PNNL-34067

Sequim Bay Underwater UXO Demonstration Site: Field Operations Summary, 2022

May 2023

D Woodruff
J Haxel
T Myers
J Vavrinec
S Zimmerman

U.S. DEPARTMENT OF ENERGY

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D Woodruff
J Haxel
T Myers
J Vavrinec
S Zimmerman

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

This report provides a summary of the Pacific Northwest National Laboratory's (PNNL's) conduct of operations of the Sequim Bay Underwater Unexploded Ordnance (UXO) Demonstration Site in Washington State. More than 400 underwater locations in the U.S. have been identified by the U.S. Department of Defense as containing munitions from past military training and weapons testing, thereby posing a threat to human health and the environment. To address the challenge posed by this threat the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) underwater Munitions Response (MR) program is supporting the development and operation of several standardized UXO demonstration sites ("testbeds") to rigorously evaluate technologies that can detect, geolocate, and classify proud and buried munitions in 0–35 m water depths. Sequim Bay in Washington state is one of four demonstration sites located in U.S. coastal waters. PNNL-Sequim is located near the entrance to Sequim Bay, where it provides operational, logistical, and facilities support for testbed activities.

The primary objectives of testbed operations for the 2022 field season were as follows:

1. Deploy a calibration line and blind site test area at the Sequim Bay demonstration site, including placement, geolocation, and retrieval of a variety of inert UXO and clutter items on sand/mud sediments in ~25 m deep water.
2. Provide operational support for scored demonstrations of the Applied Physics Laboratory – University of Washington (APL-UW) multisensory towbody (MuST) and the Black Tusk Geophysics/Tetra Tech UltraTEMA-4, an electromagnetic induction (EMI) technology.
3. Operationalize a commercial, ultra-short baseline (USBL) target geolocation technology for use at the demonstration site.
4. Collect target ground-truth data and environmental site information to support testing and evaluation scoring protocols.
5. Install a permanent Global Navigation Satellite System base station referenced to a known geodetic marker on PNNL property to be used for real-time kinematic Global Positioning System operations at the Sequim Bay demonstration site.

The 2022 demonstration area was in the same vicinity as previous years (2020–2021). The site plan included a 100 m diameter "blind" site circle and a single calibration line to the north used by both technology demonstration performers. A total of 80 targets were emplaced at the underwater demonstration sites for 2022. Sixty-one targets were emplaced at the blind site, including 37 inert and replica munitions, 2 industry standard object (ISO) pipes, and 22 clutter items. An additional 19 objects were emplaced along a 100 m calibration line (10 inert UXO items, 2 Howitzer replicas, 4 ISO pipes, and 3 clutter objects). All targets were placed proud on the seabed surface, except for four that were buried flush with the seabed on the calibration line.

Ground-truth information collected by PNNL divers for each target included target type, placement characteristics in/on the seabed, and underwater geolocation. The information from the calibration lines was provided to the technology developers prior to their respective demonstration tests. All information related to the blind site targets was withheld until the results of a scored target detection and classification exercise were evaluated by the Institute for Defense Analyses (IDA), the independent SERDP/ESTCP scoring team. The demonstration by Black Tusk/Tetra Tech's UltraTEMA-4 technology was conducted during the third week of

September 2022, followed by the APL-UW demonstration of the MuST technology during the first week of October. After the field trials, targets were retrieved from Sequim Bay by PNNL divers and stored at PNNL-Sequim for deployments in future years.

The fiscal year 2022 field operations were executed effectively. Early planning with the SERDP/ESTCP office and collaborative discussions with APL-UW, Black Tusk, and IDA resulted in successful munitions remediation technology demonstrations. Risk mitigation protocols, adaptive management, and flexibility implemented by PNNL and all collaborators allowed continued and successful completion of field activities.

Acknowledgments

We thank David Bradley for guidance and support from the SERDP/ESTCP office. We also thank Mike Richardson, Mike Tuley, Dan Kolodrubetz, and Jacob Bartel of the Institute for Defense Analyses for insightful conversations related to target layout, target geolocation, and scoring. Collaboration with project teams, including APL-UW (Kevin Williams-PI), Black Tusk Geophysics and Tetra Tech (Steve Billings-PI), was critical to successful 2022 field operations.

Acronyms and Abbreviations

3-D	three-dimensional
ADCP	Acoustic Doppler Current Profiler
APL	Applied Physics Laboratory
AUV	autonomous underwater vehicle
CTD	conductivity, temperature, depth
DoD	U.S. Department of Defense
eBOSS	EdgeTech Buried Object Scanning System
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GAPS™	Global Acoustic Positioning System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEAT	high-explosive anti-tank (projectile)
IDA	Institute for Defense Analyses
ISO	industry standard object
MCRL	Marine and Coastal Research Laboratory
MR	Munitions Response
MuST	Multi-Sensor Towbody
NGS	National Geodetic Survey
PFFP	portable free-fall penetrometer
PNNL	Pacific Northwest National Laboratory
PSU	Practical Salinity Unit
RMSE	root mean square error
ROV	remotely operated vehicle
RTK	real-time kinematic
SERDP	Strategic Environmental Research and Development Program
TEMA	towed electromagnetic array
USBL	ultra-short baseline
UW	University of Washington
UXO	unexploded ordnance
WSRN	Washington State Regional Network

Contents

Figures

Tables

1.0 Introduction

Military munitions exist in more than 400 underwater locations in the United States as a result of past training and weapons testing activities at current and former U.S. Department of Defense (DoD) sites. Underwater sites include ponds, lakes, rivers, estuaries, and coastal ocean areas ranging from very shallow (<5m) to deeper (5–35 m) water locations, and they can pose a threat to human health and the environment. The DoD's Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) Munitions Response (MR) programs have been funding the development and demonstration of technologies that can detect, geolocate, and classify military munitions in underwater sites. A key aspect is development of standardized demonstration sites ("testbeds") for underwater unexploded ordnance (UXO) at which to demonstrate and verify the detection, classification, and localization (DCL) systems. Testbeds currently under development or in operational use include Moku o Lo'e, HI; Panama City, FL; La Spezia, Italy; and Sequim Bay, WA. Each site has unique environmental and geophysical features that allow evaluation and comparison of technologies in well characterized and controlled settings. A variety of platforms (e.g., towed systems, autonomous underwater vehicles [AUVs], remotely operated vehicles [ROVs], airborne) and sensors (acoustic, magnetic, electromagnetic induction [EMI], optical) are being evaluated.

An underwater UXO demonstration site has been established in Sequim Bay, WA, with operations supported by Pacific Northwest National Laboratory (PNNL). Initial development beginning in 2016 (SERDP project MR-2735), focused on site evaluation and characterization; permitting; development of testbed designs; and establishing techniques for accurate placement, geolocation, and recovery of targets from the seafloor. PNNL hosted several prototype demonstration surveys in 2019 and 2020, providing testbed operational support for the Applied Physics Laboratory – University of Washington's (APL-UW's) multisensory towbody (MuST) acoustic technology. In 2021, operations were expanded to include a scored demonstration of the MuST technology and support for an engineering test of Black Tusk/TetraTech's EMI UltraTEMA-4 technology.

This report summarizes 2022 operations at the Sequim Bay underwater UXO demonstration site, including planning and permitting, testbed design, target placement and retrieval, target geolocation and ground-truth data collection, environmental data collection, and operational support for two technology demonstrations.

2.0 Project Overview

Sequim Bay underwater UXO demonstration testbed operations this year included scored demonstrations of two DCL systems, one acoustic and one EMI, during the fall of 2022. Operations to support technology demonstrations included the following tasks:

1. Planning and permitting for testbed activities during the field season
2. Developing a testbed design for target placement
3. Acquisition and deployment of an ultra-short baseline (USBL) underwater navigation system for target placement
4. Emplacement and retrieval of inert UXO and clutter items at the demonstration testbed
5. Installation of a Global Navigation Satellite System (GNSS) base station for accurate geopositioning support
6. Collection of target ground-truth information and environmental data
7. Hosting Black Tusk/Tetra Tech's demonstration of the EMI UltraTEMA-4 technology (September 19–22) and APL-UW's demonstration of the acoustic MuST technology (October 3–6).

PNNL-Sequim staff, with concurrence from the SERDP/ESTCP office, selected a test area in Sequim Bay for demonstrations to be conducted in 2022 (Figure 1). This year's testbed was in the same vicinity as the testbed in 2020 and 2021, with some site design modifications. The site plan included a 100 m diameter "blind" site circle and a calibration line (Figure 2). Divers emplaced 61 objects at the blind site, including 37 inert munitions, 2 industry standard object (ISO) pipes (Nelson et al. 2009), and 22 clutter items. An additional 19 objects were emplaced along a 100 m calibration line (10 inert UXO, 2 Howitzer replicas, 4 ISO pipes, and 3 clutter objects). All targets along the calibration line were placed on the seabed surface (proud) except for four targets that were buried flush with the seabed.

PNNL divers and support vessel crew collected a suite of ground-truth information including target metadata (e.g., geolocation, burial depth, tilt, orientation) and environmental characterization data (e.g., wave height, wind speed, turbidity) during field operations to support the evaluation of DCL technology effectiveness. Calibration line target information was provided to the technology developers prior to their respective demonstrations. Information related to the blind site targets was withheld until the results of the independently scored target detection and classification were evaluated by the Institute for Defense Analyses (IDA). The demonstration of the UltraTEMA-4 technology occurred in late September 2022, followed by the MuST technology demonstration in early October 2022.

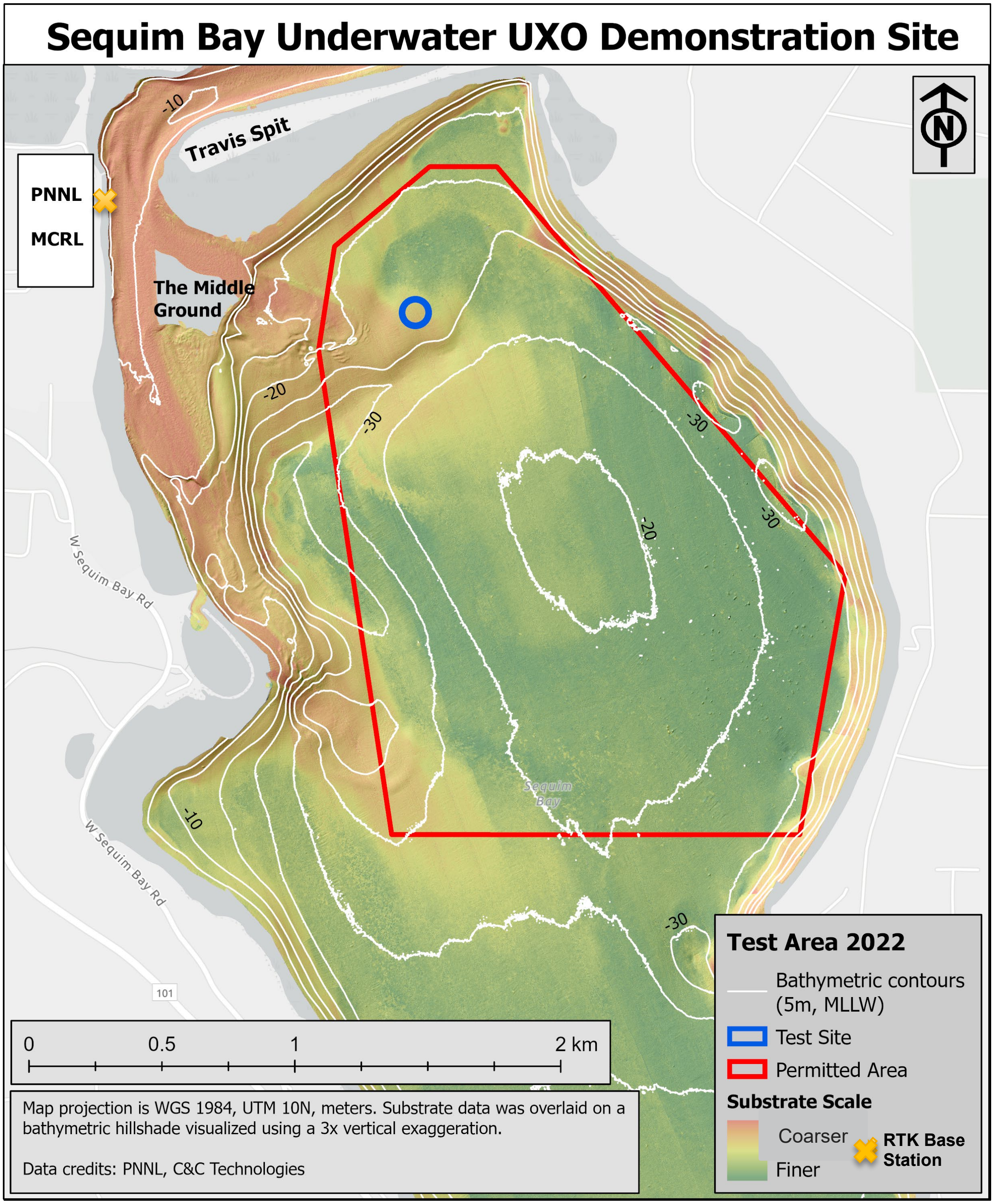


Figure 1. Location of the Sequim Bay underwater demonstration site (blue circle) for the 2022 field season.

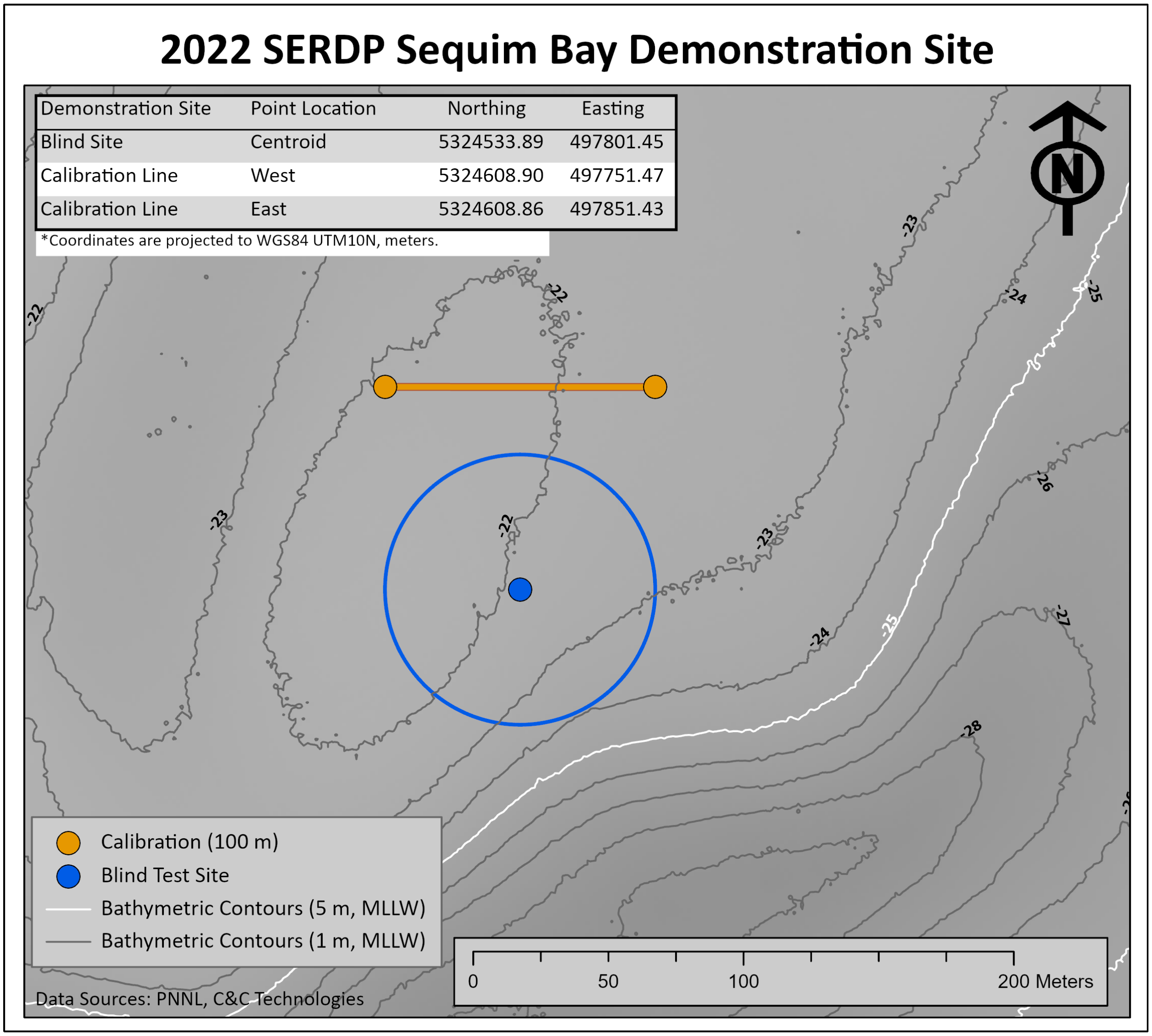


Figure 2. Location of the blind site (blue circle) relative to the calibration site (orange line) in Sequim Bay in 2022.

3.0 Project Planning

Project planning for the Sequim Bay underwater demonstration test site involved discussions regarding site selection and location, target layout design, permitting for test site use, and coordination with technology developers related to logistical operations.

3.1 Timeline

The schedule of planning and operations for 2022 (Table 1) was similar to previous years.

Table 1. Timeline of events for the 2022 Sequim Bay demonstration test site activities.

2022 Sequim Bay Test Site Activities	2021	2022												2023		
	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Administrative/Planning/Operational Support																
Scoping / Target Field Design	■	■	■	■	■											
Permitting for Test Site / Technology Use				■	■	■	■	■	■							
Target Selection / Acquisition / Inventory / Preparation					■	■	■	■								
Hosting Test Site Observers										■	■					
Field Operations																
Environmental Characterization										■	■	■				
Target Placement								■								
UltraTEMA-4 (Black Tusk, Tetra Tech) Sept 19th-22nd										■						
MuST (APL-UW) Oct 3rd-6th											■					
Target Geolocation / Ground Truthing										■	■	■				
Target Retrieval															■	■
Field Summary Reporting													■	■	■	■

Planning and scoping for testbed demonstrations began in late 2021 and were built upon previous years' activities and test site designs (Woodruff et al. 2022, 2021, 2020). Permitting for target placement at the test site and technology use of the site were governed by existing permit authorizations described in Section 3.2.

Field operations (Section 4.0) were coordinated between technology demonstrators and PNNL staff emplacing targets and collecting ground-truth information. Most field activities occurred between July and November of 2022. Targets were retrieved beginning in February 2023.

3.2 Environmental Permit Authorizations

An existing 5-year PNNL Scientific Research Plan and associated environmental authorizations related to the Department of Energy's marine research activities were used for the 2022 field season activities to the extent possible. The permits and authorizations included those related to and received from the following:

- *National Environmental Protection Act* – Department of Energy's Categorical Exclusion for Aquatic Research
- Section 106 of the *National Historical Preservation Act*, Cultural Resources Review – Washington State Historic Preservation Officer
- *Endangered Species Act*, 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 – 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.

Under the Research Plan and associated authorizations, SERDP/ESTCP testbed-related activities were approved for use in the permitted area (Figure 1), including the following:

1. The placement and surficial burial of targets, and placement of diver-installed anchors and survey grids
2. The operation of an iXblue Global Acoustic Positioning System ultra-short baseline (GAPS™ USBL) acoustic tracking system on several research vessels
3. The operation of APL-UW's doppler velocity log sonar, side scan sonar, EdgeTech Buried Object Scanning System synthetic aperture sonar (eBOSS SAS), and multibeam sonar. Concurrence/authorization for each activity was granted prior to work commencing.

As part of the PNNL permit requirements, a trained marine mammal observer or designated observer was aboard each research vessel during use of the geolocation equipment (iXblue GAPS USBL), and the operation of the MuST. Observations of cetaceans (whales) within a prescribed area around the acoustic source would have resulted in a temporary shutdown of acoustic activity. Observations of killer whales specifically (*Orcinus orca)* anywhere in Sequim Bay, regardless of the mitigation zone, would have resulted in the cessation of all acoustic activity until it was confirmed that the whale had left the bay. Their presence was not expected and was not observed during any test activities. Harbor seals (*Phoca vitulina*) were occasionally present in the study area and, while their presence does not require a shutdown of acoustic activity, they were visually monitored for behaviors indicative of stress or injury. No such behavior was observed.

3.3 Target Acquisition and Storage

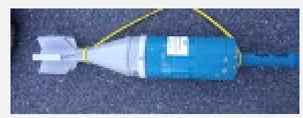
Targets from the PNNL inventory (described by Woodruff et al. [2022]) were supplemented with additional targets from the U.S. Army Aberdeen Training Center; the type and number were selected by the SERDP office and PNNL. All targets are labeled and inventoried as described by Woodruff et al. (2022). Targets were deployed in July 2022. All items were retrieved after the demonstrations and ground-truth data collection was complete. The targets are stored at PNNL-Sequim in secured, covered storage facilities with appropriate administrative oversight.

3.4 Testbed Design

The 2022 demonstration area (Figure 1) was in the same vicinity as 2021 area; however, the calibration line was located to the north of the blind site (Figure 2), compared to the 2021 test site design that had two calibration lines located south of the blind site. The design this year for the calibration line included reference targets for both demonstration teams' technologies (i.e., inert UXO and replicas, ISO pipes, clutter) (Section 3.4.1), and the blind site included inert UXO, ISO pipes, and clutter items (Section 3.4.2). The blind site provided the basis for an independently scored evaluation of the demonstrators' technologies.

The types of targets used in 2022 are listed in Table 2.Additional specifications and details about the targets used are described in Section 4.4.

Table 2. Types of targets used in the Sequim Bay underwater testbed during 2022.

Type	Description	Length (cm)	Width (cm)	Weight (kg)	Photo
Inert Munition	155 mm Howitzer replica	59	20	40.6	
	155 mm Howitzer M107	60	15.5	36.5	
	105 mm projectile, high-explosive anti-tank (projectile) (HEAT)	65	9	10.9	
	105 mm projectile, M60	39	10	13.4	
	81 mm mortar, M889	26	8	2.9	
	81 mm projectile, M821	43	8	3.9	
	60 mm mortar, M49	15	6	0.9	
	40 mm shell, L70	21	4	0.9	
ISO Pipe	8" ISO pipe	20.4	5.8	0.9	

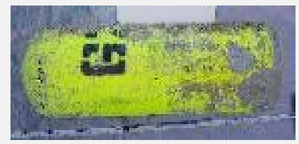
Type	Description	Length (cm)	Width (cm)	Weight (kg)	Photo
	12” ISO pipe	65	18	4.1	
Example Clutter	Scuba tank	65	18	14.7	
	Anchor	48	30	5.4	
	Cement block	40	20	18.1	

Table 3 lists the number of each target type emplaced at the reference and blind sites. A total of 80 objects were placed in the testbed, including 61 items at the blind site, and 19 items along the calibration line.

Table 3. Number of targets and clutter emplaced at the calibration and blind sites.

Type	Description	Number of Objects Blind Site	 Calibration Site	 Total
Inert UXO	155 mm Howitzer replica	0	2	2
Inert UXO	155 mm Howitzer M107	1	2	3
Inert UXO	105 mm projectile HEAT	4	2	6
Inert UXO	105 mm projectile M60	4	2	6
Inert UXO	81 mm mortar M889A1	9	1	10
Inert UXO	81 mm mortar M821	9	1	10
Inert UXO	60 mm mortar M49	8	1	9
Inert UXO	40 mm shell L70	2	1	3
	Total # of Inert UXO	**37**	**12**	**49**
ISO Pipe	12” ISO pipe	0	2	2
ISO Pipe	8” ISO pipe	2	2	4
	Total # of ISO Pipes	**2**	**4**	**6**
Clutter*	**Total # of Clutter Objects**	**22**	**3**	**25**
Total # of Objects in Site		**61**	**19**	**80**

* Clutter Items (eg. crab traps, scrap metal, propeller, chain, radar reflector, anchor, cement block, scuba tank)

3.4.1 Calibration Site

The calibration site was established by divers using a 100 m long baseline consisting of 3/8” (9.5 mm) Everson Proline groundline. It was placed in an east–west configuration and secured at each end by screw anchors at 0 and 100 m. The remaining targets were placed along the baseline at 5 m intervals, alternately offset to each side of the baseline with 2 m tethers made of 1/8” Amsteel line. The placement configuration is shown in Figure 3. Four targets were buried flush with the sediment (155 mm Howitzer, 155 mm Howitzer replica, 105 mm high-explosive anti-tank [HEAT] projectile, 105 mm M60). Other inert UXOs and clutter were placed proud on the seabed surface.

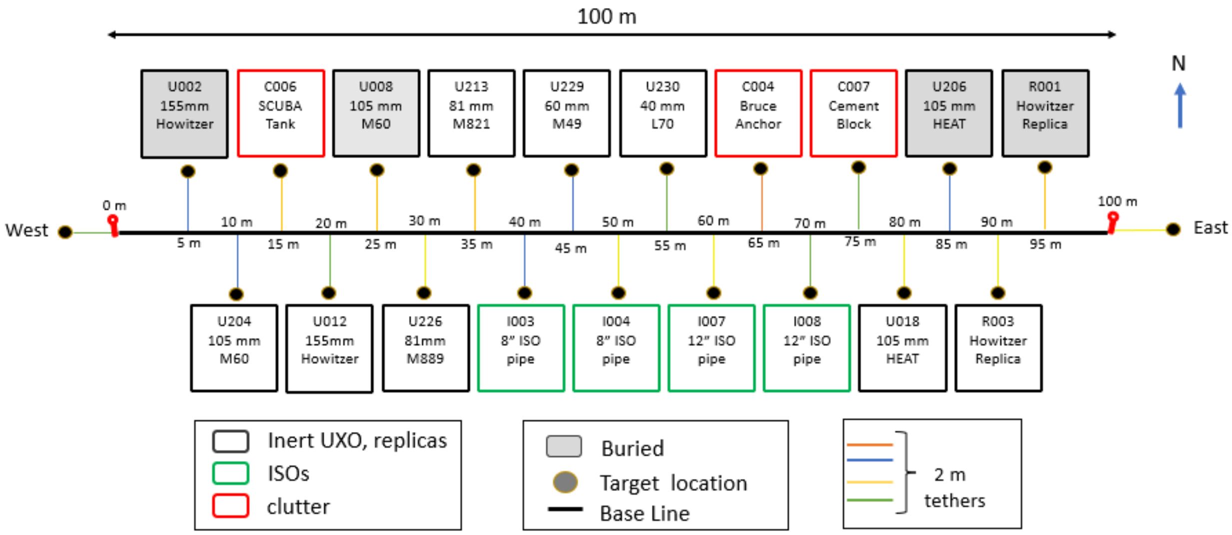


Figure 3. Layout of the targets at the Sequim Bay 2022 calibration site.

3.4.2 Blind Site

The blind site was configured as a 100 m diameter circle. Divers placed 37 inert UXOs, 2 ISO pipes, and 22 clutter items in 10 clusters within the blind site grid (Figure 4). Each cluster was oriented around a central target with tethers attached to the other targets in the cluster. To minimize scoring ambiguities, minimum target distances between UXO-to-UXO were planned to be 9 m and UXO-to-clutter distances to be 3 m. Distances between clutter items could be <3 m. The number and location of items placed in the blind site were not known to the technology demonstrators until their detection and classification results had been evaluated by IDA.

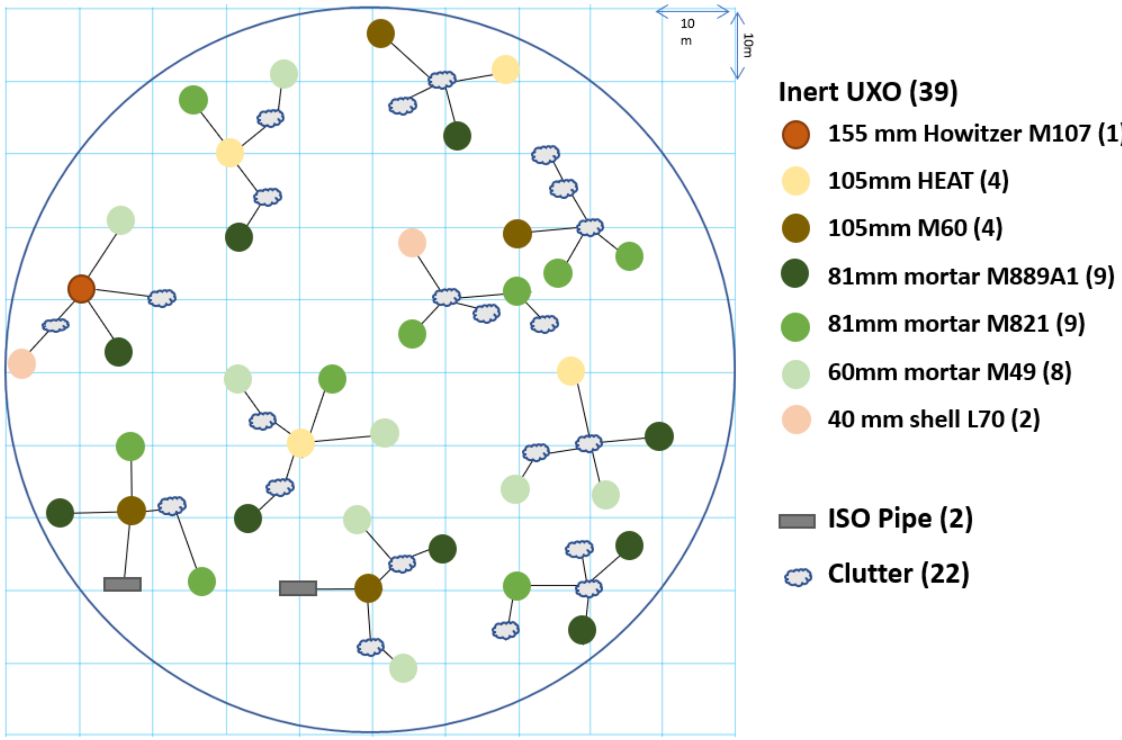


Figure 4. Conceptual design of the 2022 blind site showing the planned location of targets in a 100 m diameter test grid. The target type legend on the right corresponds to locations in the grid. The number of each target type is provided in parentheses ( ).

4.0 Testbed Operations

PNNL testbed operations in 2022 involved implementation of a USBL geolocation technology, target preparation, emplacement, ground-truthing, and recovery. PNNL provided logistical support for visiting technology demonstrators and other SERDP collaborators working in Sequim Bay and collected relevant environmental data before, during, and after the technology demonstrations.

4.1 Implementation of a USBL System for Target Geolocation

Based on results from the geolocation positioning system trials performed in 2021, PNNL acquired and operationalized an iXblue GAPS™ model M7, USBL in 2022 for target geolocation in the Sequim Bay test area. The GAPS™ USBL was integrated with a real-time kinematic Global Positioning System (RTK-GPS) system for high-accuracy surface input.

The GAPS™ relies on an internal high-grade inertial motion unit, compass, and a four-element internal transceiver array to generate single-range geolocation solutions for remote transponder beacons underwater. The advanced GAPS™ USBL calculates 3-D geolocation positions from phase delays in the received acoustic ping replies from the individual beacons and can track and locate multiple beacons at the same time. The GAPS™ transceiver was pole-mounted on a PNNL vessel with hydrophone sensors positioned 1 m below the boat's keel (Figure 5A).

The RTK-GPS system consists of an Emlid model Reach RS2™ GNSS base station positioned on a tripod over a known National Geodetic Survey (NGS) geodetic marker located on the PNNL-Sequim campus. This base station position has a clear line of sight to the demonstration area in Sequim Bay (Figure 6). The Emlid model Reach RS2™ receiver was mounted on top of the USBL transceiver pole (Figure 5B), directly over the GAPS unit to minimize horizontal bias (Figure 5C), and connected to the base station over a radio frequency link for real-time position corrections. Using the RTK-GPS base station corrections, the horizontal error estimates in the rover position were consistently on the order of 1–3 cm. The vertical offset between the RTK-GPS antenna and subsurface GAPS ™ transceiver was measured and remained consistent throughout the field season.

During geolocation ground-truth operations, divers carried handheld transceiver beacons from Applied Acoustics (Micro Beacon 1329A) encoded to interface with the GAPS™ USBL. At each emplaced object, the divers notified the surface vessel and USBL operator via underwater acoustic comms link that they were "on-station". A 30-second dwell period for data collection would commence with the diver holding the beacon over a repeatable measurement point of the target (Figure 7). After the USBL system operator collected the USBL data positions and visually confirmed the quality of the data using mapping software, the divers were notified to move on to the next object.

Horizontal underwater geolocation accuracies for objects placed in the testbed ranged from 4–35 cm Root Mean Square Error (RMSE) (Figure 8). The distribution of RMSEs was positively skewed, reflecting that the majority of errors are below the mean error value in the distribution. This is a significant improvement over previous years where horizontal accuracies were estimated > 1 m. This method provided added efficiency for ground-truth data collection operations at the Sequim Bay demonstration site saving both time and cost.

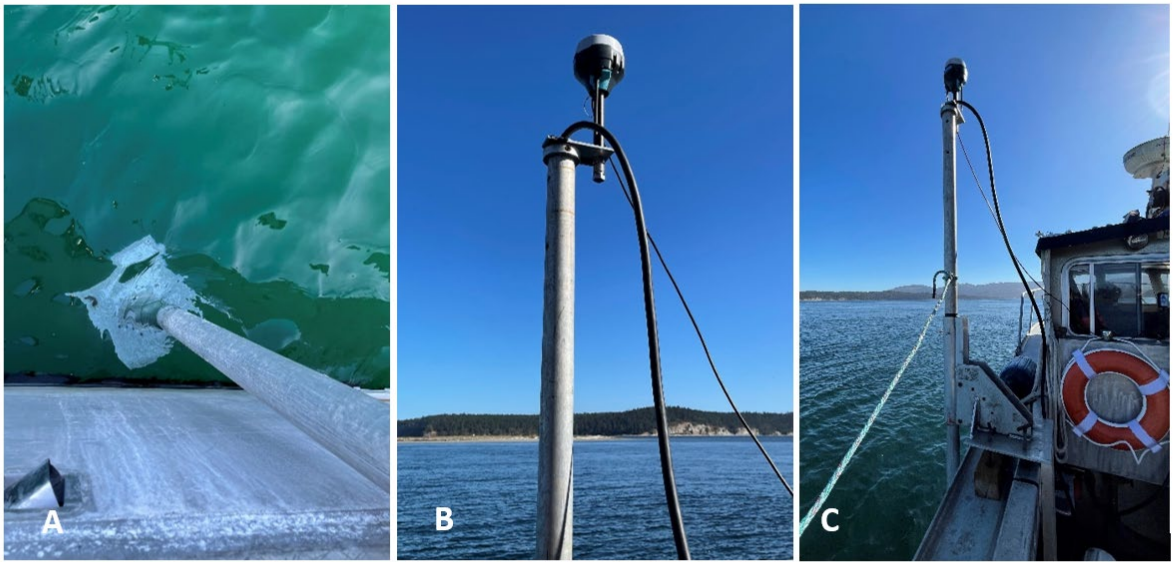


Figure 5. (A) Pole-mounted GAPS transceiver positioned 1 m below the boat's keel. (B) RTK-GPS mounted on top of the transceiver pole. (C) Pole-mounted GAPS transceiver on the PNNL vessel.

Figure 6. (A) Tripod-mounted RTK-GPS base station over the geodetic marker. (B) NGS geodetic marker on the PNNL-Sequim campus.

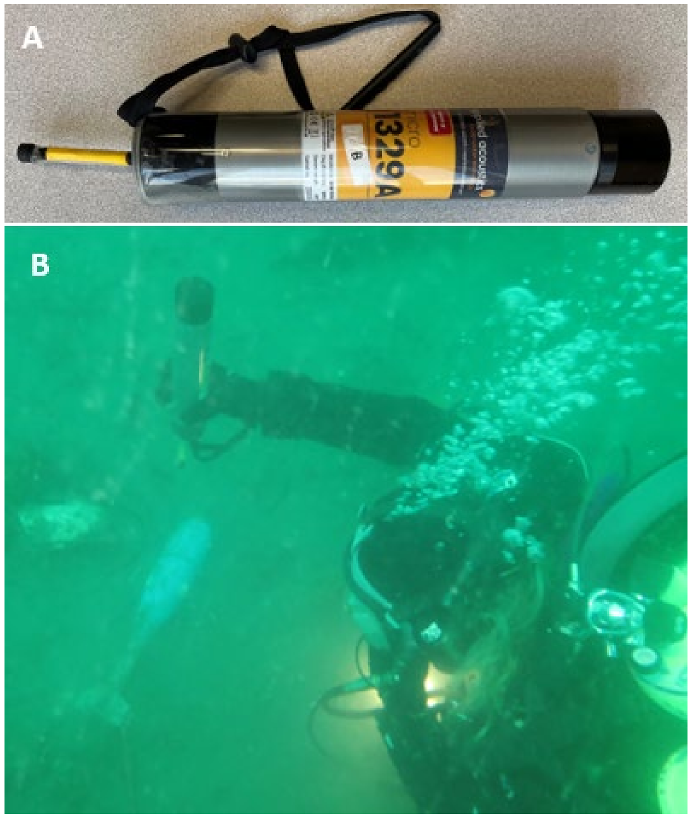


Figure 7. (A) Handheld transceiver beacon. (B) Diver using a handheld transceiver beacon over a target in Sequim Bay.

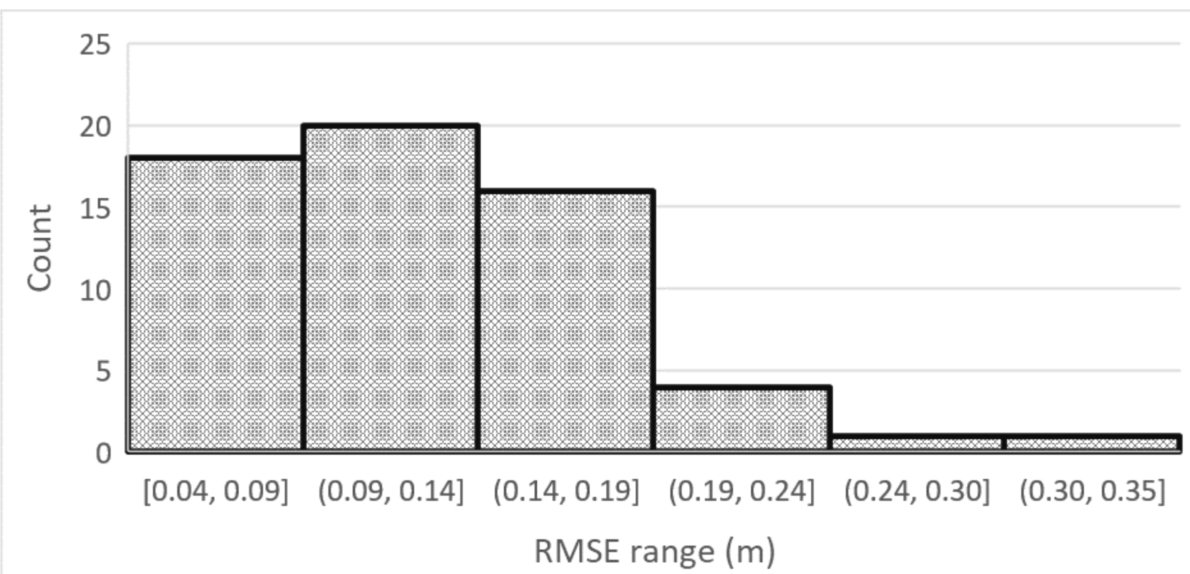


Figure 8. Distribution of error estimates (RMSEs) of target position from GAPS USBL target geolocation data.

4.2 Target Preparation

All targets, including tethers, were prepared for deployment on land to minimize dive time. Tethers were used to ensure proper target placement and recovery, and help the divers navigate in poor visibility. In all cases, Amsteel line was attached directly to the target to minimize unintended acoustic cues during technology demonstrations. Various attachment mechanisms were used to attach tethers in the most low-profile manner possible (Figure 9A–C).

For the calibration line, the 2 m target tethers were attached to the baseline using 3/4” (19 mm) flat side quick-release plastic buckles to allow quick and connections during deployment and recovery (Figure 9D). At the blind site, the tethers were of various lengths, depending on the layout of the cluster. To minimize acoustic cues or interference, no clips, buckles, or thicker lines were used at the blind site. The distal end of the tether was left free for divers to tie to the center target in each cluster. Further detail regarding target preparation is provided by Woodruff et al. (2022).

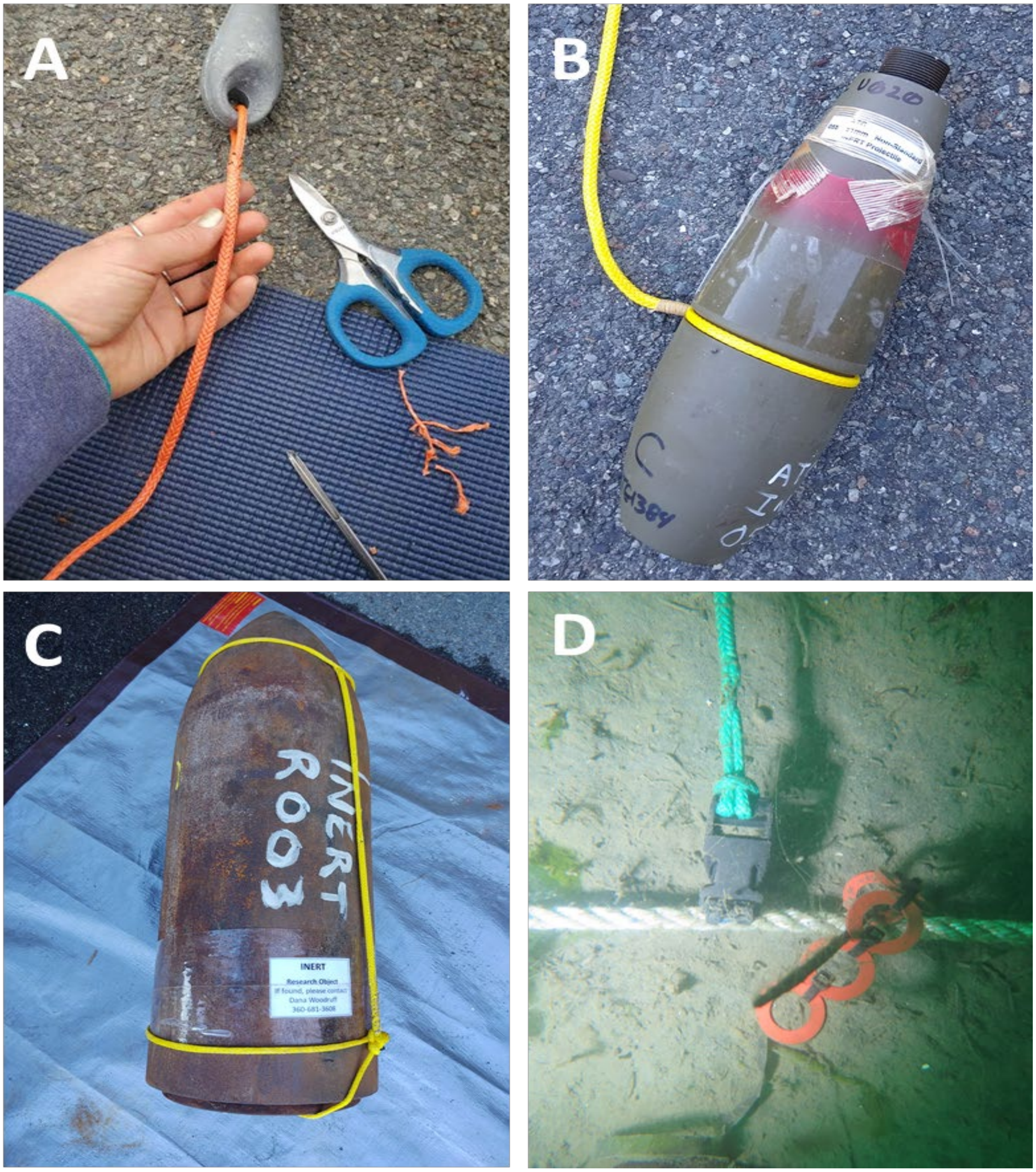


Figure 9. Attachment mechanisms for the target tethers. (A) Tether is spliced directly to the target. (B) Tether is wrapped around the target; note the whipping (tan) on the line at the target to tighten the line. (C) Harness constructed around the target. (D) Side-release clips used to attach the tether line (green) to the baseline (white); note the hose washers used to mark distance along the baseline.

4.3 Target Emplacement

After the targets were prepared with labels and tethers, they were placed in the testbed using methods similar to those used in 2020 and 2021 (Woodruff et al. 2022). Targets were prepared so they could be placed on the bottom at the predetermined coordinates and dispersed by the divers. The primary difference in 2022 was the use of additional subcontracted research divers from RSS (Research Support Services, Inc., Bainbridge Island, WA) for the target deployment activities. RSS used their own vessel (*R/V Carolyn Dow*). The RSS divers received real-time guidance from the PNNL Dive Officer, who was onboard during all operations, to oversee the correct placement of the targets. RSS divers were tethered to the *R/V Carolyn Dow*, providing a continuous hard-wired communication link from the surface to the diver. Additionally, RSS divers worked individually with one diver on the bottom at a time.

The depths of the testbed limited the dives to approximately 25–30 minutes of bottom time. The blind site targets were deployed during 10 dives (i.e., one per cluster), the calibration site was deployed during 10 dives, and an additional two PNNL dives were used to document the sites with photographs and videos. All deployments were conducted in July 2022.

4.3.1 Calibration Site

A single calibration line was deployed this year using methods similar to those used in 2021 (Woodruff et al. 2022). The end of the baseline was placed by the *R/V Carolyn Dow* at the western GPS point of the calibration line and weighted with a heavy anchor. The remaining length of the baseline was then deployed by the boat at the surface to the eastern coordinate and placed using a buoyed dropline to mark the site. RSS divers anchored each end of the baseline with a helical screw anchor into the seafloor. Uplines were placed at both ends of the calibration line to mark the site for the subsequent deployment dives.

RSS divers then populated each of the target positions, using the *RV Carolyn Dow*, secured in a three-point anchor configuration, to precisely drop the targets onto the baseline. A third screw anchor was installed at the halfway point on the baseline to install another upline for reference purposes. Target labels, baseline markings (Figure 9D), and communications with the boat ensured proper target positioning. Once the target was at the appropriate position along the baseline, the end of the tether was clipped into the buckle and the target was moved perpendicular to the baseline to the full extent of the tether (i.e., 2 m). All UXOs were placed with “noses” pointed to the north. PNNL divers deployed the last target on the east end due to a technical difficulty. PNNL divers also verified and photo-documented the site after target deployment.

4.3.2 Blind Site

The blind site targets were deployed in clusters in the same manner as the previous year (Woodruff et al. 2022). Targets were grouped into 10 clusters consisting of 5 to 7 targets tethered radially around a central target. During deployments, the targets for each cluster were lowered by the anchored *RV Carolyn Dow* and placed at the position of the center target. Divers then descended the downline, located each radial target, and pulled the target to the full extent of the tether line in a pre-determined compass bearing.

4.3.3 GNSS Base Station Installation

An Emlid RS2 RTK GNSS receiver was installed near the PNNL-Sequim pier to serve as a continuously operating base station for future operations requiring RTK GNSS positioning support. The receiver was mounted on the top of a pole extending approximately 1 m above the roof of the building (Figure 10) nearest to the PNNL-Sequim pier and surveyed for high-accuracy geolocation position (-123.04552618 E, 48.07912105 N) using the Washington State Regional Network (WSRN) and several local geodetic markers in the area. The receiver was supplied with a continuous power feed so that it could be set to continuously broadcast and store reference data. The receiver's internal LoRa radio was turned on so that it was continuously broadcasting reference data at a frequency of 902.2 MHz and a data rate of 18.23 kb/s using an RTCM3 message format. The receiver is accessible via Bluetooth if reconfigurations are required.

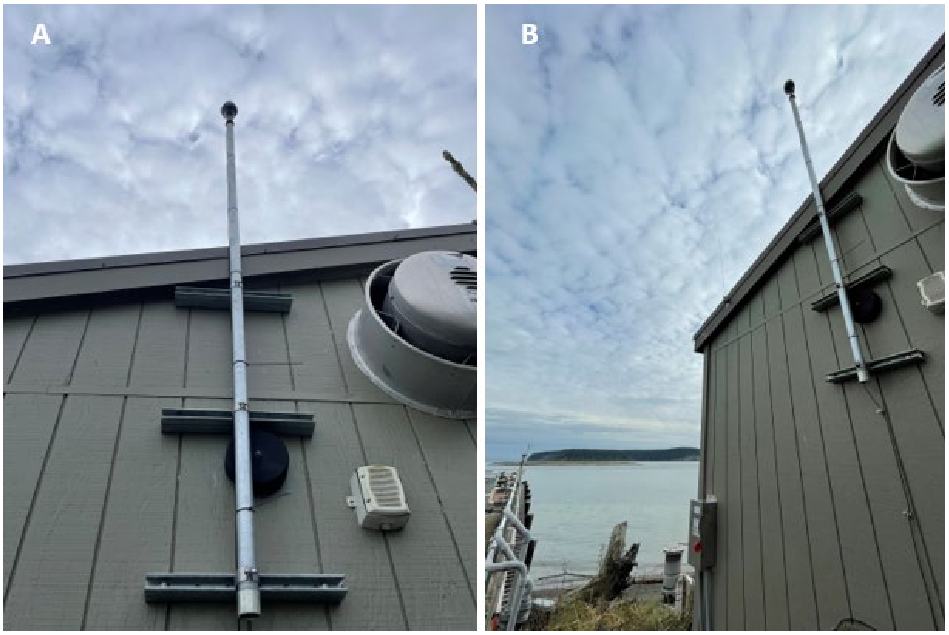


Figure 10. RTK GNSS receiver mounted on the building on PNNL-Sequim's campus.

4.4 Target Ground-Truthing

A full suite of descriptive information was recorded for each target (UXOs and clutter items) during the ground-truth data collection. Descriptions included the following information:

- relative position of each target along the baseline at the calibration site or cluster grouping at the blind site
- target type
- unique PNNL identification number
- coordinates of the fiducial point of each emplaced target in Universal Transverse Mercator units to two decimal points, and latitude/longitude (WGS 84) to seven decimal points
- burial depth of each target to the top center (within 5 cm)
- azimuth (orientation) of each target (within 10°, magnetic north)
- inclination (tilt) of each target (within 5° from horizontal); + is nose up, - is nose down
- other diver observations (e.g., biofouling, tether status—taut, loose, disconnected).

The inclination of the target was estimated from the perceived centerline of the target if there was no obvious edge (e.g., a crab trap has an obvious edge but the curved sides of the finned mortar do not). To measure buried targets, the target was unburied enough to find the upper edge, which was used to estimate the centerline.

Ground-truth information collected for the calibration line and blind site are listed in Table 4 and Table 5, respectively. Ground-truth information for the calibration line was collected during three dives between August 24 and September 15, and four additional geolocation/ground-truth confirmation dives were conducted in October.

Table 4. Ground-truth information collected by divers from the calibration site.

Date	PNNL ID	Target Type	Description	Target Burial[(a)]	Diver Compass Orientation (deg magnetic)	Tilt (deg)[(b)]
10/24/22	R001	Replica	155 mm Howitzer replica	Fully buried	350	0
10/24/22	R003	Replica	155 mm Howitzer replica	Partially proud	320	0
10/24/22	U206	UXO	105 mm projectile HEAT	Fully buried	0	-
10/24/22	U018	UXO	105 mm projectile HEAT	Partially buried	140	3
10/25/22	C007	Clutter	Cement block	Proud	240	0
10/25/22	I008	ISO	12” ISO pipe	Proud	150	10
10/25/22	C004	Clutter	Bruce anchor	Partially proud	320	0
10/25/22	I007	ISO	12” ISO pipe	Partially buried	230	0
10/25/22	U230	UXO	40 mm shell L70	Partially proud	330	3
10/25/22	I004	ISO	8” ISO pipe	Partially proud	180	0
10/25/22	U229	UXO	60 mm mortar M49	Partially buried	330	-2
10/25/22	I003	ISO	8” ISO pipe	Partially buried	140	0
10/25/22	U213	UXO	81 mm projectile M821	Partially buried	330	-2
10/26/22	U226	UXO	81 mm mortar M889A1	Partially buried	0	-2
10/26/22	U008	UXO	105 mm projectile M60	Fully buried	-	-
10/26/22	U012	UXO	155 mm Howitzer projectile	Partially buried	20	-5
10/26/22	C006	Clutter	SCUBA tank	Proud	340	0
10/26/22	U204	UXO	105 mm projectile M60	Partially buried	0	-2
10/26/22	U002	UXO	155 mm Howitzer projectile	Fully buried	-	-

(a) buried = targets are buried flush with the seabed surface; proud = targets exposed fully; partial = targets partially buried/exposed.
(b) tilt + = nose up, - = nose down.

Ground-truth information for the blind site was collected by PNNL divers during 11 dives from all targets (inert UXO and clutter) between or shortly after demonstrations were complete (September and October 2022). Three additional geolocation confirmation dives were conducted at the end of October. Table 5 includes ground-truth information for 37 inert UXOs emplaced at the blind site. Appendix A lists the geolocation information and target type for all items emplaced at the blind site (inert UXO, clutter, ISO pipe).

Table 5. Ground-truth information collected by divers from inert UXO and ISO pipe targets at the blind site. Clutter items are not listed.

Cluster	Date	PNNL ID	Target Type	Description	Target Burial[(a)]	Diver Compass Orientation (deg magnetic)	Tilt (deg)[(b)]
1	10/18/22	U001	UXO	155 mm projectile Howitzer	Partially buried	175	+1

Cluster	Date	PNNL ID	Target Type	Description	Target Burial[a]	Diver Compass Orientation (deg magnetic)	Tilt (deg)[b]
1	10/18/22	U020	UXO	81 mm mortar M889A1	Partially buried	340	+5
1	10/18/22	U227	UXO	60 mm mortar M49	Partially buried	50	+5
1	10/18/22	U247	UXO	40 mm shell L70	Partially buried	20	0
2	10/19/22	U015	UXO	81 mm mortar M889A1	Partially buried	5	-4
2	10/19/22	U016	UXO	105 mm projectile HEAT	Proud	70	-5
2	10/19/22	U214	UXO	81 mm mortar M821	Partially buried	230	-3
2	10/19/22	U228	UXO	60 mm mortar M49	Partially buried	70	0
3	9/26/22	U009	UXO	105 mm projectile M60	Partially buried	150	+3
3	9/26/22	U014	UXO	105 mm projectile HEAT	Buried	190	-2
3	9/26/22	U019	UXO	81 mm mortar M889A1	Partially buried	160	-6
4	10/12/22	U006	UXO	81 mm mortar M821	Proud	0	0
4	10/12/22	I005	ISO	8” ISO pipe	Proud	335	+5
4	10/12/22	U010	UXO	105 mm projectile M60	Proud	0	+10
4	10/12/22	U209	UXO	81 mm mortar M821	Partially buried	60	+2
4	10/12/22	U225	UXO	81 mm mortar M889A1	Partially buried	340	+2
5	10/14/22	U017	UXO	81 mm mortar M889A1	Partially buried	330	+2
5	10/14/22	U210	UXO	81 mm mortar M821	Partially buried	300	-2
5	10/14/22	U235	UXO	105 mm projectile HEAT	Partially buried	0	0
5	10/14/22	U237	UXO	60 mm mortar M49	Partially buried	310	0
5	10/14/22	U238	UXO	60 mm mortar M49	Fully buried	335	+3
6	10/12/22	U211	UXO	81 mm mortar M821	Partially proud	140	+4
6	10/12/22	U215	UXO	81 mm mortar M821	Proud	240	+3
6	10/12/22	U231	UXO	40 mm shell, L70	Proud	240	0
7	10/14/22	U011	UXO	105 mm projectile M60	Proud	115	+1
7	10/14/22	U216	UXO	81 mm mortar M821	Partially buried	165	+5
7	10/14/22	U217	UXO	81 mm mortar M821	Partially buried	225	-3

Cluster	Date	PNNL ID	Target Type	Description	Target Burial[(a)]	Diver Compass Orientation (deg magnetic)	Tilt (deg)[(b)]
8	9/28/22	U007	UXO	105 mm projectile M60	Partially buried	230	-4
8	9/28/22	I006	ISO	8” ISO pipe	Partially buried	30	-5
8	9/28/22	U236	UXO	81 mm mortar M889A1	Proud	230	1
8	9/28/22	U239	UXO	60 mm mortar M49	Proud	0	-10
8	9/28/22	U240	UXO	60 mm mortar M49	Partially buried	150	-10
9	9/29/22	U003	UXO	105 mm projectile HEAT	Partially buried	250	-10
9	9/29/22	U224	UXO	81 mm mortar M889A1	Partially buried	130	+1
9	9/29/22	U242	UXO	60 mm mortar M49	Partially buried	10	0
9	9/29/22	U241	UXO	60 mm mortar M49	Partially buried	310	0
10	9/27/22	U212	UXO	81 mm mortar M821	Partially buried	350	+5
10	9/27/22	U222	UXO	81 mm mortar M889A1	Partially buried	290	-5
10	9/27/22	U223	UXO	81 mm mortar M889A1	Partially buried	130	-5

(a) buried = targets are buried flush with the seabed surface, proud = targets exposed fully, partial = targets partially buried/exposed.
(b) tilt + = nose up, - = nose down.

Figure 11 shows the placement of inert UXOs, ISO pipes, and clutter items in the blind site on the dates of the ground-truth collection. This target field was used for the demonstration of the UltraTEMA-4 and the MuST in late September and early October 2022, respectively (Section 4.5).

The conceptual design of the blind site target field called for at least a >9 m separation between UXO and UXO, and a >3 m separation between UXO and clutter. The nearest neighbor distances between some of the UXO-UXO and UXO-clutter objects were less than that. Several factors potentially contributed to this, including the complexities of accurate target placement by divers in a crowded target field and movement of targets after placement by accidental snagging of tether lines due to fishing activity. The displacement of one cluster outside the blind site, shown in Figure 11, was likely due to snagging and dragging of the targets during or after the demonstration. A summary of target geolocation challenges that are encountered by testbed managers and technology demonstrators, and subsequent scoring challenges at demonstration sites including Sequim Bay, are discussed by Cazares and Bartel (2021).

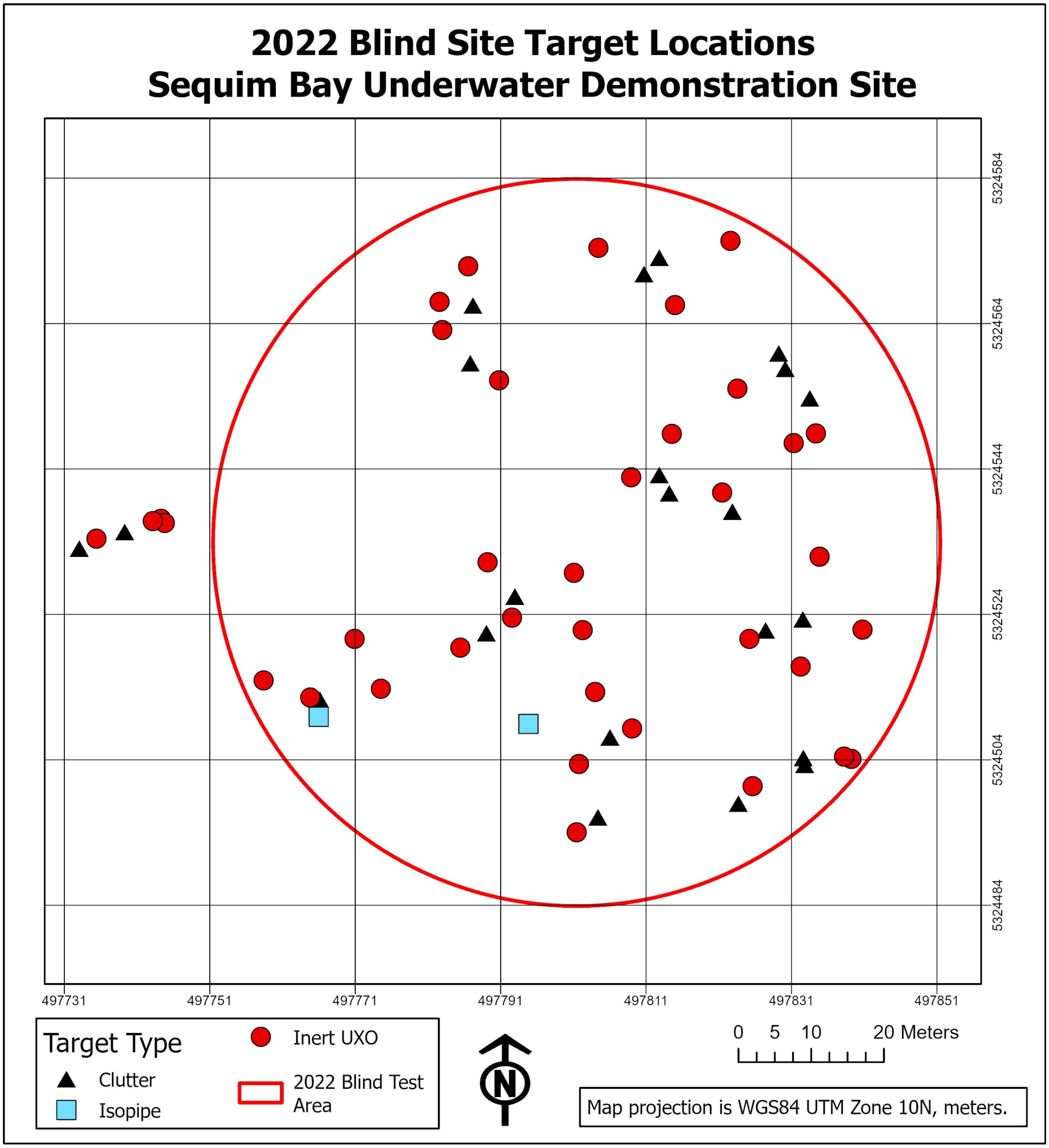


Figure 11. Location of the 2022 target locations at the blind site, including 37 UXOs, 2 ISO pipes, and 22 clutter items.

4.5 Technology Developers and Collaborators

4.5.1 Demonstration of Black Tusk/Tetra Tech UltraTEMA-4 Technology

The Black Tusk Geophysics/TetraTech team conducted a demonstration test of the UltraTEMA-4 technology in Sequim Bay from September 19–22, 2022, supported by the *R/V Ugle Duckling*.

PNNL-Sequim staff provided logistical support as needed to the UltraTEMA-4 team during the demonstration. Prior to the demonstration, position and ground-truth information was provided to the UltraTEMA-4 team for each target along the calibration line (Figure 3). Additionally, a list of target types that were present along the calibration line and could also be present in the blind site (Table 3) was also provided.

4.5.2 Demonstration of the APL-UW MuST Technology

The APL-UW team conducted a demonstration of the MuST in Sequim Bay from October 3–6, 2022, supported by the *R/V Jack Robertson*. Logistical support from PNNL-Sequim was provided as needed to the APL-UW staff during the demonstration. As with the previous demonstration, prior to the MuST demonstration, position and ground-truth information was provided for each target along the calibration line in addition to a list of target types that were present along the calibration line and could be present in the blind site.

4.6 Target Recovery

Target recoveries were conducted in the same manner as in 2020 and 2021. After the target characterization and geolocation were completed, the divers attached buoyed uplines to each target for retrieval. This was done for individual targets if they were large, heavy, or a farther distance from other targets. Multiple smaller targets were brought to a common location and attached to the same upline to be lifted to the surface. The vessel would then go to each upline buoy and lift the targets to the surface either by hand or using the hydraulic davit.

Target retrieval was conducted during February and March 2023. The blind site clusters required 10 dives and the calibration line required 5 dives.

4.7 Environmental Characterization

4.7.1 Environmental Data Collection

Quantitative and qualitative environmental measurements and observations were collected during the field season at the calibration site and blind site. An environmental data collection log sheet was developed in consultation with IDA's scoring team to identify the environmental observations that best inform both ground-truth data collection activities and demonstrator technology performance. The latter would also assist in performance comparisons of UXO remediation technologies in different testbed environments and project sites. Environmental data logged during each vessel operation included the following:

- tidal stage (slack high, ebb, slack low, flood)
- average/gust wind speed (handheld anemometer) and direction
- air temperature
- conductivity, temperature, depth (CTD) profiles using a Sontek Castaway™ CTD, which also provides salinity and sound speed
- secchi depth – turbidity
- wind wave height (qualitative)
- precipitation and cloud cover (qualitative).

In addition to data collection from the PNNL vessel during daily activities, an Acoustic Doppler Current Profiler (ADCP) was deployed between the blind and calibration sites to record water current velocities. A Nortek ECO™ ADCP measured water column speed and direction every 5 minutes from September 17, 2022, to October 28, 2022. The ADCP was suspended 1 m from the seafloor and recorded 11,977 samples in three layers below the surface at 12.55 m, 16.08 m, and 19.6 m depths. Hydrostatic pressure, temperature, and tilt were also measured by the ADCP.

4.7.2 Environmental Data Summary

The 56 CTD profiles are summarized in Figure 12. Mean levels for variables at each depth are shown as bold lines, and the range of values is highlighted. Variability was greatest in the top 5 m of the water column, caused by mixing from winds, freshwater input from precipitation, and solar surface warming and cooling. Mean profiles from the CTD measurements show little variation with depth, yet individual profile measurements could vary substantially.

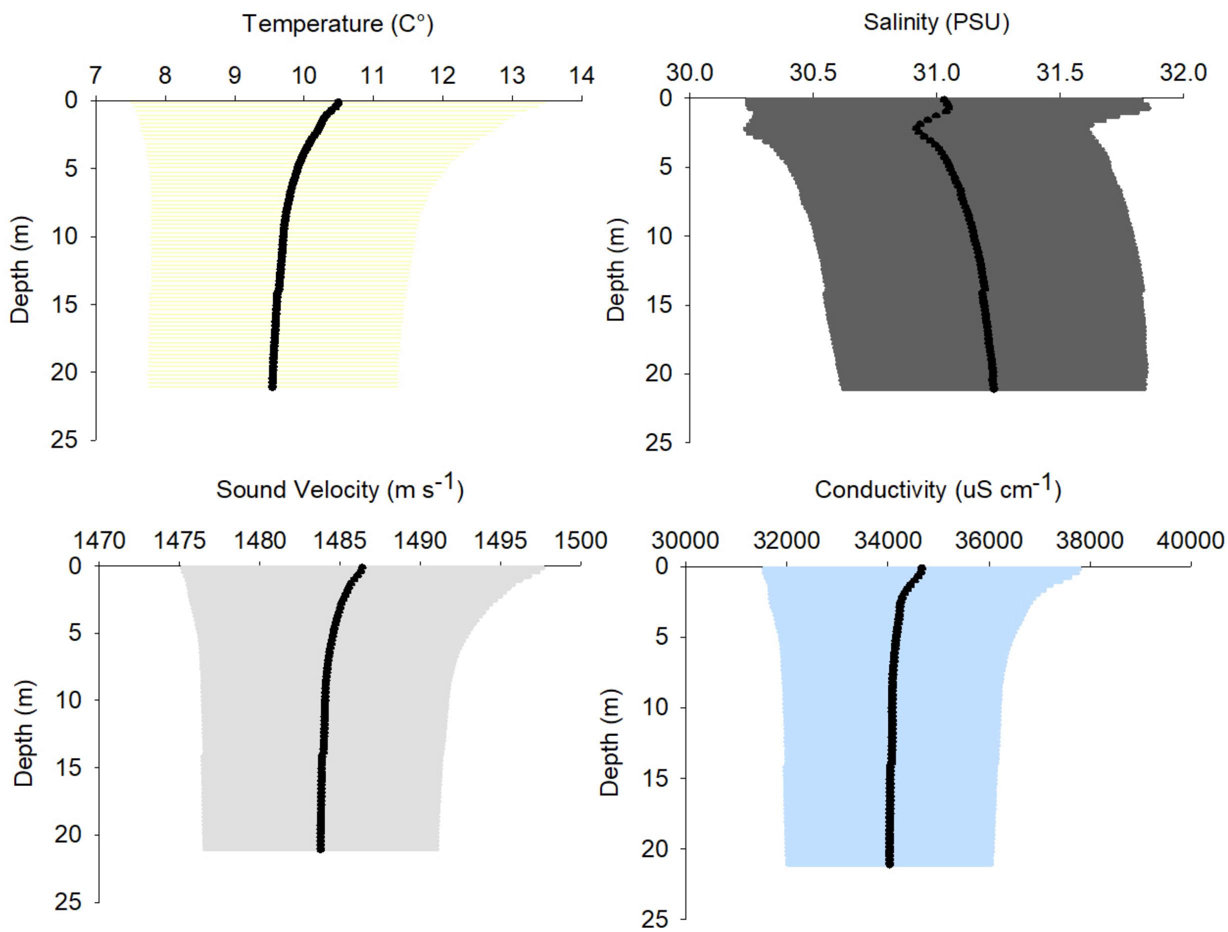


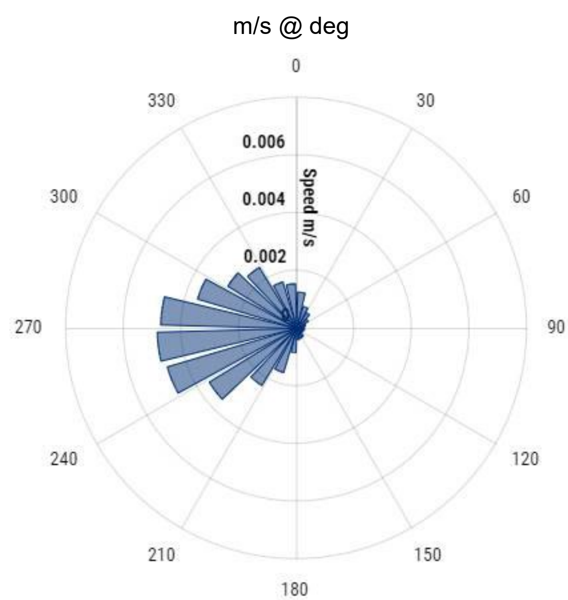
Figure 12. Clockwise from top left: temperature, salinity, sound velocity, and conductivity versus depth summary plots from 56 individual CTD casts in the Sequim Bay testbed in 2022. Bold black lines show mean values and shading represents the range of values.

The 6 weeks of data collected by the ADCP showed the mean flow was generally strongest and most frequently observed coming from the west (Figure 13), with an average speed of 0.04 m/s.

This pattern is observed most strongly in the upper water column; near the seafloor at 19.6 m the mean flow speed is more symmetric between ebb and flood tides moving in the southwest and northeast directions. The maximum current speeds and directions show that flows coming from the northeast are strongest, likely associated with peak flows during the larger excursions of the spring/neap tidal cycle. Summary statistics are given in Table 6.

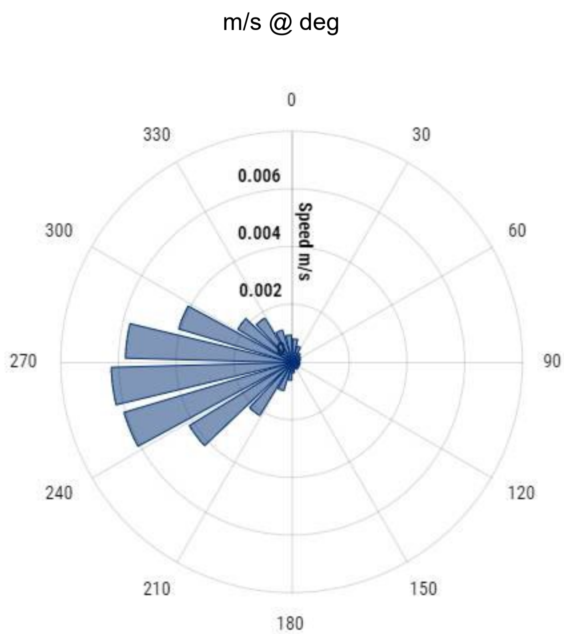
Table 6. Summary statistics of current speeds and directions at three depth layers (upper = 12.55 m, middle = 16.08 m, lower = 19.6 m) measured by the ADCP in the Sequim Bay testbed during September 17, 2022–October 28, 2022.

		Upper	Middle	Lower	Unit
Speed	Mean	0.04	0.04	0.04	m/s
	Max	0.32	0.30	0.28	m/s
	Min	0.00	0.00	0.00	m/s
	Std. dev	0.03	0.03	0.03	m/s
	Mean	Max	Min	Std. dev	Unit
Temperature	10.7	18.8	10.0	0.4	°C
Pressure	22.1	23.3	0.0	1.4	m
Tilt	1.0	16.7	0.3	0.4	deg

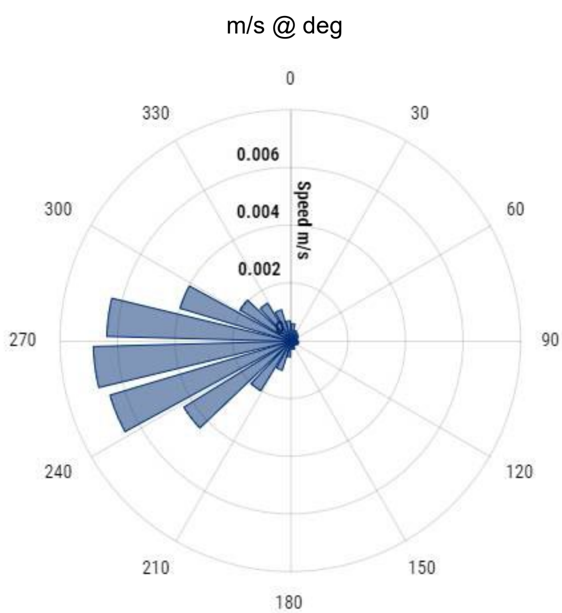


(a)

Figure 13. Polar histogram plots of the mean current speed and direction at each of the three depths: (a) upper 12.55 m, (b) middle 16.08 m, and (c) lower 19.6 m.



(b)

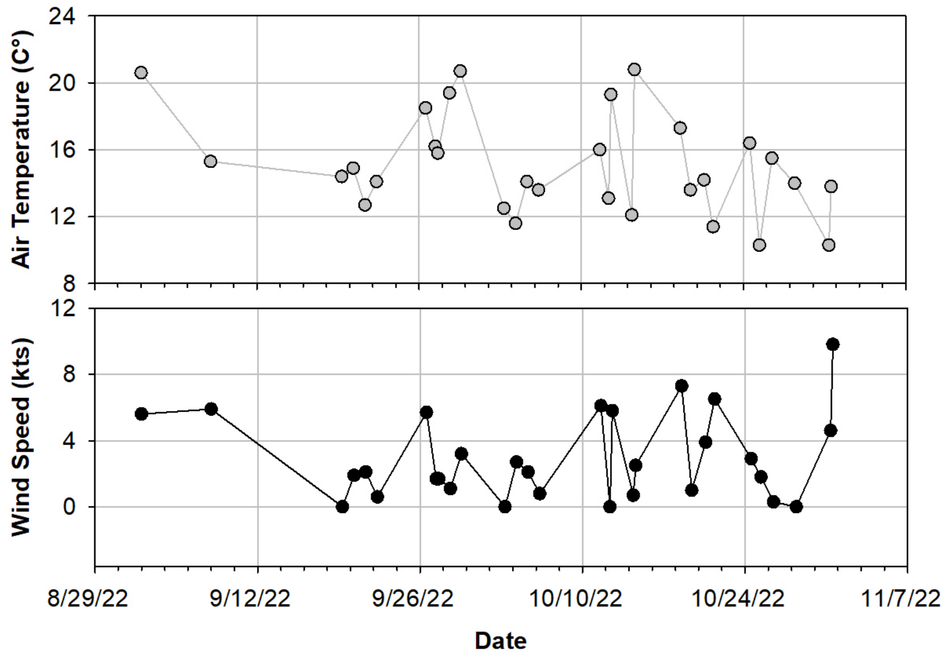


(c)

Figure 13. (contd) Polar histogram plots of the mean current speed and direction at (b) middle 16.08 m and (c) lower 19.6 m.

Recorded average wind speeds and gusts were generally below 8 kts, likely due to the extended summer and favoring of calmer days for GAPS™ data surveys. Air temperatures declined gradually from ~20°C to just above 10°C during September through the end of October (Figure 14a), and secchi depths (Figure 14b) indicate significant changes in turbidity and visibility near the surface with a peak in visibility observed in mid- to late October.

(a)



(b)

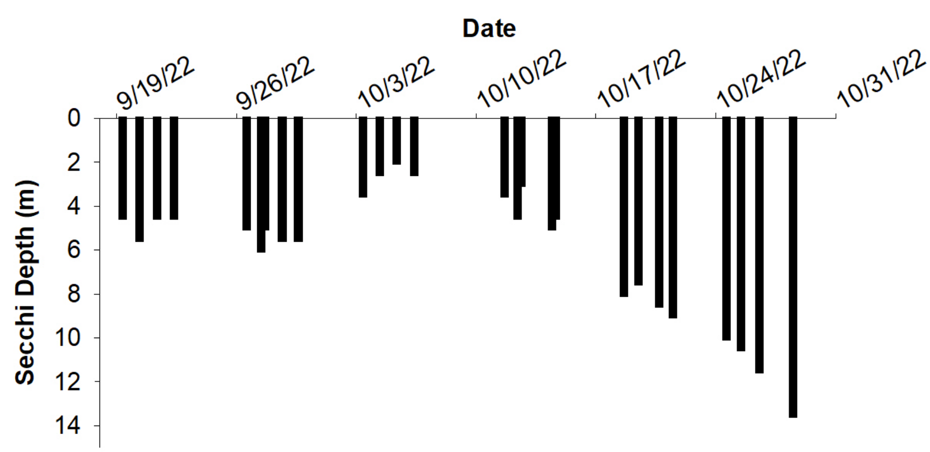


Figure 14. Environmental data collected during PNNL vessel operations between September and October 2022, including (a) average wind speed (kts) and air temperature (°C), and (b) secchi depth (m).

4.7.3 Environmental Data Collected During Demonstrations

This section summarizes the environmental data collected during each team's demonstration. The UltraTEMA-4 and MuST teams each collected data for one week during September 19–22 and October 3–6, 2022, respectively. The CTD casts collected during the teams' demonstration weeks are summarized in Figure 15. Each line/bar represents a single cast collected daily during each demonstration week. During both weeks, variability was greatest in the top 5 m of the water column, caused by mixing from winds and solar surface warming and cooling.

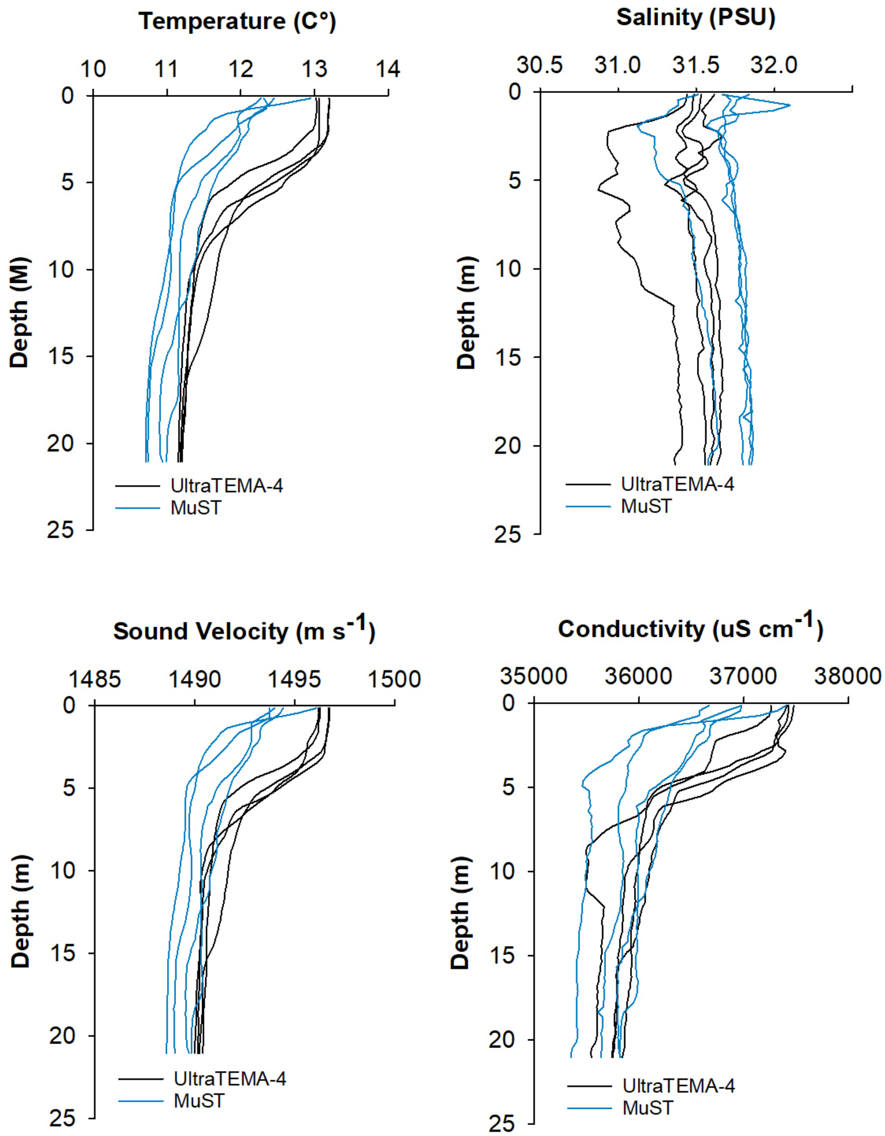


Figure 15. Clockwise from top left: temperature, salinity, conductivity, and sound velocity versus depth summary plots from individual CTD casts in the Sequim Bay testbed during the UltraTEMA-4 and MuST demonstration weeks. Each colored line represents an individual day's cast.

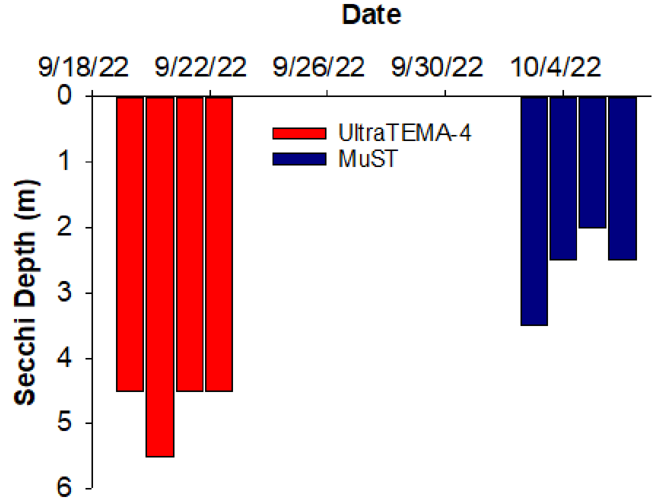
CTD data were comparable across the two demonstration weeks. During the UltraTEMA-4 demonstration temperature in the upper 10 m was slightly more stratified but remained within the same range as the week of the MuST demonstration. Sound velocity was also slightly more stratified during the UltraTEMA-4 demonstration but did not vary overall by more than 5–8 m s^{-1} during both weeks. Salinity remained relatively constant during both weeks, varying by about less than one unit (PSU).

Additional environmental data were collected daily within the demonstration area during both weeks of developer testing. Data were collected each morning prior to demonstrator surveys. During the UltraTEMA-4 demonstration, average wind speeds and gusts were recorded between 0 and 2.8 kts, resulting in negligible wind wave heights (Table 7). Air temperatures ranged from 12.7–14.9 °C, and secchi depths were between 4.5 and 5.5m (Figure 16a). During the MuST demonstration, average wind speeds and gusts were recorded between 0 and 3.6 kts, also resulting in negligible wind wave heights. Air temperatures ranged slightly cooler from 11.6–13.6 °C, and secchi depths decreased to between 2 and 3.5 m. The tidal range was similar during both weeks with a high of approximately 2.54 m and an average low ranging between 0.76 and 0.87 m (Figure 16b). Due to mild wind, low tidal current speeds, and the lack of precipitation, the environmental conditions remained relatively constant throughout both demonstration weeks.

Table 7. Summary statistics of environmental data collected from the Sequim Bay test site during both demonstrations, September 19–22 and October 3–6, 2022.

Demonstrator	Date	Wind Gust (kts)	Avg. Wind Speed (kts)	Wind Direction	Wind Wave Height (m)	Air Temp (°C)	Precipitation	Tidal Stage	Secchi Depth (m)
UltraTEMA-4	9/19/2022	0	0	NA	0	14.4	None	Flood	4.5
	9/20/2022	2.8	1.9	N	<0.5	14.9	None	Flood	5.5
	9/21/2022	2.8	2.1	W	0	12.7	None	Slack low	4.5
	9/22/2022	0	0.6	E	0	14.1	None	Ebb	4.5
MuST	10/3/2022	0	0	NA	0	12.5	None	Flood	3.5
	10/4/2022	3.6	2.7	W	0	11.6	None	Flood	2.5
	10/5/2022	2.2	2.1	SW	0	14.1	None	Flood	2
	10/6/2022	0.9	0.8	W	0	13.6	None	Slack low	2.5

(a)



(b)

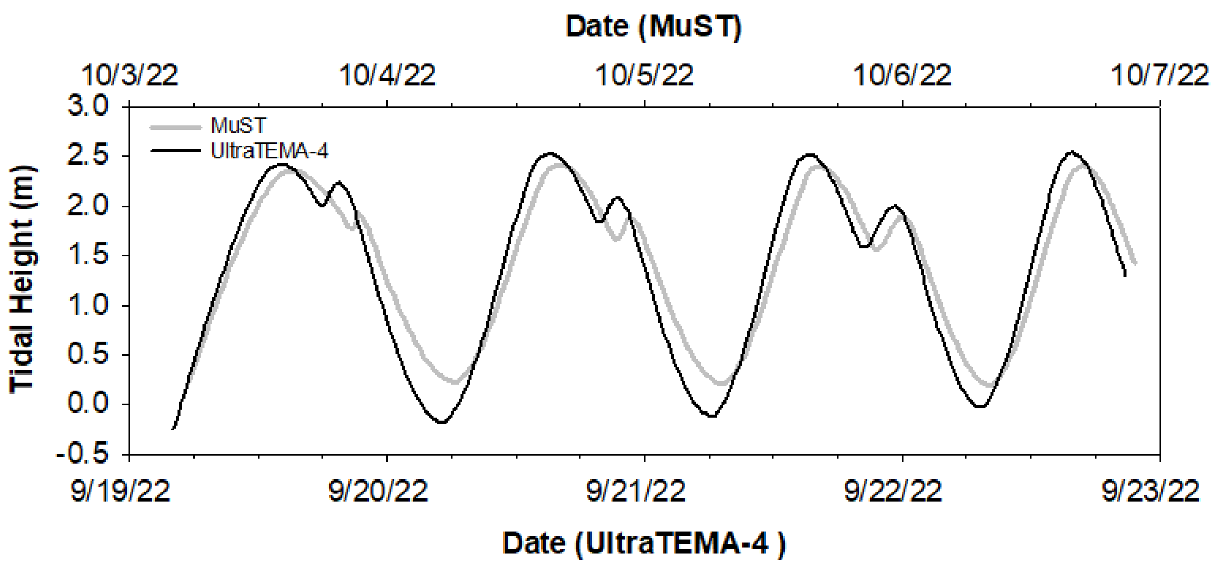


Figure 16. Environmental data conditions observed during the UltraTEMA-4 and MuST demonstrations, including (a) secchi depth (m) and (b) tidal height (m). The MuST and UltraTEMA-4 teams are represented by the grey and black lines, respectively.

4.8 Time and Effort Summary

The time and effort required to conduct a successful demonstration is extensive. The initial planning, permitting, testbed design and coordination with technology developers occurred during a nine-month window prior to field demonstrations. Field operations, including diver support, also require extensive effort. For this year’s testbed design, 20 dives were required to emplace 80 tethered targets in prescribed locations. Target placement occurred in late July, two months prior to the first developer technology demonstration. Fourteen dives were required to retrieve all targets in February and March 2023.

PNNL dive operations for ground-truth data collection (i.e., accurate target geolocation and metadata collection) required an additional 18 dives. The use of the GAPS™ USBL system resulted in a significant reduction in dive effort and time required to collect geolocation information for each target in the demonstration area compared with the methods and technologies used in previous years (Woodruff et al. 2021, 2022).

5.0 Lessons Learned and Next Steps

The 2022 field operations were executed successfully. Planning with the SERDP/ESTCP office, IDA, and early discussions with the performers Black Tusk Geophysics/Tetra Tech and APL-UW resulted in two successful technology demonstrations. The new use of a local, commercial dive subcontractor for target deployment activities provides important additional resources for some dive operation capabilities in the testbed. Additionally, the successful procurement, training of PNNL staff, and implementation of the GAPS™ USBL technology system made a significant improvement in the operational efficiency and geolocation accuracy results in 2022. The lessons learned from 2022 field efforts will inform future testbed operations and technology demonstrations. Adaptive management and flexibility, especially with respect to remediation system developers' varying requirements and target grid layouts, are recognized as being essential moving forward.

- Target Field and Site Design. In fiscal year 2022, a significant expansion of targets in the blind test area resulted in a highly crowded target field. Although offset distances were planned as described earlier, many targets were found to be deployed within the planned nearest neighbor zones due to the limited amount of spatial tolerance afforded by the 100 m diameter blind site boundary. Future demonstration site designs with similar target numbers in the blind area may require a larger boundary to accommodate current nearest neighbor offsets (9 m UXO – UXO; 3 m UXO – clutter; 1 m clutter – clutter).
- Scheduling and Planning. Understanding far in advance which developers and technologies will be hosted is necessary for successful demonstrations. The target field design preferences of the SERDP office and scoring team should be determined well before the field season (e.g., spring for fall testing). Information regarding the number and types of targets, minimum spacing between targets, and testing area size should be confirmed during the early planning stages. The timing for diver operations to set up and deploy the targets in the testbed, ground-truth data collection, and technology demonstration testing occurring within a condensed time period is optimized by having early knowledge of the site design preferences. This also promotes longer time periods (e.g., at least 30 days) between target deployment and testing to allow for sediment disturbances to "heal," thereby reducing the deployment footprint.
- Fishing, Shrimping and Crabbing Activity. Throughout the year, Sequim Bay attracts recreational, commercial, and tribal fishermen. During crab and shrimp seasons, boat traffic increases and marker buoys for crab and shrimp traps are present in the bay. These markers can impede a research vessel running along predetermined track lines or create a hazard for expensive research equipment being towed behind the vessel. In addition, the fishing activity may introduce additional, undocumented clutter to the study area (e.g., crab traps). Shrimp and crab seasons are generally predictable, but specific dates for openings and closings are not always set until shortly beforehand for some fisheries. Late September and early October have generally been relatively quiet with respect to fisheries, although early October 2022 during the APL-UW MuST demonstration was an exception; an unforeseen crab and tribal subsistence shrimp fishery affected the MuST demonstration. Continued active engagement and education between PNNL with fishery managers before demonstration testing may help alleviate some of the fishing pressure around the testbed. Still, this is recognized as being an unpredictable and potential hazard for research vessel operators, technology demonstrators and targets being disturbed.

- Target Geolocation System. In 2022, the procurement, staff training, and operationalization of the iXblue GAPS™ USBL system for collecting geolocation information about targets in the demonstration area was a success. Use of the GAPS™ reduced the number of dives and bottom time needed to complete testbed ground-truth data collection in comparison to other methods. Additionally, the GAPS™ is not as restricted by environmental conditions (e.g., tidal currents and weather) as other previously employed geolocation technologies. With the GAPS™, PNNL has demonstrated timely target geolocation ground-truth data collection at sub-meter accuracy—a key technology advancement and implementation for Sequim Bay demonstrations in the future.

6.0 References

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Appendix A

Table A.1. Geolocation information for the 2022 blind site targets in the Sequim Bay underwater testbed.

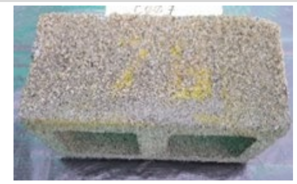
Cluster ID	Type	PNNL ID	Description	Northing[a]	Easting[b]	Longitude[c]	Latitude[d]
1	clutter	C024	Propeller	5324533.2	497733	-123.030434	48.074069
1	clutter	C205	Scrap metal	5324535.5	497739.3	-123.03035	48.07409
1	UXO	U001	155 mm, Howitzer	5324534.4	497735.4	-123.030401	48.07408
1	UXO	U020	81 mm mortar, M889A1	5324536.6	497744.8	-123.030276	48.0741
1	UXO	U227	60 mm mortar, M49	5324537.2	497744.3	-123.030282	48.074105
1	UXO	U247	40 mm shell, L70	5324536.8	497743.2	-123.030298	48.074102
2	clutter	C012	Small screw anchor	5324558.7	497786.8	-123.029712	48.074299
2	clutter	C016	Small grapnel anchor	5324566.7	497787.2	-123.029707	48.07437
2	UXO	U015	81 mm mortar, M889A1	5324556.2	497790.8	-123.029658	48.074276
2	UXO	U016	105 mm projectile, HEAT	5324563.1	497782.9	-123.029764	48.074338
2	UXO	U214	81 mm projectile, M821	5324567	497782.6	-123.029768	48.074373
2	UXO	U228	60 mm mortar, M49	5324571.9	497786.5	-123.029716	48.074418
3	clutter	C005	SCUBA tank	5324573.2	497812.8	-123.029363	48.07443
3	clutter	C203	Large scrap	5324571	497810.7	-123.029391	48.074409
3	UXO	U009	105 mm projectile, M60	5324574.4	497804.5	-123.029475	48.07444
3	UXO	U014	105 mm projectile, HEAT	5324575.4	497822.6	-123.029231	48.074449
3	UXO	U019	81 mm mortar, M889A1	5324566.6	497815	-123.029334	48.07437
4	clutter	C200	Large Scrap	5324512.4	497766.1	-123.029989	48.073882
4	ISO	I005	8" ISO Pipe	5324509.9	497766	-123.029991	48.07386
4	UXO	U006	81 mm projectile, M821	5324520.7	497770.9	-123.029925	48.073956
4	UXO	U010	105 mm projectile, M60	5324512.6	497764.8	-123.030007	48.073884

Cluster ID	Type	PNNL ID	Description	Northing[a]	Easting[b]	Longitude[c]	Latitude[d]
4	UXO	U209	81 mm projectile, M821	5324513.8	497774.5	-123.029876	48.073895
4	UXO	U225	81 mm mortar, M889A1	5324514.9	497758.4	-123.030093	48.073905
5	clutter	C026	Metal sign	5324526.6	497792.9	-123.029629	48.07401
5	clutter	C202	Scrap metal	5324521.6	497789	-123.029682	48.073965
5	UXO	U017	81 mm mortar, M889A1	5324519.4	497785.5	-123.02973	48.073945
5	UXO	U210	81 mm projectile, M821	5324529.7	497801.1	-123.02952	48.074038
5	UXO	U235	105 mm projectile, HEAT	5324523.6	497792.5	-123.029635	48.073983
5	UXO	U237	60 mm mortar, M49	5324531.2	497789.2	-123.02968	48.074051
5	UXO	U238	60 mm mortar, M49	5324521.9	497802.3	-123.029504	48.073967
6	clutter	C015	Large grapnel anchor	5324540.8	497814.2	-123.029344	48.074138
6	clutter	C028	Crab pot	5324538.3	497822.9	-123.029228	48.074115
6	clutter	C030	Chain	5324543.4	497812.8	-123.029363	48.074161
6	UXO	U211	81 mm projectile, M821	5324540.7	497821.5	-123.029246	48.074137
6	UXO	U215	81 mm projectile, M821	5324542.9	497809	-123.029414	48.074156
6	UXO	U231	40 mm shell, L70	5324548.8	497814.5	-123.02934	48.07421
7	clutter	C002	Crab pot	5324553.9	497833.5	-123.029085	48.074256
7	clutter	C029	Crab pot	5324560.1	497829.2	-123.029143	48.074311
7	clutter	C206	Scrap metal	5324557.9	497830.1	-123.02913	48.074292
7	UXO	U011	105 mm projectile, M60	5324555.1	497823.5	-123.029219	48.074266
7	UXO	U216	81 mm projectile, M821	5324548.9	497834.3	-123.029074	48.07421
7	UXO	U217	81 mm projectile, M821	5324547.6	497831.3	-123.029114	48.074199
8	clutter	C013	Radar reflector	5324496.3	497804.4	-123.029476	48.073737
8	clutter	C032	Wheel	5324507.3	497806	-123.029454	48.073836
8	ISO	I006	8” ISO pipe	5324508.9	497794.8	-123.029604	48.073851

Cluster ID	Type	PNNL ID	Description	Northing[(a)]	Easting[(b)]	Longitude[(c)]	Latitude[(d)]
8	UXO	U007	105 mm projectile, M60	5324503.4	497801.8	-123.02951	48.073801
8	UXO	U236	81 mm mortar, M889A1	5324508.3	497809	-123.029413	48.073845
8	UXO	U239	60 mm mortar, M49	5324513.3	497804	-123.029481	48.07389
8	UXO	U240	60 mm mortar, M49	5324494	497801.5	-123.029515	48.073717
9	clutter	C011	Screw anchor	5324523.5	497832.5	-123.029098	48.073982
9	clutter	C033	Pulley	5324522	497827.4	-123.029167	48.073968
9	UXO	U003	105 mm projectile, HEAT	5324531.9	497834.8	-123.029067	48.074058
9	UXO	U224	81 mm mortar, M889A1	5324521.9	497840.8	-123.028987	48.073968
9	UXO	U241	60 mm mortar, M49	5324520.7	497825.2	-123.029196	48.073957
9	UXO	U242	60 mm mortar, M49	5324516.8	497832.3	-123.029101	48.073922
10	clutter	C003	Bruce anchor	5324504.4	497832.6	-123.029097	48.07381
10	clutter	C201	Scrap metal	5324503.5	497832.8	-123.029094	48.073802
10	clutter	C204	81 mm projectile, M821	5324498.1	497823.7	-123.029217	48.073754
10	UXO	U212	81 mm mortar, M889A1	5324500.4	497825.6	-123.029191	48.073774
10	UXO	U222	81 mm mortar, M889A1	5324504.1	497839.2	-123.029008	48.073808
10	UXO	U223					

(a) Northing = Mean X-coordinate projected to WGS84 UTM Zone 10N, meters.
(b) Easting = Mean Y-coordinate projected to WGS84 UTM Zone 10N, meters.
(c) Longitude = Mean Y-coordinate, WGS 1984, decimal degrees.
(d) Latitude = Mean X-coordinate, WGS 1984, decimal degrees.

Table A.2. Clutter objects deployed in the calibration and blind sites in 2022.

# in Cal Line	# in Blind Site	Description	PNNL ID(s)	Length (mm)	Width (mm)	Weight (kg)	Target Photo
1	1	SCUBA tank	C005, C006	655	181	14.95	
1	1	Bruce anchor	C003, C004	484	266	5.55	
1	0	Cement block	C007	400	200	18.1	
0	3	Crab pot	C028, C002, C029	622.0	606.7	4.2	
0	1	Small screw anchor	C012	762	76	1.4	
0	1	Screw anchor	C011	1219	152	3.9	
0	1	Metal sign	C026	533	229	0.9	

# in Cal Line	# in Blind Site	Description	PNNL ID(s)	Length (mm)	Width (mm)	Weight (kg)	Target Photo
0	1	Propeller	C024	305	305	2.7	
0	1	Metal chain	C030	300	300	10	
0	1	Small grapnel anchor	C016	406	60	1.8	
0	1	Large grapnel anchor	C015	457	110	4.8	
0	1	Metal wheel	C032	310	310	2.5	
0	1	Radar	C013	1245	89	0.9	
0	1	Pulley	C033	300	100	1.1	

# in Cal Line	# in Blind Site	Description	PNNL ID(s)	Length (mm)	Width (mm)	Weight (kg)	Target Photo
0	1	Scrap metal	C205	447	127	6.6	
0	1	Scrap metal	C202	120	250	1.8	
0	1	Scrap metal	C206	440	111	5.4	
0	1	Scrap metal	C204	406	152	2.5	
0	1	Scrap metal	C201	300	150	1.1	
0	1	Large scrap metal	C203	300	250	1.1	

# in Cal Line	# in Blind Site	Description	PNNL ID(s)	Length (mm)	Width (mm)	Weight (kg)	Target Photo
0	1	Large scrap metal	C200	610	450	10.9	

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov