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Preliminary Design Study for Munitions Response Underwater Test Site

SERDP Final Report, MR-2735

February 2018

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U.S. DEPARTMENT OF ENERGY

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14. ABSTRACT

This report describes a preliminary study conducted by Pacific Northwest Laboratory (PNNL) at its Marine Sciences Laboratory (MSL) on the Olympic Peninsula in Washington State. The objective was to acquire information to further inform the design of a final test site for evaluating unexploded ordnance (UXO) detection technologies and equipment for the Strategic Environmental Research and Development Program (SERDP).

The technical approach for the preliminary study consisted of three tasks: 1) obtain knowledge about typical UXO sites and their substrates, 2) characterize Sequim Bay and locate areas of substrates similar to those described at typical UXO sites, and 3) propose test areas in Sequim Bay that could be used in a final test site design.

Task 1 focused on determining the sediment properties at a representative sample of current and former military sites where underwater munitions are a concern.. This survey of the Munitions Response Site Inventory found that a large majority of the underwater sites of UXO concern lie in rivers, lakes, and coastal waters of the continental United States. The bottom compositions at these sites are mixtures of sand, soft sediments, and gravel, consistent with the range of sediments found in Sequim Bay.

Task 2 included underwater video, diver surveys, and substrate coring to find flat bottom areas that have a consistent substrate type for a distance of at least 150 m to 200 m.

Task 3 identified six areas of varying sizes, depths, and substrate types as potential test site areas.. Environmental permits and approvals would be required for most of the proposed areas. SERDP will need to review the proposed areas and make final recommendations regarding test site areas.

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Abstract

This report describes a preliminary study conducted by Pacific Northwest Laboratory (PNNL) at its Marine Sciences Laboratory (MSL) on the Olympic Peninsula in Washington State. The objective was to acquire information to further inform the design of a final test site for evaluating unexploded ordnance (UXO) detection technologies and equipment for the Strategic Environmental Research and Development Program (SERDP).

The technical approach for the preliminary study consisted of three tasks: 1) obtain knowledge about typical UXO sites and their substrates, 2) characterize Sequim Bay and locate areas of substrates similar to those described at typical UXO sites, and 3) propose test areas in Sequim Bay that could be used in a final test site design.

Task 1 focused on determining the sediment properties at a representative sample of current and former military sites where underwater munitions are a concern. This information was collected from reports provided by or publicly available from the Military Munitions Response Program, the U.S. Environmental Protection Agency, the Naval Facilities Engineering Command, various state agencies, and scientific literature. While the reports primarily focused on the sediment types available at these sites, additional information about the bathymetry, currents, tides, and wave action was included when available. This survey of the Munitions Response Site Inventory found that a large majority of the underwater sites of UXO concern lie in rivers, lakes, and coastal waters of the continental United States. The bottom compositions at these sites are mixtures of sand, soft sediments, and gravel, consistent with the range of sediments found in Sequim Bay.

Task 2 included underwater video, diver surveys, and substrate coring to find flat bottom areas that have a consistent substrate type for a linear distance of at least 150 m to 200 m. Locations surveyed covered approximately 8 hectares of bottom area. Researchers documented the presence of mud/silt in central Sequim Bay, silt and sand along Travis Spit, gravel and sand near the PNNL facility at the entrance to Sequim Bay, and mixed substrate (sand and gravel) near Middle Ground. This information was recorded and mapped. Additional video surveys documented sandy substrates outside Sequim Bay.

Task 3 identified six areas of varying sizes, depths, and substrate types as potential test site areas. One area south of Travis Spit in Sequim Bay may meet more prerequisites expressed by SERDP, but any of the sites could potentially be developed. Environmental permits and approvals would be required for most of the proposed areas. The test site design, number and type of objects, specific locations of objects, the methods of emplacement of objects, monitoring for movement, and retrieval of objects must all be addressed prior to approaching the stakeholders for permits. SERDP will need to review the proposed areas and make final recommendations regarding test site areas.

The overall conclusion, however, is Sequim Bay could be a unique test facility for testing technologies designed to locate UXO materials. The location is marine, nearshore but relatively protected, has a variety of sediment types, and is located near a federal marine sciences laboratory that can support operations.

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- Figure 11 – Integral Consulting, Inc. 1205 West Bay Drive NW Olympia, WA 98502
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Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
AP	armor piercing
ATE	Average Tidal Elevation
°C	degrees Celsius
CTD	Conductivity/Temperature/Depth sensor
DNR	Washington Department of Natural Resources
DOC	dissolved organic carbon
DOD	Department of Defense
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
Ft	feet
GPS	Global Positioning System
ha	hectare
in	inch
JWM	John Wayne Marina
km	kilometer
µm	micrometer
m	meters
m/s	meters per second
MLLW	Mean Lower Low Water
mm	millimeter
MMRP	(Department of Defense) Military Munitions Response Program
MRS	Munitions Response Site
MSL	Marine Sciences Laboratory
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
PI	principal investigator
PNNL	Pacific Northwest National Laboratory
POC	particulate organic carbon
psu	practical salinity unit
SERDP	Strategic Environmental Research and Development Program
SPI/PV	sediment profile imaging and plan view
USACE	U.S. Army Corps of Engineers
UXO	unexploded ordnance
yr	year

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1.0 Introduction

Developing technologies and equipment for detection and classification of unexploded ordnance (UXO) requires standardized test sites where the performance of technologies and detection equipment can be evaluated under controlled conditions using inert munitions. Several land-based test sites have been established in the United States, but an underwater test site is needed to consistently evaluate underwater munitions detection technologies. The Department of Defense (DOD) Strategic Environmental Research and Development Program (SERDP) issued a Statement of Need, MRSON-17-02, "Preliminary Design Study for Munitions Response Underwater Test Site," and accepted a proposal from Pacific Northwest National Laboratory (PNNL) to look at Sequim Bay, Washington, as a potential location for an underwater UXO test site. Sequim Bay is a small embayment of the Strait of Juan de Fuca in northwest Washington State (Figure 1).

PNNL's Marine Sciences Laboratory (MSL), located on the shore of Sequim Bay near its mouth, serves as a coastal site for testing marine hydrokinetic energy devices as well as for conducting other environmental research involving marine resources. MSL research activities over the past 40 years have built an extensive knowledge base regarding the tidal zones, tidal channel, inner bay, and tidal current profiling of the water column circulation. The bay has hosted scientific experiments conducted by PNNL for the U.S. Department of Energy (DOE) and other federal, Tribal, state, local, and industrial agencies and clients. Onsite staff include certified scientific divers with thousands of cumulative diving hours in Sequim Bay and the Puget Sound region. PNNL has an established environmental permitting process that is followed to obtain approval for research conducted in the bay. PNNL's MSL is a federal facility with the potential to host a year-round test site for visiting scientists to test munitions detection technologies and devices in an underwater environment.

This report describes the Preliminary Design Study for a Munitions Response Underwater Test Site in Sequim Bay, conducted by PNNL. The study was conducted during 2017 to acquire information to further inform the design of a final test site for evaluating UXO detection technologies and equipment. The study objective, technical approach, results, supplemental information from other federally funded projects, conclusions to date, and environmental permitting are described in the following sections.

2.0 Objective

The objective is to perform a preliminary study of Sequim Bay in Washington State to determine its suitability for becoming an underwater test site for evaluating UXO detection technologies and equipment and to develop a preliminary test site design. The design will be based on the characteristics of known UXO locations of concern. Sequim Bay bottom types will be matched to documented UXO locations and the best fit locations will be prioritized for test site development and environmental permitting.

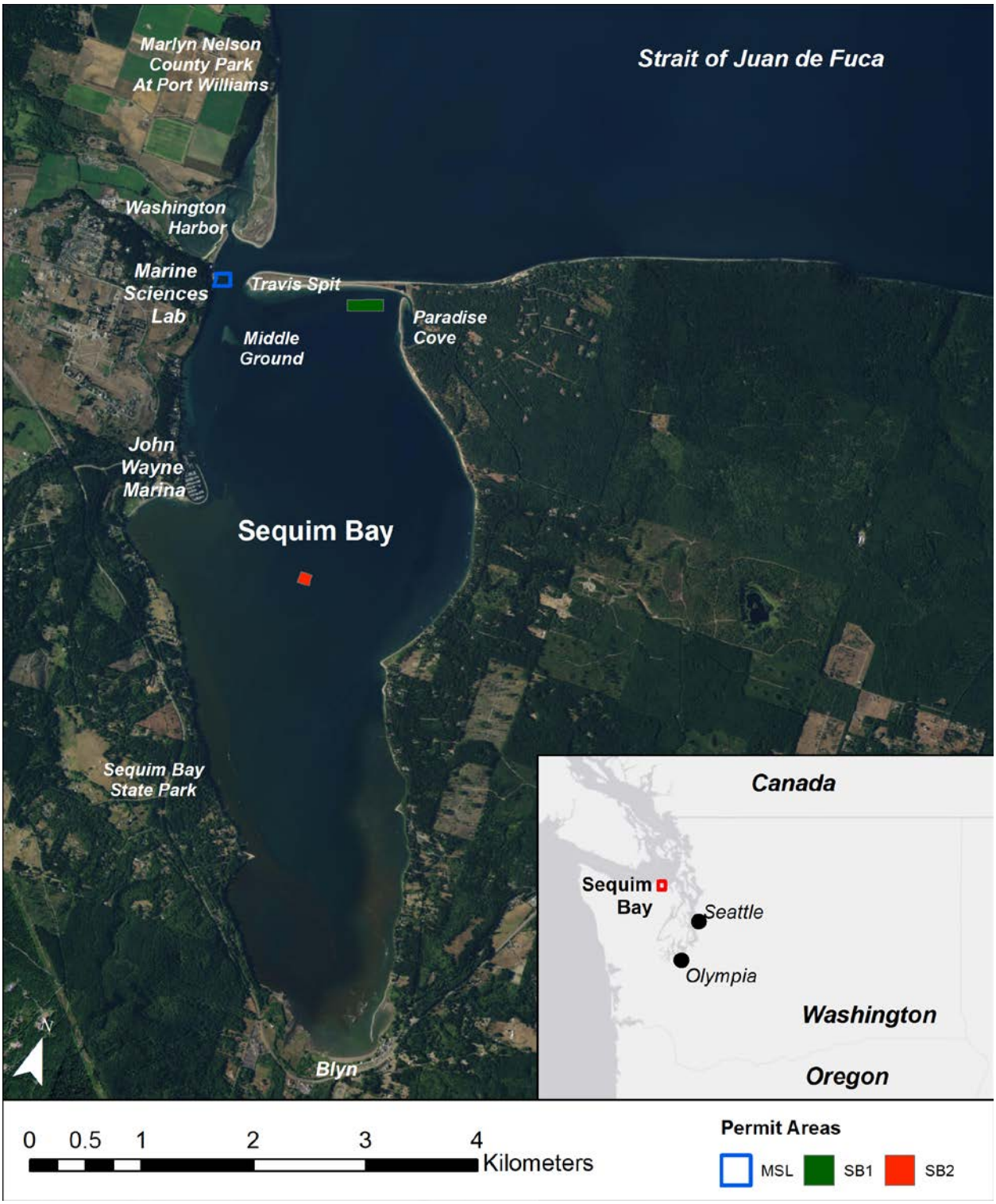


Figure 1. Site map showing Sequim Bay and landmarks of note.

3.0 Technical Approach

The technical approach for the preliminary study consisted of three tasks: 1) obtain knowledge about typical UXO sites and their substrates, 2) characterize Sequim Bay and locate areas of substrates similar to those described at typical UXO sites, and 3) propose test areas in Sequim Bay that could be used in a final test site design.

The first task encompassed compiling existing UXO site knowledge from Strategic Environmental Research and Development Program (SERDP) workshops and from UXO site owners, including as much information as possible about the range of underwater site and sediment characteristics at known sites. This task was performed by the University of Washington.

The second task was to determine the general locations of various substrate types in Sequim Bay and conduct ground truth efforts to verify bottom characteristics and sediment types. Exploration of Sequim Bay was conducted using a drop camera to perform the initial substrate investigations, and diver investigations, including sediment sampling. In addition, other federally funded projects have characterized Sequim Bay and we made use of two projects to contribute to our efforts.

PNNL began performing preliminary field assessments of substrate types in Sequim Bay after funding for the project was received. PNNL researchers first evaluated the existing data for a pair of related bathymetric surveys recently performed in Sequim Bay as part of a DOE-sponsored project. The first study, conducted by Solmar Hydro, Inc., used a georeferenced multibeam echosounder to provide a coarse survey of most of Sequim Bay. They were able to infer substrate composition by the reflection and backscatter of the signal to provide basic sediment categories. Integral Consulting (Integral) then used their sediment profile imaging system to map substrates in Sequim Bay. Integral's instrument drives an optical wedge into the sediments and takes a horizontal image with a high-resolution camera. This work covered a grid of most of the area of Sequim Bay. These point data were integrated with a multibeam echosounder survey data, thereby creating a large-scale, ground-truthed benthic habitat map.

The PNNL researchers evaluated these data with their familiarity of the bay through previous diving and boat operations to determine what areas should be targeted with video drop cameras. The intent was to provide higher resolution surveys in strategic areas to identify the most promising locations for setting up test lanes in various substrate types. The drop camera was used to ground truth substrate types and to try to identify flat bottom areas that have a consistent substrate type for a distance of at least 150 m to 200 m. An underwater video camera was lowered over the side of the research vessel and live images were assessed by researchers on board. Still images were captured at representative locations and Global Positioning System (GPS) data were recorded along with information about substrate type, vegetation observed, and water depth at that particular time. Areas targeted for this initial investigation included PNNL's currently permitted locations along Travis Spit and adjacent to the PNNL facility as well as six kilometers of shoreline on the east and west sides of Sequim Bay south of PNNL's facility (Figure 2). Altogether, these data locations covered approximately 8 hectares of bottom. Areas that were not level, were too close to areas frequented by boat traffic, and that contained mooring buoys or other conditions that were not conducive to setting up a test area were excluded from future sampling.

Promising locations were then targeted for sediment grab samples and coring so sediment grain size could be quantified. A 2-inch diameter sediment coring device was obtained from the University of Washington along with a set of sieves to analyze sediment grain size. Four areas were originally sampled for sediment sampling. A research boat with a davit was used to deploy the gravity coring device and a grab sampler at Travis Spit, at Middle Ground, and near the MSL. Partial samples were obtained, but researchers were not confident they were representative of the sediment type because the samplers had a hard time penetrating

the surface (in gravel) or lost the sample as the coring device was raised when the sediments were extremely fine. Researchers decided it would be more effective for divers to collect cores under water.

Divers dove at five predetermined locations, including the four previously attempted at Travis Spit, Middle Ground, and near the PNNL facility and one additional site in deeper water in the center of the bay. The areas targeted were relatively flat and were expected to cover a variety of substrate types (silt, sand, gravel). Divers carried a video camera and still camera with them to document what they saw as they swam along each transect. Divers entered the water at a predetermined GPS location and swam on a compass bearing for 150–200 m, with the exception of SB2 (Figure 1) where divers did not swim along a transect. Sediment core samples (2 in. diameter) were collected at each end of each transect. At SB2 a single core sample was collected for a total of nine diver-collected sediment samples. Divers used a mallet to pound the coring device into the sediment when they were unable to collect a sample easily by hand. The samples were labeled and kept in cold storage (4 °C) until they could be dried and sieved. When processed, samples were removed individually and the overlying water was carefully decanted off. The sediment from each core was placed in a pre-labeled baking dish to air dry for a week. Additional overlying water was removed daily with an eyedropper. When the sediment appeared to be mostly dry, the samples were placed in drying oven set to 100°C to finish drying completely before sieving. Researchers then put each sediment sample through a set of five sieves (8 mm, 4 mm, 2 mm, 355 µm, and 63 µm) to separate the material, by proportion, into:

- medium coarse gravel and larger
- medium pebble gravel
- fine pebble gravel
- coarse sand
- fine sand
- mud/silt.

Lastly, underwater snapshots were taken with a drop camera at two areas outside Sequim Bay to determine substrate type in those regions. One area was near the Marilyn Nelson County Park at Port Williams and the other was located on the shore of the Miller Peninsula to the east of Sequim Bay. Researchers watched the underwater video in real time. At depths of 30, 40, 50, 60, 90, and 120 ft at each of the two sites, the water depth, substrate type, vegetation observations, a GPS location, and still camera image were recorded.

All the locations sampled to validate sediment condition are shown in Figure 2. These include all the various camera surveys conducted by PNNL and Integral. The diver surveys were conducted near the sites indicated as “SERDP-UXO Drop Camera Sites Inside Sequim Bay”.

The third task was intended to document the preliminary test site design approach and finalize the site suggestions. The goal was to provide SERDP and its principal investigators (PIs) with the widest variety of site conditions that could be used for target emplacements and potential long-term testing. This process synthesized all the information from literature reviews, previous studies in Sequim Bay, local knowledge of the MSL researchers, data collected during this study, and conditions expressed by SERDP to delineate potential sites to suggest for further development. These sites are ones that met the SERDP requirements (at least in part), could feasibly be operational as a test site, and do not have obvious conflicts (e.g., permitting problems, conflicting users, protected habitats). Boundaries for these sites were determined in a GIS program to maximize total area within the contours of Sequim Bay. This task will provide the context SERDP will need to move forward in determining if Sequim Bay is developed as a test site and which areas are to be used.

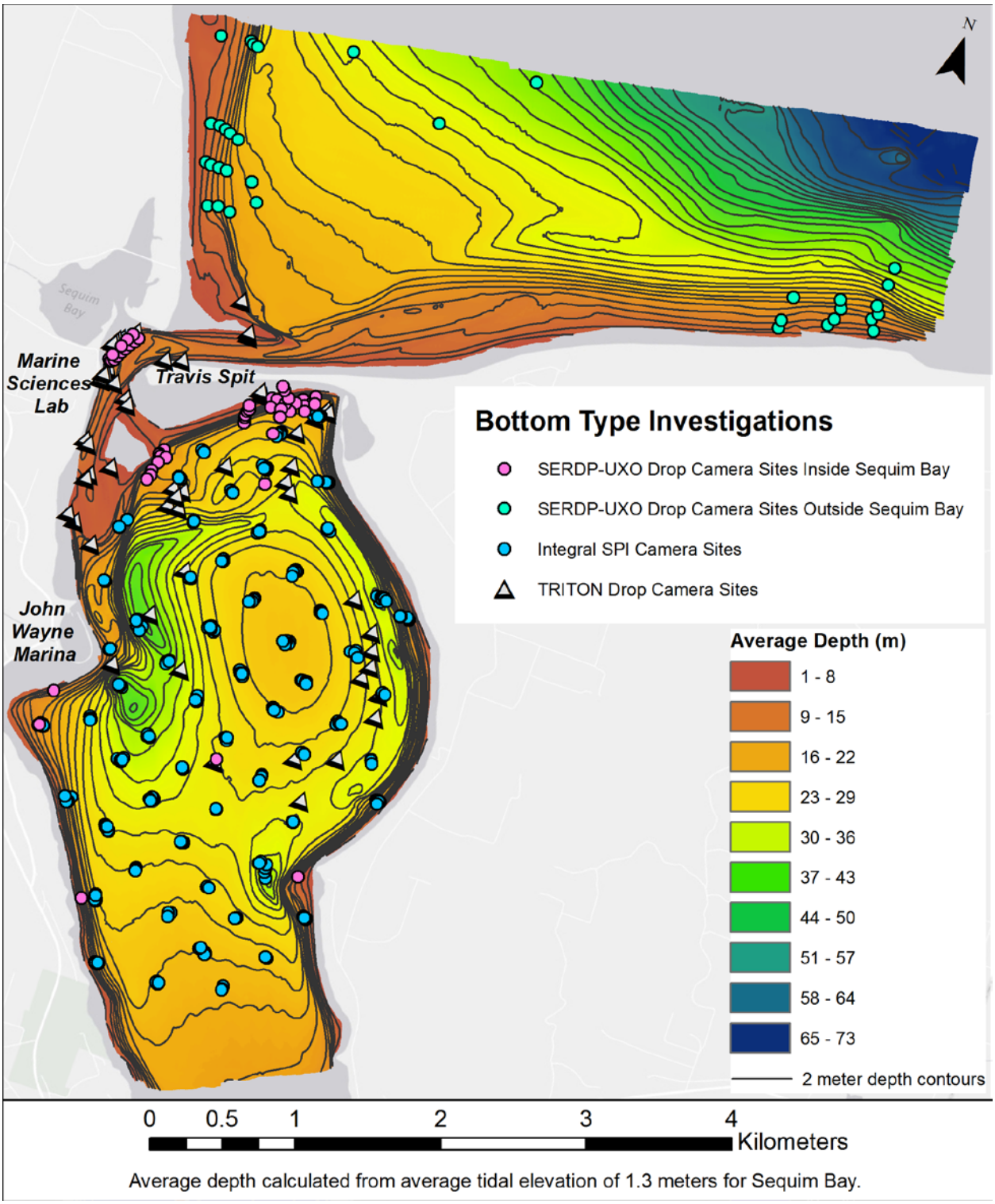


Figure 2. Locations where bottom type investigations were performed.

4.0 Results and Discussion

Preliminary results are discussed by task below.

4.1 Typical UXO Sites and Their Substrates (Task 1)

The goal of Task 1 was to provide a coarse determination of the range and prevalence of different bottom types that potentially have or are known to have UXO and/or munitions or explosives of concern, and to document a number of former and current military sites that are representative of these bottom types. Information was collected from reports provided by or publicly available from the Military Munitions Response Program, the U.S. Environmental Protection Agency, the Naval Facilities Engineering Command, various state agencies, and scientific literature. While the reports primarily focused on the sediment types available at these sites, additional information about the bathymetry, currents, tides, and wave action was included when available.

This section summarizes available information about common environments in which acoustic systems may be deployed to detect and identify UXO for eventual remediation. Currently, SERDP has focused on two approaches to acoustic sensing: high-frequency acoustic systems for the detection of UXO rested proud on the sediment interface and low-frequency, downward-looking systems to detect both proud and buried objects. For both types of systems, the geo-acoustic properties of the sediment have the greatest influence on the ability to both detect and classify UXO. Properties such as sediment density and sound speed influence how much acoustic energy is reflected from or transmitted to the seafloor, while sediment roughness and volume heterogeneity generate reverberation that can mask the UXO response. For survey planning, the sediment composition can also be important for predicting UXO mobility and burial, which can influence the choice of sensor. The UXO sites presented here were chosen to cover a range of sediment types to help determine the applicability of the Sequim Bay environment as an acoustic sensing testbed.

4.1.1 Prevalence of Different Environments in the Munitions Response Site Inventory

As part of the effort to address the hazards posed by current and former defense sites associated with unexploded munitions, the DOD Military Munitions Response Program (MMRP) maintains the Munitions Response Site (MRS) Inventory (DENIX 2017). This inventory provides maps of MRSs and their prioritization “for funding and cleanup of MRSs that pose the greatest threat to safety, human health, and the environment.” Although the inventory does not provide information about the environments at these sites, the maps make it possible to determine whether UXO might be present in lakes, bays, rivers, or in nearshore waters. This is a very broad environmental classification and while lake, river, and bay sediments are typically composed of mud, silt, or sand, the seafloors in nearshore waters can be composed of a wide range of materials. This is exemplified by the seafloors at both Naval Defense Sea Area (NSDA) Pearl Harbor and the Vieques Naval Training Range, both of which have areas with hard bottoms and areas with sandy bottoms. Along the coast of the continental United States, these hard seafloors are less prevalent. For the analysis here, the focus will remain on the environment type, classifying the underwater areas within the MRSs as either Lake, River, Bay, or Nearshore. The goal of this analysis is to identify the percentage of facilities within the MRS inventory that have sites in these environments and have been identified as priority through the MRS Prioritization Protocol or that need further investigation.

The procedure used to identify facilities with underwater MRS was as follows:

1. For each location designated with a Federal Facility Identification within the MRS inventory, the available maps were used to determine whether they had sites that overlapped with any bodies of water. The sites that did not have a map were excluded from the analysis.
2. From these potential underwater sites, those with MRS Prioritization Protocol scores of either "No known or suspected hazard" and "[MRS Prioritization Protocol] evaluation no longer required" were excluded.
3. The remaining facilities were then examined to determine the types of bodies of water that lay within the UXO sites. These were classified as Lake, River, Bay, or Nearshore. The category of "Lake" broadly encompasses any closed body of water including ponds or reservoirs. The category "Bay" also encompasses harbors. Some sites were found to fall into multiple categories such as River and Lake.

Following this procedure, 191 installations were identified as having sites that are under water and either are or may potentially be a MMRP priority. The number of installations with sites falling into each category are given in Table 1. While 51.2% of the installations have sites in nearshore environments, 75% of the installations have sites that are in lake, bay, or river environments. As a result, the majority of underwater MRSs have sediments composed of silt, mud, or sand.

Table 1. Categorization of the underwater sites within the MRS inventory. Note, some sites fall into multiple categories.

Category	Number of Installations	Percentage of Total Number of Installations
River	45	25.9%
Lake	46	26.4%
Bay	53	30.5%
Nearshore	89	51.2%

4.1.2 Representative Underwater UXO Sites

A list of the representative UXO sites discussed in this document is given in Table 2 along with the sediment types found at each site and the range of depths present in the areas of UXO concern. This list is not by any means exhaustive, but it is representative of UXO sites of concern. Some of these sites are of ongoing concern while others have already undergone extensive cleanup efforts. Even this small sample of UXO sites covers nearly the entire range of sediment types. A short description of the UXO concern, depths, currents, and hydrodynamics present, and the sediment types encountered at the site are provided in Appendix A.

In summary, the survey of the MRS Inventory found that a large majority of the underwater sites of UXO concern lie in rivers, lakes, and coastal waters of the continental United States. The bottom compositions at these sites are mixtures of sand, soft sediments, and gravel, consistent with the range of sediments found in Sequim Bay.

Table 2. UXO sites evaluated in this report.

Site Name	Environment Type	Sediments	Depth Range (ft)
San Diego Bay (CA)	Bay/Harbor	Silty to clayey sands and poorly graded sands with some gravels and cobbles	0–69 (mean: 16)
Naval Supply Depot Annex Pearl Harbor (HI)	Near Shore	Limestone/old reef with pockets of sand	0–120
Naval Support Facility (NSF) Great Lakes (IL)	Lake	Silty-sand bottom with mussel habitat	0–120
NSF Indian Head (MD)	River	Silty/clay-like sand	0–78 (mean: 7-10)
Vieques Naval Training Range (PR)	Near Shore	Coral/hard bottom, sand, and some areas with soft bottoms/sea grass	0–150
Mare Island Naval Shipyard (CA)	Bay/Harbor	Silt	0–30
NAS Patuxent River (MD)	River	Sand	0–10

4.2 Characterization of Sequim Bay and Location of Areas of Similar Substrates (Task 2)

This section is a compilation of literature review, local knowledge, and active field investigation conducted as part of this project. The intent is to give a comprehensive picture of Sequim Bay and its characteristics that could influence a site testing facility in the area.

4.2.1 Regional Geology

The project area is located within the Puget Sound basin in the northern portion of the Puget Trough physiographic and geologic province of Washington State (Franklin and Dyrness 1973). The Puget Sound basin is a depressed glaciated area with moderate topographic relief. The geology and topography of the region is the result of glacial action of the Pleistocene epoch. Sedimentary deposits throughout the region range from porous gravels and sands to a hard till containing clay, silt, and coarser particles. The topography of the region is dominated by the terminal moraine of the Vashon glacier and the Puget Sound (Franklin and Dyrness 1973). As the weight of glacial ice reduced during glacial retreat, isostatic rebound reached heights of 140 m (460 ft). The configuration of the modern shoreline and sea levels stabilized approximately 5000 years ago (Thorson 1981).

Figure 3. Bluffs on the northwest shore of Sequim Bay near the MSL facility.

4.2.2 Bathymetry and Circulation

Sequim Bay is a protected embayment toward the eastern end of the Strait of Juan de Fuca. Prevailing longshore sediment transport created and maintains a sand spit (Travis Spit; see Figure 1) that almost completely seals the mouth of the bay, leaving a narrow navigation channel through which all water exchange between the Strait and Sequim Bay occurs. Because there is relatively limited freshwater input from the few small streams in the Sequim Bay basin most of the year, compared to the other areas of the peninsulas, most of the circulation is driven by tidal exchange.

Sequim Bay experiences mixed semidiurnal tides (e.g. Figure 4 and the yellow surface line in Figure 5). The result of this tidal pattern is that the two high tides (and low tides) are uneven during the course of the day. During neap tides this will often mean that the exchange is more limited between the two high tides and there is only one larger lower low tide in the tidal cycle. The average tidal exchange (i.e., between Mean Lower Low Water [MLLW] and Mean High High Water) is 2.41 m although the most extreme tidal exchanges can be greater than 3.5 m.

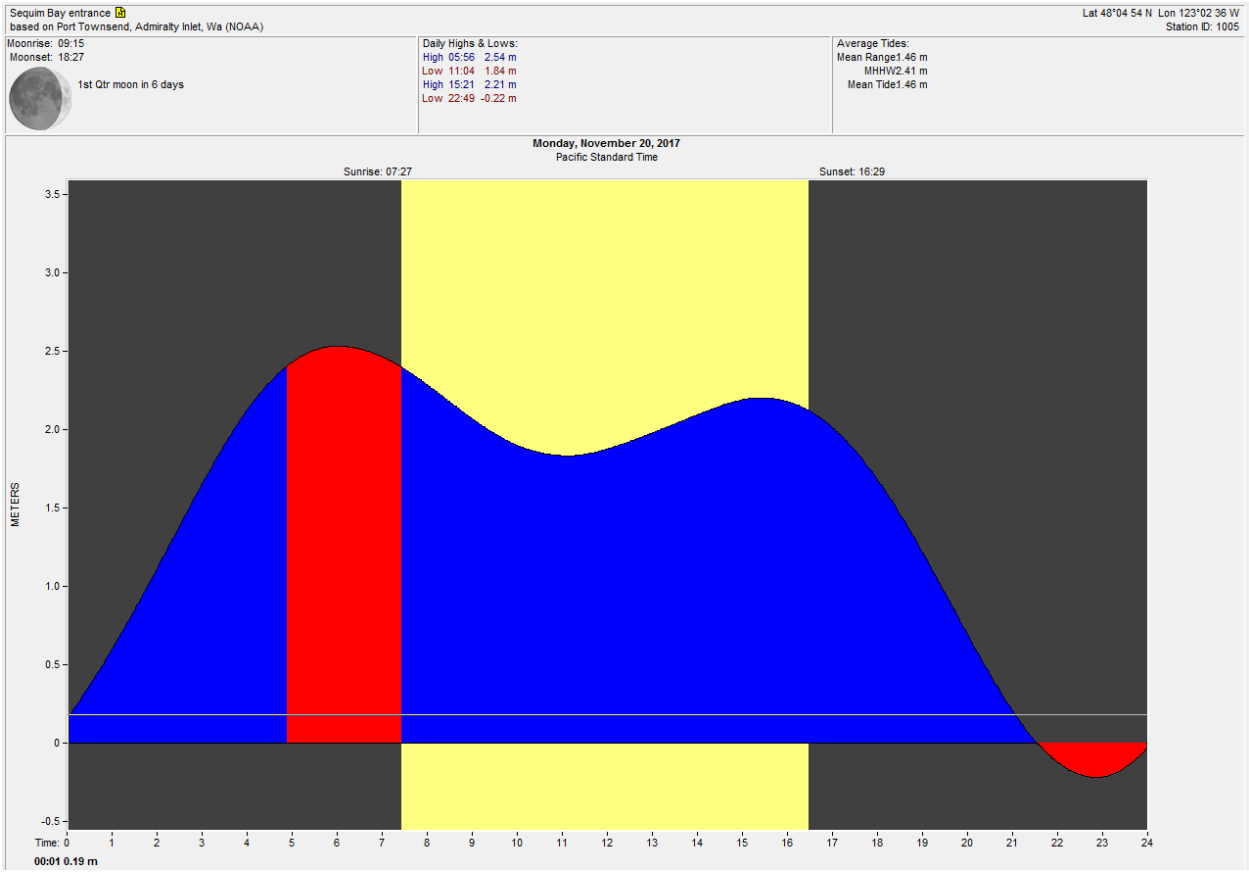


Figure 4. Example of the mixed semidiurnal tide pattern in Sequim Bay.

These tides can create strong tidal currents in more constrained parts of Sequim Bay and drive most of the circulation throughout the bay. As water enters Sequim Bay, it is funneled into a channel created by Travis Spit and the mainland (Figure 6, Figure 5) at velocities approaching 2 m/s. A sand shoal called the Middle Ground further constrains flow in the channel and directs most of the water south toward John Wayne Marina. While some of the incoming flow passes between the Middle Ground and Travis Spit, especially during lower low tides, the primary flow is along the primary channel. Once the water leaves the constraints of the channel to the south the velocity decreases by an order of magnitude (Figure 5) and the water can move throughout the bay creating slow eddies inside Sequim Bay (Figure 7). These more diffuse water movements create uneven flushing in the bay. Dye studies done by PNNL show that the greatest exchange happens in the channel and mouth of the bay, while areas on the mud flats to the south and nearshore areas inside Travis Spit may have less exchange (e.g., Figure 8). Both Figure 7 and Figure 8 are simulations from a simplified 2D version of the Delft3D model presented in Hibler et al (2008). These graphics are presented only to give a general indication of tidal current and mixing patterns in Sequim Bay.

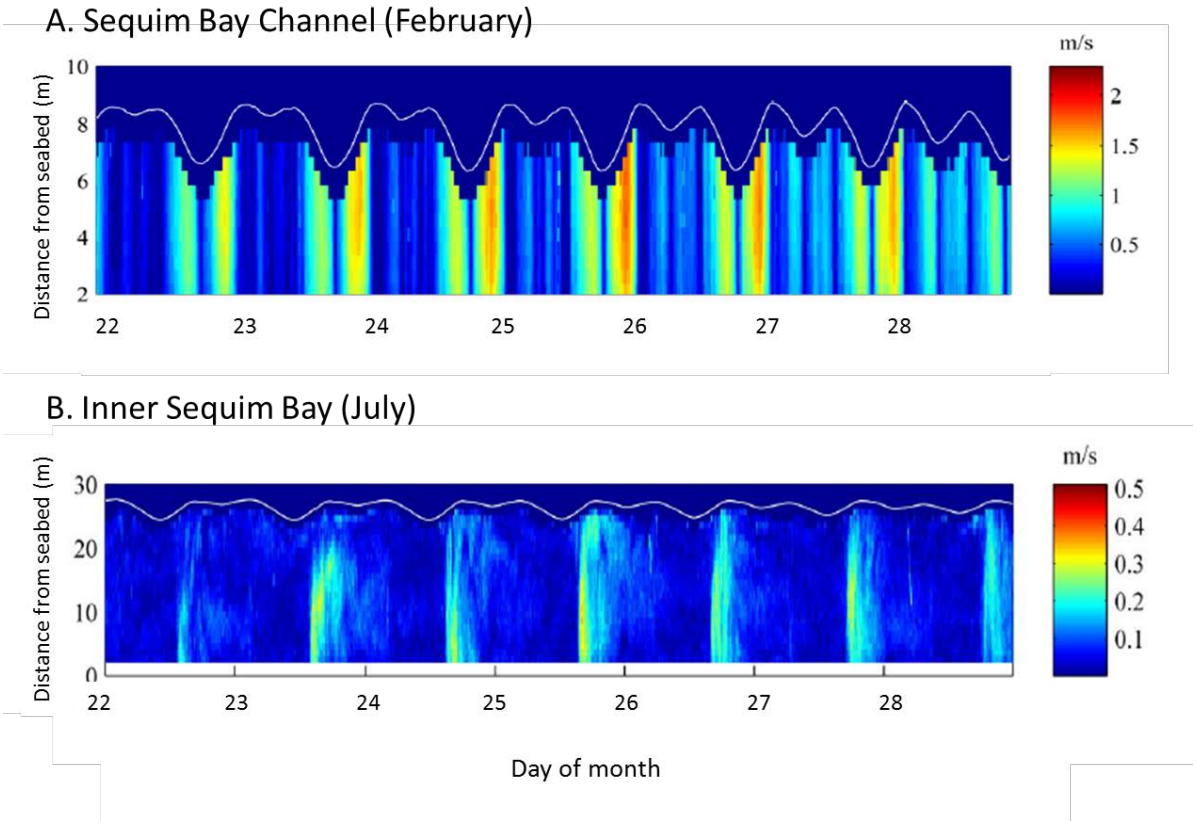


Figure 5. Excerpts from previous 2017 ADCP deployments (a) in the Sequim Bay Channel and (b) in the center of Sequim Bay showing velocity magnitude and water depth over a typical spring tide week (adapted from Harding and Harker-Klimes 2017 a,b). Yellow line indicates the sea surface. Note the velocity and depth scale differences between the sites.

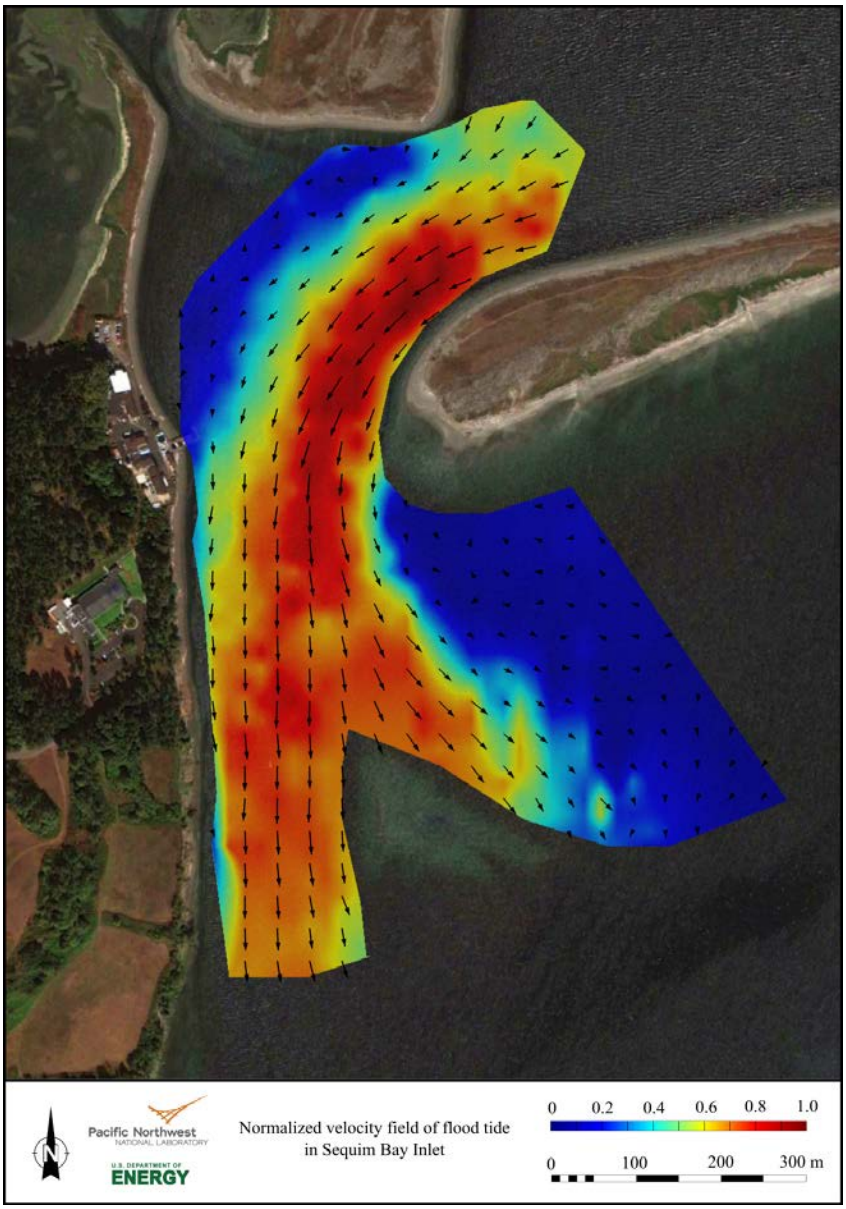


Figure 6. Normalized flow field in the mouth of Sequim Bay near the MSL during an incoming tide (from Harding et al. 2016).

The bathymetry of the Sequim Bay is largely maintained by interactions with these tidal currents and is relatively stable on average. Normally, for work around Sequim Bay, MSL uses all depths referenced at the MLLW, which is essentially the average lowest tide mark. For SERDP visiting PIs we may take advantage of the changing tide to provide varying depths at test locations; therefore, we reference the depths in the figures using elevations from mid tide. Tidal elevation at mid tide represents the average water surface elevation relative to MLLW; depths will increase at high tide or decrease at low tide. Average depths shown in the bathymetric figures are the depths below the average water surface or level at the mid tide average.

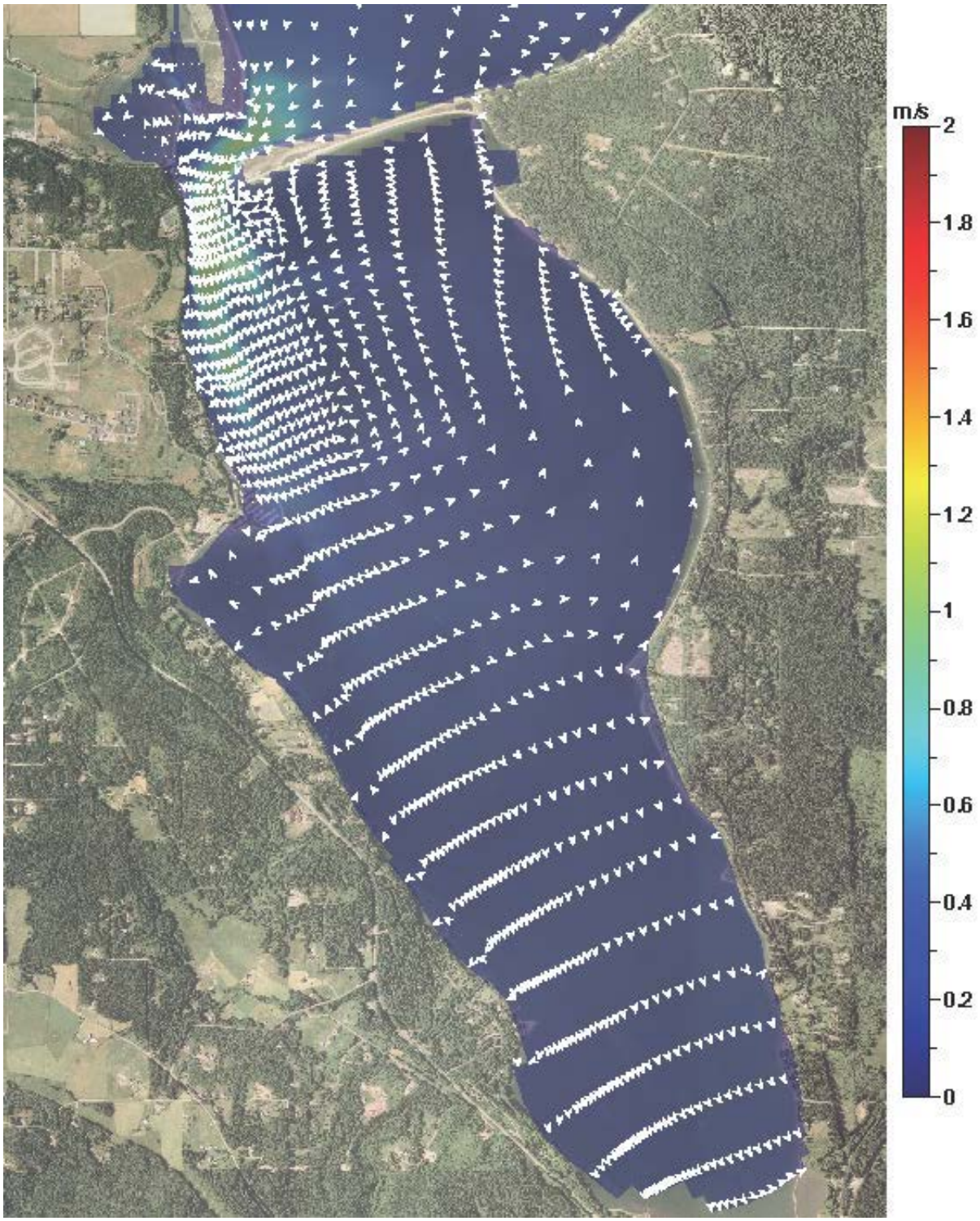


Figure 7. Output of a PNNL model of current flow for a tidal exchange in Sequim Bay (from Hibler et al. 2008)

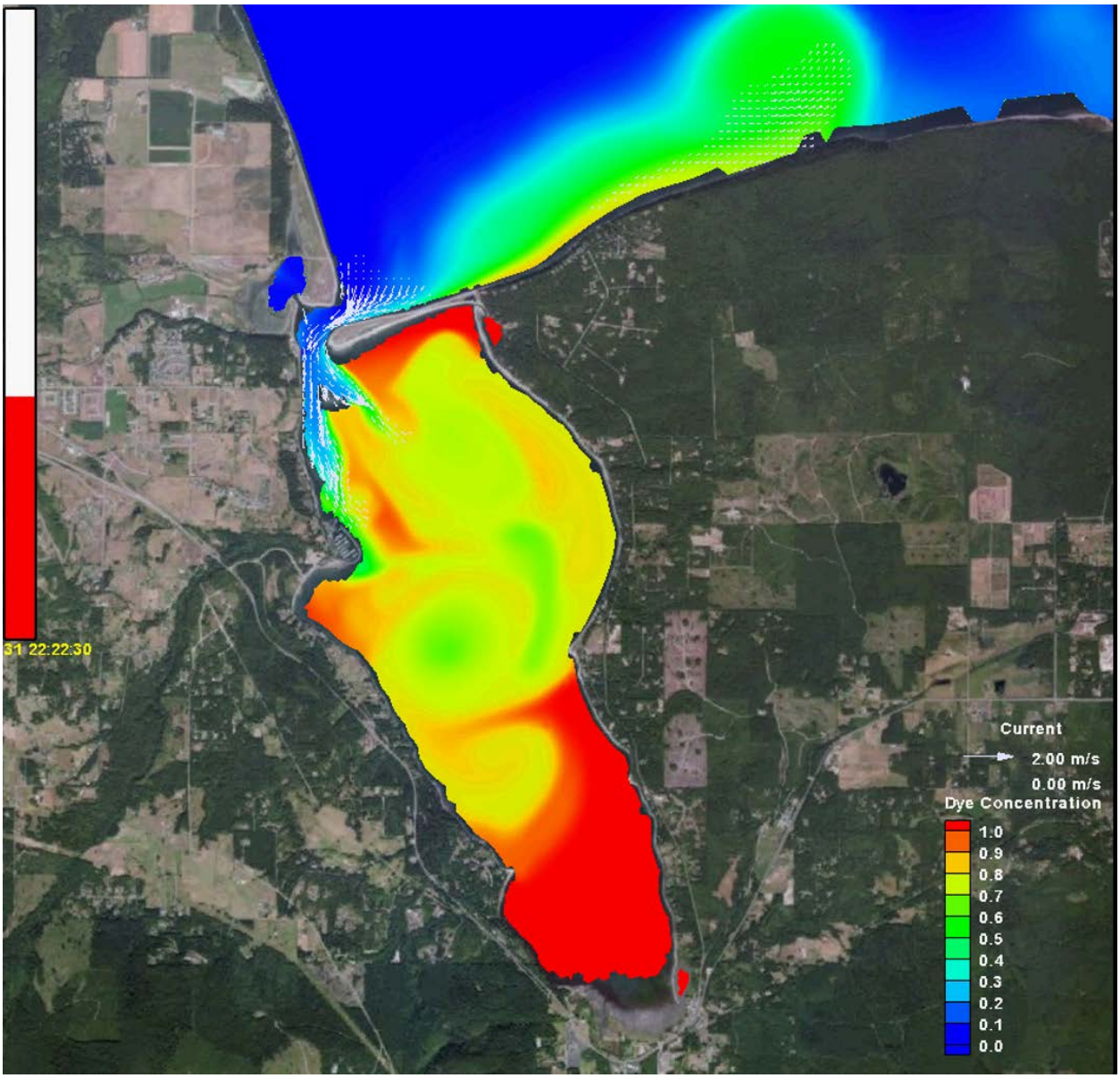


Figure 8. Snapshot from the PNNL circulation model of currents in Sequim Bay marked by dye concentrations in the water column. This is an incoming tide after a low low tide and after the model has run for a couple of tidal flushes (compiled from work associated with Hibler et al. 2008?)

Multiple bathymetry surveys have been conducted in Sequim Bay, so the bathymetry is fairly well known (Figure 9). There is a sand or mud shelf that rings most of Sequim Bay in varying widths. The channel is fairly uniform in depth before emptying into Sequim Bay proper and becoming much deeper in places. The aforementioned shoals at the Middle Ground, which are exposed during spring low tides, separate the channel from the interior of the bay. The southern end of Sequim Bay is characterized by a large, relatively shallow flat (to the south of the surveyed portion in Figure 9). Maximum depths in the bay can approach 35 m deep, although the average in the center is closer to 20 to 25 m deep.

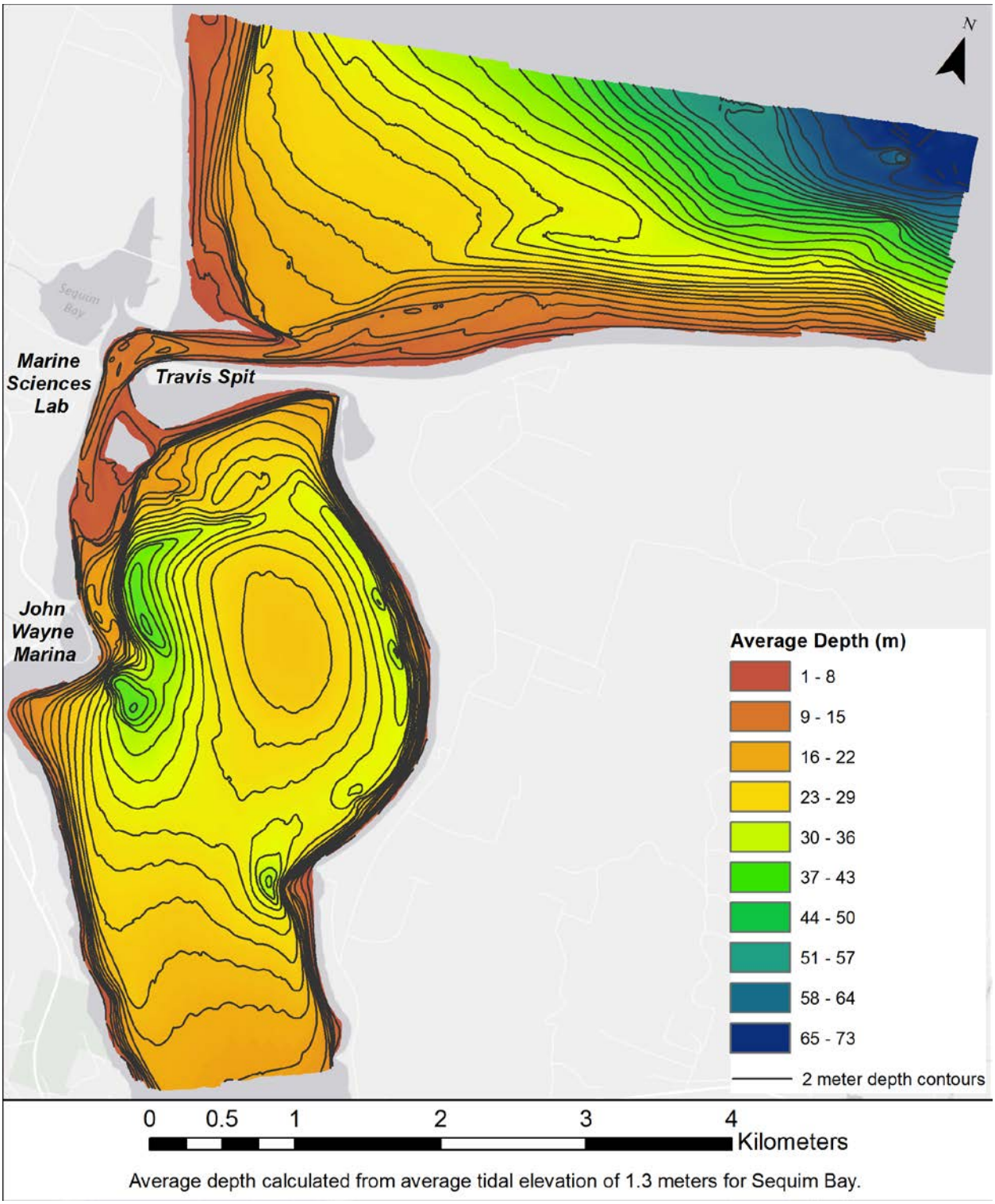


Figure 9. Bathymetry of Sequim Bay and areas north of the bay (from Integral Inc., unpublished data).

4.2.3 Bottom Type/Sediment Characterization

As described earlier, the PNNL researchers were generally familiar with Sequim Bay through previous diving and boating operations and had an idea of areas to target that might meet the SERDP criteria for a testing facility. However, a number of studies and methodologies were utilized to identify substrate types on multiple scales.

A coarse overview of the entire bay except for the southern mudflats and shallow edges were obtained with the Solmar Hydro multibeam survey. This study reflected sound waves off the bottom and applied algorithms to the acoustic backscatter to partition substrates into broad categories (Figure 10). In this map, muddy substrates show as blues and dominate the interior of the bay. The yellow and orange returns are sandier and concentrate around Travis Spit, the middle Ground, and along many of the edges of the bay. The harder substrates, red in the figure, are primarily located in the channel where water currents can scour away finer sediments.

The penetrating camera provided photos of the sediment over a large proportion of Sequim Bay for sediment characterization (Figure 11) and served to ground truth the backscatter data. In general there was good correlation between the different methodologies. Data from the diver surveys and cores were also compared to these data with good agreement and are presented in Figure 12 , but they will be discussed further in Section 4.3 along with the area descriptions.

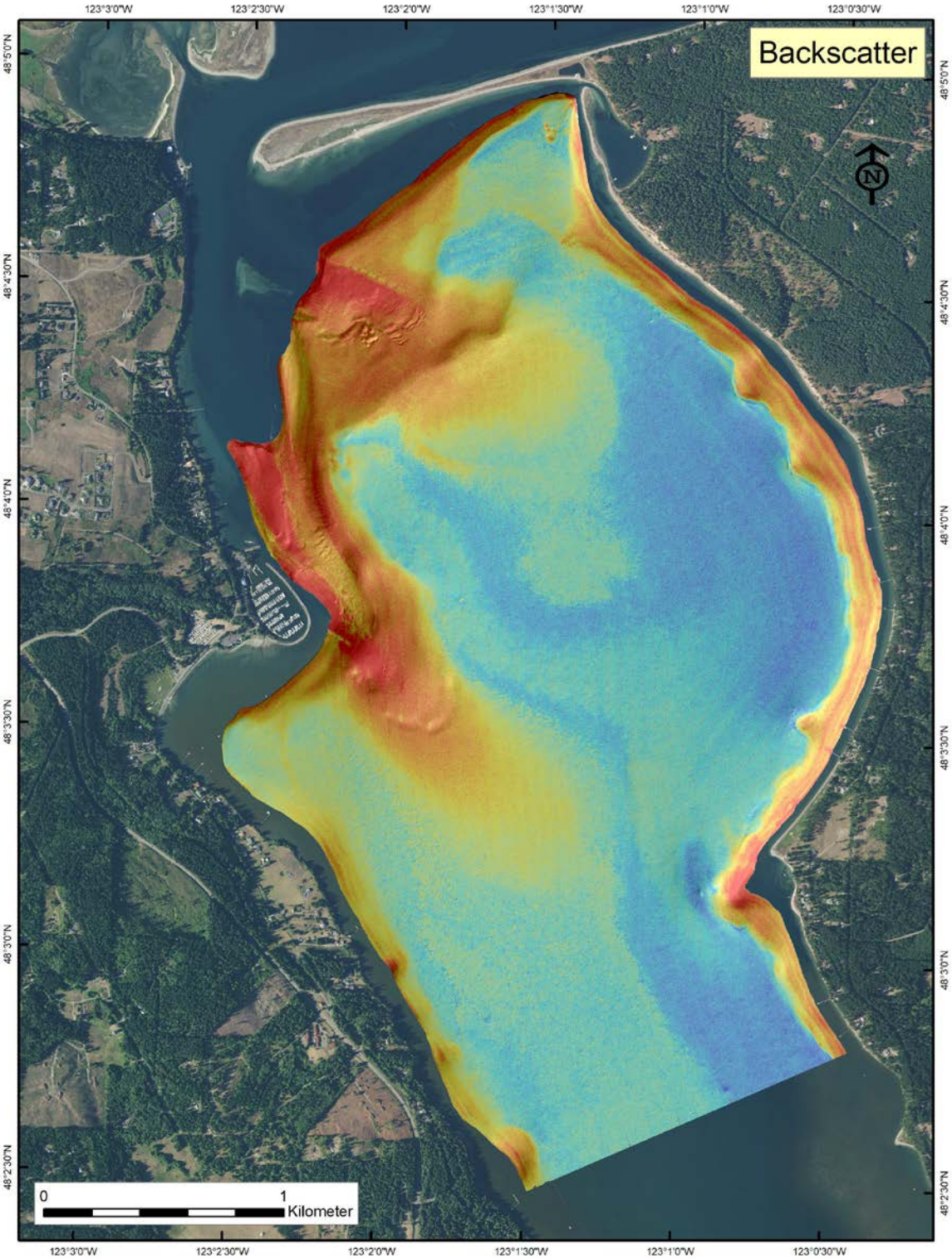


Figure 10. Solmar Hydro multibeam backscatter data plot of Sequim Bay. More dense returns are red in color in this plot.

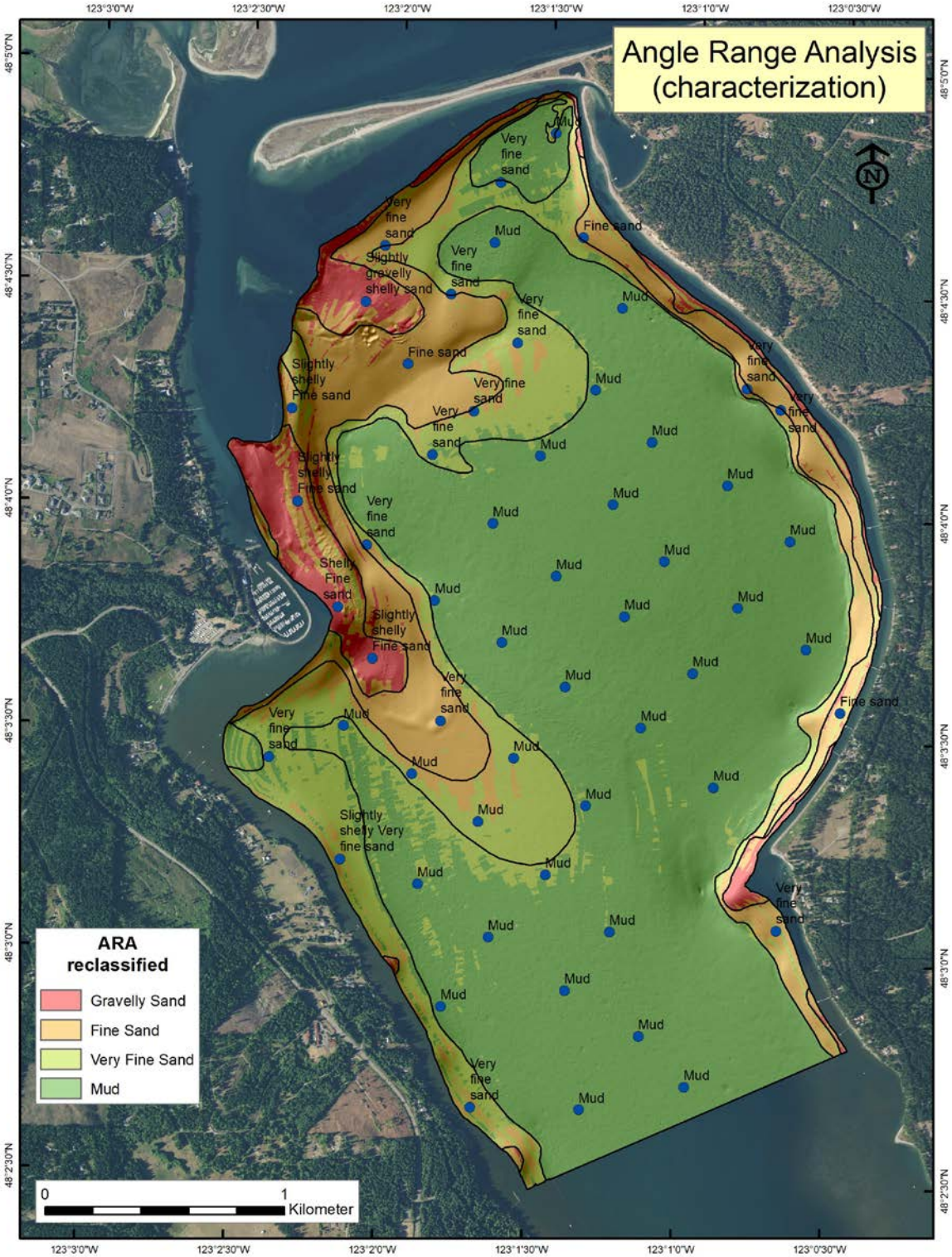


Figure 11. The classified bottom types as depicted by Integral using their SPI/PV system.

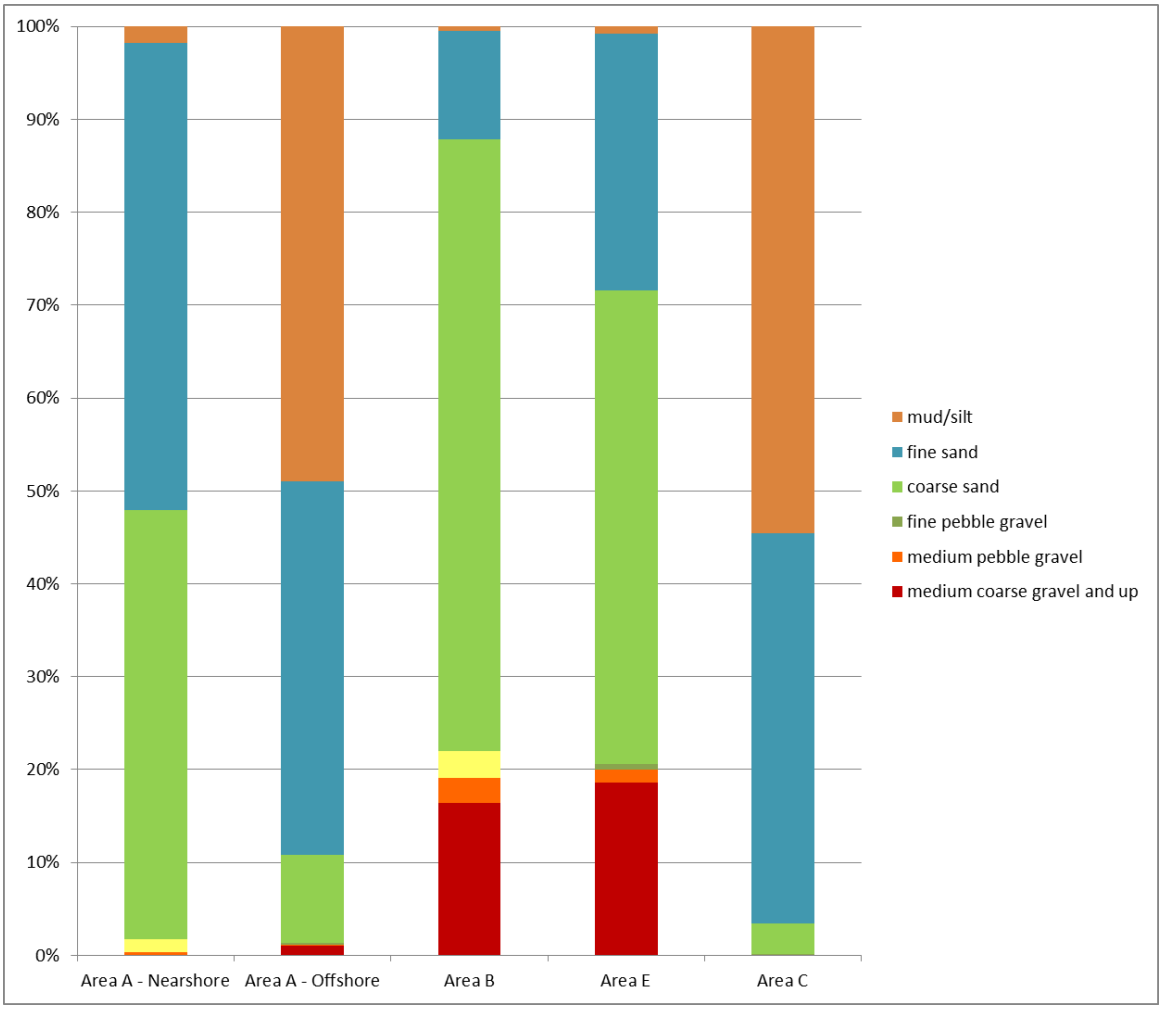


Figure 12. Percent sediment type by weight in sampled areas inside Sequim Bay. Key to locations names: Area A is in the vicinity of SB1; Area B is on the east side of Middle Ground; Area E is near the MSL; Area C is at SB2 (see Figure 1).

4.2.4 Sequim Bay Water Properties

Despite the small channel at the entrance, Sequim Bay has open connectivity to the Strait of Juan de Fuca and therefore exhibits marine conditions. General ranges are shown Table 3 where water quality data were collected over a year at the MSL dock (D. Woodruff, unpubl. data). The salinity is a little lower than average ocean water but still generally between 31 and 33 psu. Temperatures are temperate and generally in the teens in the summer and single digits in the winter. CTD (Conductivity, Temperature, Depth sensor) casts (Figure 13) show that the water can show some stratification toward the surface, especially in the summer, but it is generally well mixed to depth.

Table 3. Ambient Water Quality Conditions for MSL dock, Sequim Bay Washington, June 2009 through August 2010 during outgoing tides (from D. Woodruff, unpubl. data).

Parameter	Season	N	Median (s.d.)	Min	Max
Salinity at 1 meter depth (psu)	Spring	13	31.5 (0.1)	31.2	31.6
	Summer	23	31.5 (0.5)	30.5	32.3
	Fall	13	32.2 (0.3)	31.6	32.6
	Winter	12	31.4 (0.3)	30.9	31.9
Temperature at 1 meter depth (°C)	Spring	13	9.9 (1.1)	8.8	11.8
	Summer	23	12.8 (1.6)	11.3	17.0
	Fall	13	10.4 (1.4)	9.1	13.2
	Winter	12	7.8 (0.4)	7.4	8.4
POC (mg C/L)	Summer	9	0.92 (0.17)	0.53	1.06
DOC (mg C/L)	Summer	9	1.2 (0.1)	1.1	1.4
Organisms > 50 µm (cells/ m^3)	Spring	13	5.4×10^7 (2.4×10^8)	2.8×10^6	5.4×10^7
	Summer	18	2.2×10^7 (5.6×10^8)	4.6×10^5	2.2×10^7
	Fall	13	1.1×10^7 (4.3×10^7)	8.3×10^5	1.1×10^7
	Winter	12	2.2×10^6 (2.3×10^6)	6.2×10^5	2.2×10^6
Chlorophyll a (µg/L)	Spring	11	3.0 (4.0)	0.6	15.0
	Summer	29	4.9 (2.5)	0.7	11.3
	Fall	13	1.5 (2.1)	0.2	7.8
	Winter	10	0.3 (0.4)	0.2	1.6

The clarity of the waters in Sequim Bay can be quite variable. At certain times of the year, the water can be relatively clear with decent visibility (pers. obs. from the dive team) and very few organisms in the water (e.g., Table 3) but at other times plankton blooms can severely reduce the local visibility and dramatically increase the attenuation of light in the water. Unpublished (D. Woodruff) secchi depths off the MSL dock taken over the last three years has indicated an average secchi depth of 4.4m, although extremes have been 0.8m and over 6.5m (the bottom is at 6.5m in that location). Generally plankton bloom conditions are more prevalent during the spring through late summer, and surface stratification of the water can exacerbate the poor visibility by concentrating the plankton in a thinner layer of water. Under these conditions the deeper layers can actually have good visibility although the amount of ambient light is much lower since most light is attenuated in the surface layer with the plankton (J. Vavrinec, pers. obs.).

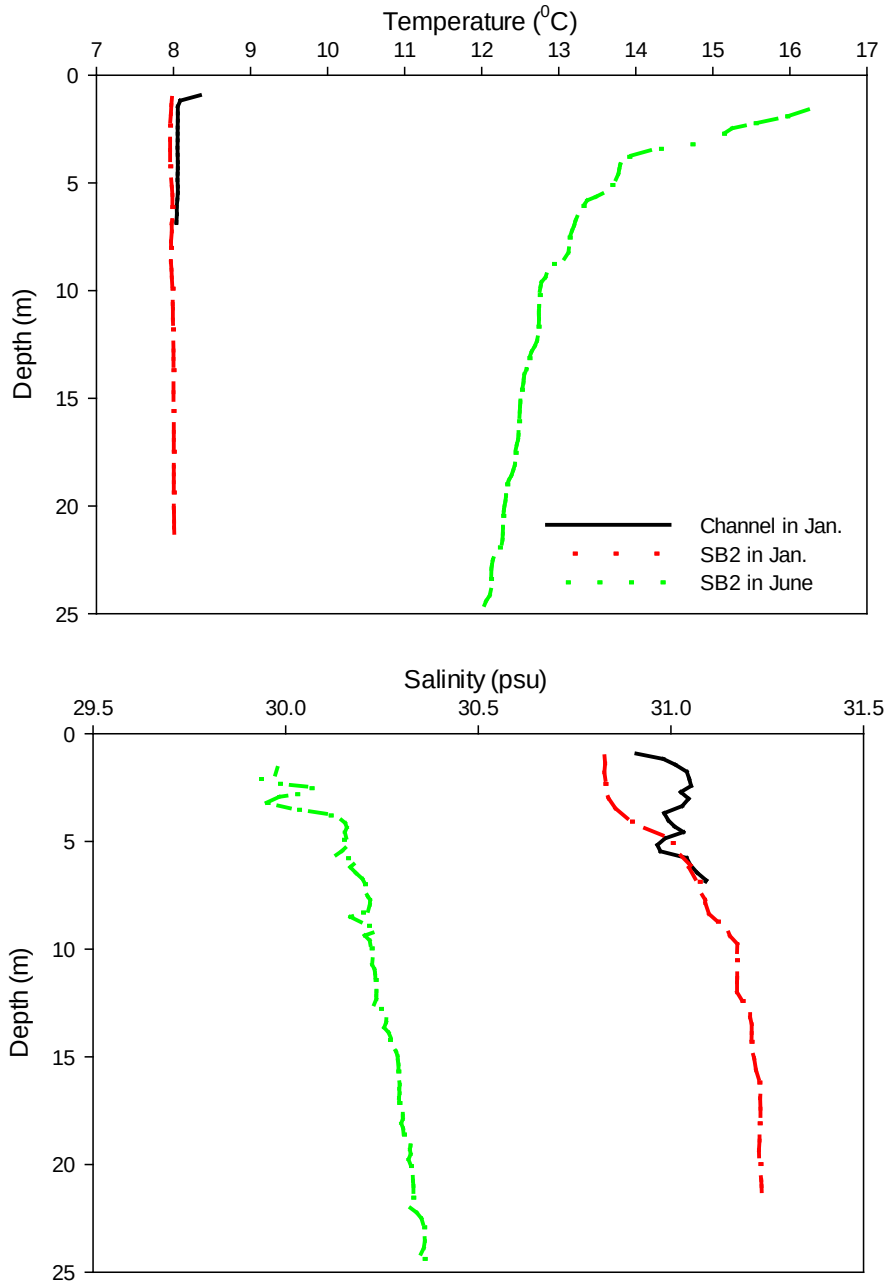


Figure 13. Representative CTD cast data for the channel at the opening of Sequim Bay and SB2 in the middle of Sequim Bay. The channel data were collected in January, and the SB2 data were in January (red line) and June (green line). From G. Staines, unpubl. data.

4.2.5 Current Uses

Presently, Sequim Bay is used frequently for a variety of activities and has facilities to accommodate diverse users. The Jamestown S'Klallam Tribe still has a strong presence in the bay, especially on the southern end of Sequim Bay near their Tribal campus, where they engage in fishing, aquaculture, and cultural activities. The Sequim Bay State Park is located on the western shore of southern Sequim Bay and has moorings for recreational boaters, a pier for fishing, and a boat ramp. John Wayne Marina, run by

the Port of Port Angeles and just to the north of the park, houses small boats, live-a-boards, commercial harvesters, and agency vessels. There is also a public ramp at the marina that is heavily used during fishing openings, creating a lot of vessel traffic between the marina and the Strait of Juan de Fuca through the channel. A large sailing community is based out of the marina as well, and periodic races in Sequim Bay are sponsored by the Sequim Bay Yacht Club. The MSL is located at the mouth of Sequim Bay and frequently conducts research off its pier, inside Sequim Bay, and in the surrounding waters.

Fishing is a very popular in Sequim Bay and the vicinity. Two of the more popular fishing seasons inside the bay involve the use of traps to target Dungeness crabs and shrimp. Multiple open seasons for both species cover recreational, commercial, and Tribal fishers. Salmon (predominantly in the spring and late summer) and Pacific Halibut (summer) are also very popular, although more so outside Sequim Bay. A host of other fishing seasons are smaller but can have longer seasons including a number of rockfish, lingcod, and Cabazon fishing seasons.

4.2.6 Excluded Areas

In the course of evaluating Sequim Bay for potential test sites, a few areas were ruled out of contention at least at this first stage of the evaluation process (Figure 14). It is possible that the permissions and/or permitting could be obtained for some of these areas or logistical problems could be solved, but they would likely need additional effort to bring the site online. It was determined that if appropriate alternatives were available these “out of contention” areas would be of lower priority.
First, surveys were targeted to avoid meadows of eelgrass *(Zostera marina*; e.g., Figure 15*)*, the predominant local seagrass that is protected at state and federal levels. Eelgrass is located in shallow areas (approximately 0 to -15 ft MLLW) where light is abundant and where the appropriate sandy-to-muddy sand substrate is found. If vegetated areas are desired for testing, there is a possibility divers may be able to carefully place materials within some of these meadows, but extra steps (and possibly mitigation) would be required for the permitting of these areas and the technologies tested would need to be able to operate in relatively shallow waters without damaging the eelgrass population.

Figure 14. Exclusion area map.

Figure 15. Eelgrass photos (clockwise from upper left): MSL researcher working on exposed eelgrass meadow at low tide; MSL diver counting eelgrass underwater; MSL diver working in eelgrass meadow underwater; perch swimming on edge of eelgrass meadow.

In addition, two other areas were excluded because of conflicting uses. The southern flats at the end of Sequim Bay are extensively used, and in some cases owned, by the Jamestown S'Klallam Tribe and were therefore avoided. The area around the Sequim Bay State Park would be difficult to permit and would be heavily populated by recreational users many times of the year. Lastly, the flat embayment to the south of John Wayne Marina was also removed from consideration because the area is used for permanent and temporary moorage of boats. Not only would the site be difficult to navigate with the moorings, the bottom could be disturbed enough by frequent anchoring to dislodge and relocate any targets placed in the substrate in the testing zone.

4.2.7 Facilities in Sequim Bay

One of the potential advantages of Sequim Bay as a test site is the availability of facilities located in the bay that could support operations. The first is the PNNL's MSL and the second is the John Wayne Marina. While there are other facilities (e.g., shipyards) relatively close in Port Angeles and Port Townsend, these two facilities are in Sequim Bay and will be the focus of this section.

4.2.7.1 PNNL Marine Sciences Laboratory

The MSL is the only marine laboratory in the DOE's National Laboratory system and it is dedicated to research and development focused on helping the nation meet needs for sustainable energy, a sustaining environment, and robust security in coastal environments. It is situated on 140 acres of land at the mouth of Sequim Bay (Figure 16) and has approximately 1400 m^2 of laboratory space, half of which is connected to flowing seawater system. The facility also has a shop, electronics/optics laboratory, and pier with floating dock to support operations on land. To support operations on the water the MSL owns a number of research vessels (Figure 17), including:

- 33-ft SAFE Boat with davit and optional gantry system (*Desdemona*)
- 28-ft Aluminum vessel with A-frame and davit (*Strait Science*)
- 23-ft SAFE Boat (*SAFE Boat*)
- 17-ft- Aumaweld Super-Vee LS (*Tenacious-A*)
- Sun Tracker 20 Fun Fish (*Sun Tracker*)

The MSL can lease larger vessels if needed and has standing contracts with the University of Washington for use of their vessel.

Figure 16. Aerial photograph of the PNNL's Marine Sciences Laboratory located on the mouth of Sequim Bay.

Figure 17. MSL vessels available to support operations in Sequim Bay. From the upper left moving clockwise: *Desdemona, Strait Science, Tenacious A., Sun Tracker, and SAFE Boat.*

The MSL also houses the PNNL Research Dive Team. These divers are all scientists, adept at accomplishing scientific tasks in a variety of underwater environments. The team has advanced standardized equipment including full-face masks with wireless communications, a closed-circuit rebreather, and a variety of underwater scientific and video-/photographic equipment. The divers have an intimate knowledge of Sequim Bay and are an invaluable resource when assessing habitats and other underwater features.

Lastly, the MSL has staff that spans multiple disciplines, including oceanography, modeling, biogeochemistry, sensor development and field deployments. The potential help from this staff to PIs ranging from assisting with troubleshooting, idea development, and execution of tests is not likely to be found near other potential test locations.

4.2.7.2 John Wayne Marina

John Wayne Marina (JWM), run by the Port of Port Angeles, is located inside Sequim Bay south of the MSL. JWM is a full service marina that offers permanent and transient moorage, fuel, and a boat ramp. Vessels can be moored at the marina at night to facilitate operations so there is no need to launch and trailer the vessels each day.

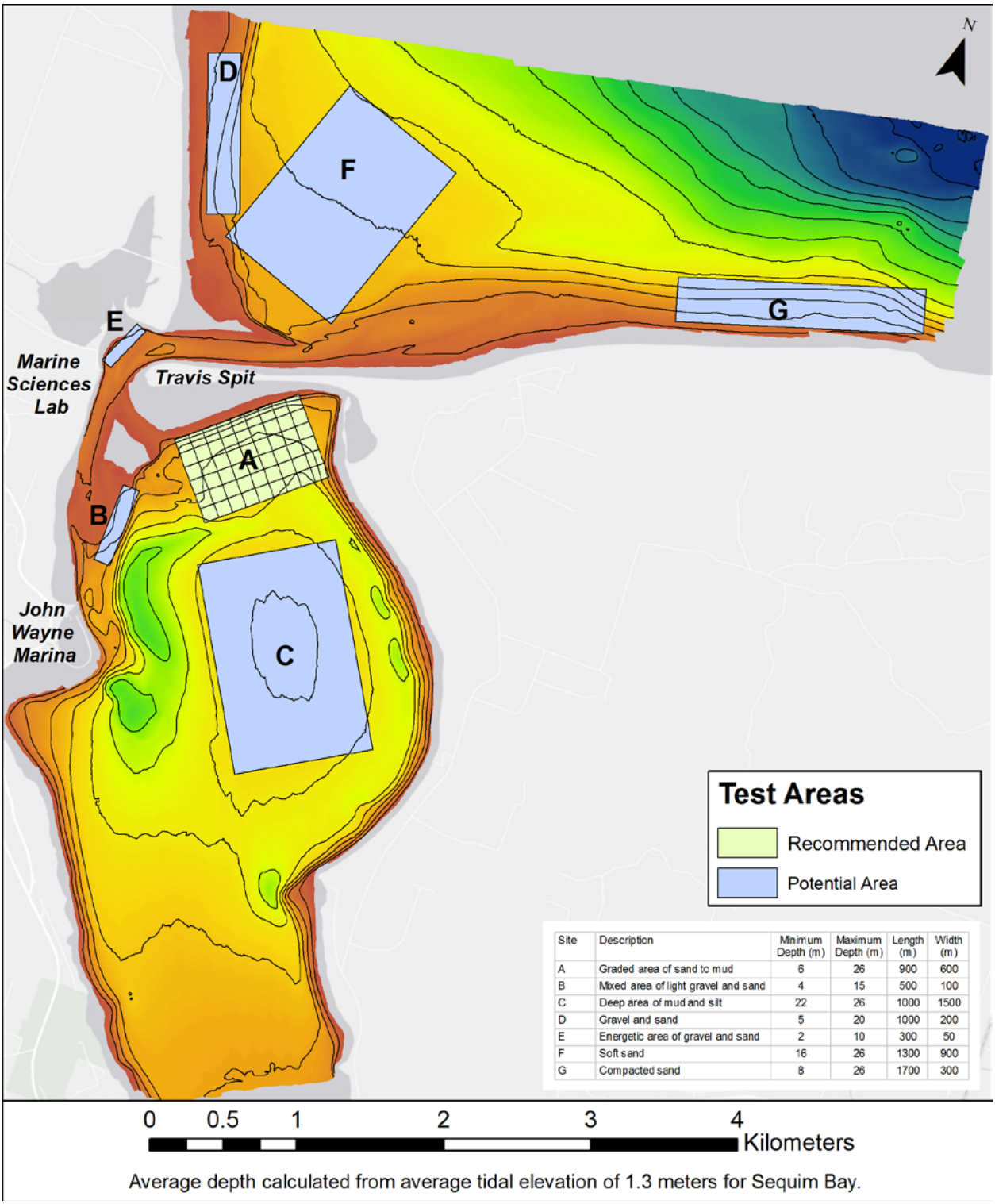
Figure 18. Aerial of John Wayne Marina in Sequim Bay (from marinas.com).

4.3 Potential Test Site Areas for the Final Test Site Design (Task 3)

Using the results described above, the diver surveys, and local knowledge of boat operations in the area, seven sites were identified that MSL thinks are most relevant to SERDP's desired test site and the areas for which permits for the project are most likely to be obtained (Figure 19). All sites are described below and in Table 4.

While each area has obvious and subtle differences (see below), they do share some commonalities. All the areas are in the marine environment and in relatively close proximity to support provided by PNNL's MSL. The sites are all tidally influenced, although the extent of the currents produced by these tides varies greatly. The sites are in relatively protected waters, although this also varies by site depending on the direction of the winds. Lastly, all the proposed areas are largely unvegetated and at most have patches of sparse macroalgae (i.e., seaweed).

Descriptions of each of the areas are presented below, along with some discussion of important considerations, as needed:



Site	Description	Minimum Depth (m)	Maximum Depth (m)	Length (m)	Width (m)
A	Graded area of sand to mud	6	26	900	600
B	Mixed area of light gravel and sand	4	15	500	100
C	Deep area of mud and silt	22	26	1000	1500
D	Gravel and sand	5	20	1000	200
E	Energetic area of gravel and sand	2	10	300	50
F	Soft sand	16	26	1300	900
G	Compacted sand	8	26	1700	300

Figure 19. Possible test areas for a UXO testing site around Sequim Bay. See text for site descriptions.

Table 4. Summary matrix of potential test areas.

	Potential Test Area						
Design Considerations	A	B	C	D	E	F	G
Size	900 x 600 m 54 ha	500 x 100 m 50 ha	1000 x 1500 m 150 ha	1000 x 200 m 20 ha	300 x 50 m 1.5 ha	1300 x 900 m 117 ha	1700 x 300 m 51 ha
Depth (m ATE)	6 to 26	4 to 15	22 to 26	5 to 20	2 to 10	16 to 26	8 to 26
Bottom Type	Sand to mud (graded with depth)	Sand with pockets of gravel and shell	Mud and silt	Mixed sand and gravel	Gravel and cobble in sand	Soft sand	Compacted sand, some gravel
Tidal currents	Minimal impact	Potentially some minor impact	Minimal impact	Potentially some minor impact	Can be strong	Potentially some minor impact	Potentially some minor impact
Use/Exclusion Considerations	• Permitting already exists for part of area • Might have sailboat racers at times		• Permitting already exists for part of area • Might have sailboat racers or fishermen at times	• Permitting may be more difficult because of DNR reserve • Near public boat ramp • Might have fishing at times	• Permitting already exists for part of area • Need to avoid navigation channel	• Permitting may be more difficult because of DNR reserve • Might have fishing at times	• Permitting may be more difficult because of DNR reserve • Might have fishing at times
Additional Considerations	• Close to land so turning might be an issue with larger equipment • Protected from most wind directions	• Protected from many wind directions • Currents might be a factor at times	• Some protection from many wind directions • Deep depths might limit dive durations • Very soft sediment may not hold targets	• Can be exposed in northerly winds • Greater likelihood of fishing pressure outside the bay	• Very close to MSL for ease of work • Protected from most wind directions • Currents can be very strong • Very shallow, so bottom might be impacted by large SE storms	• Can be exposed in northerly winds • Greater likelihood of fishing pressure outside the bay • Deep depths might limit dive durations	• Can be exposed in northerly winds • Greater likelihood of fishing pressure outside the bay

ATE = Average Tidal Elevation; DNR = (Washington) **D**epartment of **N**atural **R**esources (Aquatic Reserve)

4.3.1 Area A

Area A is located inside Sequim Bay on the southern side of Travis Spit and relatively protected from all but southerly winds. It is one of the larger areas inside Sequim Bay (540,000 m^2 or 54 ha; Figure 19 shows it broken into 100 x 100 m blocks), although its proximity to the shore might make turning at the ends of sampling runs in a vessel difficult if towing a long line for certain test equipment. The depth can range from just deeper than the eelgrass zone (approximately -6 m) to -26 m ATE. The sediment composition grades with depth; the shallower edge is predominantly sand and the deepest edges having muddy sand with flocculent surface layers (Table 5, Figure 20, Figure 21).

Table 5. Sediment cores for Area A: composition by percent weight.

	Mud/Silt	Fine Sand	Coarse Sand	Fine Pebble Gravel	Medium Pebble Gravel	Medium Coarse Gravel and Up
Area A Inshore	2	50	46	1	0	0
Area A Offshore	49	40	9	0	0	1

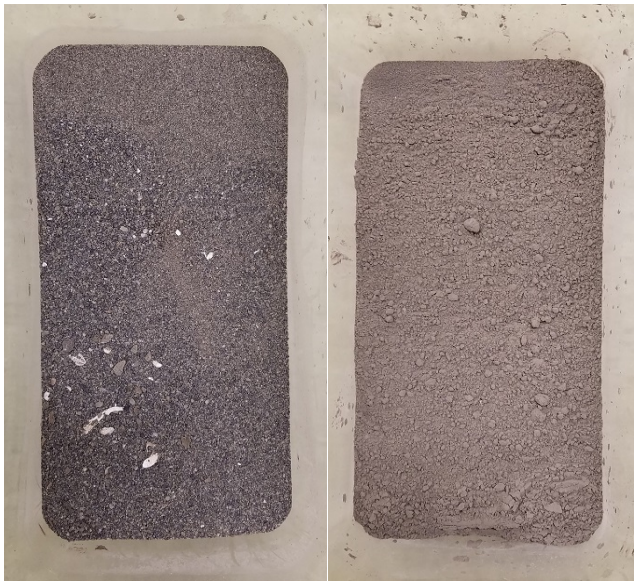


Figure 20. Sediment collected in Area A: inshore (left) and offshore (right).

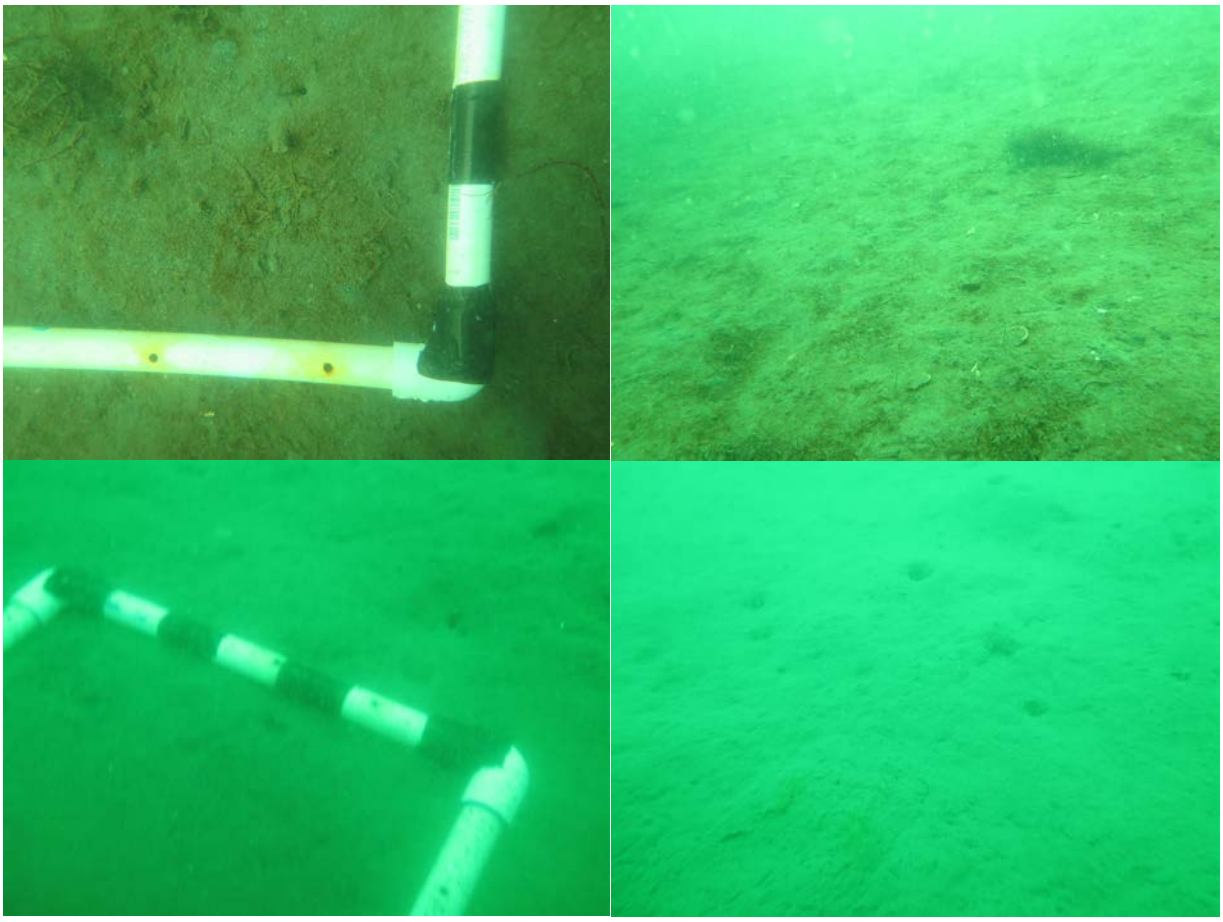


Figure 21. Representative underwater photos of Area A. Upper photos are from a shallower location in the area than the lower two photos.

Area A includes a site for which MSL has a 5-year permit for conducting a variety of research activities (i.e., SB1; Figure 1), including placing objects on the bottom, but not to the extent of an array of surrogate munitions. PNNL would request that the permitting agencies allow us to expand the already-permitted area slightly to include the SERDP project needs, which theoretically should be easier than initiating permitting for a completely new site. The area is not heavily used for fishing, but occasional crab pots are seen at the site. The area is sometimes on the northern end of the race courses set up by the Sequim Bay Yacht Club for sailboat races, but these races are usually at advertised or set times.

MSL is recommending Area A be developed as the initial test area. It is being recommended because of its protection from waves and currents, its predictable range of substrate, its shallow to moderate depths that will accommodate dive operations, and its likely "easier to permit" status. It is a site known to the MSL researchers and should be relatively easy to work in.

4.3.2 Area B

Area B is close to Area A inside Sequim Bay on the inside of Middle Ground. It is protected from winds from the west and north and the currents are predictable and not as swift as those in the channel. Area B is relatively small at 50,000 m^2 (5 ha) and features a band of depths between -4 and -15 m ATE although we would probably recommend using the narrower shelf at the deeper end of the box. The potential benefit of this site is the sediment; while it is predominantly sandy, there are pockets of shells, rocks, cobble, and

gravel (see Table 6, Figure 22, Figure 23). The sediment at this site is not as homogeneous as other sites inside Sequim Bay and could therefore provide a more challenging site for detection of UXO, if needed.

Table 6. Sediment cores for Area B: composition by percent weight.

	Mud/Silt	Fine Sand	Coarse Sand	Fine Pebble Gravel	Medium Pebble Gravel	Medium Coarse Gravel and Up
Area B	0	12	66	3	3	16

Figure 22. Sediment collected in Area B.

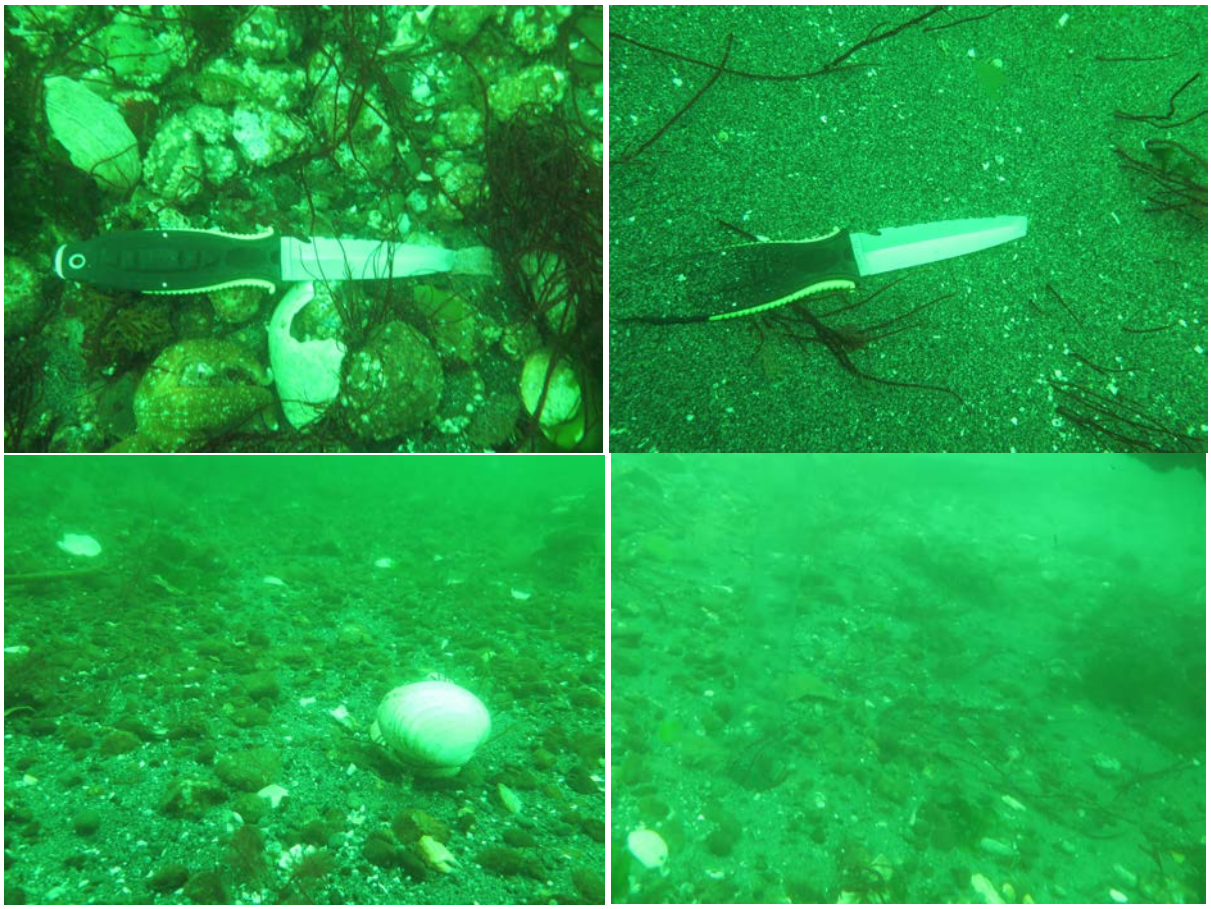


Figure 23. Variety of substrate types in Area B.

Area B does not have preexisting permitting for activities on the bottom like Area A, but it is also not frequented by the sailing community or fishermen like some of the other areas. The bottom in Area Be is assumed to be relatively stable, although there is potential for some shifting of the sandy sediment that could affect the position of placed targets. Determining this will require more investigation by MSL researchers.

4.3.3 Area C

Area C is located in the deeper center of Sequim Bay. It is the largest site on the list at 1,500,000 m^2 (150 ha) and has a buffer around the whole area that could be used for turning vessels, etc. Area C is also the deepest site inside Sequim Bay (-22 to -26 m). The sediment is very silty and muddy (Table 7, Figure 24, Figure 25), and has a lot of flocculent material that is easily disturbed and resuspended into the water column. The substrate is soft enough that it forms an indistinct layer making the determination of sea floor or water column difficult.

Table 7. Sediment cores for Area C: composition by percent weight.

	Mud/Silt	Fine Sand	Coarse Sand	Fine Pebble Gravel	Medium Pebble Gravel	Medium Coarse Gravel and Up
Area C	55	42	3	0	0	0

Figure 24. Sediment collected in Area C.

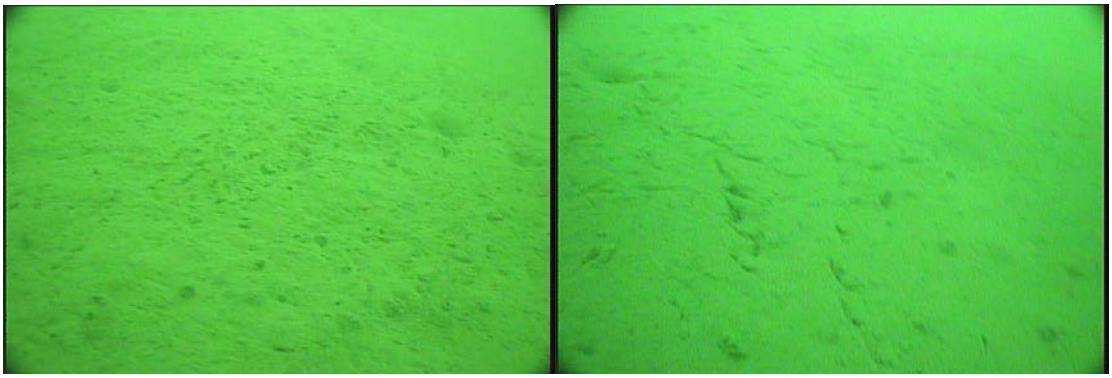


Figure 25. Representative photos of the substrate in Area C from the drop camera. Poor visibility once the substrate was disturbed made collecting quality photos difficult.

While Area C has some positive features, such as its size, spatial buffer, and uniform substrate, a number of characteristics would make this a difficult test site. The deeper depth would mean that divers would be able to spend much less time on the bottom preparing, validating, or changing test targets. This would require greater resources (e.g., time, money) than a similarly sized area elsewhere in shallower water. The very soft sediment makes working near the bottom difficult, and it would be very hard to specifically place materials on the bottom because of the potential for sinking, shifting, or sliding. Divers have reported being able to stick their arms into the sediment up to their shoulders in this area with little resistance, so it may not be firm enough to stabilize targets.

Like Area A, Area C includes an area already permitted for similar work (i.e., SB2; Figure 1), but the existing area is a small fraction of the potential area that may be used for applications related to UXO detection exercises.

4.3.4 Area D

Area D is just outside the mouth of Sequim Bay and represents our attempt to find a slightly deeper and coarser site for testing. The area is a relatively narrow band, 200,000 m^2 (20 ha), on a wider section of the nearshore shelf. Being outside Sequim Bay the area is more exposed to wind and waves, especially if the wind is coming from the north, but protection is afforded by the mainland to the west, Dungeness Spit, and Protection Island. The sediment is predominantly course sand and gravel and spans a depth range of -5 to -20 m (Figure 26). Coring was not performed in Area D.

Area D may have a number of restrictions that could make logistics or permitting difficult. Area D is offshore of a County Park, which has a boat ramp that is frequently used by locals, so vessel traffic could be an issue as vessels are concentrated into the approach to the ramp. A wastewater treatment plant outfall is located near the park and would be located near, or even inside, the area. Fishing is popular just outside Sequim Bay especially for those in smaller boats or during poor weather. Lastly, the outer areas (i.e., D, F, and G) are on the corner of a Washington Department of Natural Resources Aquatic Reserve, so there may be use restrictions or resistance to permitting.

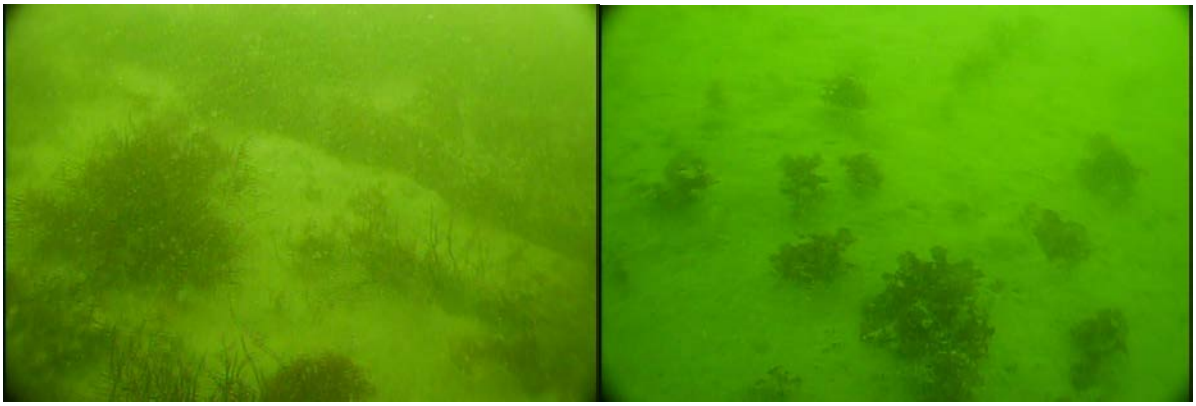


Figure 26. Drop camera images of the bottom in Area D

4.3.5 Area E

The closest site to the MSL is Area E, which is just offshore of the Lab on the edge of the navigation channel. It is a small area bordered by the navigation channel and eelgrass, so its area is estimated to be approximately 15,000 m^2 (1.5 ha). It is also shallow (-2 to -10 m). The proximity to the higher currents at the mouth of the bay and the shallow depths mean this is one of the coarser sites; the bottom is predominantly sections of cobble and gravel embedded in sand (Table 8, Figure 27, Figure 28). The currents can be very strong here, although eddies that often form on the edge of the channel here can make the currents harder to predict. The area is protected from winds in all directions except the southeast, and even then conditions bad enough to prompt a small-craft advisory would be required to cause difficulty in conducting fine-scale vessel operations.

Table 8. Sediment cores for Area E: composition by percent weight.

	Mud/Silt	Fine Sand	Coarse Sand	Fine Pebble Gravel	Medium Pebble Gravel	Medium Coarse Gravel and Up
Area E	1	28	51	1	1	19

Figure 27. Sediment collected in Area E (two cores from the same general area).

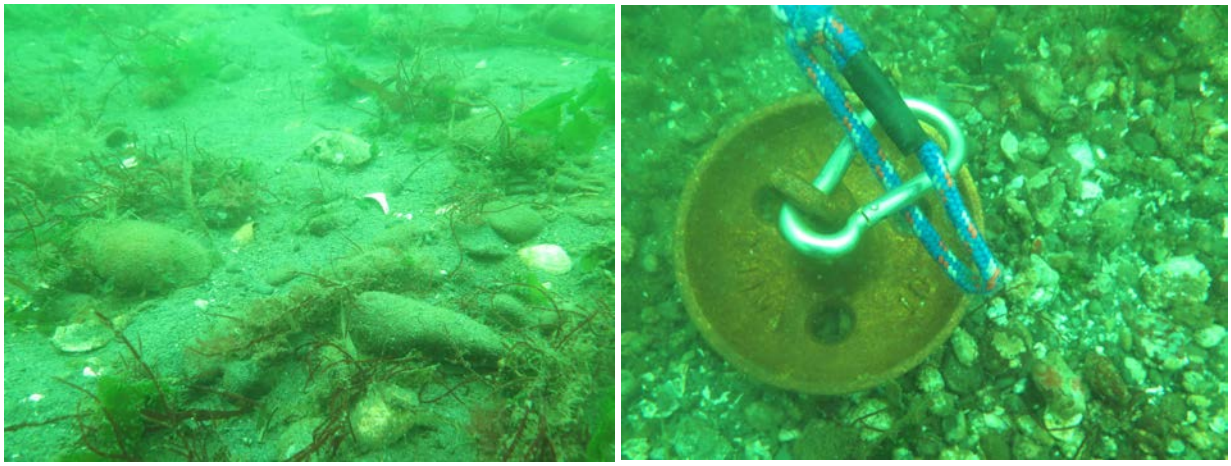


Figure 28. Examples of sediment types at Area E.

The area characteristics, good and bad, are well known to the divers at the MSL. Its proximity to the Lab makes for easy access—indeed the divers often do shore dives at the site without the aid of a vessel. The shallow depth means that bottom times are not limited by nitrogen loading and there is ample light for working. However, the proximity to the channel means currents can get very strong at the site, limiting dive operations to slack tides. The water velocity could also shift targets around, especially those that are lying on the surface of the substrate. This would especially be true during storms or spring tides, although the currents are strong during neap tides as well.

4.3.6 Area F

Area F is similar to Area D in that it is outside Sequim Bay in order to encompass a larger area (1,170,000 m^2 or 117 ha in this case). Area F is a little deeper at -16 to -26 m and is almost all soft sand (Figure 29). While Area F is a large relatively flat area that could accommodate a larger test site that is slightly farther away from the county boat ramp and the outfall, it has many of the same issues with permitting, use, and exposure, as well as being deep enough to start limiting diver bottom time. Coring was not performed in Area F.

Figure 29. Photo of the bottom in Area F.

4.3.7 Area G

The last area is also outside Sequim Bay along the north edge of the Miller Peninsula just east of Travis Spit. This area is long and narrow, 510,000 m^2 (51 ha), and composed mostly of compacted sand on the bottom (Figure 30). Just shoreward of the site, large boulders can be found often associated with understory kelp/macroalgae communities. The bathymetry is a little steeper here and it is possible that big storms could move items placed on the bottom. The area is located away from the park and outfall discussed under Area D, but the DNR reserve and the increased proximity to Protection Island (a U.S. Fish and Wildlife National Refuge) would need to be considered in the permitting process. Coring was not performed in Area G.

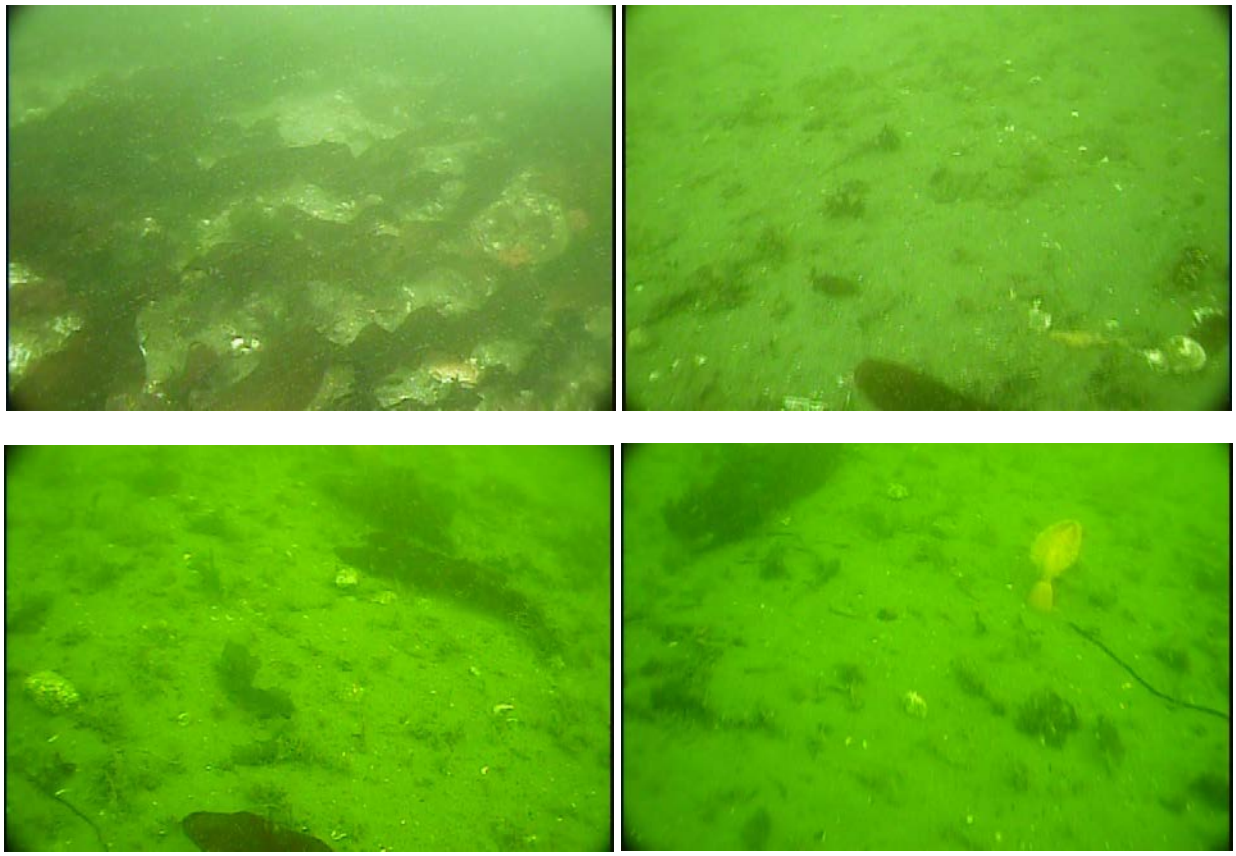


Figure 30. Photos from the drop camera in Area G.

5.0 Permitting

PNNL recognizes that environmental permitting is a sensitive issue. The actual test site design, number and type of objects, specific locations of objects, the methods of emplacement of objects, monitoring for movement, and retrieval of objects must all be addressed prior to approaching the stakeholders for permits.

Aquatic projects will have federal, state, and Tribal, and local permitting or compliance conditions. The PNNL permitting team has experience with these permit types and a relationship with the associated agencies. PNNL met with the local concerned Native American tribes and they did not voice any concerns at the time, but were interested in keeping abreast of where SERDP might want to develop a test site. Lists of some of the most common federal, state (Washington), and local permits/authorizations are provided below.

Permit application preparation may take weeks to months depending on how quickly project scope information becomes available. Permit approval is likely to take 3 to 6 months minimum. Additionally, permit approval is dependent on the following factors:

- Some federal permits require National Environmental Policy Act (NEPA) authorization, National Historic Preservation Act Section 106 consultation, and/or review, signature, and submission by the Pacific Northwest Site Office, or the federal client, which can take up to an additional 2 weeks.

- Some permits or authorizations may require prior approval/permits from other federal agencies prior to submission.
- PNNL has no control over the predetermined review periods agencies have established before they must render a decision on a permit application.

Federal permits/authorizations include the following:

- NEPA –Evaluation of the project for NEPA compliance.
- National Historic Preservation Act Section 106 Consultation – *State Historic Preservation Officer/Tribes* –Discovery of or damage to cultural or historic artifacts.
- Endangered Species Act Section 7 consultation – *U.S. Fish & Wildlife and/or National Marine Fisheries Service* – Evaluation of effects on federally threatened or endangered species and critical habitats.
- Essential fish habitat consultation – *National Oceanic and Atmospheric Administration* – Evaluation of the effects on essential fish habitats.
- Nationwide Permit – *U.S. Army Corps of Engineers* – A general permit issued on a nationwide basis for 52 predetermined activities classified as having national impacts.
- Private Aids to Navigation – *U.S. Coast Guard* – Navigation aids may be required to indicate the location of a structure or floating object within a navigable waterway.

State (WA) and local county permits/authorizations include the following:

- Hydraulic Project Approval – *Washington Department of Fish and Wildlife* – Approval required for work that may use, divert, obstruct, or alter the natural bed or flow of water, or work that may potentially affect fish or shellfish and their habitat.
- Aquatic Right of Entry Lease/Use Authorization – *Washington Department of Natural Resources* – Authorizes use of public lands.
- Shoreline Permits – *Washington Counties* – Regulates the development and use of waterbody shorelines.

6.0 Conclusions to Date

Our findings indicate that the majority of Sequim Bay bottom sediments are mostly mud/silt at deeper depths with areas of very fine sand, fine sands, and a lesser amount of gravelly sand in shallow waters. We did not find significant cobble in Sequim Bay or nearby, but cobbles do exist in energetic shoreline areas where wave action is frequent and inside the channel at the mouth of the bay. These findings are consistent with MSL's understanding of the bottom types within Sequim Bay both historically and based on observations made by divers on a series of diverse projects.

All the potential areas are largely unvegetated and at most have patches of sparse macroalgae (i.e., seaweed). If vegetated areas are desired for testing, there is a possibility divers may be able to carefully place materials within some eelgrass meadows, but there would be extra steps (and possibly mitigation) for the permitting of these areas and the technologies tested would need to be able to operate in relatively shallow waters without damaging the eelgrass population.

A number of locations around Sequim Bay may be relevant for SERDP testing objectives (see Figure 19). MSL researchers are recommending Area A on the south side of Travis Spit for future development as a test area because it is felt that this area best meets the stated needs of the SERDP testing objectives and minimizes some of the logistical and environmental liabilities some sites have. However, since a number of the areas will likely serve SERDP technology testing purposes, SERDP review and recommendations are required to finalize the locations to be used for the test site design.

There are still a number of uncertainties in moving forward with a test site, most of which the SERDP program or some additional data collection should be able to address. Specific needs for various technologies to be tested (e.g., magnetic, acoustic, optical) will have to be identified and potentially addressed. The actual material to be placed as targets, their size and weight, and any potential environmental impacts need to be identified to properly prepare a plan for installations and monitoring as well as environmental permitting. Lastly, once the site(s) is identified more detailed analysis of the subsurface sediment, ease of placing target material, and logistical concerns can be addressed.

Lastly, reviewers should keep some of the liabilities in mind as the process moves forward and other potential sites are considered. For example, deeper sites will require that divers make more numerous but shorter dives because nitrogen loading becomes a limiting factor during extended dive operations. Similarly, areas with high currents will only be able to be accessed by divers during periods of slack waters. Both these scenarios will potentially increase the time and resources needed to prepare, maintain, validate, and demobilize the test sites. With this in mind however, the researchers at the MSL are confident that they can make any of the proposed sites work, barring any unforeseen external factors (e.g., permitting).

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Appendix A

Bottom Properties of Representative Underwater Munitions Sites

Appendix A

Bottom Properties of Representative Underwater Munitions Sites

A.1 Introduction

This appendix provides additional information about seven underwater unexploded ordnance (UXO) sites reviewed for Task 1 of the preliminary design study for a munitions response underwater test site in Sequim Bay, Washington. These sites were selected as being representative of the range of sediment types, range of water depths, and range of UXO concerns identified in the review of nearly 200 installations identified as having underwater UXO. For each site, there is a short description of the UXO concern, a description of the site presenting information about the depths, currents, and hydrodynamics present, and finally a description of the sediment types encountered at the site. This information was assembled from documents either provided by or publicly available from the Military Munitions Response Program (MMRP) Munitions Response Site (MRS) Inventory [1], the U.S. Environmental Protection Agency (EPA), the Naval Facilities Engineering Command (NAVFAC), the United Stated Army Corps of Engineers (USACE), various state agencies, and the scientific literature.

A.2 Representative Underwater Munitions Sites

A.2.1 San Diego Bay (Navy)

A.2.1.1 UXO Concern

Of primary concern in San Diego Bay are munitions that were disposed by Naval vessels prior to docking at bases within the bay. Sediments were dredged from the bay to deepen the harbor in the late 1990s and UXO were found when the sediments were being used for beach replenishment. The munitions ranged from small arms shells to a live 81 mm mortar round [2, 3].

A.2.1.2 Site Description

The bay is roughly 15 mi (25 km) long and varies in width from 0.3 to 2.5 mi (0.5 to 4 km). The area of the bay is approximately 16.5 mi^2 (41 km^2) at Mean Lower Low Water (MLLW) and it has an average depth of approximately 16 ft (5 m). Water depths in the south bay range from 3 to 13 ft (1 to 4 m) outside the main shipping channel, which is dredged to a depth of about 39 ft (12 m). Depths generally increase toward the entrance, reaching a maximum depth of about 69 ft (21 m) [2].

Currents in the bay are primarily the result of tidal processes. Average water levels range from 0.9 ft (0.27 m) above MLLW at ebb tides to 5.9 ft (1.8 m) above MLLW at flood tide. Tidal currents within the bay range from 1.0 to 1.6 ft/s (30 to 50 cm/s) near the bay entrance and 0.3 to 0.6 ft/s in the south end of the bay [2].

A.2.1.3 Sediment Description

From [2]:

> Review of previous marine and terrestrial geotechnical and environmental investigations indicates that bay deposits typically consist of silty to clayey sands and poorly graded fine sands with shell fragments. The beach and channel deposits typically consist of poorly graded sands with some gravels and cobbles. These deposits may also include localized lenses or layers of clay and silt. The Bay Point Formation in the area of San Diego Bay is composed mostly of marine, fine- to medium-grained, pale brown, fossiliferous sandstone. Additional information indicates that the Bay Point Formation is also composed of lenses or layers of silty to clayey sand, sandy clay to clay, sand, and gravel.
>
> In general, the grain-size distribution of sediments in the North Bay is coarser, while those of the South Bay are composed more of silt and mud. However, the distribution can vary from this general pattern, with some areas that are almost exclusively sand, such as the area off North Island, and other areas that are predominantly silt, such as those within Shelter Island. Although the distribution of sedimentary materials in the bay is reasonably consistent with source and depositional environments, two processes redistribute them.
>
> The first process is dredging, which artificially alters areas of high deposition through the wholesale removal of material. The second process is both a man-made and natural process in which sediments are resuspended into the water column and redistributed by currents. Natural resuspension occurs from tidal or wind-generated currents moving over the bottom in shallow regions such as the South Bay. Man-made resuspension results from ship propeller wash that occurs primarily during ship movements in and out of pier areas or even in the deeper, mid-channel region during the transit of large ships such as aircraft carriers.

While migration of UXO or burial by hydrodynamic processes would seem unlikely at this site due to the weak hydrodynamic forcing (tidal or waves), the presence of localized silt and clay layers/lens indicates that at times significant sediment transport takes place. This makes it likely that over the course of decades there may be episodic events that could lead to UXO burial in both soft and sand sediments. The more gradual deposition and resuspension of soft sediments could also lead to UXO burial.

A.2.2 Naval Defensive Sea Area (NDSA) Pearl Harbor (Navy)

A.2.2.1 UXO Concern

Over the last century, a series of coastal artillery sites and shore batteries were constructed to provide security for the southern shoreline of Oahu and the approaches to Pearl Harbor. Artillery training took place at these sites from the 1920s through the end of World War II, using targets towed at sea and in the air. Ordnance fired from these sites ranged from 37 mm projectiles to 16 in. high-explosive projectiles, and a wide collection of small arms ammunition. Danger zones established during the training activities ranged from 2.25 to 11 miles from shore, but munitions have been found closer to shore as well [4].

A.2.2.2 Site Description

The submerged area of concern extends from the shoreline to a depth of 120 ft (37 m). While the area of concern includes the Pearl Harbor Entrance Channel, this area is restricted to public access and not of immediate concern for UXO. The area undergoing investigation as of 2012 encompassed shallow water shorelines, shoal water reef areas, and deeper waters extending up to 2 miles from shore [4].

Site conditions can include large open-water swells (3 to 12 ft), turbulent surf zones, and rapid tidal and surge currents (1 to 3 knots). At times, south wave swell and other forceful weather patterns can generate significant wave action, resulting in the creation of strong underwater currents and the suspension of bottom sediments throughout the water column [4].

A.2.2.3 Sediment Description

From [4]:

> The encountered seafloor bottom composition consisted of a flat base of limestone and old reef material, with pockets and channels of sand distributed throughout the area. The area was also heavily populated dense concentrations of rocks and boulders of varying size and shape.
>
> In certain areas, significant quantities of debris material and general trash were encountered as both individual items and dense collections. The majority of this debris material was situated on the surface of the seafloor, and was covered with significant marine growth. The hard condition of the seafloor bottom, and the resulting marine growth that was exhibited on even the smallest items, indicated that these materials do not regularly settle into the bottom and do not become buried over time.

While Sequim Bay is unlikely to have a hard bottom similar to that encountered off Oahu, it is important to note that objects at this site do not become buried over time, making the use of high-frequency sonar systems or magnetometers the most likely candidates for UXO detection. The performance of these systems on a hard bottom could be similar to their performance on sand or gravel bottoms. Classification can be difficult in this area due to marine growth, but it’s unclear whether that is an aspect of the problem that should be addressed with a UXO testbed.

A.2.3 Naval Station (NS) Great Lakes (Navy)

A.2.3.1 UXO Concern

An anti-aircraft (AA) range and target training area was located on the eastern edge of NS Great Lakes and the area of concern is focused on 3725 acres extending east over Lake Michigan. The potential munitions used at the range include 20 mm and 40 mm high-explosive, 1.1 in. anti-aircraft artillery, 2 in. 0.50 caliber artillery and dark-ignition tracers. These rounds were fired at targets towed by plane with cables over Lake Michigan. Several million rounds were fired over the range’s existence. “The expected dud rates of the types of AA ammunition used was five percent resulting in several hundred thousand rounds containing explosives which may be present in Lake Michigan sediment” [6].

A.2.3.2 Site Description

The site extends from the shoreline eastward until the 120 ft depth is reached. While the Great Lakes are considered non-tidal, wind and weather conditions may create seiches that can produce tide-like behavior. Winds can also generate significant wave events on the lake [6].

A.2.3.3 Sediment Description

In the area of NS Great Lakes, the sediment is generally classified as coarse to fine sand (1-4 phi) [6]. A site investigation in 2010 [7] noted the following:

> No MEC [Munitions and Explosives of Concern] items were identified in the drop camera video. However, given the cloudiness of the water, heavily populated mussel habitat, and sandy bottom this was expected. The gently rolling waves of the lake caused the camera to move up and down in the water column, obscuring the camera's view by disturbing the soft silty-sand bottom and by moving in and out of focus.

The drop camera was deployed to visually investigate magnetic anomalies (potential munitions) detected in a survey using a marine gradiometer system. While not clear from the text, it appears the expectation was that the munitions would either be obscured by the mussels or buried in the sand. It's also unclear whether the bottom at the site is a silty sand or if there might be a layer of silt overlying the sand.

A.2.4 Naval Support Facility (NSF) Indian Head (Navy)

A.2.4.1 UXO Concern

There are a number of MEC concerns at this site stemming from a long history of Naval testing and training along this stretch of the Potomac River. The site investigations of this area focused on three primary regions [8]:

1. UXO 18-Battle Range Firing Area: This site was potentially used in the 1900s for battle range firing, high-powered firing, and for studying underwater impacts. Projectiles tested may have consisted of 3, 5, 8, 12, and 14 in. armor-piercing (AP) shells.
2. UXO 31-Pope's Creek: This site, 30 miles downstream from NSF Indian Head was used in the 1940s for underwater testing of demolition charges and explosives.
3. UXO 33-Water Impact Area: This is a large site that encompasses the two listed above. Concerns in this site include strayed ordnance from battleship gun testing that took place from 1891–1921 as well as other guns and rockets that were fired there until 1946 and underwater explosives testing that occurred in the 1960s.

A.2.4.2 Site Description

The Battle Range Firing Area is located at the mouth of Mattawoman Creek. Average depths in the region are 7 to 10 ft. The area used for explosives testing near Pope's Creek was on the eastern shore of the Potomac River. Testing was conducted in the deepest portion of the navigation channel, which had a depth of 78 ft. The Water Impact Area encompasses more than 12,000 acres and covers the full range of bathymetric features in the lower Potomac River, from shallow flats to deep portions of the main river channel. This area also contains the dredged navigation channel off NSF Indian Head [8].

A.2.4.3 Sediment Description

The preliminary assessment quotes a sediment composition from the U.S. Geological Survey for the Potomac River [8]:

> The average bottom sediment sample collected in the Potomac was composed of 36 percent clay, 27 percent silt, and 37 percent sand. The average value of the median grain size was 0.010 millimeter (silt).

This is consistent with the assessments of the MEC burial at the Indian Head site. For UXO 18 and UXO 33, the report notes that, "MEC items from the explosive fragments of gun firing may have been partially or fully buried by a combination of sediment deposition and sinking into soft bottom sediments. [8]"

For UXO 31, the report states [8]:

> The (navigation) channel appears to be migrating eastward; the eastern bank of the navigation channel shallows from more than 70 feet to under 10 feet over a short distance. As the channel migrates to the east, the western portion of the channel is filled by sediment. MEC items may have been partially or fully buried by a combination of sediment deposition and sinking into soft bottom sediments.

Sedimentation rates near NSF Indian Head exceeded 0.72 cm/yr for the period from 1840 to 1978.

A.2.5 Vieques Naval Training Range (VNTR) (USACE)

A.2.5.1 UXO Concern

Munitions concerns listed in [9]:

> Naval gunfire and air-to-ground bombing of munitions intended for offshore targets south of the LIA (Live Impact Area) and targets on cliff faces along the southern portion of the LIA; Naval gunfire and air-to-ground bombing that may have missed their intended targets in the LIA and SIA (Surface Impact Area) or deflected from land to offshore; overshooting of Marine artillery at the ranges and gun positions in the EMA (Eastern Maneuver Area); kick-outs of munitions from the OB/OD areas at the LIA and at the western end of Vieques; and inadvertent release of munitions during their transfer at the anchorage areas and Mosquito Pier.

A.2.5.2 Site Description

Because the site covers all sides of the island, VNTR is a fairly complicated site. From the Conceptual Site Model in the Work Plan:

> The bathymetry around Vieques differs markedly between the north and south shore. North of the island, the seafloor is generally uniform and shallow, interrupted only by patch reefs and a sand and gravel shoal denoted as the Escollo de Arenas on the northwestern end of the island. The sea floor in this area slopes gently (e.g. 1:100) from the shore to a depth of approximately 50 feet, with a broad 80 foot deep shelf that extends to the north and west. The south side of Vieques is characterized by numerous small inlets and lagoons, and a shore-parallel coral reef at a depth of 50 to 65 feet

approximately one to two miles offshore. South of the reef, there is a steep slope (e.g. 1:10) where the seafloor drops abruptly to depths over 3,000 feet. The bathymetry to the east of the island features an 80 to 150 foot depth transition between the shallow shelf on the north and the edge of the steep slope to the south.

The majority of UXO 16 is less than 60 feet deep. The deepest portion is approximately 80 feet within the northern portion of the site near the site boundary.

The water level around the island is dominated by tides, but storm surge can be significant during storms. Waves are driven by easterly trade winds from March to November, and northeasterly winds drive the waves in the winter. Tropical storms and hurricanes can produce significant, episodic wave events during the summer and early fall.

A.2.5.3 Sediment Description

The seabed around the island is predominately 1) coral and hardbottom and 2) unconsolidated sediment. As indicated in Table A.1, these unconsolidated sediments are primarily sand, with the exception of muds in bays or other sheltered areas [10]. Also, “Seagrass communities, which are generally limited to shallow depths and protected, low-energy regions, are widespread northwest of Vieques where depth is shallow and conditions are relatively calm” [9].

Table A.1. Bottom structures at Vieques (reproduced from [9]).

Major Structure	Area (km^2)	Percent Area	Detailed Structure	Area (km^2)	Percent Area
Coral Reef and Hardbottom	119.56	33.44	Rock/Boulder	1.38	0.39
			Aggregate Reef	13.79	3.86
			Individual Patch Reef	6.46	1.81
			Aggregated Patch Reef	1.91	0.54
			Spur and Groove	0.02	0.01
			Pavement	39.37	11.01
			Pavement with Sand Channels	5.98	1.67
			Reef Rubble	17.53	4.90
			Rhodoliths	33.11	9.26
Unconsolidated Sediment	237.95	66.56	Sand	220.39	61.64
			Mud	7.88	2.20
			Sand with Scattered Coral and Rock	9.69	2.71
Other Delineations (land excluded)	0.05	0.01	Artificial	0.05	0.01
Total	**357.56**	**100.00**		**357.56**	**100.00**

A.2.6 Mare Island Naval Shipyard (Navy)

A.2.6.1 UXO concern

The MEC concern at the site of the former Mare Island Naval Shipyard is primarily related to accidental or intentional disposal of munitions into the water from the Navy piers and along the shoreline. The shipyard included piers used for storage of the Reserve Fleet after World War II, berths used by Explosive Ordnance Disposal Mobile Unit 9, and offshore areas adjacent to the Ammunition Production and Manufacturing Area [10].

A.2.6.2 Site Description

The Shipyard sits on the Mare Island Strait, which is the mouth of the Napa River. The piers and offshore areas of interest extend from the shoreline into the Mare Island Strait to a depth of 30 ft. According to assessments performed for the Naval Shipyard, the shoaling rate in the strait is 4 to 6 ft/yr and the Navy dredged the portion of the strait that ran along the berths up until 1996 [11]. While munitions were unlikely to be buried by wave action or hydrodynamics, the sedimentation and resuspension during dredging operations would bury any munitions dropped on the bottom.

A.2.6.3 Sediment Description

The sediment in the strait is predominantly silt that is carried in from the Napa, Sacramento, and San Joaquin Rivers [10,11].

A.2.7 Naval Air Station (NAS) Patuxent River (Navy)

A.2.7.1 UXO Concern

From approximately 1954 to 1974, NAS Patuxent River personnel discarded a variety of excess munitions, both live and inert, into the Chesapeake Bay along the southeastern base boundary. It's not clear what munitions were disposed of in this area, but munitions items from the disposal areas have been moved by tides and currents such that they have washed up on shorelines outside of the disposal area [10].

A.2.7.2 Site Description

The area of concern extends out roughly 750 ft from shore, reaching a maximum depth of 10 ft, but most of the area has depths of 3 ft or less. The water is turbid, hence water clarity is poor. There is evidence of non-MEC metallic objects in the water, which makes identification of MEC difficult [10].

A.2.7.3 Sediment Description

This area is predominantly sand, but there may be regions where the sediment could be classified as silty sand due to transport of materials from the Pine Creek Run and the nearby Patuxent River [12]. This area is subject to significant erosion due to normal wave and storm events. These dynamics can lead to burial and re-exposure of munitions over time.

A.3 References

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