, and 38, notification is required in accordance with General Condition 13, for any activity proposed in the designated critical resource waters including wetlands adjacent to those waters. The District

Engineer may authorize activities under these NWPs only after he determines that the impacts to the critical resource waters will be no more than minimal.

26. Fills Within 100-Year Floodplains. For purposes of this general condition, 100-year floodplains will be identified through the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps or FEMA-approved local floodplain maps.

(a) Discharges Below Headwaters. Discharges of dredged or fill material into waters of the United States resulting in permanent, above-grade fills within the 100-year floodplain at or below the point on a stream where the average annual flow is five cubic feet per second (i.e., below headwaters) are not authorized by NWPs 29, 39, 40, 42, 43, and 44. For NWPs 12 and 14, the prospective permittee must notify the District Engineer in accordance with General Condition 13 and the notification must include documentation that any permanent, above-grade fills in waters of the United States within the 100-year floodplain below headwaters comply with FEMA or FEMA-approved local floodplain construction requirements.

(b) Discharges in Headwaters (i.e., above the point on a stream where the average annual flow is five cubic feet per second).

(1) Flood Fringe. Discharges of dredged or fill material into waters of the United States resulting in permanent, above-grade fills within the flood fringe of the 100-year floodplain of headwaters are not authorized by NWPs 12, 14, 29, 39, 40, 42, 43, and 44, unless the prospective permittee notifies the District Engineer in accordance with General Condition 13. The notification must include documentation that such discharges comply with FEMA or FEMA-approved local floodplain construction requirements.

(2) Floodway. Discharges of dredged or fill material into waters of the United States resulting in permanent, above-grade fills within the floodway of the 100-year floodplain of headwaters are not authorized by NWPs 29, 39, 40, 42, 43, and 44. For NWPs 12 and 14, the permittee must notify the District Engineer in accordance with General Condition 13 and the notification must include documentation that any permanent, above grade fills proposed in the floodway comply with FEMA or FEMA-approved local floodplain construction requirements.

Special Conditions
Corps File No. POH-2006-449

Endangered Species

1. Under Section 7 of the Endangered Species Act (ESA), the National Marine Fisheries Service (NMFS) requires you to contact and report the "take" of any ESA-listed species such as the Hawaiian monk seals *(Monachus schauinslandi)*, humpback whales (*Megaptera novaeangliae*), green sea turtles (*Chelonia mydas*), and hawksbill turtles (*Eretmochelys imbricata)* that are known to occur in the vicinity of the project area. The definition of "take" includes harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, collecting, or attempting to collect. Although no adverse effects are anticipated for the aforementioned listed species, injuries are to be reported to NOAA Fisheries Service at 1-808-983-5730. Information to be reported shall include the name and phone number of a point of contact, location of the incident or sighting, and nature of the take and/or injury. Consultation must be reinitiated if a take occurs or new information reveals effects of the action not previously considered, or the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat in a manner or to an extent not previously considered, or if a new species is listed or critical habitat designated that may be affected by the identified action.

2. A survey of the project area will be performed just prior to commencement or resumption of surrogate placement or removal and monitoring to ensure that no protected species are in the project area. If protected species are detected, activities will be postponed until the animal(s) voluntarily leave the area.

3. All on-site personnel must be apprised of the potential presence of the listed species in the project vicinity and the protections afforded to them under Federal laws. A brochure explaining the laws and guidelines may be downloaded from http://www.nmfs/noaa.gov/prot_res/MMWatch/hawaii.htm.

4. Under the Marine Mammal Protection Act (MMPA), NMFS has also expressed consideration and concern for the spinner dolphins (*Stenella longirostris*) that are known to inhabit the study area. Any observed behavioral disturbance to the spinner dolphins in the area shall also be reported to NOAA Fisheries Service at 1-808-983-5730.

Historic Resources

5. To date, the Corps has not received a concurrence response from the State Historical Preservation Department (SHPD) for its no historic properties affected determination as part of the consultation initiated under Section 106 of the National Historic Preservation Act (NHPA). Based on our available information and the current National and State Register of Historic Places list, we have determined no historical resources are likely to be affected within the project area, or Area of Potential Effect (APE). As noted in the permittee's Record of Categorical Exclusion dated September 11, 2006, should human remains or possible archaeological artifacts be encountered during the project, work in that area shall stop, and the NAVFAC Pacific Archaeologist will be immediately notified. No excavation of human remains or artifacts (other than clearing to confirm that the remains are human or the artifacts have archaeological value) shall proceed without consultation with the NAVFAC EFD Pacific Archaeologist. If the remains

are identified as human, or the archaeological value of artifacts is confirmed, reasonable precautions will be taken for their preservation until final disposition can be determined.

General Administrative Requirements

6. The permittee shall provide the following information to the U.S. Coast Guard after the deployment of the UXO models and measuring devices:

1) Location of UXO models and measuring devices
2) Date of planned removal
3) Any special request of the maritime public
4) Information should be forwarded to:

Commander (oan)
Fourteenth Coast Guard District
Prince Kuhio Federal Building
300 Ala Moana Boulevard
Honolulu, Hawaii 96858-4982
Phone: (808)-541-2315

7. All reasonable efforts shall be made to retrieve the surrogates from the test area at the conclusion of the model testing period.

8. The permittee understands and agrees that, if future operations by the United States require the removal, relocation, or other alteration, of the structure of work herein authorized, or 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, without expense to the United States. No claim shall be made against the United States on account of any such removal or alteration.

NOTE: In addition to the above conditions, you are advised that this authorization does not relieve you of any need to obtain other Federal, State or local authorizations required by law; it does not grant any property rights or exclusive privileges, and it does not authorize any injury to the property or rights of others, nor any interference with any existing or proposed Federal projects.

COMPLIANCE CERTIFICATION

PERMIT NO. POH-2006-449 **DATE OF ISSUANCE:** 21 NOV 2006

Name of Permittee:

Commander, Naval Facilities Engineering Command, Pacific
c/o Mr. Leighton Wong, Environmental Business Line Manager
258 Makalapa Drive, Suite 100
Pearl Harbor, Hawaii, 96860-3134

Upon completion of the activity authorized by this permit and any mitigation required by the permit, please sign this certification and return it to the following address:

U.S. Army Corps of Engineers
Honolulu District
Attn: Regulatory Branch
Building 230
Fort Shafter, Hawaii 96858-5440

Please note that your permitted activity is subject to a compliance inspection by a U.S. Army Corps of Engineers representative. If you fail to comply with this permit, you are subject to permit suspension, modification or revocation.

I hereby certify that the work authorized by the above referenced permit has been completed in accordance with the terms and conditions of the said permit, and required mitigation was completed in accordance with the permit conditions.

Signature of Permittee Date

Enclosure 3
POH-2006-449

Enclosure 4

Additional Information:

1. 33 CFR 330. NATIONWIDE PERMIT PROGRAM. Section 330.6 Authorization by nationwide permit.**(b) Expiration of nationwide permits.** The Chief of Engineers will periodically review NWPs and their conditions and will decide to either modify, reissue, or revoke the permits. If an NWP is not modified or reissued within five years of its effective date, it automatically expires and becomes null and void. Activities which have commenced (i.e, are under construction) or are under contract to commence in reliance upon an NWP will remain authorized provided the activity is completed within twelve months of the date of an NWP's expiration, modification, or revocation, unless discretionary authority has been exercised on a case-by- case basis to modify, suspend, or revoke the authorization in accordance with 33 CFR 330.4(e) and 33 CFR 330.5(c) or (d). Activities completed under the authorization of an NWP which was in effect at the time the activity was completed continue to be authorized by that NWP.

Appendix B: Test Hardware

NOTE: This discussion of Test Hardware –with more detail on manufacturing processes for the surrogates appears in the UXO Measurement Method Field Test Plan of 29 March 2004, reference 4 of this report).

Surrogates

The core of the surrogates is a steel all-thread bar with exercise weights on it to produce the proper overall weight and CG. The body is formed from a cast elastomer, which completely encloses the metal core. This plastic is very strong and resistant to water absorption. The strength enables the design to be much simpler and, therefore, allows the modeling to be much more accurate.

The finished surrogates are shown in Figure x. They are international orange in color, with identifying numbers and a base plate label. An acoustic marker pinger with a unique frequency is mounted in the nose of each surrogate.

Figure x. 5”/38 Surrogates for Field Demonstration.

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 Table B-1 for typical plastic properties.)

Table B-1 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

ACOUSTIC LOCATION SYSTEM

Each surrogate was equipped with a Sonotronics EMT pinger, each with a different frequency. To measure each surrogate's location, divers descended in the general area of the first surrogate, set the DH4 receiver to the correct frequency and then swept it back and forth to get a maximum signal. Once the followed the signal to the surrogate

location, they used the Benthos transponders to get ranges from 3 or 4 fixed points and determine surrogate location.

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

SELF-CONTAINED 1200kHz ADCP
The wave profiling device to be used at the test site is the WORKHORSE SENTINAL SELF-CONTAINED 1200, kHz ADCP.

ADCP (Acoustic Doppler Current Profiler) will profile up to 165 Meter range. The ADCP will be mounted on the seafloor at 10 meters depth (during high tide), and data will be stored internally until the information is retrieved at regular intervals by divers.

Power
DC input: 20–60VDC; internal battery pack, external battery pack, or external power supply
Voltage: 42VDC new; 28VDC depleted
Capacity: @ 0°C: 400 watt hours
Transmit:
• 16W @ 35V (1200kHz)

Environmental
Standard depth rating:
200m; optional to 6000m
Operating temperature: -5° to 45°C
Storage temperature: -30° to 75°C
Weight in air: 13.0kg
Weight in water: 4.5kg
1200kHz 24 2 3.5

Profile Parameters
Velocity accuracy:
• **1200, 600:** ±0.25% of the water velocity relative to the ADCP ±0.25cm/s
Velocity resolution: 0.1cm/s
Velocity range: ±5m/s (default)
±20m/s (maximum)
Number of depth cells: 1–128
Ping rate: 2Hz (typical)

Echo Intensity Profile
Vertical resolution: Depth cell size
Dynamic range: 80dB
Precision: ±1.5dB (relative measure)

Transducer and Hardware
Beam angle: 20°
Configuration: 4-beam, convex
Internal memory: Two PCMCIA card slots; one memory card included
Communications: Serial port selectable by switch for RS-232 or RS-422. ASCII or
binary output at 1200–115,400 baud.
Standard Sensors
Temperature (mounted on transducer)**:**
Range: -5° to 45°C
Precision: ±0.4°C
Resolution: 0.01°
Tilt: Range: ±15°
Accuracy: ±0.5°
Precision: ±0.5°
Resolution: 0.01°
Compass (fluxgate type, includes built-infield calibration feature)**:**
Accuracy: ±2° 4
Precision: ±0.5° 4
Resolution: 0.01°
Maximum tilt: ±15°
4 @ 60° magnetic dip angle, 0.5G total field
177.0mm
203.0mm
228.0mm
403.0mm

Workhorse Waves Array

DIRECTIONAL WAVE GAUGING AND CURRENT PROFILING ADCP

Technical Specifications

Measurement Technique	
Derivation of directional distribution	*Array processing*
Location of sensors	*Remotely measured near surface*
Number of independent sensors	*12*
Array aperture	*~0.7 x depth*
Acoustic sensor signal processing	*BroadBand*
Simultaneous sampling of wave burst + standard current profile	*Yes*

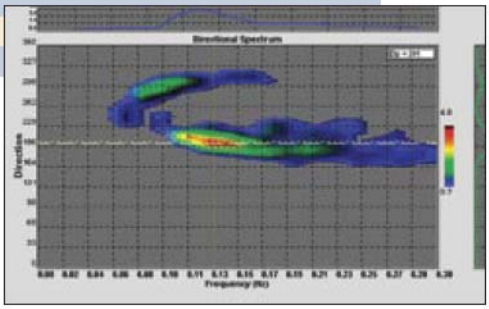
Calculated Wave Parameters						
Primary data source	*Near-surface velocity sensors*					
Redundant data sources	*Pressure sensor and "surface track" derived parameters for data QA*					
Height	H_s	H_{max}	H_{mean}			
Period	T_p	T_{mean}				
Direction	D_p					
Custom	H_{sea}	H_{swell}	T_{sea}	T_{swell}	D_{sea}	D_{swell}

Minimum Wave Period Measured			
Deployment Depth (m)	Surface Track High-Freq. Cutoff[1] (sec)	Non-Directional High-Freq. Cutoff (sec)	Directional High-Freq. Cutoff (sec)
5	1.0	*1.7*	*1.8*
20	1.0	*2.2*	*3.5*
80	1.0	*4.4*	*7.0*

Recommended Deployment Depths	
ADCP Frequency	Depth (m)[2]
1200	*2.5–14*
600	*5–45*
300	*10–80*

[1]Acoustic surface track is only reliable in non-"whitecapping" conditions

[2]Assumes bottom-mounted ADCP, near-surface deployment on top of a current meter mooring is possible.



Frequency/Direction spectrum. The ADCP is showing multiple waves at similar frequencies that arrive from different directions.

Raw Sensor Data

Velocity:
1200 kHz accuracy ±0.3% ±0.3cm/s
600 kHz accuracy ±0.3% ±0.3cm/s
300 kHz accuracy ±0.5% ±0.5cm/s

Precision: See Workhorse ADCP brochure

Surface track range:
Accuracy 1.0% of full scale
Precision ADCP bin size/3.5

Pressure: Accuracy 0.25% of full scale
Precision 1/40,000 of full scale

Compass: Accuracy ±2°*
Precision ±0.5°
*±1.0° is commonly achieved after field calibration

Installation

Cable power/communications: provides unlimited duration for real-time data.
Battery power: for remote locations, power for 90 days or more available. Optional external pack available.

Software

Planning software: self-contained or real-time deployment set up with waves, current profiles, or both.
Monitoring software: data acquisition and processing.
Viewing software: zoom, animate, average. Export to bmp, png, or text files.

Upgrades

Add Directional Waves capability to your new Workhorse ADCP or upgrade your ADCPs already in the field. See other Teledyne RDI Workhorse ADCP brochures for hardware specifications.

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Specifications subject to change without notice. Rev. 0905

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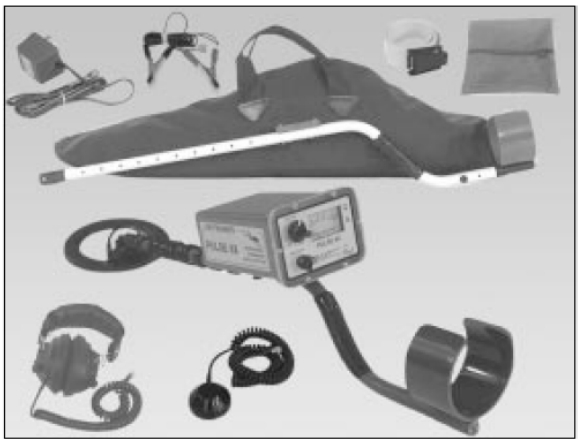
TECHNICAL DATA SHEET



- EXTREMELY SENSITIVE
- EQUALLY SENSITIVE IN SALT, FRESH, OR ON LAND
- WILL NOT DETECT MINERALS
- DETECTS ALL METALS
- INTERCHANGEABLE SEARCH COILS
- LARGE METER AND U/W EARPHONE
- RECHARGEABLE BATTERIES
- 200 FOOT DEPTH RATING
- 2 YEAR WARRANTY

PULSE 8X/6X Hand Held Detectors

Fishers Pulse 6X and 8X detectors are two of the top performing underwater metal detectors on the market today. These commercial grade detectors are specifically designed for underwater operations, but work equally well on land, in fresh water or salt water. The 6X and 8X will easily locate a variety of targets including gold and silver jewelry, coins, artifacts, weapons, ordnance, anchors, pipelines, cannons and cannon balls. These high performance Pulse Induction metal detectors detect both ferrous and nonferrous metal objects, while ignoring minerals in the environment. The detectors will not give false detection signals from salt water, coral, high iron rocks, or other ground mineralization, as some other types of detectors do. With JWF detectors the detection range is unaffected by the material between the detector's coil and the metal target. Whether detecting through air, water, silt, sand, mud, or coral, the detection range remains the same.

Both the Pulse 6X and 8X come with a complete accessory package that includes all the pieces necessary for land and underwater detecting. Included with the detectors are a corrosion proof PVC underwater handle and an aluminum land handle, underwater earphone, AC and DC battery chargers, and a hip mount kit. The 8X package also includes a carry bag and land headphones. The 6X and 8X have both visual and audio target indicators. When a metal object is detected the audio alarm sounds and a meter shows the strength of the signal. The meter is beneficial in determining the size and burial depth of the target, information not easily conveyed by the blinking LED indicators or the audio-only readout of some other detectors. The audio alarm is loud enough for a diver to easily hear without having the earphone directly over the ear.

Rechargeable batteries power the detectors for 12 hours before requiring an overnight recharge. Batteries can be easily field replaced to allow around the clock operation. Unlike some other detectors, the electronics compartment can be opened for inspection or battery replacement without voiding the warranty.

The detector's buoyancy is slightly negative in the water. This allows the diver to sit the detector on the bottom to dig a target without having it float away, which is a problem with "positive buoyancy" detectors. The underwater housing is a single solid casting with ¼" wall thickness and molded-in brass inserts. A ½' thick acrylic faceplate is fastened down with six stainless steel screws giving a maximum depth rating in excess of 200 feet.

The standard 7.5 inch coil has good sensitivity to both small and large targets, and makes target pinpointing a breeze. Other size coils are available for more specialized applications. It is necessary to have the underwater connector option to interchange coils.

The top of the line Pulse 8X is the most sensitive pulse detector you can buy, and continues to be the choice of commercial and professional divers worldwide. The 8X is in use by US and foreign Navies, Coast Guards, FBI, Secret Service, numerous federal and law enforcement agencies, and professional treasure hunters everywhere. The 6X has the same heavy duty construction as the 8X but is not as powerful. However, the 6X can be upgraded to the 8X at anytime.

WARRANTY

The Pulse 8X and 6X are covered by Fishers exclusive unconditional Two year warranty.

OPTIONS

- Connector for coil
- Interchangeable search coils
- Dual underwater earphones
- Land earphones (included with P8X)
- Carry bag (included with P8X)
- 220vac charger
- Extra battery pack

1100 GW2000/PM4/DS

FEATURES FOR THE PULSE 6X

- Can be upgraded to a PULSE 8X at any time.
- Single control knob.
- Very sensitive and stable.
- Detects both ferrous and non-ferrous metals.
- Detection indicated by both meter and earphone.
- Does not detect minerals.
- Compact underwater earphone.
- 200 foot depth rating.
- Separate handles for land and underwater use.
- Belt-holder for hip mounting the control unit.
- "Battery Low" LED.
- 120vac and 12vdc battery chargers.
- Two year warranty.

ADDITIONAL FEATURES FOR PULSE 8X

- Increased (100% more) sensitivity and detection area.
- Low, med, high, sensitivity switch allows pinpointing of targets.
- Land earphones.
- Carrying bag for detector and accessories.
- Meter shows battery voltage.
- Leak detection system.

SENSITIVITY (with 7 1/2" coil)

You can expect the following detection ranges whether in air or buried in mud, coral, sand, dry or wet, fresh or salt water.

	PULSE 6X	PULSE 8X
• Small ring	2 1/2 in.	5 in.
• Penny	4 1/2 in.	9 in.
• Quarter	5 in.	9 1/2 in.
• 4" x 4" x 1/8" Alum	9 in.	15 in.
• 1 gallon can	22 in.	30 in.
• Larger targets to a max	3 1/2 ft.	6 ft.

DIMENSIONS/WEIGHT (in air):

• Coil	7 1/2" Dia	11 oz.
• Underwater handle	31"	1.5 lbs.
• Aluminum Land handle	38"	2 lbs.
• Case	7 1/2" L x 5 1/2" W x 4" H	4 lbs.
• Shipping Box	8" x 12" W x 32" L	15 lbs.

MATERIALS/COLOR:

• Case	High impact urethane/gray
• Cable	RG58 coax with abrasion resistant jacket
• Coil	High impact ABS, epoxy/black

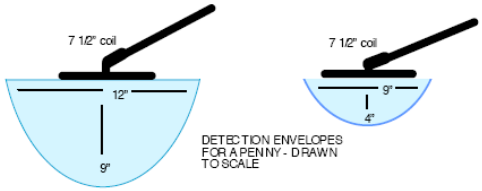
PULSE DETECTORS - GENERAL

Pulse induction detectors have had a major impact on underwater metal detecting. Their claim to fame is very simple: they are a very sensitive metal detector that does not detect minerals (extreme concentrations may give some reading). Their sensitivity is excellent, the best hand held units, with a 7.5" coil, will detect coin size targets at 9-12 inches, and larger objects to over 6 feet. Our pulse detectors are able to achieve their high sensitivity on land or in fresh or salt water without detecting either the water or the minerals on the bottom.

Non-pulse detectors use compensation networks in a effort to reduce the effect of minerals on the detector. One manufacturer uses the motion technique which requires the coil to be constantly moving to detect anything. This gets rid of the mineral background only as long as the mineral background is of an even concentration; if it is not, false readings result. When the target alarm goes off you are never quite sure if it is a real target or not.

COIL SIZES (see Pulse 6X/8X option sheet for more details)

The detection range of a pulse detector is determined to a large degree by the coil size. Larger coils will detect large targets deeper, but have reduced range for the smaller targets. The 7.5 in coil is an ideal size for detecting both small targets, such as small rings, and larger targets to 6 foot deep.



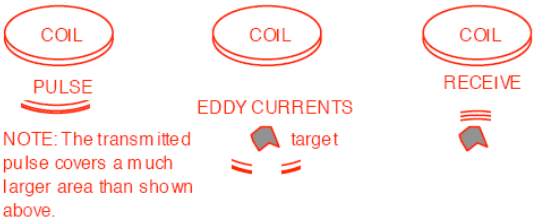
DETECTION AREA FOR A PENNY - 7 1/2" COIL

Optional coil sizes available: 10", 16", 18" with 100' cable, 8" x 48" oval with skids, and a 22" long hand probe. The larger loop sizes give wider detection envelopes allowing large areas to be covered more quickly.

- The 18" coil with 100' cable turns this diver held detector into a boat deployed detector where the coil is lowered from the boat.
- The 8" x 48" oval coil with up to 100' of cable is mounted on skids for towing along the beach or in shallow water.
- The hand probe has a small coil mounted in the tip and works extremely well in those tight areas where larger coils can't fit.

PULSE DETECTORS - HOW THEY WORK

Pulse detectors operate by transmitting a continuous stream of high energy magnetic pulses (one hundred per second) from the coil. After each pulse is transmitted the detector then listens, using the coil as the receiving antenna.



When the transmitted pulse hits a metal object, an electro-magnetic field is induced in the object. This causes eddy currents to flow in the metal, which in turn generates a second electro-magnetic field. This field is picked up by the coil, amplified and then displayed by the meter and heard in the earphones.

DISCRIMINATION - IT SURE SOUNDS GREAT !!

Discrimination is the ability to ignore the trash and only detect the "good stuff". The fact is, discrimination also rejects many good targets and the detection range for all targets can be dramatically reduced. For these reasons we do not put discrimination on our detectors. Two examples on discrimination:

In actual tests with a competitors pulse detector with discrimination, the detection range for a coin went from 6" without discrimination to less than 3" with the discrimination.

The manufacturer of a motion detector (non-pulse) held a seminar which was conducted by a professional treasure hunter who stated "I don't recommend using the discrimination control because you just can't afford to miss a target".