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Sequim Bay Underwater UXO (SBU2) Prototype Demonstration Site: Field Operations Summary, 2019

March 2020

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U.S. DEPARTMENT OF ENERGY

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Summary

This report provides a summary of the Pacific Northwest National Laboratory's (PNNL) activities to initiate Phase I of the Sequim Bay Underwater UXO (SBU2) test bed field operations that were conducted by PNNL's Marine Sciences Laboratory (MSL) in FY 2019. The field operations were conducted in support of the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) underwater Munitions Response (MR) program that is developing standardized underwater unexploded ordnance (UXO) demonstration sites ("test beds") for the purpose of evaluating sensors, equipment, and technologies that can detect, characterize, and classify proud and buried munitions in shallow water (0-35 m) in a variety of substrates. Sequim Bay meets the qualifying criteria for a test bed. It is free of native UXO, contains appropriate substrate type and minimal clutter, with nearby operational, logistical and facilities support provided by PNNL.

The objectives of Phase I were to (1) establish SBU2 "prototype" test bed as part of the SERDP/ESTCP MR program, including placement and retrieval of a nominal number of targets in 5–30 m water depth at sand and mud sites, (2) provide subsequent operational support to the University of Washington-Applied Physics Laboratory (UW-APL) for an engineering field test of their Multi-Sensor Towbody (MuST) in Sequim Bay, and (3) capture lessons learned and determine cost effective, safe and technically sound approaches to inform Phase II. Phase II will build on Phase I, with a goal of establishing a procedure for grid layouts (e.g. calibration, blind), updating the Operational Plan for the Sequim Bay test bed, improving the accuracy of target location, and developing a draft scoring approach in collaboration with the Program office.

For Phase I, two sites in Sequim Bay were selected by PNNL that met the qualifying criteria set forth by SERDP (e.g. 5-30 m water depth, mud and sand substrate, free of native UXO). An existing 5-year PNNL-MSL Scientific Research Plan and associated permits to conduct research in Sequim Bay formed the basis for securing additional authorizations to conduct test bed activities in the bay. Authorizations were requested and secured between February and July 2019, allowing test bed activities to move forward in a permitted area of Sequim Bay.

PNNL provided operational support to UW-APL, a remediation system developer. UW-APL conducted an engineering field test during FY 2019 at the SBU2 test bed. The engineering test was designed to evaluate the overall operation of the MuST with associated acoustic sensors, and to develop detection/classification algorithms for various targets on the sediment surface. Twenty targets in total (4 science, 6 inert munitions, 2 replica munitions, and 8 clutter objects) were placed at two sites (sand and mud, 10 targets each site) in an offset linear pattern along two, 50 m lines by PNNL-MSL and UW-APL divers in July 2019 in approximately 20-25 m of water. Targets were tethered together (10 at each site), and identification and positions of the targets were known to the demonstrators. The engineering test was conducted in September 2019 by the UW-APL crew operating from their research vessel, *R/V Jack Robertson*. PNNL-MSL provided additional shore support, indoor and outdoor facilities, and logistical support as needed. All targets were retrieved from Sequim Bay by PNNL-MSL divers in October/November 2019 and securely stored for future deployments.

Overall, the FY2019 field operations were a success at the SBU2 test bed in Sequim Bay. The primary challenges were related to the flocculent nature of the sediment at the mud site, causing reduced visibility. This made placement and retrieval of the targets more time consuming. In the future, the mud site will be relocated to a more favorable location. The accuracy of target geo-location will also be improved with a goal of achieving sub-meter accuracy.

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We would like to thank Drs. Herb Nelson, David Bradley and Michael Richardson for guidance and support from the SERDP/ESTCP program office during this project. Collaboration with the UW-APL MuST project team, including Dr. Kevin Williams and divers Eric Boget, Avery Snyder, and Paul Aguilar was instrumental to the success of the 2019 field operations. Dr. Daniel Steinhurst and Glenn Harbaugh provided support with acquisition of UXO. Additional support was provided by PNNL staff including Nikki Sather, Garrett Staines, Mike Sackschewsky and Kris Hand (permitting), Kate Hall and Cailene Gunn (field and logistical support), Susan Ennor and Kate Buenau (report review and editing) and Meg Pinza (project management).

Acronyms and Abbreviations

APL	Applied Physics Laboratory
DOE	U.S. Department of Energy
DVL	Doppler Velocity Logging
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
FY	fiscal year
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEAT	high-explosive anti-tank (projectile)
ITAR	International Traffic in Arms Regulations
MMO	Marine Mammal Observer
MMPA	Marine Mammal Protection Act
MR	Munitions Response
MSL	Marine Sciences Laboratory
MuST	Multi-Sensor Towbody
NEPA	National Environmental Policy Act
NRL	Naval Research Laboratory
PNNL	Pacific Northwest National Laboratory
SB3	Sequim Bay Site 3
SBU2	Sequim Bay Underwater UXO Test Bed
SERDP	Strategic Environmental Research and Development Program
USBL	Ultra-short Baseline
UW	University of Washington
UXO	Unexploded Ordnance

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1.0 Introduction

The U.S. Department of Defense (DoD) has identified more than 400 underwater sites that are potentially contaminated with munitions from past military testing exercises and that need to be remediated. Many of these sites are in shallow water (0–35 m deep) where the munitions pose a threat to human health and the environment. The Strategic Environmental Research and Development Program/Environmental Security Technology Certification Program (SERDP/ESTCP) Munitions Response (MR) program supports the development and demonstration of innovative technologies that can characterize, remediate, and scientifically manage sites affected by military munitions, including technologies that can detect, characterize, and remediate military munitions in underwater sites.

To address this challenge, SERDP/ESTCP held a workshop in 2018 to establish the requirements, framework, protocols, responsibilities and timelines for development of a series of underwater unexploded ordnance (UXO) standardized demonstration sites ("test beds"). Multiple test beds will be developed to optimize, evaluate, and formally demonstrate technologies to document and validate improved performance and cost savings for various methodologies including acoustic, magnetic, electromagnetic induction (EMI) and optical systems designed to detect and classify underwater UXO. The workshop recommended a stepwise approach to building test beds to capitalize on (1) incorporating lessons learned from existing DoD-funded projects, (2) leveraging existing underwater test bed environments funded by other programs, and (3) supporting iterative learning from early phases of the test bed development (i.e., efficiently optimizing test bed operations using a scaling-up approach). The workshop participants recommended that an initial test bed prototype should target a deeper water area (5–30 m) free of native UXO that features both sandy and muddy sediments.

Sequim Bay in Washington State was evaluated as a potential test bed between 2016 and 2018 and was determined to meet the initial qualifying criteria with respect to environmental setting, and operational, logistical, and facilities support provided by the Pacific Northwest National Laboratory (PNNL). Based on this evaluation, a phased approach was implemented in 2019 to establish a PNNL led Sequim Bay Underwater UXO (SBU2) "test bed" as part of the SERDP/ESTCP MR program. PNNL proposed a three phased approach for establishing the operational SBU2 testbed. Phase I would include the establishment of a prototype test and include the placement and retrieval of a nominal number of targets in 5–30 m water, provide subsequent operational support for one test system, capture lessons learned and determine cost effective approaches for the next phase. Phase II would develop operating plans for a formal test bed design, including grid designs, scoring approaches, environmental assessments, and logistical details. Phase III would expand on lessons learned from Phase II and develop plans for accommodating multiple system demonstrations.

Phase I of a SERDP/ESTCP SBU2 Testbed Development program was implemented by PNNL during fiscal year (FY) 2019. PNNL's Marine Sciences Laboratory (MSL) provided operational support for an engineering test conducted by the University of Washington-Applied Physics Laboratory (UW-APL) for an engineering field test of their Multi-Sensor Towbody (MuST) in Sequim Bay. Phase I included target deployment and retrieval of science targets, clutter objects, replicas, and inert munitions, as well as site selection and test layout design support.

The ensuing sections of this report provide an overview of SBU2 Testbed Development Phase I (Section 2.0) that includes a description of the engineering field test, including scheduling and timelines, the permitting process, and the acquisition, placement, and retrieval of targets.

Section 3.0 describes the field operations, including target deployment, the engineering test, and target retrieval. Section 4.0 addresses future deployments and discusses technical challenges and suggested modifications for the future use.

2.0 Project Overview

PNNL was contracted by the SERDP/ESTCP program office through Task Order 3 to develop and demonstrate a prototype standardized test bed in Sequim Bay (SBU2). This project was initiated as Phase I in FY 2019 and included the following subtasks: (1) site selection and permitting, (2) target acquisition, (3) target deployment, (4) shore-based engineering test support for a remediation system developer, (5) target retrieval and storage, and (6) field operations reporting.

For Phase I, two preliminary sites in Sequim Bay were selected by PNNL that met the qualifying criteria set forth by SERDP (e.g. 5-30 m water depth, mud and sand substrate, free of native UXO). An existing 5-year PNNL-MSL Scientific Research Plan and associated permits to conduct research in Sequim Bay formed the basis for securing additional authorizations to conduct test bed activities in the bay. Authorizations were requested and secured during a 6-month process (February to July 2019), allowing test bed activities to move forward in a permitted area identified as SB3 (Figure 1). Acoustic testing within specified frequencies and transmission characteristic are allowed in SB3. Placement of targets is also allowed in SB3.

Phase I was designed to provide operational support to one remediation system developer, UW-APL, and to capture lessons learned and develop cost effective approaches for informing Phase II. UW-APL conducted an engineering field test during FY 2019 at the SBU2 test bed. The engineering test was designed to evaluate the overall operation of the MuST (towbody and acoustic sensors) and to develop detection/classification algorithms for various targets on the sediment surface. Ten targets (science, inert and replica munitions, clutter objects) were placed at each of the two sites (sand and mud) by PNNL-MSL and UW-APL divers in July 2019 in approximately 20-25 m of water. Targets and positions were known to the demonstrators (i.e. calibration grid). The engineering test was conducted in September 2019 by the UW-APL scientific crew operating off their research vessel, *R/V Jack Robertson*. All targets were retrieved from Sequim Bay by PNNL-MSL divers in October/November and stored for future deployments. PNNL-MSL provided additional dock-side indoor and outdoor facilities, and logistical support as needed

2.1 Timeline

A timeline of events for Phase I of the SBU2 test bed development was tracked closely to evaluate this years' schedule and provide input for future operational planning at the SBU2 testbed. Planning and field operation events are summarized in Table 1.

The planning and scoping phase of the SBU2 testbed setup for the engineering test was initiated during late 2018 and early 2019. Once project authorization was received in February 2019, the PNNL permitting team began consultation with state and federal agencies to secure the necessary authorizations/permits to place underwater targets in Sequim Bay and to deploy acoustic sensors. This 6-month process is described in greater detail in Section 2.2. During the consultation process, underwater targets were acquired from UW-APL in Seattle and the Naval Research Laboratory (NRL) in Washington, D.C.

Site selection was finalized in June 2019 after a PNNL diver survey confirmed appropriate substrate and site conditions. Targets were placed in Sequim Bay in July by PNNL and UW-APL divers, and the engineering test was conducted by UW in September 2019. All targets were retrieved at the end of the field season in late October and early November 2019.

Table 1. Timeline of events for Phase 1, prototype demonstration of SBU2 test bed.

Task Order #3 Timeline	2018		2019												2020
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan
Planning															
SERDP Underwater UXO workshop	■														
Scope development		■	■												
SOW submitted to SERDP			■												
Project Authorization received				■											
Permitting Consultation/Approval				■	■	■	■	■	■						
Target Acquisition								■	■						
Field Operations															
Diver Assessed Final Site Selection								■							
Target Placement (PNNL/UW)									■						
Target Detection (UW)											■				
Target Retrieval												■	■		
Field summary reporting														■	■

2.2 Permitting of the Test Bed Location

The PNNL permitting team secured the necessary permits and authorizations prior to underwater target deployment in July 2019 and execution of the MuST engineering test in September 2019. To the extent possible, an existing 5-year PNNL-MSL Scientific Research Plan and associated permits related to the U.S. Department of Energy's (DOE's) marine research activities were used. This allowed for placement of targets, survey grids, and diver-installed anchors at a mud site (Figure 2). The permits allowed for acoustic testing within specified frequency ranges and well-defined transmission characteristics in the spatial boundaries of SB3, shown in Figure 1, which included both a sandy and a muddy site. UW-APL's Doppler Velocity Log (DVL) sonar and side scan sonar were covered under these permits. Under the current permits, operation of acoustic devices at frequencies outside of marine mammal hearing ranges (below 7 Hz or above 180 kHz), or at sound level pressures that are below the Level B harassment thresholds for marine mammals (160 dB_{rms} for impulsive; 120 dB_{rms} for non-impulsive) and behavior effects for fish (150 dB_{rms}) were allowed. However, additional consultation with federal and state agencies was needed for the sediment-penetrating sonar activities at both sites, because those acoustic frequencies were outside the currently scoped activities of the 5-year Scientific Research Plan and permits. Additional authorizations were also secured for target deployment activities at the sand site, which was not covered under the existing 5-year PNNL-MSL Scientific Research Plan.

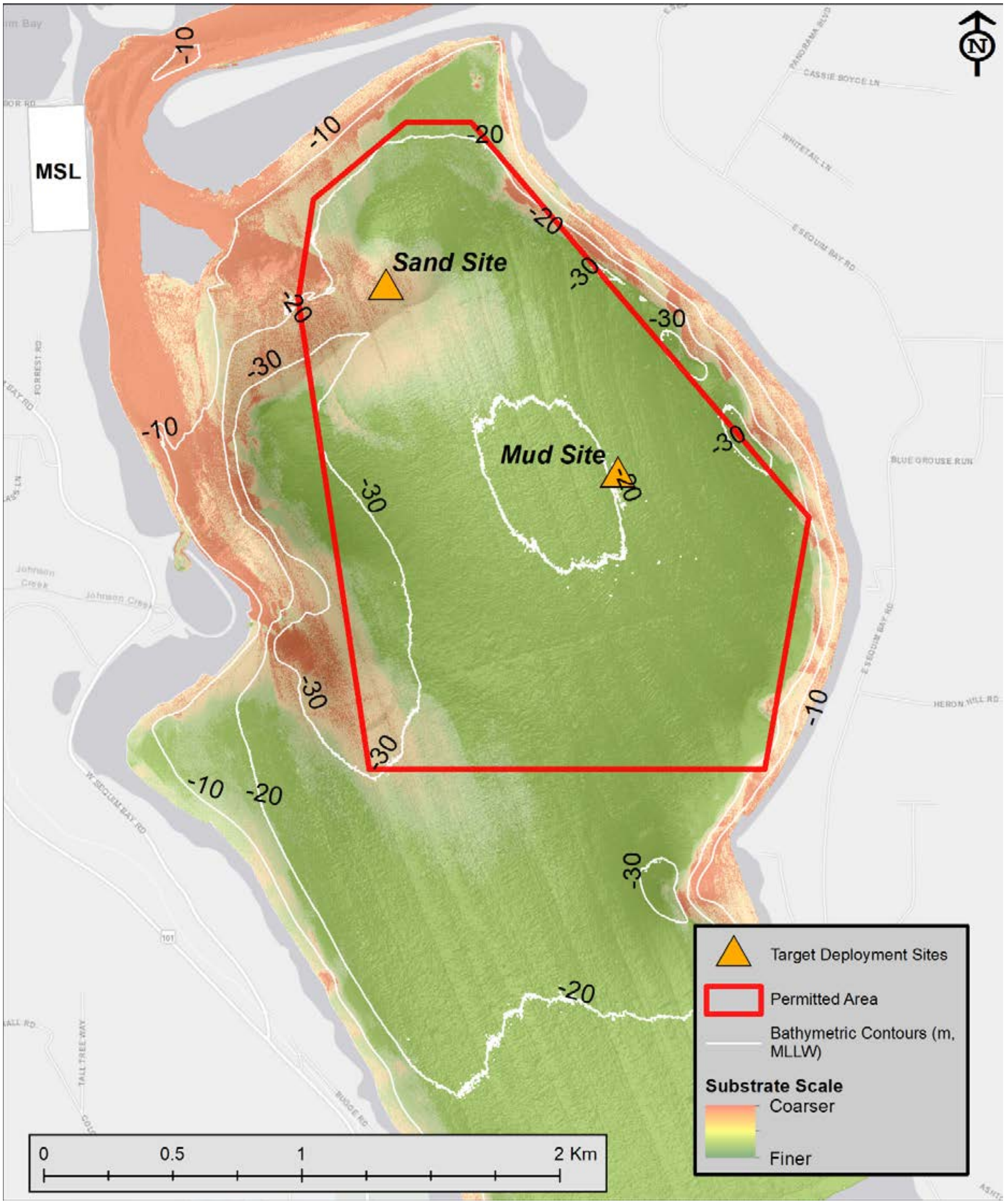


Figure 1. Sequim Bay showing the acoustic permitted area SB3 (red polygon) and the sand and mud target sites. The background shows bathymetric contours and acoustic backscatter approximating the bottom substrate type.

The following PNNL permits and authorizations were secured to conduct the FY 2019 field activities in Sequim Bay:

- National Environmental Protection Act (NEPA) – DOE Categorical Exclusion for Aquatic Research

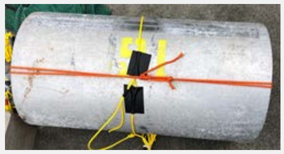
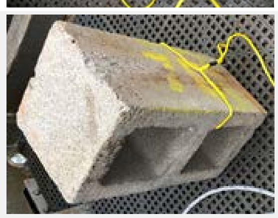
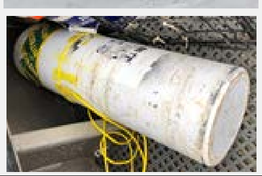
- Section 106 National Historical Preservation Act, Cultural Resources Review – Washington State Historic Preservation Officer
- Endangered Species, Section 7 – U.S. Fish and Wildlife Service
- Endangered Species, Section 7 – National Marine Fisheries Service
- Essential Fish Habitat – National Marine Fisheries Service
- Marine Mammal Protection Act (MMPA) – National Marine Fisheries Service
- U.S. Army Corps of Engineers Individual Permit
- Hydraulic Project Approval – Washington State Department of Fish and Wildlife
- Coastal Zone Management Act – Washington Department of Ecology
- Clallam County Shoreline Exemption
- Aquatic Right of Entry License – Washington State Department of Natural Resources.

The permitting required a 6-month timeframe (February through July 2019) and included the development of a detailed test plan early in the process that was a collaborative effort between PNNL and UW-APL. The test plan was reviewed by the PNNL permit team to confirm its compliance with existing authorizations and permits. Proposed activities that did not fall within the existing authorizations were moved forward to appropriate permitting agencies as proposed amendments or new authorizations/permits.

2.3 Target Acquisition and Storage

Objects used for the FY 2019 engineering test were categorized as science targets, clutter, and inert munitions/replicas. UW-APL transferred the science targets, clutter objects, and Howitzer replicas to the field for the July 2019 deployment in Sequim Bay. The inert munitions were shipped from NRL in Washington, D.C., and deployed with the other objects in the testbed by PNNL and UW-APL divers. All objects were retrieved in the fall and are currently stored at PNNL-MSL in secured, covered storage with appropriate tagging and paperwork. Table 2 lists the 10 types of objects/targets used at each site. A total of 20 test objects were placed in the testbed (i.e., 1 of each type at the sand and mud sites). In addition to the 20 test objects, two 3 m (10 ft) aluminum pipes were added to each line to calibrate the MuST sensors. These were placed at each end of the baseline resulting in 12 objects at each location.

Table 2. List of objects (science, targets, clutter) used for FY 2019 engineering test in Sequim Bay.

Object Type	Photo	Description
Science		Solid aluminum cylinder
		Hollow aluminum cylinder
Inert Munitions		Howitzer replica
		155 mm projectile
		105 mm HEAT (high-explosive anti-tank) projectile
		81 mm mortar
Clutter Objects		Cement block
		Anchor
		Crab trap
		SCUBA tank

3.0 Field Operations

Field operations consisted of three phases: target deployment, engineering test, and target retrieval. PNNL was the lead for the target deployment and retrieval tasks and provided operational support for the engineering test. Details of the three phases are described below.

3.1 Target Deployment

The first phase of field operations involved planning the deployment of targets, use of a standardized deployment approach, conducting sand site and mud site deployments, and geo-positioning the underwater targets.

3.1.1 Planning

As part of the permitting process and early planning phase, two sites (sand and mud) were selected within the SB3 permitted area (Figure 2). The early planning for site selection was a collaborative effort between PNNL and UW-APL to determine a general layout of targets at each location (i.e., sand and mud sites). Planning was also informed by prior experience with target placement from the UW-APL team coupled with PNNL-MSL diver experience working in Sequim Bay. The goal was to assure safe operations in the field while still achieving successful survey results. The FY 2019 engineering test was designed to test the overall operation of the MuST and to develop detection/classification algorithm for targets on the sediment surface; hence, collaboration between UW-APL and PNNL regarding target placement was appropriate. Future activities will include scoring demonstrations for which remediation system developers will have no *a priori* knowledge of blind and open grid designs.

Early in the planning process, it was determined that both the UW-APL and PNNL-MSL dive teams would deploy the targets in Sequim Bay. This arrangement would allow the program to draw on the experience of the UW-APL dive team with deployments of this type and allow more targets to be placed in a day. The opportunity to use more divers would reduce total bottom time at depth for individual divers. At the same time, the experience of the MSL divers in Sequim Bay would bring a knowledge base with respect to substrate type and dive conditions in Sequim Bay. PNNL and UW divers would be allowed in the water at the same time as needed, but each team would dive separately, under their own auspices and Standard Operating Procedures. The PNNL diving officer obtained a reciprocity letter from UW to assure a baseline experience/skill level that would allow UW-APL divers to safely perform under the expected conditions (i.e., up to 90 ft depth, under low-visibility conditions). Prior to accessing any MSL workspaces or the floating dock, UW staff were badged and trained per PNNL requirements.

Logistical considerations related to dive conditions were also factored into the planning. The mud and sand sites were located in relatively deep water for divers (between 20 and 25 m deep) which limited the time a diver could spend on the bottom each day. The deeper depth also reduced available light for the divers while working. Visibility was further reduced because the substrate at both locations is prone to resuspension, especially at the mud site. Reduced visibility complicates the ability of divers to orient themselves on the bottom, find targets, see their hands to perform tasks, and directly observe the placement of the actual targets. Lastly, several of the targets were quite large and cumbersome, potentially making their manipulation and movement on the bottom difficult. This was especially true at the mud site where very little leverage could be gained on the bottom because divers sank into the flocculent substrate and were unable to brace themselves against it.

The target layout design was developed in part to evaluate the effect of 2 different substrate types with respect to target placement and retrieval as well as target detection. The target layout incorporated the following characteristics:

- All target types (i.e., science, clutter, and inert targets) would be evenly split between the 2 sites such that each location had the same combination of objects.
- A 50 m rope baseline would be used to orient the targets, guide the divers, and help facilitate the later retrieval of all targets. This baseline would remain for the duration of the deployment.
- Targets would be placed at 5 m intervals along the baseline.
- Targets would be placed 2 m to the side of the baseline, alternating sides along the baseline, and attached with a tether (Figure 3) to facilitate their relocation and retrieval.
- The baseline would be oriented in the north/south direction with the 0 m end to the south. All targets would be oriented “noses north”, or pointed to the north, when a directionality could be assigned to the object. Targets with no directionality (e.g., the crab trap) would be placed as parallel to the baseline as possible.
- All targets would be placed proud on the sediment surface, although some settling might occur naturally.
- If a vertical orientation was possible for a target, it was laid down on its side.
- To prevent interference with the survey towbody, no objects on the baseline (e.g., targets or subsurface buoys) would be more than a meter off the bottom.
- The baseline would be anchored at both ends. At the south end, baselines at both sites would be attached directly to the 2 ft solid aluminum cylinder science target. These targets would be the only objects in line with the baseline. The north end of the baseline would be anchored differently depending on the site and substrate to enable experimentation with different techniques (discussed below).
- In general, larger targets would be closer to the ends of the baseline and the smaller, lighter targets would be placed toward the middle (to minimize diver time carrying the larger pieces).

The baseline served a variety of purposes. First, a taut baseline assured the targets were placed along a straight line and did not unintentionally move when there were few visual references on the bottom. The baseline was also pre-marked at 5 m increments to enable more precise positioning of the targets and allow the divers to be most efficient using their limited bottom time. Lastly, the baseline would give the divers a tactile path for orientation on the bottom and guidance to objects when working in the low-visibility environments during deployments and retrievals.

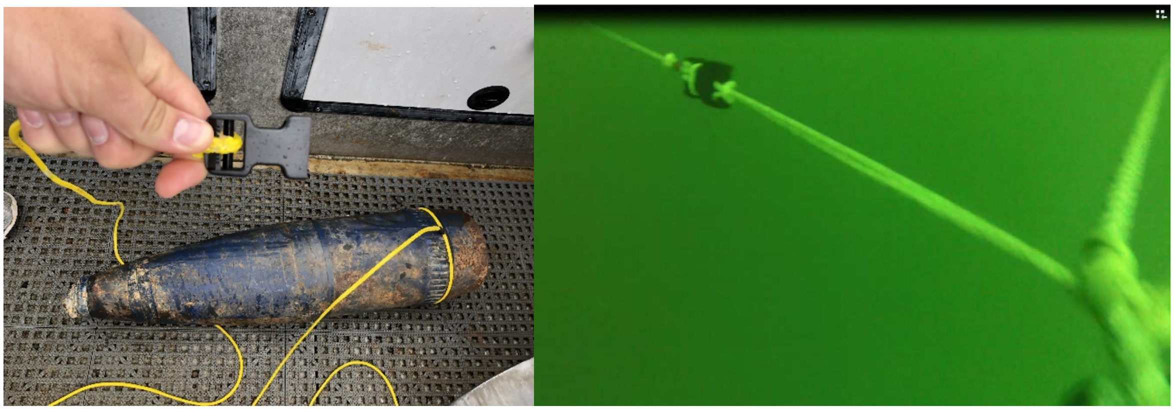


Figure 2. Example of the tether and buckle placed on the targets prior to their deployment (left), which attached to a shorter tether placed on the baseline (right). The lengths of the short and long tethers were a combined 2 m.

3.1.2 Overall Deployment Approach

To the extent possible, a standardized deployment approach was used at both sites. Specific observations of the differences encountered at each site and how they were handled are discussed in Sections 3.1.3 (sand site) and 3.1.4 (mud site). The deployment at both sites was conducted between July 22 and July 25, 2019. Three divers from UW-APL came to Sequim Bay to help with the deployments. All operations were conducted off the MSL 28 ft *R/V Strait Science* (Figure 3) operated by MSL personnel.

Figure 3. *R/V Strait Science* used during the deployment and retrieval of targets.

The baseline was prepared prior to the deployment to minimize the activities of the divers on the bottom and assure quality control. The line was marked every 5 m using a combination of hose washers and zip ties such that the divers could tell where they were on the line by touch or sight. At each of these intervals a short tether with a small side-squeeze buckle was attached (Figure 2). This was part of the 2 m tethers that connected the targets to the baseline for proper spacing, reacquisition, and navigation. These tethers were placed on the line by divers underwater at the sand site but were placed on the line prior to deployment at the mud site.

For deployments, the baseline was attached to the solid aluminum cylinder, which was the heaviest target and was used to anchor the southern end of each baseline. This cylinder was deployed with the A-frame on the *R/V Strait Science* and left on the bottom using a remote release. A tethered surface buoy (i.e., “upline”) was also attached to the solid cylinder to mark the location and provide a guideline for the divers during descents and ascents. The baseline was then stretched out 50 m to the north and anchored in place to set the north end of the line. An upline was attached to anchors on the north end of the baseline so each end of the baseline was marked at the surface.

The method of deploying the baseline varied between the two sites so that different techniques could be tested and compared for future deployments. At the sand site, divers deployed the baseline on the bottom, but at the mud site the boat deployed the baseline. In addition, the method of securing the northern end of the baselines varied. At the sand site the northern end was attached to a 3 in. x 30 in. (7.6 cm x 76 cm) helical earth anchor installed by the divers. Earth anchors have been shown to provide excellent holding power in sandy substrates that are not too soft. At the mud site, the north end of the baseline was attached to a 23 kg plate weight because the earth anchor was unlikely to hold in the soft mud.

After the baseline and uplines were deployed and in their proper place, the rest of the targets were lowered to the bottom for placement by the divers. This was accomplished by attaching the target to an upline with a tag line/tether and carabiner. The upline was then kept taut while the target was slid down the upline until it reached the bottom (Figure 4). For the heavier targets at the mud site, a slip line was used to control the descent of the target. Half of the targets were placed at each end of the baseline to minimize the distance needed to move each target to its final position.

Figure 4. Deployment of the hollow aluminum cylinder by attaching it to the upline and sliding it down to the bottom.

Once all objects were on the bottom, divers swam down for the final disposition of the targets. Divers descended along one of the uplines to a pile of targets at the end of the baseline. Divers detached the individual targets from the upline and moved them down the baseline to the marked position planned for the object. Lift bags were available for the heavier objects if needed, but most of the repositioning was done by hand. Once the target was brought to the appropriate mark on the baseline, the tether was buckled to the baseline and the object was moved out from the baseline for placement. One diver would swim with the target out the full length of the 2 m tether while the second diver stayed at the baseline to make sure it was not pulled out of position and to verify the tether was perpendicular to the baseline. The location, orientation and any other notes were provided to team members on the boat through the wireless communications and/or written on an underwater dive slate. After all the targets were placed, a diver went down the line with a video camera and verified each target was in the position recorded.

Throughout the deployment, divers deployed in a single team of two divers at a time. This was planned for two reasons. Most importantly, resuspension of the sediment was minimized by only having two divers onsite at a time, and visibility was often improved when the divers moved to the next position on the line. Secondly, the depths the divers were working at required a surface interval between dives to allow off-gassing of nitrogen. It was therefore efficient to have the second team dive while the first was in their required surface interval. Swapping teams out in this a manner allowed the work to continue throughout the day, maximized visibility on the bottom, and kept divers from getting in each other’s way.

Once the line was completely set up with the targets, including two additional calibration pipes per baseline, the positions and orientations were verified, and a GPS point was taken on each end of the baselines (Section 3.1.5), uplines were released and retrieved by the boat in anticipation of testing in September. The baseline, anchors, targets, and tethers were all left on the bottom.

3.1.3 Sand Site Target Deployment

The sand site was established first because it was expected to have better visibility and firmer substrate for moving the targets, making it easier for the divers to work out any issues with the deployment plan. A deployment schematic is shown in Figure 5. The solid aluminum cylinder was lowered to the bottom and marked with an upline. The divers spent the next two days deploying targets at this site.

On the first dive, MSL divers went down to deploy the baseline. The cylinder was first removed from the webbing carrier used to pick up the cylinder (see Table 2, solid aluminum cylinder) and the baseline was attached to the small tether around the cylinder. Divers then swam a compass bearing to the north while unspooling the baseline until it was taut. At 50 m, the vessel verified the bearing and the divers installed a helical earth anchor in the substrate to anchor the north end of the baseline. Lastly, the divers attached an upline so there were two on the baseline, one at each end.

The second dive was conducted by UW personnel. In between the first and second dives all the targets (including the pipes) were sent down the uplines as described above such that five targets were staged at the south end and six were staged at the northern end. The divers descended on the southern end and pulled the upline taut, allowing for a GPS position fix. They also spent the dive sorting out the targets that were dropped, disconnecting them from the upline and staging them on the baseline for placement during subsequent dives. They attached all the short tethers at the 5 m marks along the baseline to allow for quick connection of the targets as they were deployed.

MSL divers performed the third dive on the northern end. They were able to disconnect the targets from the upline, pull the upline taut for GPS positioning, and start placing targets according to the planned design (Figure 5). The divers were able to place the northern pipe section, 155 mm projectile, hollow cylinder, Bruce anchor, 105 mm high-explosive anti-tank (HEAT) projectile, and 81 mm mortar.

The fourth dive was conducted by the UW-APL to finish the southern section of the baseline. Divers were able to place the remaining targets (southern pipe, Howitzer replica, SCUBA tank, cinder block, and crab trap) in position and disconnect the southern upline. Before they ascended, the divers were also able to swim the length of the site with a video camera and document all but the last three objects.

The fifth and final dive by MSL documented the positions of the last three objects. The northern upline was also released. Once these tasks were completed, the original site design layout was achieved (Figure 5). All targets were oriented north (if possible), and all objects were verified as being proud on top of the substrate. No uplines or subsurface buoys were left that could interfere with the towbody to be used in September. In total, five dives were required to set up the sand site and prepare it for testing.

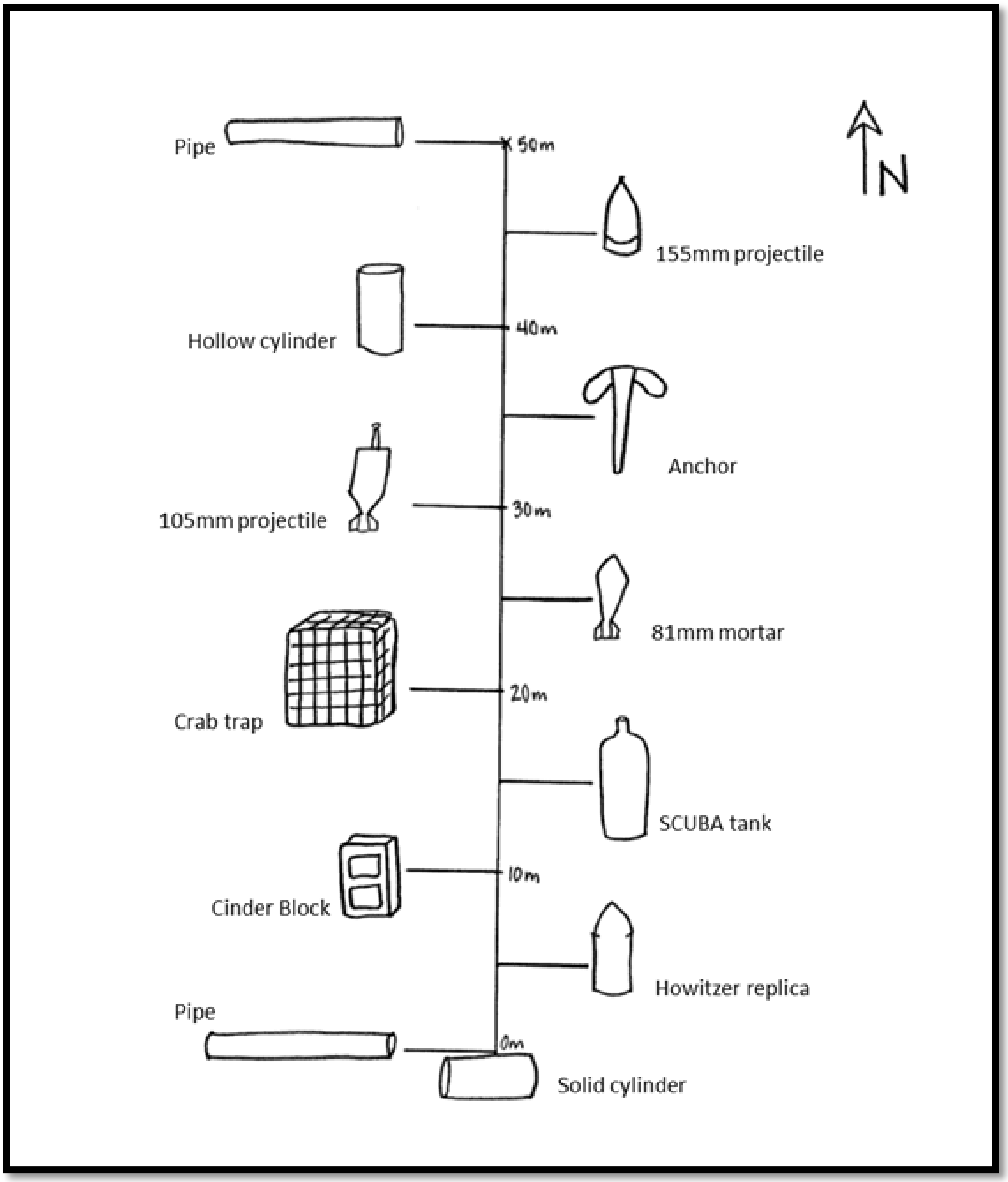


Figure 5. Deployment schematic of objects on the bottom of the sand site. Note: the drawing is not to scale.

3.1.4 Mud Site Target Deployment

The mud site was set up as soon as the sand site target placement was completed. At the mud site, the baseline deployment was approached differently based in part on experimental design differences, on lessons learned from the sand site deployment, and additional challenges expected at this site. The small tether clips were placed at the marks on the baseline rope every 5 m prior to its deployment in the water (Figure 6). In addition, small toggle floats were attached to the baseline approximately every 10 m to keep the baseline from sinking into the muddy bottom and being obscured from the divers' view. The baseline was attached to the solid aluminum cylinder, which was placed on the bottom in the same manner as that used at the sand site; however, the baseline was then stretched to the north by the boat guided by the onboard compass and GPS, and fed out from the surface. The northern end of the baseline was attached to the plate weight and lowered with the upline to keep the baseline taut. At the end of this phase of the setup dive, there was an upline on both ends of the baseline, the solid cylinder, a plate weight, and the baseline stretched between points. Because the uplines were in place all the targets were lowered to the bottom as before, six on each end of the baseline, before the divers entered the water. The two larger targets (Howitzer replica and 155 mm projectile) were placed on the southern end so lift bags could be used more easily on both if needed. In addition, the tether on the hollow aluminum cylinder was modified so it did not fall out during deployment.

Figure 6. The baseline for the mud site on the deck of the boat ready to be deployed. Visible items include the solid aluminum cylinder (bottom right corner), the baseline with small tether ends attached and small pieces of flagging tape to aid in visibility, the plate weight used to anchor the northern end, and the upline with buoy (blue bin on the upper right). Toggles used to attach floats to the line can be seen hanging in the upper left corner of the photo.

Divers from UW-APL conducted the initial dive descending on the southern upline. The goal was to tighten the upline for GPS data collection and sort out the targets that had been sent down, however because of communication and other technical issues, the divers returned to the surface earlier than expected.

The MSL divers then descended on the southern upline to continue the work, prioritizing the GPS data collection. One diver was able to pull the line taut while the other diver started to organize the targets on the baseline. The deployment scheme for the mud site is shown in Figure 7. The southern pipe was installed in position. The webbing sling on the solid cylinder was left on the object to facilitate its later retrieval. Once the GPS data collection was considered adequate (approximately 5 minutes) the team swam along the baseline to the northern point. The baseline bearing was most likely closer to 350° magnetic. At the northern end, the plate weight was checked for placement. One diver pulled the upline taut for the GPS fix while the other diver began organizing targets. One target (the hollow cylinder) was placed in position before the divers had to return to the surface.

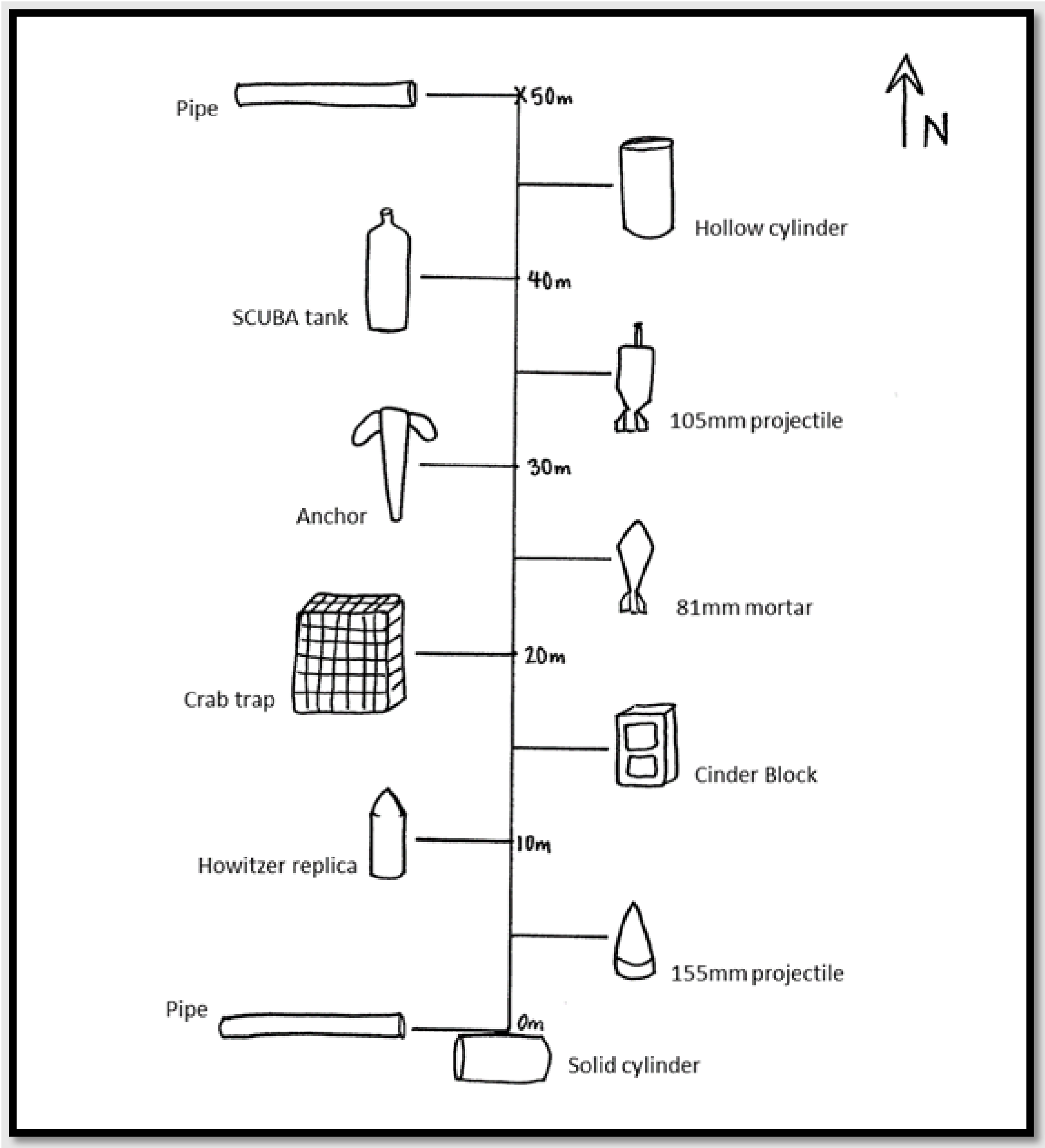


Figure 7. Deployment schematic of objects on the bottom of the mud site. Note: the drawing is not to scale.

The following morning, the UW divers entered the water at the southern end of the mud site for dive 3. They were tasked with moving the heavier Howitzer replica and 155 mm projectile into place at the beginning of the line. The divers reported that the heavier targets were difficult to move in the soft sediment because they tended to sink into the substrate and the divers could not brace themselves on the bottom without sinking in themselves. The two targets were deployed at the 5 m and 10 m marks.

The MSL divers conducted the fourth dive at the site, working from the northern end. They were able to position the northern pipe, the hollow aluminum cylinder (accidentally placed on the wrong side of the baseline previously), the SCUBA tank, 105 mm projectile, and the anchor during the dive, thereby finishing the northern end of the baseline.

The fifth dive was used to finish positioning the rest of the targets. The UW-APL divers were able to check on the position of the two larger targets before deploying the cinder block, crab trap, and 81 mm mortar. They were also able to retrieve their SCUBA tank used to fill the lift bag.

The sixth and final dive was conducted by the MSL divers to document the site and verify the position and orientation of the targets. They also decided to add two small toggle floats (Figure 8) approximately 10 m to the south of the solid cylinder to aid in finding the sites later. These toggle floats were only a few centimeters off the bottom in order to not interfere with the tow body during the engineering test. The divers descended on the southern upline to start the dive. One diver started to swim the line and verify the targets with a video camera while also transmitting the information to the boat using underwater communications. The other diver attached the two new toggle floats, with their buoyancy mitigated by dive weights, and released the southern upline before following the first diver along the baseline. The trailing diver released the small floats on the baseline as they progressed along the line, allowing the line to sit on the substrate. Once the survey was completed, the divers released the northern upline and followed it to the surface.

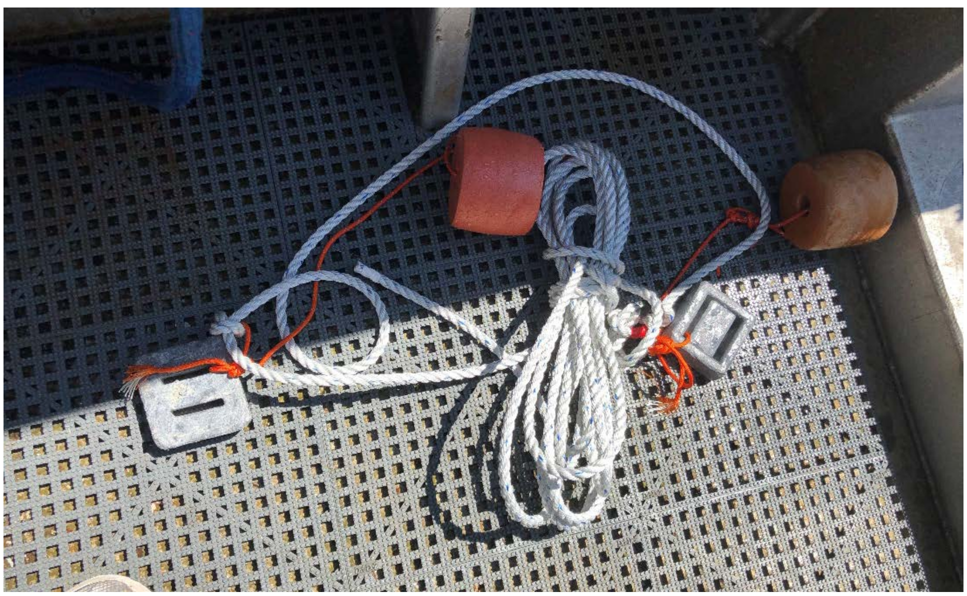


Figure 8. Toggle floats with dive weights and 10 m line added to the end of the mud site to aid in relocation.

While all targets were oriented correctly, not all targets were sitting proud on the surface. The surface of the mud substrate had a flocculent layer and many of the targets sank into the sediment and were not visible. Fortunately, the tethers allowed the divers to determine where the targets were located (e.g., Figure 9). From the south to the north the positions of the targets in relation to the surface at the time of deployment were as follows:

- southern pipe: on the surface
- solid aluminum cylinder: buried about 15 cm deep
- 155 mm projectile: buried about 8 cm deep
- cinder block: on the surface
- crab trap: on the surface
- 81 mm mortar: slightly buried
- anchor: on the surface
- 105 mm HEAT projectile: on the surface
- SCUBA tank: on the surface
- hollow aluminum cylinder: on the surface
- northern pipe: on the surface
- plate weight on the end of the baseline: buried on one end.

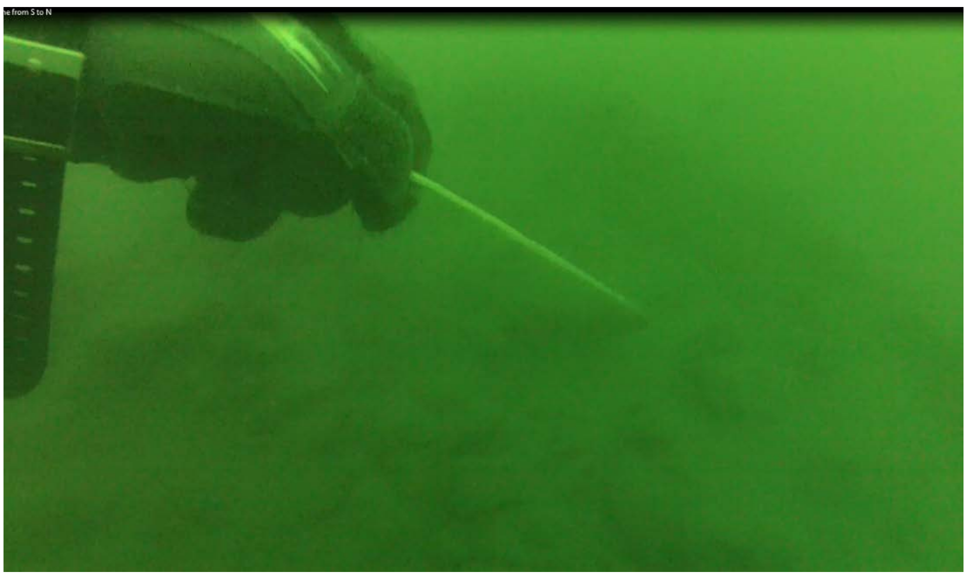


Figure 9. Example of a target (81 mm mortar) that sank into the sediment during the time of deployment without much disturbance to the bottom. The tether is the only clear indication that the target is at the designated location.

Overall, deployment of the mud site was accomplished with six dives over 2 days. Nothing was left in the water column to interfere with the tow body used during the engineering test except for two small toggles that were very close to the sediment and well below the 1 m threshold determined by UW-APL.

3.1.5 Geopositioning of Underwater Targets

The locations of the four baseline endpoints were determined using a Trimble Geo7x Global Navigation Satellite System (GNSS) device attached to an external Zephyr Model 2 antenna. The Geo7x was set to collect point data continuously at 1 Hz and was then placed in a splash-resistant container on a donut-shaped buoy. The antenna was screwed onto a 0.69 m rod that placed it approximately 0.75 m above the surface of the water and roughly in the center of the buoy. Divers took a line tied to the bottom of the buoy down to the baseline end point on the sediment surface. It was then tied to the end point or held in place with the line taut for a minimum of 5 minutes. The divers communicated to the surface when they were in position, the line was taut, and the start time was recorded on the surface.

Collected data were post-processed using Trimble Pathfinder Office software, which produces corrected positions by comparing the field data with a set of reference station data. After the field data were corrected, the 4 baseline end point data clouds were reduced to the 5-minute window described above and averaged to determine final coordinates. Figure 10 shows the reduced point cloud and averaged location for the end points of each baseline.

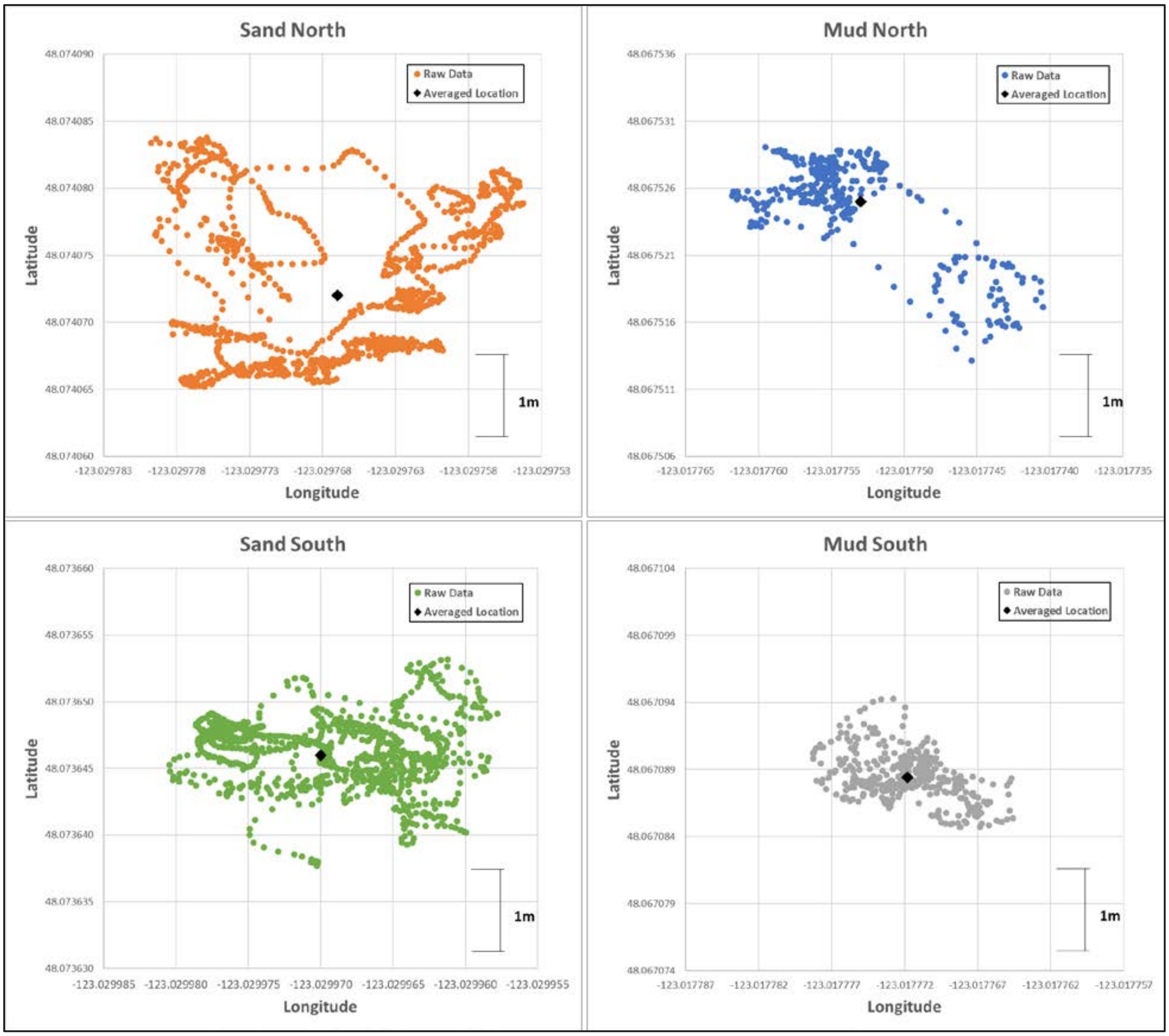


Figure 10. Reduced point cloud from GNSS data collection above the end points of the two baselines. Note that all data displayed are from the time of deployment except for the mud south site, where data were collected at the time of target retrieval.

Final GNSS positions are listed in Table 3. The standard deviation of these points was approximately 0.7 m. However, this does not consider the stretch in the buoy line or the buoy itself, so while the point cloud is relatively small there was potential shift because of wind or current. Final conservative error is estimated to be approximately 2 m.

Table 3. GNSS survey results from the deployment. All data are from GNSS measurements except for the mud south endpoints that were collected using the boat GPS.

Point Description	Target Deployment Date	Latitude	Longitude
sand south end	7/23/2019	48.073646	-123.029970
sand north end	7/23/2019	48.074072	-123.029767
mud north end	7/24/2019	48.067525	-123.017753
mud south end	7/25/2019	48.067033	-123.017767

During deployment of targets at the mud site, the south end point data became corrupted, so the position location was collected by boat GPS and used in its place. All data points were collected a second time when the targets were retrieved (October 2019) using the same collection and processing techniques as those described above. A comparison of the deployment and retrieval GNSS data is shown in Table 4. The comparison shows that the points were generally the same upon deployment and retrieval except for the mud south point, which was erroneous and expected to be different.

Table 4. GNSS survey results showing latitude and longitude collected at the time of target retrieval and the calculated difference in position between deployment and retrieval.

Point Description	GPS Date	Latitude	Longitude	Local Difference
sand south end	10/30/2019	48.073552	-123.029756	NA[(a)]
sand north end	10/30/2019	48.074069	-123.029764	0.4 m
mud north end	10/22/2019	48.067540	-123.017754	1.67 m
mud south end	10/22/2019	48.067088	-123.017772	6 m

(a) The data for the sand south end upon deployment were corrupted so a comparison could not be accurately made with the location upon retrieval.

For the FY 2019 engineering test, it was expected that a larger geolocation error might occur because of the type of equipment used for collecting positional data. The GNSS unit used for data collection is typically reserved for mapping and not recommended for survey data collection. The FY 2019 data collection effort will also inform methods for improved geolocation and positional accuracy in the future.

3.2 Engineering Test

The engineering test (reported elsewhere) was a 4-day effort conducted by UW-APL between September 9 and 12, 2019. UW-APL's research vessel, the 58 ft *R/V Jack Robertson,* was used to conduct the engineering tests of the MuST. The vessel transited from Seattle to Sequim Bay on September 8 and moored at John Wayne Marina in Sequim Bay for the duration of the field tests.

3.2.1 Shore-based Support

PNNL offered to provide shore-based logistical support and facilities at the MSL for the UW-APL staff during preparation and deployment of their towbody equipment. However, the UW-APL staff were able to perform all tasks associated with towbody deployment based out of John Wayne Marina and on the UW-APL research vessel, *R/V Jack Robertson*, without additional support.

3.2.2 Marine Mammal Observations

A trained PNNL Marine Mammal Observer (MMO) was positioned on the PNNL-MSL dock 30 minutes prior to and during acoustic operations to monitor entry of marine mammals, specifically cetaceans, into Sequim Bay. They communicated via field radio and cell phone with a UW-APL MMO aboard the *R/V Robertson* who concurrently monitored a 250 m mitigation zone around the sound source. Although no cetaceans were observed in Sequim Bay during the testing period of roughly 40 hours over 4 days, any non-Orca cetacean entering the mitigation zone would have resulted in a temporary shutdown of acoustic activity. Orca presence in Sequim Bay, regardless of the mitigation zone, would result in the termination of all acoustic activity until it was confirmed that the Orca had left the bay. Pinnipeds, specifically harbor seals (*Phoca vitulina*), were common in the study area and while their presence did not require a shutdown of acoustic activity, they were visually monitored for behaviors indicative of stress or injury. No behaviors indicative of stress or injury were noted.

3.3 Target Retrieval

The target retrieval process and its application at the sand and mud sites are described below.

3.3.1 Overall Retrieval Methods

Targets were retrieved at the end of October and beginning of November by PNNL-MSL divers, after UW-APL had finished their engineering testing. Because no surface expressions were left at the two sites, the divers initially had to find each baseline before recovering the targets. Once the baseline was located, a marking buoy was placed at the GPS location of one end of each baseline, allowing the divers to descend with a focal point for their baseline search. Once the end of the baseline was located, the marking buoy was attached to the end of the baseline and used as an upline during retrieval operations. The sites were then surveyed to determine the condition, orientation, and placement of all the targets before retrieval operations began. GPS locations were taken at each end of the baselines to compare them to the positions at deployment using the same techniques as before. Lastly, an upline was added to the northern working end of the baseline to allow the divers to access either end of the baseline during retrieval operations.

The R/V Strait Science was used to haul up targets after a line had been attached by the divers. Because there were concerns about tethers slipping off targets, lift lines were attached by other means to most targets. Items were clipped directly with a carabiner, placed in goodie bags, secured by a choke strap (i.e., lifting sling), or placed in specialized lifting harnesses (i.e., the solid aluminum cylinder). In most cases, each target was secured to its own lift line. However, some of the smaller targets were brought to a central location and attached together to a single line.

All targets were located and remained connected to the baseline and tethers, which made relocation of the objects much more efficient. While there were some issues with the substrate and visibility at times (see sections below), each site required relatively few dives to demobilize (see Table 5). All items were located and recovered from both sites.

Table 5. Summary of the number of dives and dive days needed to retrieve everything at each site.

Site	Number of Dives	Number of Days
Sand site	4	4
Mud site	7	4

An observation made at both sites was that most targets had some biofouling growth of organisms, primarily barnacles, that had occurred between their placement in July and retrieval in October. The biofouling occurred on exposed surfaces that were not buried in the sediment. In the future it is likely that targets deployed for extended periods on top of the substrate will become encrusted with biofouling organisms, which may change with the season and length of time under water. This will need to be accounted for in the setup, testing, and retrieval of the targets during future deployments. At the end of the retrieval operations, all targets were brought back to MSL and were photographed, removed of biofouling organisms, rinsed with freshwater, and securely stored.

3.3.2 Sand Site Target Retrieval

The sand site was relatively easy to locate because most objects were proud on the surface of the substrate and minimal resuspension of sediment occurred when approaching the bottom. An accurate drop of the marking buoy on the GPS point location put the divers immediately on the northern end of the site, allowing them to establish uplines and complete the survey during the first dive. All targets were accounted for but the location and/or orientation of some targets had changed. Most changes were confirmed by reviewing video recorded immediately following the target deployment and video recorded just prior to target retrieval. Figure 11 provides a diagram of the site as initially set up in July (solid lines) and before retrieval operations in October/November (dotted lines). Specifically, the differences included:

- The southern pipe was not perpendicular to the baseline and was past the end of the baseline.
- The solid aluminum cylinder was not perpendicular to the baseline.
- The crab trap had moved from the west side of the baseline to the east side of the baseline.
- The 81 mm mortar was rotated approximately 90° to the left with its nose pointing west (toward the baseline).
- The 105 mm HEAT projectile was rotated to the left and was pointing NNW. The target also appeared to be positioned a little more north because the tether was no longer perpendicular to the baseline.
- The anchor had been rotated 180° and was pointing south.

- The hollow aluminum cylinder had also moved from the west side of the baseline to the east side and probably moved a little north. The 155 mm projectile was a little closer to the baseline (i.e., the tether was loose).
- The northern pipe had moved from the west side to the east side of the baseline.

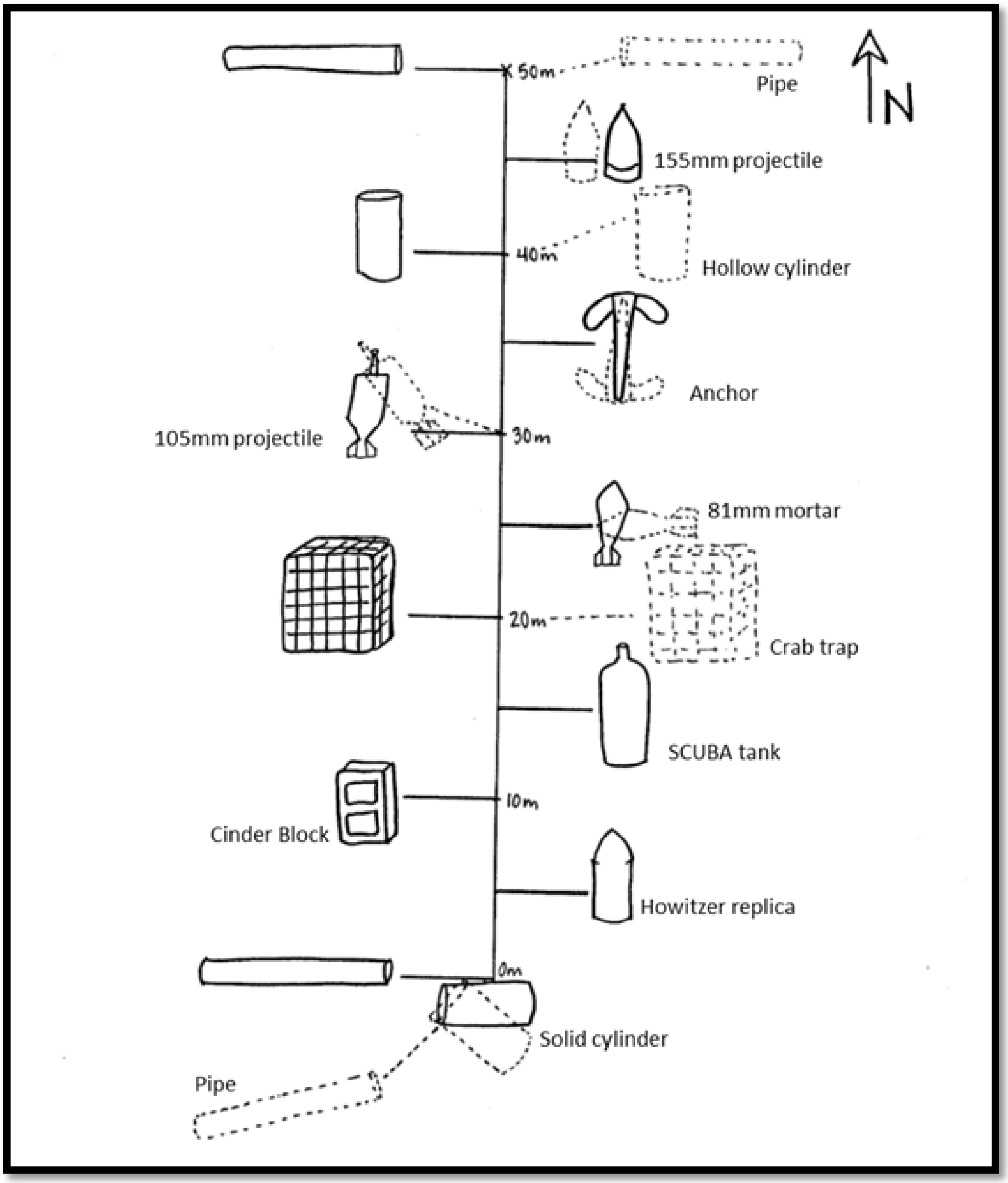


Figure 11. Deployment schematic for the sand site. The solid shapes indicate the locations of targets when they were deployed in July. The dotted shapes indicate their relative positions when they were retrieved in October, indicating movement had occurred since deployment. Note: the drawing is not to scale.

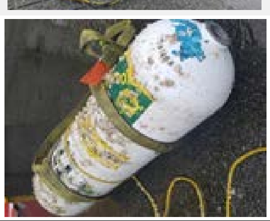
The mechanisms for these changes are still unclear, but several hypotheses are proposed:

- The initial placement was incorrectly documented. This explanation is only possible for the southern pipe. UW-APL indicated it was possible the pipe was placed farther south than intended and not noticed during the very poor visibility condition. However, all other target positions were confirmed by reviewing the initial and final survey videos, so this explanation is unlikely.
- Currents moved objects while they were deployed. Divers experienced some current on the bottom, but the current is typically not strong in this part of Sequim Bay compared to other locations (i.e., the navigation channel by MSL). The lighter, round objects such as the hollow cylinder could have been rolled by a persistent current. That would explain why the hollow cylinder, northern pipe, and the crab trap (not round but very light) all moved in the same direction from west to east. It is highly unlikely that the currents directly moved the more irregularly shaped objects. However, if the baseline was moving back and forth in the current, it could have pulled on the tethers of the targets. This is especially true in the middle of the baseline farther from the end anchors where any slack in the line would be amplified. The rotation of the 81 mm mortar and 105 mm projectile could be explained if the tethers were pulled because the mortar's tether was attached closer to the nose (pulling the nose toward the baseline if tugged) and the 105 mm projectile was tied closer to the fins (pulling the tail toward the baseline if tugged). While the baseline was relatively thin (3/8 in. potwarp) its length could produce significant drag in a current perpendicular to its orientation. However, there was no obviously visible indication of this type of disturbance to the substrate around the baseline, which would be expected if there was a persistent movement of the line.
- A target or line was snagged and dragged some of the array. The study area inside Sequim Bay is not closed to the public and there were commercial crabbing opportunities during the deployment. It is possible that a crab trap pulled part of the array and the lines as a crabber retrieved their (possibly snagged) trap. This would explain the rotation of the projectiles (described above), and the solid cylinder, the slight movement of the 155 mm projectile, and possibly the repositioning of one of the objects that moved. We would not have expected to observe the baseline as taut as was found during retrieval unless enough pressure had been placed on the line to pull the solid cylinder to the north. The slack in the line would have been dropped once a snagged crab trap became untangled and most likely not predicted to be straight, as was observed during retrieval. We also would have expected to see more of the tethers moved from perpendicular if the baseline had been moved and tugged on the tethers.

Examination of the UW-APL side scan sonar data indicates that the targets had been displaced by the time of the engineering test (Kevin Williams, personal communication). Therefore, the targets had shifted between the end of July and early September, rather than between the end of the engineering test and retrieval of targets at the end of October.

All targets at the sandy site were at least partially exposed to the water with some level of attached biofouling organisms (Table 6). It was relatively easy to determine how deep a target was buried in the substrate by the distinct line barnacles on the exterior of the target surfaces. In some cases, biofouling made recovery of targets more difficult than expected. For example, when the divers reattached the webbing harness around the solid aluminum cylinder, they found the form-fitting harness was difficult to slide over the barnacle-encrusted cylinder.

Table 6. Documentation of sand site targets at the time of their retrieval (October 2019). Notes include information about the final orientation of the objects at the sandy site.

Object type	Photo	Notes
155 mm projectile		Almost half buried in the sediment; only some barnacles on the top half
105 mm HEAT projectile		Settled into the sediment a few centimeters; only barnacles on the top portions of the projectile.
88 mm mortar		Sitting on top of substrate; nearly all unpainted surfaces with some barnacle growth
Howitzer replica		Almost half buried in the sediment; barnacles only on the top half
Solid aluminum cylinder		Approximately a third buried so the bottom was clean of biofouling (cylinder is upside down in photo)
Hollow aluminum cylinder		Almost entirely on the sediment surface. Barnacles colonized almost all the inner surface and most of the outer surface.
Cinder block		Almost entirely exposed (proud) on the surface
Anchor		Only partly buried but did not host many barnacles (likely because of the galvanized coating)
Crab trap		Sitting on the surface of the sediment; had barnacles on all but the very bottom
SCUBA tank		Approximately half buried; had some barnacles on the top

3.3.3 Mud Site Target Retrieval

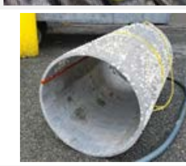
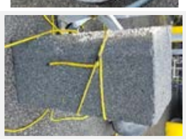
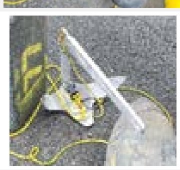
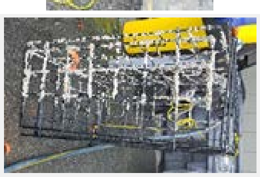
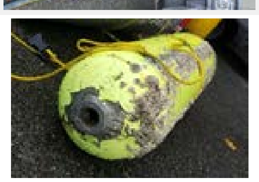
Retrieval of targets at the mud site was more difficult than at the sand site and took almost twice as long, primarily because of the difficulty in seeing the site when working on the bottom. The visibility was poor because the sediment was easily resuspended and did not settle quickly. In addition, because many targets had sunk into the flocculent sediment it was difficult to see their locations. More than half the targets were completely or nearly buried (Table 7), but all were in place and did not appear to have changed location or orientation since the time of their deployment.

Locating the muddy site required two dives. During the first dive, the divers quickly located toggles placed to the south of the baseline for relocation purposes. However, because visibility was compromised by digging to find the tagline that would lead divers to the baseline, the divers attempted instead to follow a compass bearing to find the first targets. This attempt was unsuccessful and the dive ended. During the second dive, the divers located the south end of the baseline quickly because of improved initial visibility and the use of the tagline leading from the toggles to the first target. Divers conducted the survey, collected new GPS points for both ends of the baseline, and moved several targets together for more efficient retrieval during subsequent dives.

All targets were retrieved from the mud site during subsequent dives, but these retrievals were more complicated than those conducted at the sandy site because many targets were buried. Without tethers leading from the baseline to each target, it would have been difficult to find most of the targets. In addition, it was physically challenging to dig out and attach lines to the heavy, deeply buried targets that would then allow for them to be lifted by the boat. For example, the 155 mm projectile and Howitzer replica had sunk to full arms-length depth in the mud. Digging was difficult without having a firm substrate to brace against or solid sediment to rest a partially lifted target upon. The mud continuously caved in on itself and re-filled during every attempt at excavation. In the end, a choke strap was pushed onto the target by feel inside the mud-filled “hole” with the diver’s face at the mud surface and arms holding the strap extended into the substrate. The boat had to pull the target free. Pre-planning for anticipated retrieval difficulties was key to the success in retrieving all targets, including leaving the baseline in place, tethering all targets to the baseline, leaving the lifting harness on the solid cylinder, and planning ways for the boat to pick up targets individually (e.g., with cinch straps) or in small groups (e.g., in goodie bags).

The presence of biofouling organisms on the targets was much less substantial than at the sand site, primarily because most targets were partially or fully buried in the sediment (Table 7). However, as was observed at the sand site where target surfaces were exposed, barnacles had attached on the targets.

Table 7. Photographs of and information about the final orientation of the targets at the mud site. Note: the order presented is not the order of deployment on the baseline.

Object Type	Photo	Notes
155 mm projectile		Deeply buried (>60 cm); no barnacle growth
105 mm HEAT projectile		Completely buried in 10–15 cm of sediment; no barnacle growth
88 mm mortar		Completely buried in 10–15 cm of sediment; no barnacle growth
Howitzer replica		Deeply buried (approximately 45 cm); no barnacle growth
Solid aluminum cylinder		Completely buried in the sediment; no barnacle growth. The top of the cylinder was just below the sediment surface
Hollow aluminum cylinder		Approximately half buried in the mud with some biofouling on upper half
Cinder block		One small corner of the block was exposed above the sediment; the exposed surface had barnacle growth.
Anchor		The anchor was almost entirely buried; very few barnacles on the exposed arm.
Crab trap		Rested on the surface of the sediment with only the bottom 8–10 cm buried; barnacles covered the rest of the trap
SCUBA tank		About half buried; barnacles only on the exposed surface of the tank

4.0 Future Deployments

Overall, the FY2019 field operations were a success. Pre-planning with SERDP/ESTCP colleagues, collaborative discussions with UW-APL, and previous experience of PNNL-MSL staff working in Sequim Bay allowed for a successful engineering test and associated field operations. Lessons learned from Phase I can inform Phase II and future deployments. Listed below are some challenges that were encountered, and possible solutions for some of those challenges However, it is also recognized that one solution may not solve every circumstance, especially with respect to varying remediation system developers' requirements and grid layouts.

- Test site locations. The mud site was difficult to operate in because heavy objects sank into the substrate and siltation obscured divers' ability to see. Previous bathymetry surveys (Figure 1) indicate coarser, yet still muddy substrate is located farther north. While the water depth at a more northerly site may be greater than at the 2019 mud site, it would be advantageous to move the mud site to facilitate finding and eventually removing targets in the future. Data collected in Sequim Bay by UW-APL during 2019 (i.e., Hefner MR18-1406 sediment acoustic response, Williams MR18-5004 – engineering test) could help inform relocation to a preferred mud site.
- Test deployment scheduling. Throughout the year, there are several periods of activity in Sequim Bay by recreational, commercial, and tribal fishermen. During crab and shrimp seasons boat traffic increases and marking buoys are present in the bay. These markers may impede a research vessel running along pre-determined track lines. Also, the fishing activity may introduce additional, undocumented clutter to the study area. Shrimp and crab seasons are known generally, but specific dates for openings and closings may not be set until a few days beforehand, especially for tribal fisheries. It would be a good practice to close the test bed to target testing during periods when crabbing activities are often most intense, generally in July and August. The recreational halibut season generally takes place several days per week during the month of May. While halibut are not fished for inside the bay, moorage at John Wayne Marina is often very limited unless plans have been made well in advance.
- Export Control. Several of the inert munitions used during this study were determined by PNNL to be Category III items on the International Traffic in Arms Regulations (ITAR) list and therefore subject to export control requirements by PNNL. Appropriate technology control plans may need to be established to handle equipment and inert munitions prior to its arrival at the PNNL Sequim campus.
- Permitting. Permitting for the 2019 placement of targets and the subsequent engineering test in Sequim Bay was successful. The permits expire in January 2021. The application process for renewal of existing permits for an additional 5 years is currently under way. Assuming renewal of the permits is granted, testing similar to FY 2019 will be allowed. In the future, each new technology that is brought forward by remediation system developers will need to be compared to pre-permitted conditions (e.g., acoustic signatures) to assure they meet permit requirements. Any proposed testing that falls outside the conditions allowed by the permitting agencies will require a new permit; whose acquisition is not guaranteed. Such permits may take up to 6 months, depending on the permit type and the agencies involved
- Target placement and retrieval. To date, the most challenging part of field operations has been the placement and retrieval of the target objects. The possible solutions to these challenges will vary depending on future project designs, developer systems being deployed, and the duration of deployments. It is suggested that any future activities be as

flexible as possible when considering options and tailoring solutions to a particular mission, or field season's mission. With that caveat, the following observations based on the current test could inform future activities:

- Handling of targets. The targets (clutter, scientific, and inert) used in this test were not physically altered to enhance ease of their deployment. While some clutter targets (e.g., the anchor and crab trap) could be easily attached to the tether, lift lines, etc. for deployment, most of the targets offered no secure attachment point. For example, the inert targets all had tapering cylindrical bodies, which made the possibility of straps slipping off the target a concern. Because of these constraints, the lowering and raising of targets was more time-consuming and less secure. A slight modification of some objects (e.g., adding a ring to clip capable of supporting the weight of the target) would make all stages of target manipulation more efficient.
- Underwater visibility in soft substrate. The mud site chosen for the FY 2019 test had a flocculent layer of fine sediment on the surface that was easily resuspended once the divers started working on the site, thus reducing the visibility to nearly zero at times. In addition, the flocculant layer on the bottom obscured the guidelines as they sank into the substrate; hence it was difficult for the divers to navigate the site visually. It is suggested that a mud site with less flocculent material within SB3 permitted area be used for future testing, and lines for navigation be set up to facilitate working at the site. The practice of having only one dive team (i.e., one buddy pair) in the water at a time on a site should be continued, so additional divers are not stirring up the sediment. To enhance visibility, this practice would assure undisturbed areas as a dive team is working.
- Depth. The areas chosen for this year's testing were over 20 m in depth, which proved challenging. The bottom time available to divers was limiting and divers could not stay onsite and accomplish as much during each dive compared to dives conducted in shallower locations. This reality was compounded on occasion by the attenuation of light due to plankton blooms or suspended solids increased after storm events. Consideration should be given to the selection of sites that are less than 20 m deep.
- Navigation lines. Navigation lines (e.g. the baselines and tethers) aided divers in navigating the sites more efficiently, finding sunken targets, and limiting movement of targets on the bottom. They also provided an added layer of safety for divers during periods of poor visibility. However, it is recognized that navigation lines can have negative impacts and may not be appropriate in some circumstances. Navigation lines may increase the chance of targets being moved if a line is caught by someone's anchor or fishing gear or if it provides enough drag in a current. A navigation line may also be visible to several technologies, and inappropriate for use in open and blind grid design layouts.
- Geopositioning of targets. The methods used for the FY 2019 engineering test were considered adequate, however improved accuracy is necessary to meet the long-term requirements of test bed operations. There are several options, however there are tradeoffs between cost, accuracy, and functionality depending on grid layout, number of targets, and remediation system developers' technologies.
    - Underwater positioning using divers. Ultra-short Baseline Positioning Units (USBLs) are becoming much more accurate as better GPS technology at the surface, inertial and/or bottom tracking capabilities, and better buoy-supported telemetry becomes available. Depending on the system, these units have navigation displays for the boat operators, divers, or both to monitor and record a dive. Vendors such as Shark Marine (www.sharkmarine.com), Ensign Subsea Systems (www.ensignsubsea.com),

EdgeTech (www.edgetech.com) and Kongsberg (km.kongsberg.com), for example, reportedly have units that can provide sub-meter accuracy on the bottom within a certain range of the boat. Other technologies, such as the Diver GPS from DiveNET (www.divenetgps.com) using relay buoys on the surface, can also achieve submeter accuracy. This level of accuracy is the goal in the future at the SBU2 test bed, for placing, validating placement, and retrieval of targets during test site operation. The cost of these technologies can range widely (e.g. between $40,000 and $200,000). Leasing options are available for most technologies as well.

  - Active tagging. Active tags similar to the Juvenile Salmon Acoustic Telemetry System tags developed at PNNL (https://waterpower.pnnl.gov/hydropower/pdfs/fish_tagging.pdf) could be attached to targets, and with the use of positioning buoys or bottom mounted receivers could mark all targets in range. The advantages of this technology include being able to mark many targets at once with excellent accuracy, and possible costs less than a USBL system. However, this technique can be labor-intensive when setting up receiving buoys and removing them prior to the testing and would not allow for real-time monitoring of divers' movements. Other uncertainties at this time relate to how functional they would be if buried in substrate and the inability to cover a larger grid area without substantial investment of more infrastructure in the water. In addition, the acoustic signal would be visible to some developers' technologies.
  - Boat-based Acoustic Surveying. It is possible to use a survey-grade single-band sonar to map a grid if the targets are visible to the equipment. This capability could be enhanced by adding a reflector to the targets for a survey, but the reflectors would need to be removed for testing, which would require another round of dives. This also has the disadvantage is not having a real-time tracking component to guide divers to the site.
  - Use of a landmark. A more simplified technology could be used to locate targets by placing various markers in the substrate, such as the helical anchor that was used to secure the northern end of the sand site baseline, and then determining a distance and bearing to each target. However, this methodology would require numerous markers that would likely be visible to all technologies being tested at the site. The accuracy of the target positioning would depend on the method used to survey the markers and would decrease with greater distance from the markers.

- Target array design. For the FY 2019 engineering test, targets were placed in an offset linear fashion with short distances between targets. A navigation baseline was also used to support deployment and retrieval of the targets. The proximity of targets to each other was very efficient for the divers, simply because more targets could be placed during any given dive. With the appropriate positioning equipment and a reasonable expectation that targets would not sink to unreasonable depths into the substrate, a larger grid array is possible. However, this will require additional resources in terms of the number of dives and time, both for deployment and retrieval. Pre-planning and thoughtfully carried out logistics will help assure an efficient operation.

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