Naval Information Warfare Center PACIFIC

TECHNICAL REPORT 3340
APRIL 2024

Flexible Under-Pier Sediment Assessment NESDI Project #572

Jessica Carilli, Ph.D.
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James Leather, Ph.D.
Mario Malfavon, Ph.D.
Joel Guerrero
Benjamin Whitmore, Ph.D.
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Naval Information Warfare Center (NIWC) Pacific
San Diego, CA 92152-5001

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NIWC Pacific
San Diego, CA 92152-5001

NIWC Pacific
San Diego, California 92152-5001

P. M. McKenna, CAPT, USN
Commanding Officer

M. J. McMillan
Executive Director

ADMINISTRATIVE INFORMATION

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Cyber/Science and Technology Department

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Editor: RJP & MGK

EXECUTIVE SUMMARY

The goal of this project was to create a simple and cost-effective solution to quantify the volume and contaminant loads of under-pier sediments. This challenging environment is constrained by tides, ship movements, varying pier architectures, and sporadic or non-existent global positioning system (GPS) signals. To quantify the potential magnitude of recontamination from sediments under Navy piers, we broke the project down into two major components. The first was to estimate the amount of sediment under the Navy piers, and the second was to collect samples of and analyze the concentration of various contaminants in sediment from under the piers. The results from these two components were then brought together to estimate the size of this potential recontamination source, which will allow the site remediation program managers (RPM) to determine whether the under-pier sediments are or are not a significant source of potential recontamination, and whether further actions are necessary to evaluate or remediate these sediments.

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ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act, also known as Superfund
COVID-19	Coronavirus disease 2019
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DEM	digital elevation model
DGPS	differential global positioning system
ERL	effects range low
ERM	effects range median
ERDC	U.S. Army Engineer Research and Development Center
GPS	global positioning system
HDOP	horizontal dilution of precision
Lidar	light detection and ranging
MLLW	mean lower low water
NAVFAC SW	Naval Facilities Engineering Systems Command Southwest
NAVD88	North American Vertical Datum of 1988
NBSD	Naval Base San Diego
NESDI	Navy Environmental Sustainability Development to Integration Program
NIWC	Naval Information Warfare Center
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
NOAA18	18 particular polychlorinated biphenyl compounds (PCBs) selected to represent total PCBs by the NOAA
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyl compounds
PPPAHs	priority pollutant polycyclic aromatic hydrocarbons
RF	radio frequency
RPM	remediation program managers
SOP	standard operating procedure
TIA	tidally influenced area
TOC	total organic carbon
USB	universal serial bus
USBL	ultra-short baseline
UXO	unexploded ordnance

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1. INTRODUCTION

The goal of this project was to create a simple and cost-effective solution to quantify the volume and contaminant loads of under-pier sediments. This challenging environment is constrained by tides, ship movements, varying pier architectures, and sporadic or non-existent global positioning system (GPS) signals. To quantify the potential magnitude of recontamination from sediments under Navy piers, we broke the project down into two major components (Figure 1). The first was to estimate the amount of sediment under the Navy piers, and the second was to collect samples of and analyze the concentration of various contaminants in sediment from under the piers. The results from these two components were then brought together to estimate the size of this potential recontamination source, which will allow the site remediation program managers (RPM) to determine whether the under-pier sediments are or are not a significant source of potential recontamination, and whether further actions are necessary to evaluate or remediate these sediments.

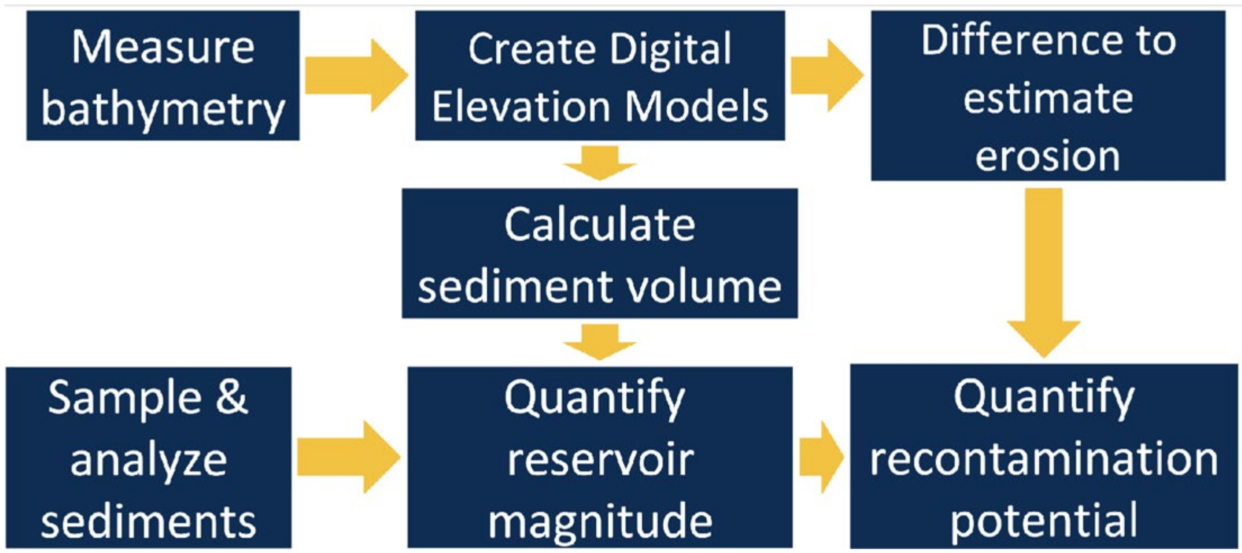

Figure 1. Flow chart of the performance objectives to quantify the recontamination potential of sediments under Navy piers.

For the project's first component, we used a small, remotely operated surface vessel (Teledyne Z-Boat 1800) with an integrated single-beam sonar system (for depth, z measurements) and GPS; for latitude/longitude, x/y measurements. We also added a diver tracker (SeaTrac) ultra-short baseline (USBL) acoustic positioning system to the Z-boat and support vessel to determine GPS position when GPS was denied under the pier. For the second prong, we used grab and core sampling methods, modified for work under a pier with low overhead clearance. Due to the complicated under-pier environment and Coronavirus disease 2019 (COVID-19) related delays, this project required more methods development than initially expected. However, we could measure bathymetry at all 5 piers, multiple times at each, sample and analyze sediments from 4-5 sampling locations per pier, ultimately estimate the recontamination potential at these piers.

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2. OVERVIEW

2.1 PROBLEM STATEMENT

This project was conducted in response to the Navy Environmental Sustainability Development to Integration Program (NESDI) need N-1196-18 submitted by Len Sinfield of the Naval Facilities Engineering Systems Command (NAVFAC) Southwest. Remediating contaminated sediments in Navy harbors is estimated to be a $2 billion problem. Recontamination of previously remediated sites can compound these costs, requiring further cleanup and monitoring efforts than originally planned. One potential source of recontamination is sediment built up underneath Navy piers, where sediment assessment and dredging typically do not occur. These sediments may contain legacy contaminants such as heavy metals, polychlorinated biphenyl compounds (PCB), and pesticides; the specific types and quantities of potential contaminants of concern vary by site. Cores are collected in the dredge footprint for dredge projects adjacent to Navy piers, and the sediment quality of the material that will be removed and that which will be exposed post-dredging is quantified (Figure 2). However, sediments can fill in on top of this post-dredge surface from under piers, for example by slumping. If these under-pier sediments are contaminated, then post-dredge monitoring samples will show re-contamination, requiring further costly cleanup efforts. No volumetric assessment of under-pier sediments has been conducted at these sites, limiting the ability to quantify the potential for recontamination from this source. Sediment that accumulates underneath piers is typically difficult to sample due to the combination of tight spaces with tidal flows impeding the use of traditional oceanic sediment sampling instrumentation and methods. These sediment piles could be important sources of recontamination, thus disregarding them because of sampling difficulties could result in decreased remediation efficacy and increased costs.

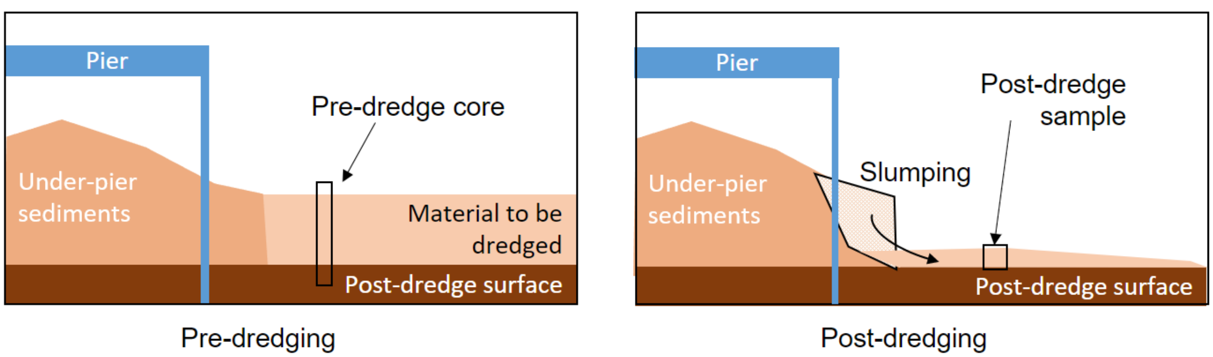

Figure 2. Diagram showing how a pre-dredge core is taken from the sediments to be dredged next to the pier (left). After dredging, sediments from under the pier may slump into the new hole left from dredging (right). The post-dredge sample may then contain sediment that was previously under the pier.

2.2 OBJECTIVE OF THE PROJECT

This project aimed to provide a simple and cost-effective solution to ascertain the potential magnitude of recontamination occurring from un-remediated under-pier sediments slumping into dredged and/or remediated between-pier areas. To quantify the level and extent of contamination, and design effective solutions to remediate under-pier sediments, the (1) volume, (2) contaminant concentrations, and (3) the slumping potential of under-pier sediments were required. The goal of this project was to demonstrate and validate several creative solutions to accurately assess under-pier sediments at a reasonable cost. Sediment volume and slumping were quantified at five piers at Naval Base San Diego (NBSD) using repeat acoustic-bathymetry surveys conducted using a small, remotely controlled vessel that could fit under tight spaces (Z-Boat). Sediment samples were collected using tools specific to a given pier's geometry, access points, and state of repair, selected from a "menu" of available sampling methodologies developed under this project. Together, these data were used to ascertain whether under-pier areas are significant sources of (re)contamination at a given site.

2.3 BACKGROUND

At the Federal level, contaminated sediments are regulated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as Superfund). Under CERCLA, suspected contaminated sites are assessed, and if determined contaminated, they are placed on the National Priorities list. Currently, this list contains 39 Navy sites. Many of these sites have numerous piers, such as the Pearl Harbor Naval Complex, Norfolk Naval Shipyard, and Puget Sound Naval Shipyard. Other Navy sites with piers that are not currently on the National Priorities list, such as NBSD, must also address regional and state regulator concerns (investigative orders, cleanup and abatement orders) regarding potentially contaminated sediments. This problem is therefore likely to be widespread across Navy sites.

In preparation for navigational dredging at NBSD, sediments to be dredged were analyzed for contaminants in surface layers. These analyses indicated that the areas that had been previously dredged several decades ago and deemed clear of contamination had higher contaminant levels than regulatory benchmarks measured during this recent monitoring (for PCBs, polycyclic aromatic hydrocarbons [PAHs], chlorinated pesticides, and metals), thus requiring upland disposal of the dredge material instead of open-ocean disposal (which is less costly, but only allowed when sediments are appropriately clean). Sources of these contaminants such as discharge from shipyard work and stormwater have been monitored and controlled, so the site manager suspected an additional uncontrolled source was recontaminating these sites. Sediments that have accumulated under piers and are not dredged were identified as possibly representing this unidentified and uncontrolled source of contamination that has not been adequately addressed. This discovery spurred Len Sinfield (NAVFAC Southwest) to submit the need for this project to the NESDI program.

Past contamination issues at many locations on land and in submerged lands controlled by NBSD are being addressed under the CERCLA process. Bay sediments around piers at NBSD are considered in an "Open – Inactive" status undergoing regulatory action by the California Water Board. This means that sediment assessment and cleanup activities are largely on hold at this time. The Water Board indicates that this status is the result of ongoing pollutant sources, such as several sites undergoing the CERCLA process on land adjacent to the bay, that are not yet controlled (Geotracker 2019). The NBSD Environmental Restoration Fact Sheet (2015) provides a history and overview of this process and describes where individual sites within NBSD fall in the CERCLA process. In addition to contaminants such as metals and PCBs, NBSD munitions have been discovered in sediments at many locations around San Diego Bay, including NBSD. Cleanup of these munitions is being addressed under the Munitions Response Program (Site 100). Because of safety concerns related to possible munitions in the sediments during sediment sampling efforts, the areas sampled required screening using a magnetometer by a professional unexploded ordnance (UXO) technician to clear the area. NAVFAC Southwest contracted a UXO technician to provide clearance for this project as a leveraged contribution.

Bathymetric maps are typically created using multi-beam sonar from a hydrographic survey vessel. Survey vessels cannot transit under piers, but multi-beam sonar can obtain some depth soundings, mainly of the outer portions of the under-pier areas, from outside the pier. Pilings can also create "shadows" and/or multiple returns that can confuse the data, and hydrographic surveys are costly. However, the Naval Information Warfare Center (NIWC) Pacific owns a Z-Boat, a small, remotely operated surface vessel with an integrated single-beam sonar system and GPS. Because the under-pier area is GPS-denied, we added a SeaTrac USBL acoustic positioning system to determine the x,y location of the Z-boat when it was under the pier and used this system to survey the under-pier bathymetry by running the Z-boat beneath the piers during low tides, between the rows of pier pilings.

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3. TECHNOLOGY DESCRIPTION

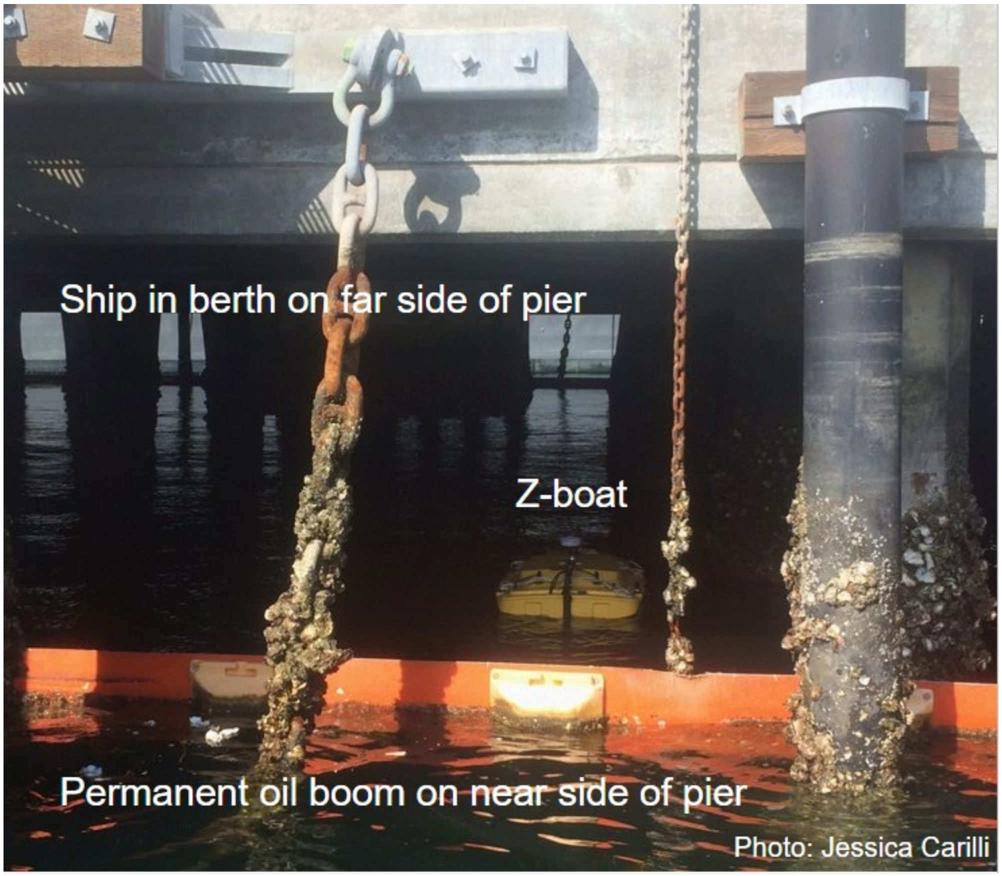
3.1 TECHNOLOGY OVERVIEW

The project has demonstrated and validated the use of three (3) main technologies to quantify the volume and potential contaminant loads of under-pier sediments:

1. **Under-pier bathymetry using a small unmanned platform.**

The volume of under-pier sediments must be quantified to determine the potential for under-pier sediments to represent a significant source that could reasonably affect site contaminant exceedances. For example, if the total volume of sediments under piers was minute, it would be unlikely to make any impact to surrounding sediments. In contrast, if the volume was substantial, it could represent an important recontamination source. We estimated the volume of sediments under the piers using data collected with a remotely operated unmanned surface vessel, the Teledyne Z-boat 1800 (Figure 3). This is a small platform (approximately 1.8 m long, 1 m wide, and 1 m tall, inclusive of antennas) specifically designed for hydrographic surveys in hard-to-access environments. NIWC's Z-boat is equipped with a 200 kHz echo sounder and an onboard GPS. The Z-boat was controlled by a person using a handheld remote control from a support vessel (a 17-foot Boston Whaler). The Z-boat driver navigated the vessel between pilings and other obstacles, back and forth between rows of pilings, collecting data mostly on tracks oriented perpendicular to the length of the pier (Figure 4). The Z-boat did not send depth or GPS data back to the operator in real-time. Instead, it stored the bathymetric and GPS-based location data in standard National Marine Electronics Association (NMEA) sentence formats on its on-board computer. These data were downloaded by connecting a field computer directly into the Z-boat with a universal serial bus (USB) cable.

Figure 3. Z-boat used for bathymetric mapping under pier areas.



- This photo shows typical obstacles present under and around the pier, which often made it impossible to exit from underneath the pier before or after many transects.
- The pier extends from right to left in this picture.

Figure 4. The Z-boat in action collecting bathymetric data under the pier.

When the Z-boat was underneath the piers, it could not receive a GPS signal. Originally, we had planned on conducting surveys in which the Z-boat exited the pier on either side of a given transect between pilings, and obtained GPS fixes on either side of the pier. This would have allowed the x,y position data to be simply interpolated between positions on both sides of the pier for the portion of the track where there was no GPS. However, obstacles such as oil booms and ships at berth made it impossible to exit the pier on one or both sides of a transect for most completed surveys. To solve this problem, we incorporated a USBL acoustic “diver tracker” system (SeaTrac, Figure 5). This system has two beacons that communicate between one another underwater using sound. One beacon is rigidly mounted underwater over the side of the support vessel, and one beacon is rigidly mounted underneath the Z-boat. The support vessel beacon is connected to a field computer which is also connected to a separate GPS antenna located on the support vessel. The support vessel beacon generates acoustic pings which are received by the Z-boat beacon, which then responds with pings. The support vessel beacon contains three receivers that register the reply ping and use the difference in timing that the reply is registered to triangulate the distance and bearing to the Z-boat beacon. Proprietary SeaTrac software called PinPoint calculates the position of the Z-boat relative to the support vessel and then generates Latitude and Longitude coordinates of the Z-boat based on the coordinates of the support vessel from the GPS antenna. We monitored the Z-boat ‘s calculated location in real time using the PinPoint software to ensure that the system was operating correctly (Figure 6).

USBL systems operate by “line of sight.” Sometimes communication between the beacons was interrupted by obstructions; however, this was minimized through careful piloting of the Z-boat and support vessel.

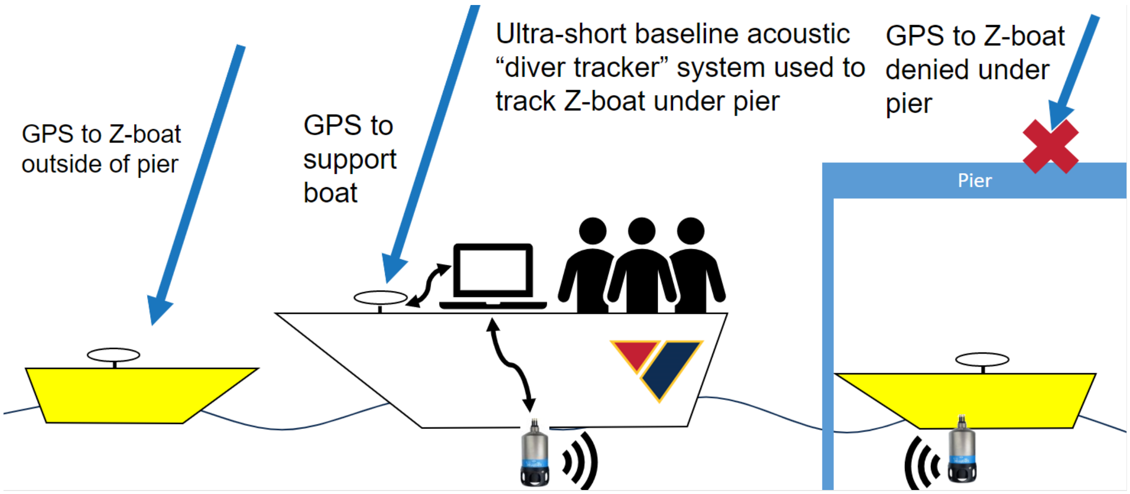
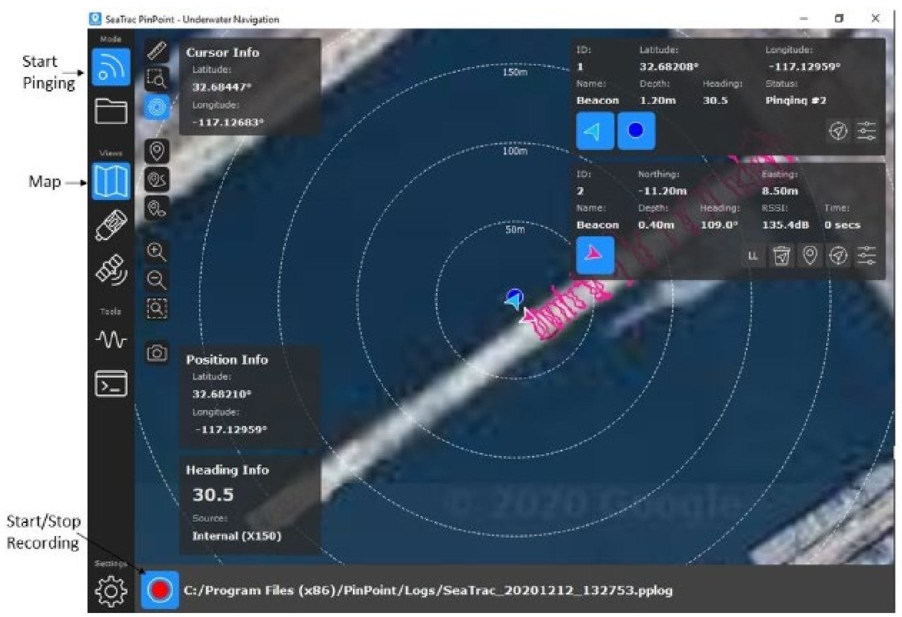


Figure 5. Diagram of the SeaTrac ultra-short baseline acoustic “diver tracker” system used to estimate the coordinates of the Z-boat when it was in the GPS-denied environment under the piers.



- Real time is shown in the pink track.
- The status of communications between beacons is shown in the top right of figure.

Figure 6. Screenshot of PinPoint software used to monitor the calculated position of the Z-boat in real time.

2. Sediment volume and erosion assessment.

To quantify the volume of under-pier sediments, bathymetric data collected from the Z-boat and SeaTrac positioning system were processed using a custom Matlab code (detailed in the attached

Standard Operating Procedures [SOP] in Appendix B). Briefly, water depths (z-measurements) were adjusted for tide height based on timestamps associated with the depth data, and x,y positions from either the onboard GPS or the SeaTrac USBL system were tied to the depth measurements using timestamp matching. Data were also filtered to remove spurious errors, resulting in a final x,y,z dataset along the track covered by the Z-boat for a given survey. From these x,y,z files, digital elevation models (DEMs), 3-dimensional models of the sediment surface were created by gridding the area covered during a survey and interpolating between survey tracks to create a continuous surface. Each DEM therefore represents the sediment surface at a given time when the survey was conducted. From these DEMs, sediment volume under the pier was calculated by analyzing the volume of sediment above the dredge design depth, which was used to represent the "bottom" of the sediment. Note that it is possible that the actual sediment depth/volume is less than this, if the native bedrock (sandstone Baypoint formation) is actually located above this dredge design depth for any portion of the area under the pier. However, no sub-surface data were collected for this project (which could be used to determine the depth where sediments transition to the underlying sandstone, and thus the thickness of the sediment layer).

To assess whether the magnitude of under-pier sediment movement (erosion/slumping) into adjacent areas could be quantified with these methods, DEMs created from subsequent survey datasets were differenced and evaluated.

NIWC Pacific is a leader in unmanned vehicle development, yet these tools are just starting to be incorporated to their full potential in the environmental space. The Teledyne Z-boat 1800 that was used to acquire bathymetric data is highly maneuverable, compact, and has a very shallow draft to allow data collection in tight and shallow spaces. Likewise, DEMs (often created from Light detection and ranging [Lidar] data) are routinely used to estimate the volume of material that has been mobilized and transported between subsequent surveys on the earth's surface. Still, these methods are not commonly employed in marine sediment contamination investigations. Incorporating these technologies into sediment investigations was therefore innovative and cost-effective.

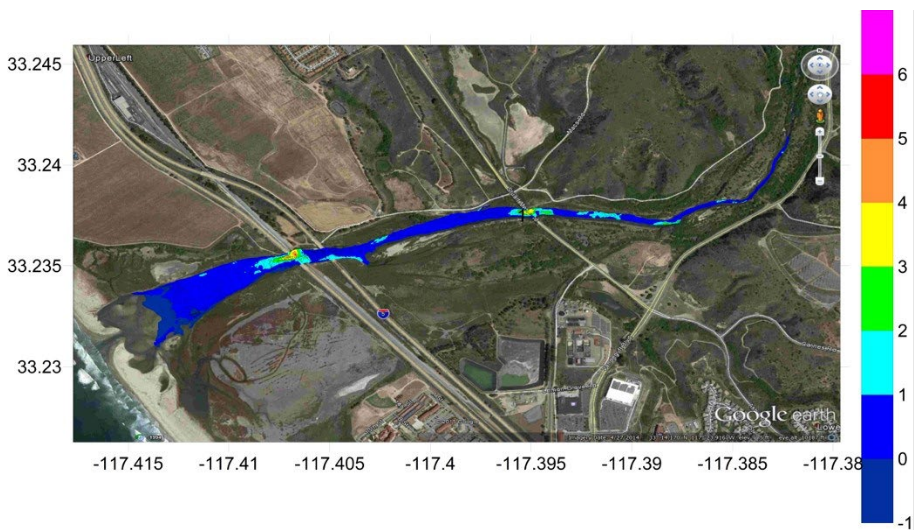
3. Quantifying contaminant concentrations.

To select appropriate sediment sampling strategies for a given location, a menu of under-pier-appropriate sampling methods was created. This menu, including requirements and constraints for each technique, is included in Appendix B. This menu would allow for selecting appropriate sampling methods at each site, based on the structure and depth of the pier, the estimated depth of the sediment pile to be assessed, and other requirements. This demonstration used two different main sediment sampling tools – a mini Ponar for collecting grab samples from the surface layers of sediments, and a handheld coring device that allowed collection of vertical cores of sediment from the surface and deeper layers. These tools were used in two main sampling configurations: at some piers, all sampling was conducted from underneath the pier, and at other piers, access panels allowed a portion of the sampling team to work from the pier surface with support from other team members below the pier.

3.2 TECHNOLOGY DEVELOPMENT

The technology demonstrated for this project was adapted from previous applications and from the oceanographic technology marketplace, proven for other applications.

Bathymetric (depth) measurements: An existing NIWC-owned remotely operated surface vessel now called a "Z-boat" was used to obtain depth (z) measurements under and around piers using an integrated single-beam sonar system (Ceepulse 100 from CEE Hydrosystems) and positions (x,y) when the boat had open sky-view outside of an at the very edges of piers using an integrated GPS system (Hemisphere). This system had previously been used by NIWC Pacific to create bathymetric maps of shallow estuaries, for example in Pearl Harbor and Marine Corps Base Camp Pendleton (Figure 7). When the Z-boat did not have sky view (i.e., underneath piers), positions (x,y) of the boat to match to depth measurements needed to be obtained from an alternate source. We worked with Teledyne, CEE Hydrosystems, and several other companies to attempt to devise a cost-effective approach to obtain positions under the piers, but these approaches were either not possible (i.e. the technology was not proven or commercialized) or were extremely expensive (>$200k). Therefore, we integrated an existing NIWC-owned acoustic-based underwater positioning system (SeaTrac from Blueprint Subsea) that was previously used to record underwater tracks of divers conducting environmental survey work to track the positions of the Z-boat under the piers. The integrated system was first tested in a pool, then at piers around NIWC Pacific, and at the construction site of the new Pier 8 at NBSD after pilings but before the new pier top was installed, before it was used to collect survey data below piers at NBSD. Data stream processing and integration were developed during this project.



- Created by the Z-boat (depth shown using color scale in meters)
- Overlaid on a Google Earth image (From Chuck Katz).

Figure 7. Example of a bathymetric map of the Santa Margarita estuary, Marine Corps Base Camp Pendleton.

Sediment sampling: Existing sediment sampling equipment (mini Ponar grad sampler and manual core-sampler) owned by NIWC Pacific was used to collect samples both through and beneath piers for this demonstration. To allow the use of the manual core-sampler entirely below piers, a new attachment device was designed and fabricated to allow the coring device to be attached to might lighter aluminum extension poles instead of the standard heavy steel poles that are typically used when the coring system is deployed from a large survey boat or from a fixed platform such as a quaywall or pier. The lighter extension poles allowed the coring system to be deployed from a small skiff under the pier by a team of two scientists. Once collected, samples were processed and analyzed with standard methods.

3.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Quantification of potential recontamination from under-pier sediments will allow the Navy to direct resources to adequately address contamination problems. Cleaning up contaminated sites is a priority for the Navy, as well as regulatory agencies. Remediation is slow and expensive, and can become even slower and more expensive when sites are cleaned up and subsequently recontaminated because all sources of contamination were not addressed. By determining whether the under-pier environment is a source of recontamination, the Navy can improve the efficiency of its remediation efforts, saving the Navy expenses by reducing future treatment.

One major limitation to using a Z-boat to measure the bathymetry underneath piers is that GPS is denied, and the sides of piers are usually blocked, so the Z-boat cannot exit to obtain new GPS positions. As a result, a separate method is required to provide x,y positions when the Z-boat is under the pier, and that data stream must be merged with the depth and (intermittent) GPS data collected by the Z-boat. This limitation was addressed by using a USBL "diver tracker" system to provide Z-boat positions under the piers, and a Matlab-based data processing code was developed to process and merge these data with the Z-boat depths and positions. During the development of this data processing code, an additional limitation was discovered, wherein the timestamps associated with the SeaTrac USBL positions were sourced from the field computer clock and not from the connected GPS. Because all clocks drift to some degree, this led to timestamp-offset mismatches during some surveys that had to be manually corrected during data processing. We have recommended that the SeaTrac PinPoint software should be updated to avoid this problem in the future. An additional limitation of USBL positioning is that it can suffer from interference in environments with obstructions. Indeed, the underwater under-pier environment is complicated with pier pilings, camels, mooring dolphins, and more acoustically reflective objects (Figure 8). These structures can temporarily obstruct communication between the support vessel and the Z-boat, or can cause echoes which can result in false apparent positions of the Z-boat. However, using the field and data processing methods developed during this project, these limitations can be minimized.

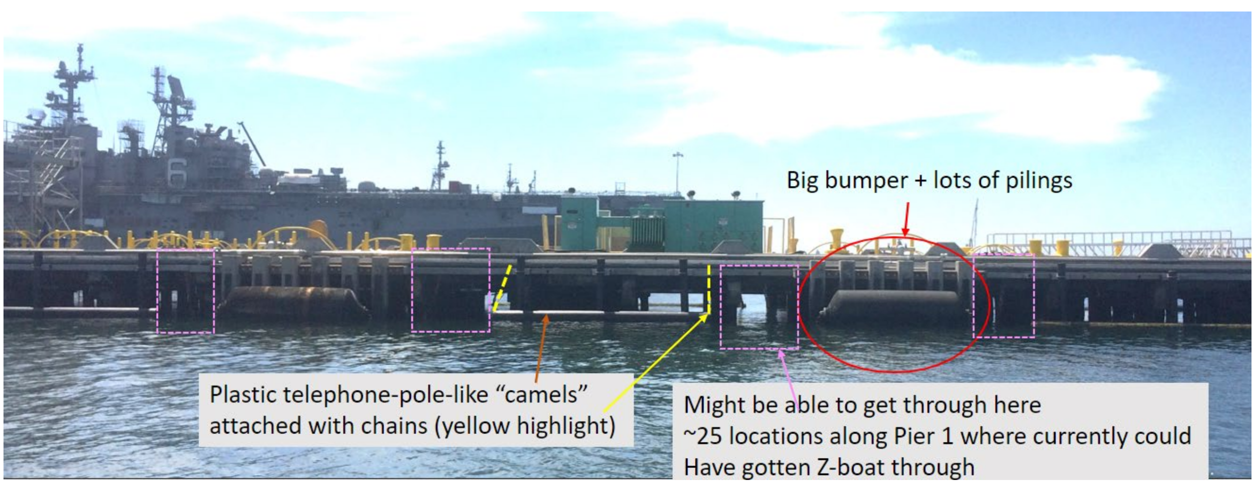


Figure 8. Photo of Pier 1 at NBSD showing example of obstructions for navigating the Z-boat and acoustically reflective objects that block the transmission of sound between the SeaTrac beacons.

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Therefore, this project provided a new, low-cost method to quantify the magnitude of this potential recontamination source, ultimately benefiting the overall Navy cleanup mission as well as individual Superfund sites that include pier structures with accumulated sediments. There are 39 Navy sites categorized as Superfund sites, and more that have cleanup or investigative orders from regional or local regulators. Most of these Navy sites have multiple piers where the technological approach outlined in this report could be applied as part of each intermittent dredging operation in pier areas.

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4. FACILITY/SITE DESCRIPTION, LOCATION AND OPERATIONS

NBSD was chosen as the site for this project. This site was where the NESDI need was generated, and it was easily accessed by the project team, based at NIWC Pacific just across San Diego Bay. The original project plan intended to conduct a relatively small-scale demonstration at NBSD, followed by a larger-scale demonstration at Pearl Harbor, Hawaii. However, the Pearl Harbor cleanup program has reached sufficient maturity, and this demonstration did not appear to fit into ongoing needs and operations. At the same time, NBSD began a new sediment investigation during this project. Therefore, in addition to being more feasible with logistical constraints to the project related to COVID-19 travel restrictions, the demonstration was wholly completed at NBSD to ensure the resulting dataset would be most useful for the Navy.

NBSD is located on the eastern shoreline of San Diego Bay (Figure 9). The area is physically protected from the open ocean and relatively quiescent. Two creeks, Chollas and Paleta, deposit sediments immediately to the north and south of the base, respectively, and other waterways also empty into the bay (Figure 9 and Figure 10). The sediments in the pier areas around NBSD and the South Bay are relatively fine material with silts and clays. Sediments generally become coarser, with some sand, to the west and north of NBSD and within the main shipping channel in the northern portion of the bay. NBSD is the homeport of more than 46 Navy vessels, with over a dozen pier structures.

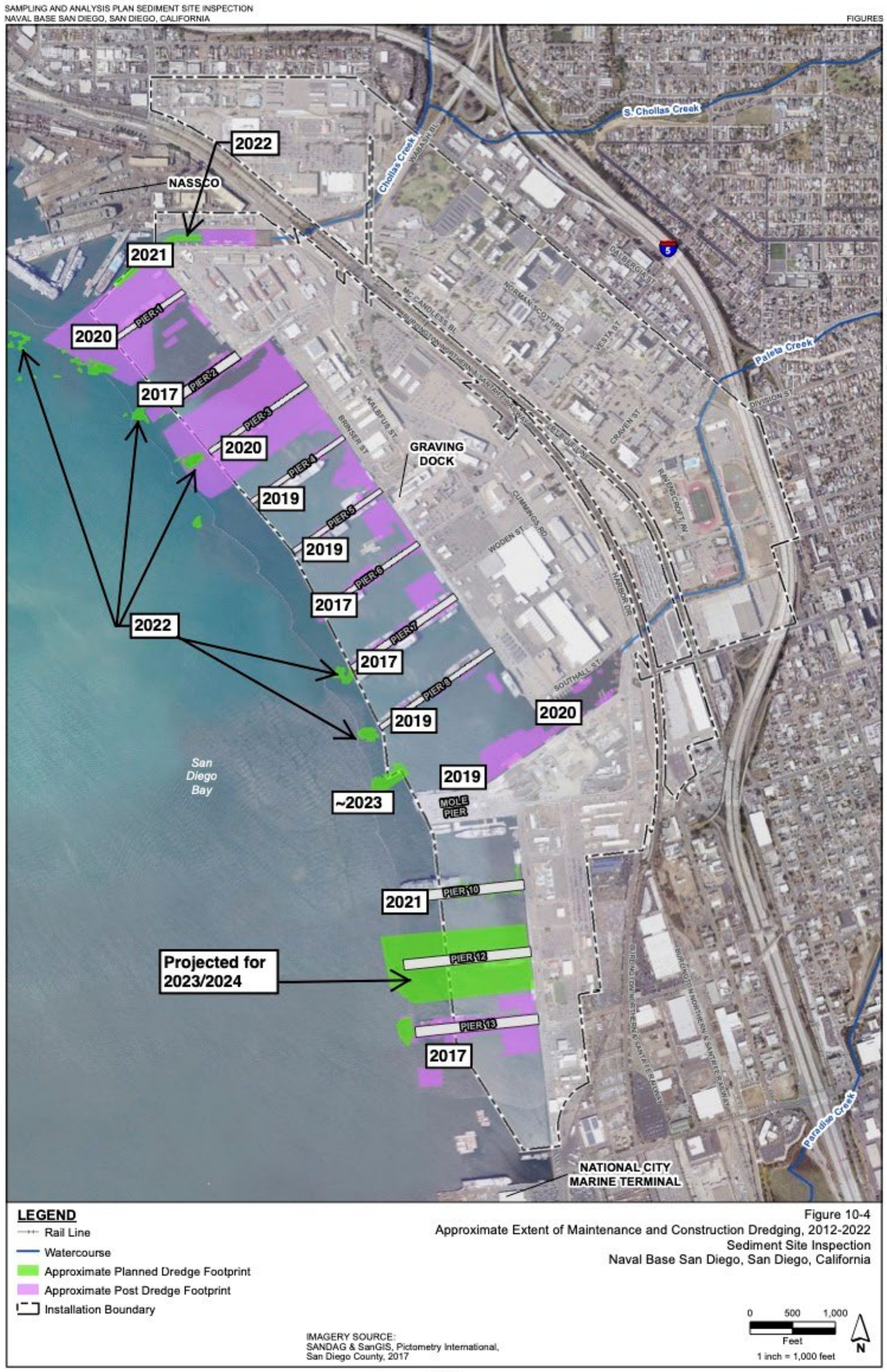
Navigational dredging was planned around Piers 1, 3, 4, 5, 10, Chollas Creek, and Paleta Creek at NBSD in 2020 and 2021. Dredging targets sediments that have built up around the edges of the piers and the quaywall (Figure 11 and Figure 12). For navigational dredging, sediments that have built up above the required clearance depth for ship traffic must be removed to ensure the bay bottom is deep enough for ship activities. Navigational dredging improves operational efficiency and has the side effect of removing some contaminated materials from the site, particularly if after dredging, the newly exposed sediments have lower contaminant concentrations. Sediments in the areas to be dredged were tested for a wide range of contaminants of potential concern. Elevated levels of metals, PCBs, chlorinated pesticides, and/or PAHs were found in all samples (US Department of the Navy, 2017); thus, the dredged sediments at NBSD generally require upland landfill disposal instead of ocean disposal or re-use. Dredging does not occur under the piers, and sediments under the piers had not been previously assessed for sediment volume or concentrations of contaminants. Therefore, whether this dredging could then be followed by recontamination from contaminated sediments slumping from under the piers was unknown. Interestingly, other sediment assessment work completed by NIWC Pacific suggests that legacy contamination from sewage sludge discharged into the bay near Pier 5 at NBSD, until 1963, could be a main source of bay-wide PCB contamination (Leather et al. 2020). Core samples collected under piers at NBSD, where sediments have not been removed by dredging, were also targeted to test this hypothesis.

- Imagery from Google Earth.

Figure 9. San Diego Bay, with NBSD piers indicated (black and white circles), as well as Chollas and Paleta creeks that bracket the base identified. Imagery from Google Earth.

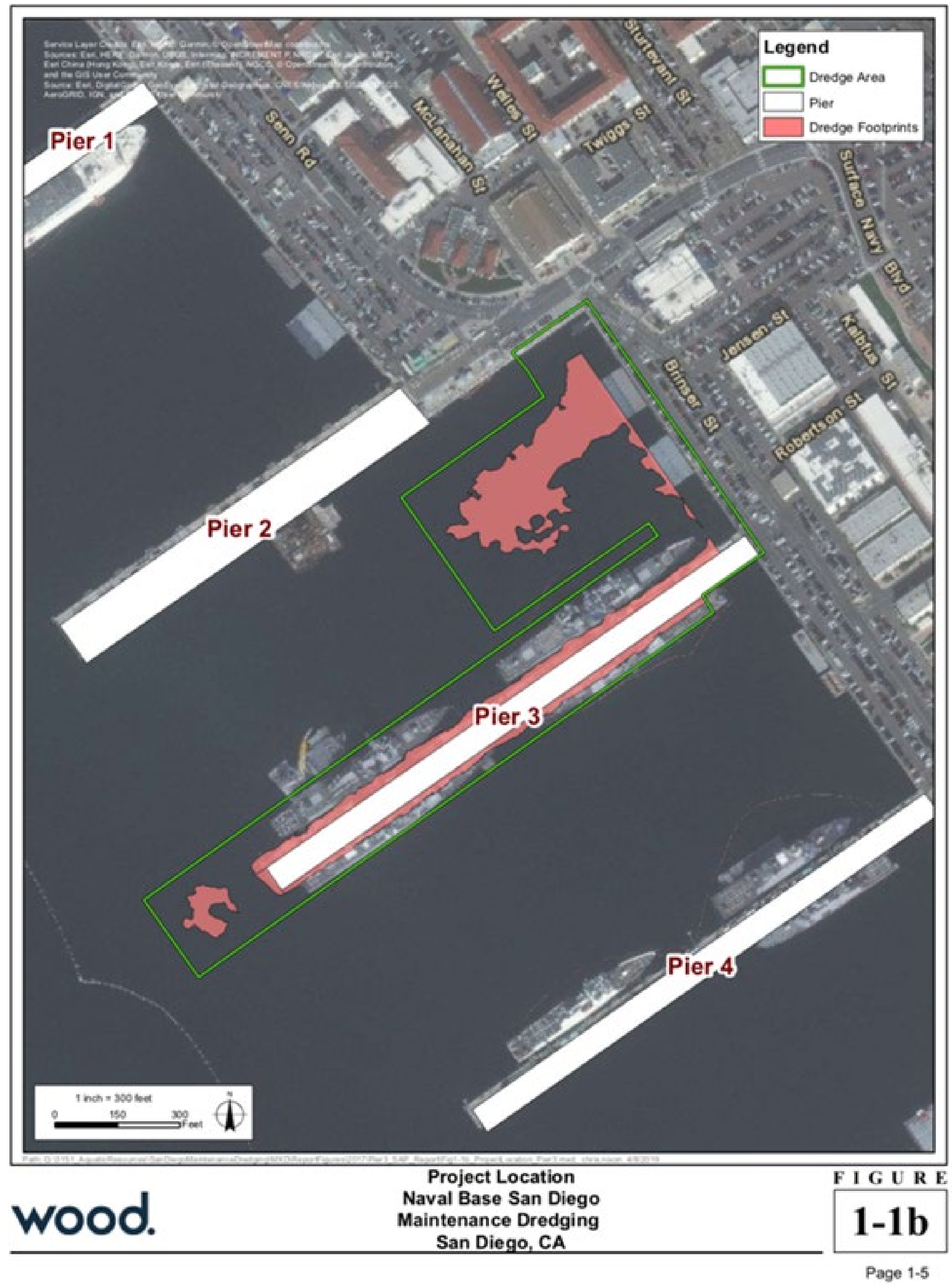
- Imagery from Google Earth.

Figure 10. NBSD piers (numbered and named), with creek mouths to the North and South of the base marked.



- Figure from US Department of the Navy (2022).
- Imagery from Google Earth.

Figure 11. Map of planned generalized recently dredged (purple) and planned dredge (green) areas around NBSD.



- Surveys indicated sediments were shallower than the dredge design depth of –30 feet below mean low low water, and would be removed during dredging, while green provides an outline of the general work area of the dredge equipment.
- Figure from US Department of the Navy (2019).
- Imagery from Google Earth.

Figure 12. Example of Pier 3 areas targeted for dredging. Pink shading shows locations where pre-dredge bathymetric.

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5. TEST DESIGN

5.1 DEVELOPMENTAL TESTING

Jessica Carilli (PI) visited NBSD with another project to view and photograph the piers from a small boat, assess the conditions and constraints, and plan how to best conduct bathymetry surveys and sediment sampling under the piers. From this initial site visit, the team learned that it would not be possible to drive the Z-boat directly across from one side of the pier to the other side, which would have allowed the system to acquire GPS positions on either side of the pier, and thus linear interpolation of positions for the time period the vessel was under piers with no GPS signal. It was therefore imperative to integrate instruments to independently track the position of the vessel at times that the vessel was under piers with a non-GPS-based approach. The team worked with Teledyne, CEE Hydrosystems, and other companies that advertise systems for positioning in GPS denied environments (e.g., using cell phone triangulation, for example). However, all potential solutions were determined either to be too expensive, impractical (i.e. requiring installation of multiple modems at different locations underneath each pier for each survey) or were not yet commercially available (i.e. advertised solutions were not yet in production). Therefore, the team decided to test a USBL "diver tracker" system (SeaTrac) to independently track the position of the Z-boat during each survey and provide positions when the boat was in a GPS-denied location during the survey.

Initial Z-boat testing and SeaTrac integration testing was completed at a private swimming pool. We compared the plotted the GPS and SeaTrac positions on Google Earth to ensure they aligned with the pool location and with one another. We also plotted the depth measurements to confirm accuracy based on the known depth and contour of the pool bottom.

To prepare for the data and sample collection efforts at NBSD, we tested all equipment at NIWC Pacific. Additional preparation testing included setting up the Z-boat and completing a practice survey around and under some of the piers at NIWC Pacific. In addition to retesting the echosounder and GPS in an under- and around-pier environment to determine if and when the GPS signal could not be received, we also tested the SeaTrac system and compared the track with the GPS track when both were available. We also tested the steering capability and the motor because the under-pier environment requires tight turns. Finally, we monitored the battery usage of the Z-boat and the remote control during these tests to make sure the battery life was sufficient for completing a survey at NBSD. We tested the remote-control range to the boat and verified that when the boat lost remote control signal, it stopped the propeller. The data from these tests also showed that timestamps were continuously logged in the Z-boat datafiles and incremented forward in time, even when the Z-boat was not able to get a GPS position. During this test, we also discovered some problems with the SeaTrac software (PinPoint) that needed to be corrected, which BluePrint Subsea then fixed, and also worked with BluePrint Subsea to identify particular parameter adjustments within the software to ensure our resulting position data could be integrated with the depth measurements from the Z-boat.

Next, we tested the Z-boat at a pier under construction at NBSD (Pier 8). This pier had all the new pilings in place, but the pier surface had not been constructed yet. In this way, we were able to test the feasibility of our survey pattern, running perpendicular transects beneath the piers and practice driving the boat in the constrained spaces between pilings, but with enhanced visibility. We also tested the Z-boat under a small section of the new pier that had been completed. One of the takeaways from this test was that the location and orientation of the Z-boat was hard to see in the shade under the pier, so we purchased and mounted battery-operated boat lights onto the bow and stern of the Z-boat so we could more readily see its position and orientation. We also tested various methods to mount the SeaTrac beacons on the Z-boat and over the side of the support boat. Since we were deploying the Z-boat from the support vessel, we also practiced safely deploying and recovering the Z-boat to avoid injury to personnel or damage to the equipment. We also purchased a cart to transport the Z-boat to and from the support vessel and secure the Z-boat when it was on the support vessel deck.

During these tests, we developed and refined SOPs to ensure that every survey was successful, even if different people were conducting the survey. The finalized SOPs are included in the Appendices to allow transition of the results of this project to other sites.

To prepare for sediment sampling, we consulted the Under-Pier Sediment Sampling Menu that was developed as an early task for this project and summarizes different possible approaches to collecting sediments underneath piers. From this document, we selected two methods to collect samples at NBSD for this demonstration: the first was a mini Ponar system to collect surface grab samples, and the second was a manual push-core system to collect core samples. These sampling devices were tested at NIWC Pacific to determine if they could be used in the NBSD under-pier settings, or if any adjustments were required. These tests showed that the mini Ponar could be deployed and retrieved by hand from a small skiff, and therefore would be possible to use in the cramped under-pier environment without the use of a davit or other load-bearing equipment available on larger vessels. The testing also revealed that the steel extension poles typically used with the manual push-coring equipment were too heavy to be used from a small skiff, and therefore the system needed to be slightly redesigned to allow use of much lighter aluminum extension poles. Before sampling methods were used under piers at NBSD, they were also tested at the base next to the quaywall adjacent to Pier 3.

Before samples could be collected at NBSD, the area to be sampled had to be cleared with a magnetometer operated by a trained UXO technician, and after collection, grab samples were placed into a plastic bowl and core samples in plastic sleeves were removed from the metal sampling device and were further screened by the UXO technician. Initial test-sampling at the quaywall adjacent to Pier 3 was also used to test the approach to conduct this screening.

Table 1. Dates and descriptions of developmental test events.

Date	Developmental Test Event
6 May 2020	PI visit to NBSD to assess piers
3 August 2020	Z-boat test at NIWC PAC (1)
8 August 2020	Z-boat test in private pool
13 August 2020	Z-boat test at NIWC PAC (2)
2 September 2020	Z-boat test at NBSD
17 September 2020	Z-Boat test at NIWC PAC (3)
8 October 2020	Z-boat test at NIWC PAC (4)
5 November 2020	Z-boat test at NIWC PAC (5)
June 2021	Sediment sampling equipment test at NIWC PAC
7 September 2021	Sediment sampling test at NBSD quaywall

5.2 CONCEPTUAL TEST DESIGN

The conceptual experimental design for the field demonstration focused on testing the performance of the Z-boat for bathymetric mapping and under-pier sediment sampling methods under realistic field conditions, and then analyzing the resulting data and comparing these results to other relevant sediment quality studies completed at the NBSD demonstration site. The piers selected for this demonstration at NBSD span a range of sizes, styles, elevations above the water surface, ages since construction, times since adjacent navigational dredging, and had varying degrees of through-pier access to the water and sediments below the piers. This provided a variety of conditions under which to test the Under-pier sediment assessment approaches developed here, including different amounts of space in which to work under the piers, variability in sediment depth and topography, current speeds, debris and physical obstructions such as ships, camels, and oil booms. To bring further value to the demonstration, collected bathymetric data and sediment samples were analyzed and evaluated so that the data from the demonstration can help inform ongoing monitoring and assessment of the sediments at NBSD and help guide future decision making. Analysis of the datasets also helped to identify unanticipated issues and thus refine the SOPs resulting from the project, such that the technology can be transitioned more effectively to other sites. Therefore, the conceptual design for the demonstration encompassed the preparation and mobilization of equipment, logistical coordination, field efforts, data and sample analysis, and interpretation of results associated with assessing the quantity and quality of sediments under Navy piers.

The project followed an approach that consisted of seven primary tasks:

1. Testing and refining the technologies to be used in the field,
2. Completing the field demonstration plan,
3. Completing field bathymetric surveys,
4. Analyzing bathymetric data to create maps of sediment under piers,
5. Collecting and analyzing chemistry and physical characteristics of sediment samples,
6. Integrating and interpreting the results from bathymetric mapping and sediment sample analysis to quantify the magnitude of under-pier sediments as a possible source of recontamination,
7. Performance and cost analysis based on initial testing and field demonstration.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 Z-Boat

The remotely operated surface vessel, Z-boat (Figure 13), used for this project has become a relatively standard tool for shallow water bathymetric survey projects without overhead obstructions such as piers. The overall Z-boat system and incorporated components are described in detail in the operation manual provided by Teledyne (Z-boat 1800 Users Guide) as well as the Under Pier Bathymetric Survey SOP attached in Appendix B.

Briefly, the Z-boat incorporates a small electric outboard motor that drives the boat and is controlled with a remote control, a single-beam echosounder (CEEPulse 100) to measure depth at high frequency (usually 10 Hz, or 10 measurements per second) below the boat, a compass to record the heading of the vessel (usually every 2 seconds) and a GPS system that records the x,y position of the Z-boat (usually every second). The position, heading, and depth data are saved on an onboard computer in NMEA format ordered in sequence based on when the position, heading, or depth information were queried by the incorporated instruments and communicated to the computer. These data can then be downloaded from the boat computer after a survey is complete for processing. The integrated GPS antenna (white disk shown in Figure 13) is located on the top of the vessel, along the midline and approximately 1/3 of the way between the stern and the bow. The integrated echosounder is located directly below the GPS antenna.

Figure 13. The NIWC Pacific Z-boat during testing at a private pool (left) and a survey under a pier at NBSD (right). This survey was completed during an extreme low tide.

5.3.2 SeaTrac USBL Acoustic Positioning System

To provide independent x,y positions of the Z-boat when the integrated GPS system could not obtain accurate positions underneath the surveyed piers, a SeaTrac brand USBL system, typically used for tracking underwater assets such as divers at underwater autonomous vehicles, was rigidly mounted beneath the Z-boat using a custom mounting system. This system is described in detail in the operation manual provided by Blueprint Subsea (SeaTrac Beacon User Guide) as well as section 3.1, and the Under Pier Bathymetric Survey SOP attached in Appendix B.

The USBL beacon was attached to the Z-boat along the midline with a custom mounting system (Figure 14). It was located approximately 2/3 of the way between the stern and the bow (i.e. closer to the bow than the stern, and approximately 18 inches forward of the echosounder, with attachments threaded through the front set of black handles on the boat visible in Figure 13). This position on the Z-boat was selected to minimize interference from bubbles and sound produced by the outboard motor with the SeaTrac system's acoustic communications, and to avoid interfering with the function of the onboard echosounder.

The so-called topside USBL beacon was rigidly mounted over the side of the support vessel (Boston Whaler) using a custom mounting system (Figure 14). This beacon was then cabled to a field computer on the support vessel. A directional GPS was placed on the bow of the support vessel and was also cabled to the field computer. The relative x,y offsets between the support vessel GPS and the topside beacon were measured and entered into the PinPoint software that is used to calculate the position of the topside beacon relative to the GPS positions of the support boat, as well as the distance and bearing to the beacon on the Z-boat, and from those measurements, to calculate a real-world x,y position (latitude and longitude) of the Z-boat at the time of each position query.

- Mounting system for USBL beacon on Z-boat (left) mounting system for topside USBL beacon (right).

Figure 14. The custom mounting systems for the SeaTrac beacons used for this project, used to hold the beacons at a fixed depth and orientation relative to the Z-boat and support vessel, respectively, during the survey.

5.3.3 Sediment Samplers

Two general types of sediment samplers were used for this project: a mini Ponar grab sampler and a manual push-coring device (Figure 15). These samplers, and the different ways they were used for this project, are described in detail in the Under Pier Sediment Sampling Menu and the Under Pier Sediment Sampling SOP (Appendix B). Briefly, at each NBSD sampling site, after the target sampling site was scanned with a magnetometer and determined to be clear of potential munitions according to a trained UXO technician, the mini Ponar was used at each station first, to collect a scoop of sediment of approximately 2 L volume from the top of the under-pier sediment. Larger samplers are often used for this purpose, but their weight requires use of a winch or other mechanical device. For this project, a small grab sampler was selected to allow the device to be deployed and retrieved without any mechanical devices, and thus allow the system to be used in the constrained under-pier environment. Following grab sampling, the manual coring device was deployed to collect a continuous core of sediment from the top surface to a depth of approximately 24 inches below the surface. Similar to the choice of a small-scale grab sampler, this relatively small manual coring device was selected because it could be deployed and samples could be recovered with a team of 2-3 people without use of mechanical devices like a winch or A-frame that would not fit in the under-pier environment.

Figure 15: (Left) Mini ponar sampler used to collect grab-samples of surface sediments under piers and (right) Manual coring system used to collect push-cores up to 24 inches long under piers.

5.4 OPERATIONAL TESTING

Because the NBSD piers were built with very little clearance over the water, we needed to carefully time surveys during the lowest tides of the month to provide a long enough period of time, during daylight hours, to complete survey activities with sufficient space between the water surface and the pier for the Z-boat to operate. The project team also had to coordinate with NBSD port operations to determine which berths would be open on low tide days, to allow access to at least one portion of one or more piers targeted for the demonstration. Finally, days with open berths at target piers with daylight low tides also had to coincide with dates that the support vessel was not already reserved for another project and enough personnel were available to complete the survey (one certified small boat captain for the support vessel; one person to drive the Z-boat; and at least one person to assist with launching/recovering the Z-boat, monitoring the SeaTrac software, and logging all events on a datasheet).

Originally, the project planned to complete one survey for each pier before adjacent areas were dredged, followed by one or two surveys after the dredging occurred. However, due to COVID-related fieldwork delays, and the above constraints to survey planning, the pre-dredge bathymetry surveys could not be completed; instead, at least two surveys were conducted at each target pier post-dredging with the goal to evaluate whether changes in the shape and volume of sediment piles under piers could be resolved by comparing subsequent surveys.

Sediment sampling similarly had to be coordinated to occur during low tides during daylight hours, with open berths to allow access to under-pier areas, vessels and sufficient personnel and to complete the sampling effort, and also had to be coordinated to ensure that a UXO technician was available to support the work. Samples were processed at the NIWC Pacific laboratory and shipped to the U.S. Army Engineer Research and Development Center (ERDC) for sediment quality analysis. Details describing field operational processes are provided in the SOPs in Appendix B.

Table 2. Dates when operational testing was conducted for bathymetry surveys and sediment sampling.

Date	Operational Test Event
12 December 2020	Pier 3 Bathymetry Survey 1
14 December 2020	Pier 1 Bathymetry Survey 1
15 December 2020	Pier 5 Bathymetry Survey 1
10 February 2021	Pier 4 Bathymetry Survey 1
11 February 2021	Pier 10 Bathymetry Survey 1
9 March 2021	Pier 1 Bathymetry Survey 2 Pier 3 Bathymetry Survey 2
17 June 2021	Pier 5 Bathymetry Survey 2
25 August 2021	Pier 4 Bathymetry Survey 2 Pier 10 Bathymetry Survey 2
26 August 2021	Pier 5 Bathymetry Survey 3
7 September 2021	Pier 1, 3 Sediment sampling
8 September 2021	Pier 1, 3, 4 Sediment sampling
5 October 2021	Pier 4, 10 Sediment sampling
2 December 2021	Pier 5 Sediment sampling

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6. PERFORMANCE OBJECTIVES AND ASSESSMENT

The following performance objectives were evaluated for this project.

Performance Objective	Data Requirements	Success Criteria	Achieved (Yes/No)
QUANTITATIVE			
Bathymetric accuracy	Bathymetry collected using Z-boat; processed; ground-control points to quantify accuracy.	Bathymetry measurements are accurate to within 1m of ground control points (depths measured independently). It is expected that this accuracy level will be acceptable given the anticipated magnitude of bathymetric variability likely encountered.	Yes
Mapping accuracy	Z-boat locations under pier throughout survey; ground-control points to quantify accuracy.	Horizontal locations of Z-boat under pier are accurate to within 3m, which is similar to accuracy of most standard hand-held GPS devices.	Partially yes
Small-scale erosion of under-pier sediments can be quantified	DEMs produced from repeated bathymetric surveys.	Erosional footprint size can be detected down to approximately 50m3, or smaller. It is anticipated that given the error in both vertical and horizontal positions, footprints larger than this size would be both detectable and relevant.	No
Re-contamination source magnitude can be effectively quantified	Volume and contaminant concentrations in under-pier sediments.	The total pool of contaminants in under-pier sediments can be estimated with error similar to that associated with other potential contaminant sources such as stormwater input, to allow quantitative comparison to other potential sources.	Yes
QUALITATIVE			
Sampling menu appropriate to RPMs	Feedback from RPMs.	RPMs consider menu complete and useful for under-pier areas at their sites.	Yes
Sampling under pier using selected tool effective for demonstration	Feedback from field team and RPMs.	Selected under-pier sediment sampling procedure is logistically and cost effective for demonstration site.	Yes

Quantitative objectives:

6.1 BATHYMETRIC (VERTICAL) DATA ACCURACY

This performance objective was achieved. Similar to the method for performing a “bar check” by collecting depth data while a metal plate is held below the echosounder at a known depth, a bathymetric contour map was created from the survey tracks completed in the test pool, and the resulting depths were compared at three locations where groundtruth depths were measured with a tape measure (Figure 16). The pool was shallowest at one end (38” or 3.2 ft), deepest near the middle (47” or 3.9 ft), and also shallow at the other end (41” or 3.4 ft). The comparable depths for the bathymetric contour map were 3.2 ft, 3.8 ft, and 3.4 ft, respectively, indicating accuracy better than 0.1 ft, or 0.03 m. This indicates that the basic bathymetric depth observations from the Ceepulse Echosounder met the performance objective for accuracy within 1 m (3.3 feet).

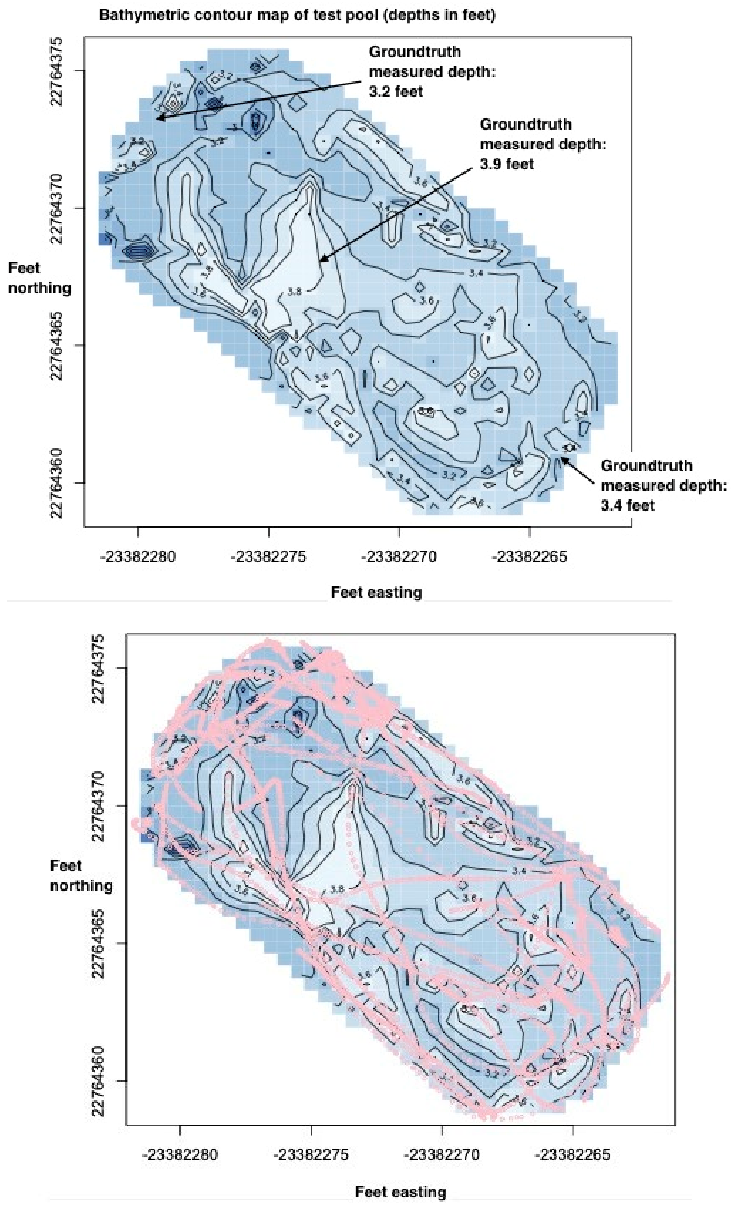


Figure 16. (Left) Bathymetric contour map of test pool, with groundtruth depths indicated. (Right) Test pool bathymetric map with Z-boat test survey track overlaid in pink.

However, during under-pier surveys, many other factors would naturally affect the apparent accuracy of the depth measurements in the field that are reduced in a pool environment. These include heave (i.e. the boat moving up and down with waves on the water surface), pitch and roll (i.e. the boat pitching forward and back or rolling side to side because of waves and turning), all of which would lead to some reduced accuracy in a given depth measurement. As well, water density may vary vertically in the ocean, which will affect the speed of sound and thus the calculated depth based on the return time of the acoustic ping from the echosounder. Further, during field surveys some obstructions were encountered such as kelp and trash; if a piece of kelp became temporarily tangled around the SeaTrac beacon, it could result in erroneously shallow depth measurements (i.e. several inches below the surface) interspersed with correct depth measurements (i.e. ~20 feet depths). To compensate for these potential artifacts, we added an additional data filtering step when processing the field-collected data to increase the accuracy of the under-pier depth measurements. To do this, we plotted measured depth versus time and visually selected the appropriate thresholds (shallow and deep) for each set of survey data that would remove obvious outliers while retaining the real data.

In addition, the field-collected depth measurements had to be corrected for changes in tide level during and between surveys, and to tie the water depths to a known fixed vertical datum so that the results from this project could be compared directly to other surveys such as pre- and post-dredge side-scan survey datasets. Those dredging surveys referenced the resulting bathymetry to mean lower low water (MLLW), and thus for the under-pier surveys, the depths were adjusted so they were also referenced to MLLW. A National Oceanic and Atmospheric Administration (NOAA) tide station is located near NBSD (Station #9410170), so we subtracted the measured depths from the Z-boat surveys from these observed NOAA water height measurements to convert our measured depths to depths (bottom height) relative to MLLW (Figure 17).

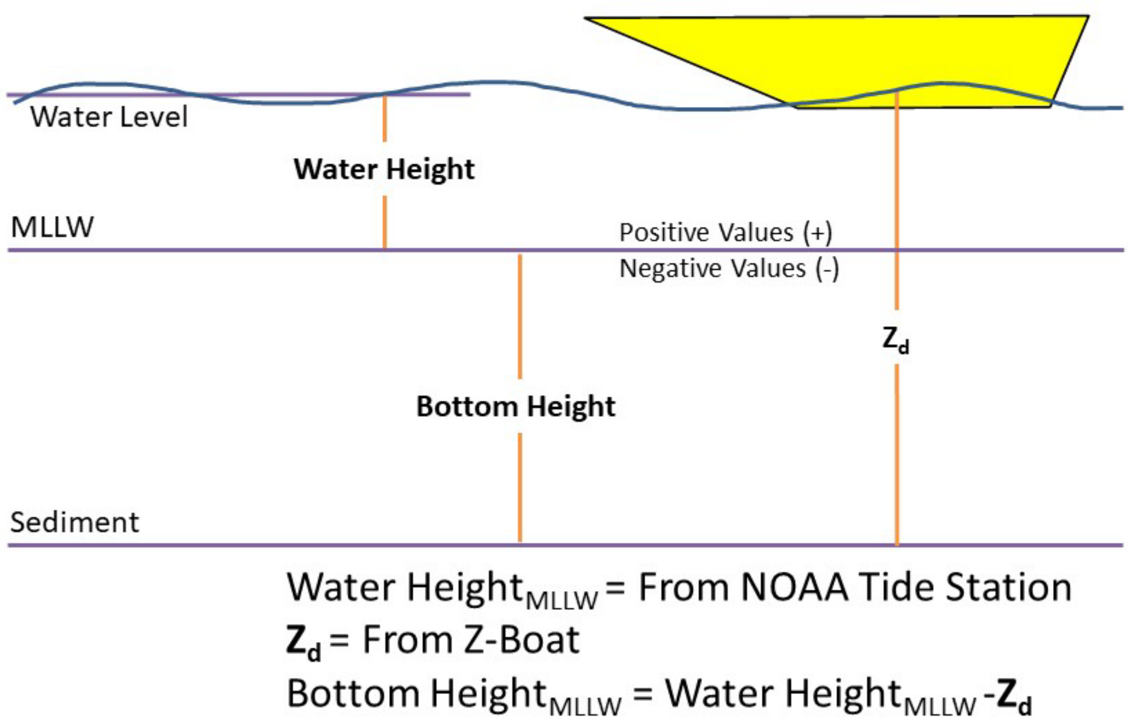


Figure 17. Diagram showing how depth measured by the Z-boat relates to water height and bottom height, in reference to the fixed vertical datum of MLLW.

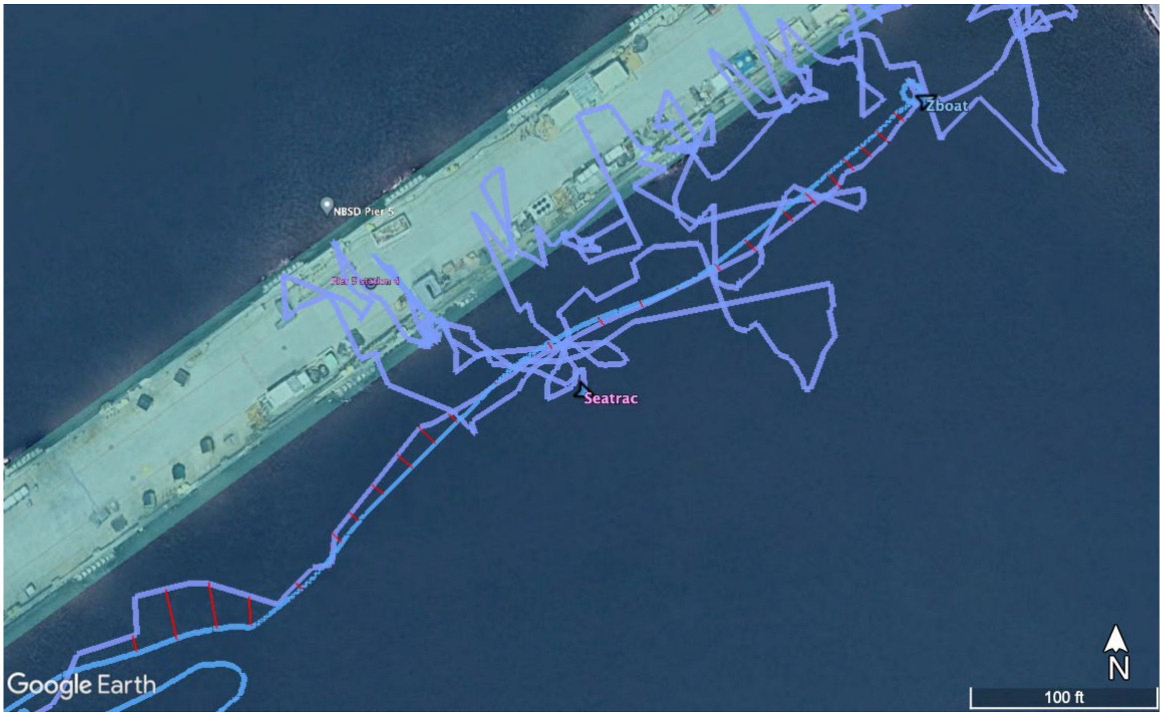
We then further reduced measurement errors (i.e. from heave, pitch, and roll) by calculating the running average of depth measurements +/- 0.5 s from every measurement time. Some data processing software intended for bathymetric surveys (i.e. Hypack) have built-in algorithms to compensate for heave, pitch, and roll, but the unique data stream for this project (i.e. using x,y positions from the SeaTrac system when the Z-boat GPS was denied) precluded their use.

Hydrographic surveying is a complex and highly technical field of engineering (see the Army Corps of Engineers Hydrographic Surveying Manual, EM 1110-2-1003 for further details). While the Ceepulse 100 echosounder used for this project is a survey-grade device (i.e. is capable of high precision measurements), the actual accuracy of the depth measurements obtained in the field for this project is difficult to quantify (see EM 1110-2-1003 for complexity of field accuracy assessment) and should not be considered survey-grade or used for requirements that require very high accuracy.

6.2 MAPPING (HORIZONTAL) ACCURACY

This performance objective was partially achieved. Although the reported accuracy of the GPS devices was <0.6 m for times when differential global positioning system (DGPS) GPS positions were reported for both the GPS antennas on the Z-boat (Hemisphere Crescent A100) and on the support vessel which informed the SeaTrac acoustic positioning system (Hemisphere Vector V103), and the reported accuracy for the SeaTrac acoustic positioning system is 50 mm, we found the actual accuracy to be significantly lower than these reported values in the complex environment around the Navy piers.

As with bathymetric (vertical) accuracy, many complex factors affect the mapping (horizontal) accuracy of these data, and a complete hydrographic-survey grade assessment (see EM 1110-2-1003) is beyond the scope of this project. We nevertheless assessed mapping accuracy in several different ways for this demonstration. For the first approach, we compared the GPS-based positions with the SeaTrac USBL-based positions for a period of time when the Z-boat was not under the pier and could therefore receive both GPS and USBL fixes. For a survey completed at Pier 5, a long track spanning most of the pier length outside of the pier was recorded by both the integrated Z-boat GPS and SeaTrac (Figure 18), and ranged between 0-8.3 m (27.2 ft). The mean difference between the tracks at these measured locations was 2.6 m (8.5 ft), the median was 2.4 m (7.9 ft), and the standard deviation was 1.9 m (6.2 ft). Therefore, on average, the relative accuracy of the positions was better than the performance objective of 3 m, using this comparison approach.



- Imagery from Google Earth.

Figure 18. Z-boat positions recorded by the integrated GPS (blue) and SeaTrac system (purple) for one of the Pier 5 surveys, with locations where the difference between positions was measured for a track along the length of the pier indicated with red lines.

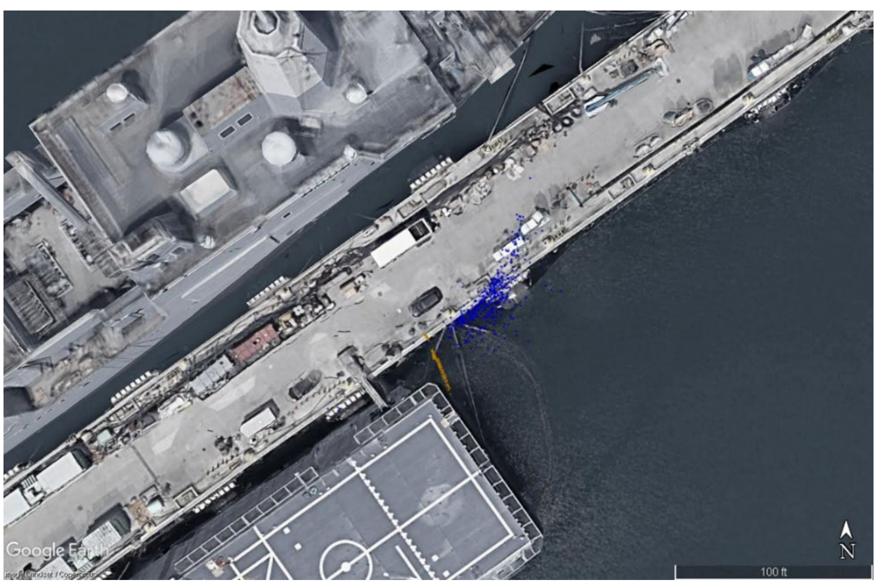
We also assessed the precision of the horizontal positions and relative accuracy again during a time period when the Z-boat became stuck in one place at the far edge of the pier during a survey at Pier 4. For this analysis, we assessed three aspects of the horizontal positions: the horizontal standard deviation in both x and y positions from the GPS positions, and the SeaTrac positions, and also the difference between the reported GPS and Seatrac positions. Although the Z-boat was stuck for an hour, we used the middle 30 min for this analysis because this is the time when the Z-boat was the most still (Figure 19), because we had stopped trying to retrieve it and were waiting for the port operations team to come to the pier and assist with freeing the Z-boat.

For the GPS position accuracy assessment while the Z-boat was mired, we only used the GPS positions that had a DGPS position and a horizontal dilution of precision (HDOP) of less than 2 (considered "excellent"). HDOP is impacted by the spatial spread of GPS satellites across the sky. More spread out satellites will result in a more accurate position than if all the satellites are clustered together. Especially in an under-pier environment, it is important to take these values into consideration because the view of the sky is limited due to the concrete pier overhead. The standard deviation of the remaining GPS positions that met our quality criteria (DGPS position and HDOP <2, meaning we would have used that position to create our maps) was 0.3 m (1.1 ft) in the x direction and 0.8 m (2.6 ft) in the y direction, for an average horizontal standard deviation of 0.6 m (1.9 ft).

Unlike the GPS positions, the SeaTrac positions unfortunately do not include an indicator of the quality of the position in the NMEA data output, so all reported positions were used during this 30-minute window. The standard deviation of the SeaTrac positions was 1.1 m (3.6 ft) in the x direction and 1.3 m (4.3 ft) in the y direction, for an average horizontal standard deviation of 1.2 m (4.0 ft).

The positions reported by the SeaTrac and GPS were also offset from each other; the difference between the mean positions was 3.7 m (12.3 ft). Note that the actual location of the GPS and the SeaTrac beacons were offset by approximately 0.5 m (1.7 ft), so subtracting this known offset results in an approximate difference between the reported SeaTrac and GPS-based positions of 3.2 m (10.6 ft). Using this accuracy estimate, the performance criteria of 3 m horizontal accuracy would not be met.

The horizontal accuracy estimated by comparing the mean difference in reported positions from the SeaTrac and Z-boat GPS is somewhat lower when calculated from the data collected while the Z-boat was stuck, compared to the estimates from outside of the pier when the Z-boat was moving (see second paragraph of this section, above). However, when the Z-boat was stuck, it is possible that its position estimations were worse than they would have been during a typical survey for possible several reasons. (1) We were concerned about retrieving the Z-boat so were not focused on ensuring that the SeaTrac beacon on the support vessel was oriented in the correct way relative to the Z-boat. If the support vessel beacon and the Z-boat beacon do not have line-of-sight communication, it can cause the system to register the sound of echos that have bounced off of obstructions as a “reply” from the Z-boat beacon. These echos would take different amounts of time to reach the support vessel receivers than a reply straight through the water between the beacons, and the software would therefore calculate incorrect positions based on these echos. (2) The Z-boat was tangled with kelp. The different density and air pockets in kelp may have influenced the sound transmission between the two SeaTrac beacons. (3) The GPS positions for the support vessel could have been degraded. GPS positions are generally worse when sitting still than when moving because the GPS uses your track to select and report the most likely new position based on your past movement. This effect would also apply to the GPS positions reported for the Z-boat in the second above. In general, GPS is also typically worse around structures such as piers than in a more open environment; part of this error may be due to signal multipath from the close proximity of the reflective surfaces of the concrete pier (similar to the multipath impacts to the USBL range and bearing calculations).

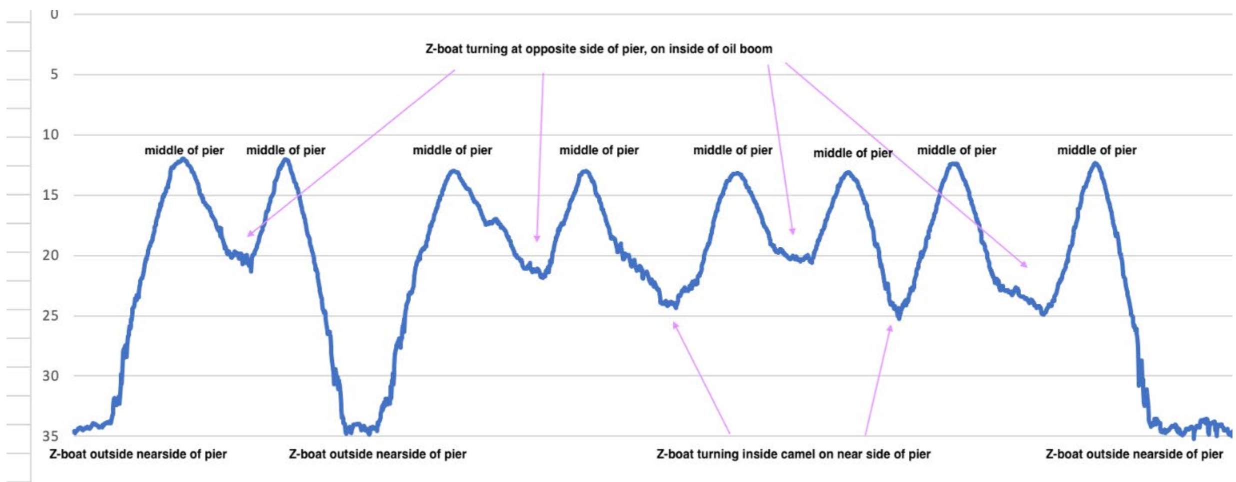


- Imagery from Google Earth.

Figure 19. Map showing the estimated positions of the Z-boat from the SeaTrac system (blue) and the Z-boat GPS (orange) when the Z-boat was stuck at the southeast edge of Pier 4 over a 30 min period.

In order to improve the accuracy of the resulting bathymetric maps, as with the depth data, we applied several filters to the x,y positions reported during the field surveys to eliminate as many poor position estimates as possible (Figure 21). For the Z-boat GPS positions, as before, we only retained reported positions that used DGPS and that had an HDOP <2. We also applied an acceleration filter to both the GPS and SeaTrac positions separately and then again after the two datasets were combined. Although different under-pier obstacles and Z-boat operators resulted in a variety of speeds for the Z-boat, the Z-boat is not capable of changing speeds abruptly. Therefore, if the difference in speed required for the Z-boat to have traveled between subsequent reported positions was greater than 2 m/s (6.56 ft/s), we removed the second point of the pair that caused the high speed-difference. We did this iteratively until there were no more positions which would have required the boat to achieve abnormally high acceleration rates to move between those locations.

In addition, we discovered that the SeaTrac positions were recorded with timestamps sourced from the computer clock instead of using timestamps from the GPS unit on the topside vessel. Because computer clocks drift with time, for nearly all surveys there was a time offset between the timestamps associated with each SeaTrac position and the more accurate GPS clock with timestamps recorded in the Z-boat NMEA. Although the PinPoint software used the input from the hemisphere GPS on the support boat to calculate the position of the Z-boat, the software developers did not choose to save the timestamps from the GPS unit in the SeaTrac log files (an issue we have brought to their attention and will hopefully be resolved in a future software update). As a result, we had to adjust the timestamps in the SeaTrac position file to align the computer times with GPS times to account for clock drift and thus ensure that the correct x,y positions were associated with the correct z depths recorded by the Z-boat. The time offsets in the survey datasets ranged from 0-25 s, and the correct offset was selected by adjusting the times in increments until the resulting x,y,z maps were visually most reasonable. We know that from looking at the raw depth datasets, as well as generally understanding the angle of repose of unconsolidated sediments, the sediment under the piers tend to form a smooth "hill" that is shallowest near the middle of the pier (the top of the hill) and deepest on the sides. When plotting depth vs. time from the Z-boat echosounder, we did not observe significant evidence of extreme changes in depth or "roughness" on the bottom (Figure 20). Therefore, resulting plots of x,y,z that appeared to show significant variability in depth over short horizontal distances and no clear pattern in bathymetry were suspicious. Figure 21 (top left panel) shows an example of a suspicious plot of x,y,z, before the SeaTrac timestamps were adjusted, compared to the much-improved result (top right panel) when the timestamps were shifted by 7 seconds.

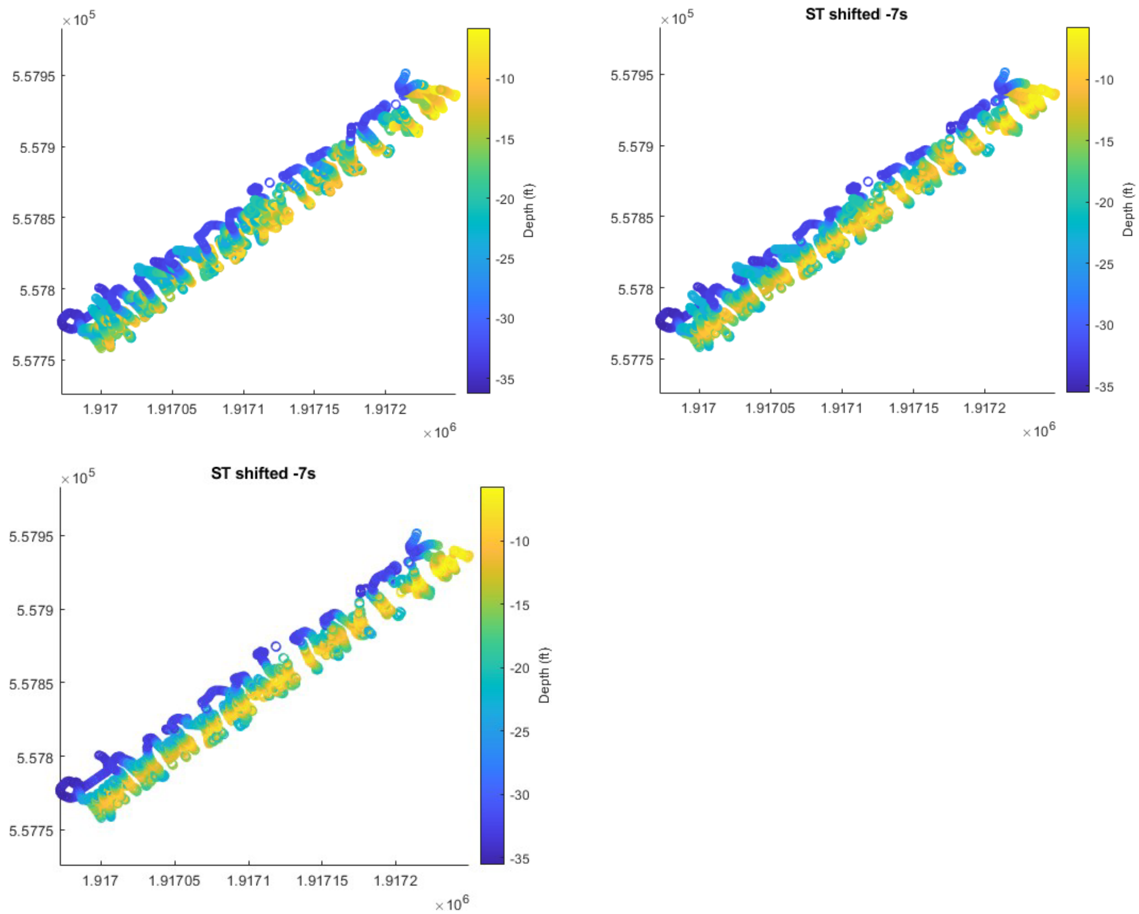


- X-axis is time, annotated to indicate where the Z-boat was driving/collecting data.
- Y-axis values are depth below the surface at the time of the survey, not yet corrected for tides or adjusted to MLLW.

Figure 20. Example section of unprocessed/corrected depth data from Z-boat.

We also assumed that given the higher overall accuracy of GPS positions compared to SeaTrac positions, when good GPS positions were available, these should be used to provide the x,y locations to match to the z measurements. Therefore, we only used SeaTrac positions if there were no good GPS positions reported within a three second window.

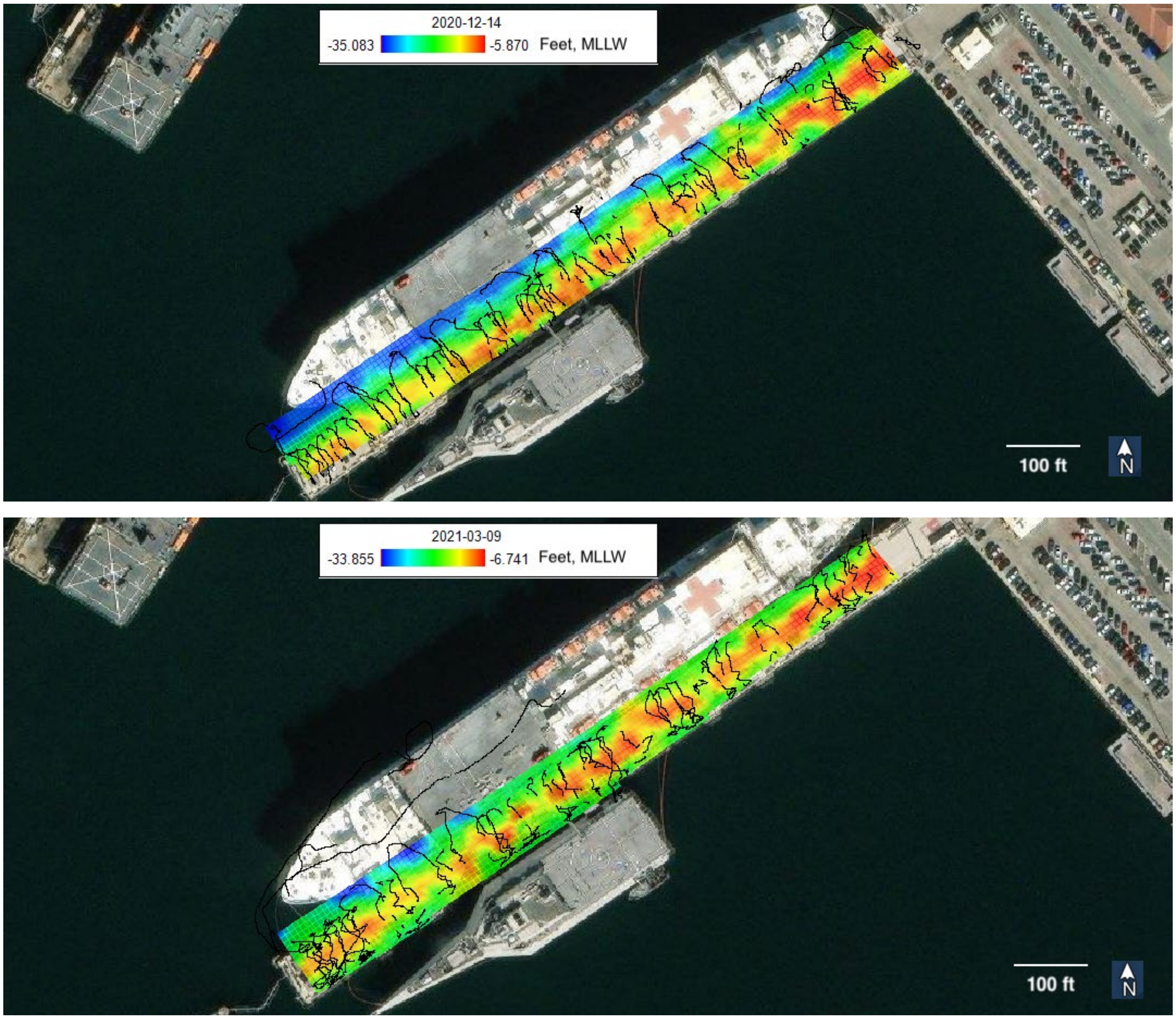
Finally, because the depth measurements were reported at a higher rate (9-10 per second) compared to the positions (at most, 1 per second and frequently less often), we used linear interpolation to estimate the position for each reported depth between subsequent x,y positions, but we also removed depth values that did not have a reported position within a 3 second cutoff, to avoid over-interpolating the positions. Generally, the Z-boat was driven in a relatively straight lines between two rows of pier pilings, then turned and came back in a relatively straight line between the pilings, before moving along the side of the pier and repeating this pattern between the next set of pilings. Typically, it took about 1 minute for the Z-boat to transit from one side of the pier to the other side, then a few seconds to turn, and another minute to transit back to the other side of the pier. Therefore, for most of the time the boat was completing a given survey, it was tracking in a relatively straight line, and thus linearly interpolating positions to match to the depth measurements was determined acceptable. For full details about the processing of the bathymetry data, please see the bathymetry SOP in Appendix B.



- The top left map shows the positions before the SeaTrac clock drift was applied.
- The top right map shows the positions after the SeaTrac clock drift of 7 seconds was applied.
- The bottom map shows the result after the filter for high-quality GPS positions was added.
- The x and y axes are in units of feet on CA State Plane 6 and the depth is feet relative to MLLW.

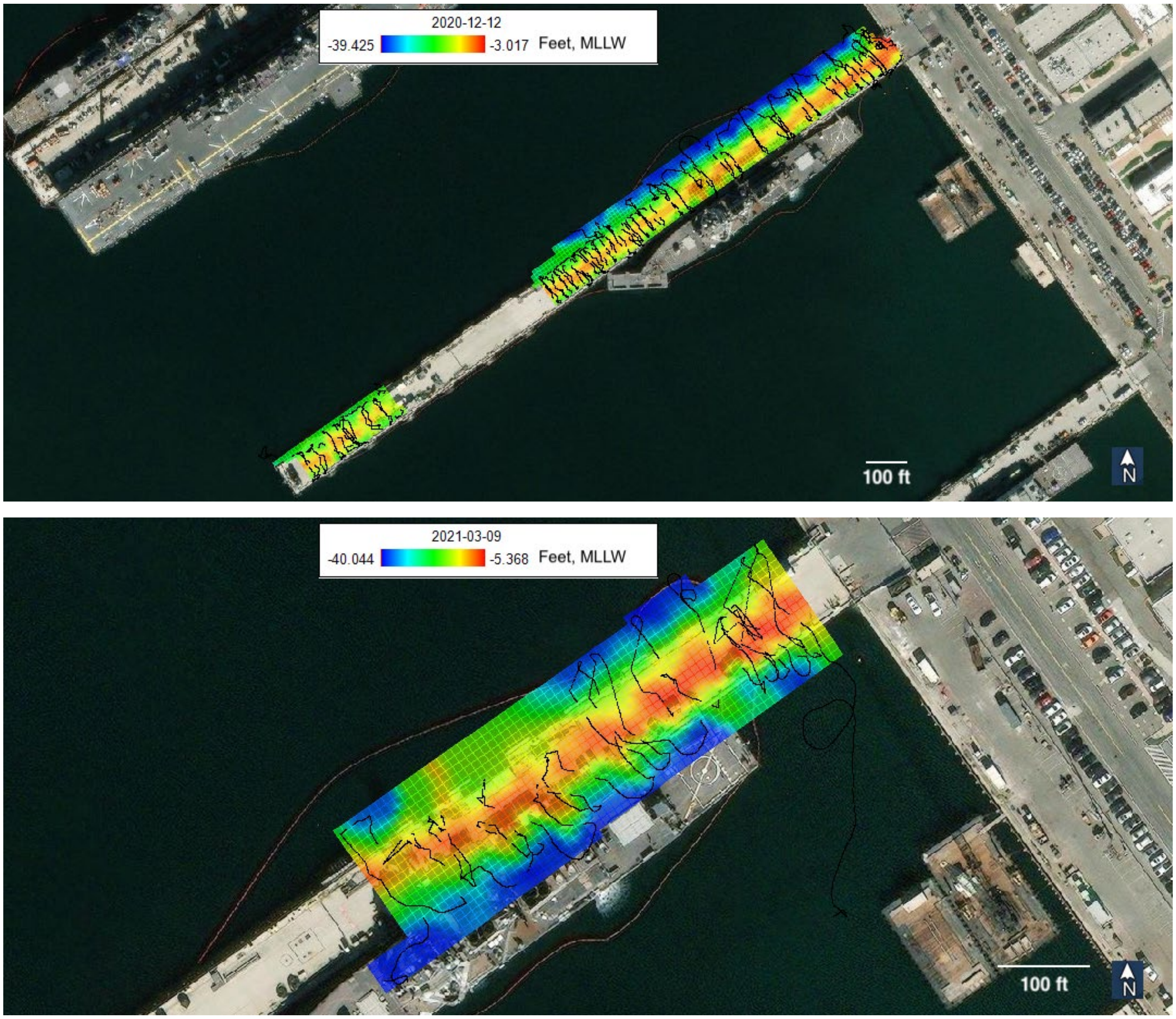
Figure 21. Examples from Pier 1 showing how the different corrections improved our position and depth measurements.

After the above-described data processing steps, a final x,y,z file was produced associated with each individual survey. To create a seamless bathymetric map that spanned the area surveyed, the x,y,z files were used to calculate the average depth for all data points that fell within a grid customized to cover the main portion of the survey track. To populate all grid cells that did not intersect the survey track, values were interpolated using inverse distance weighting and 3rd order smoothing, drawing from the 5 nearest neighbors. Please see the Bathymetry SOP (Appendix B) for more details explaining the detailed processing steps followed to create these maps. Figure 22 through Figure 26 show the complete seamless bathymetric maps from each pier for each completed survey. Note that in each map, the colorbar spans a different range of depths, and therefore individual colors are not directly comparable between maps.



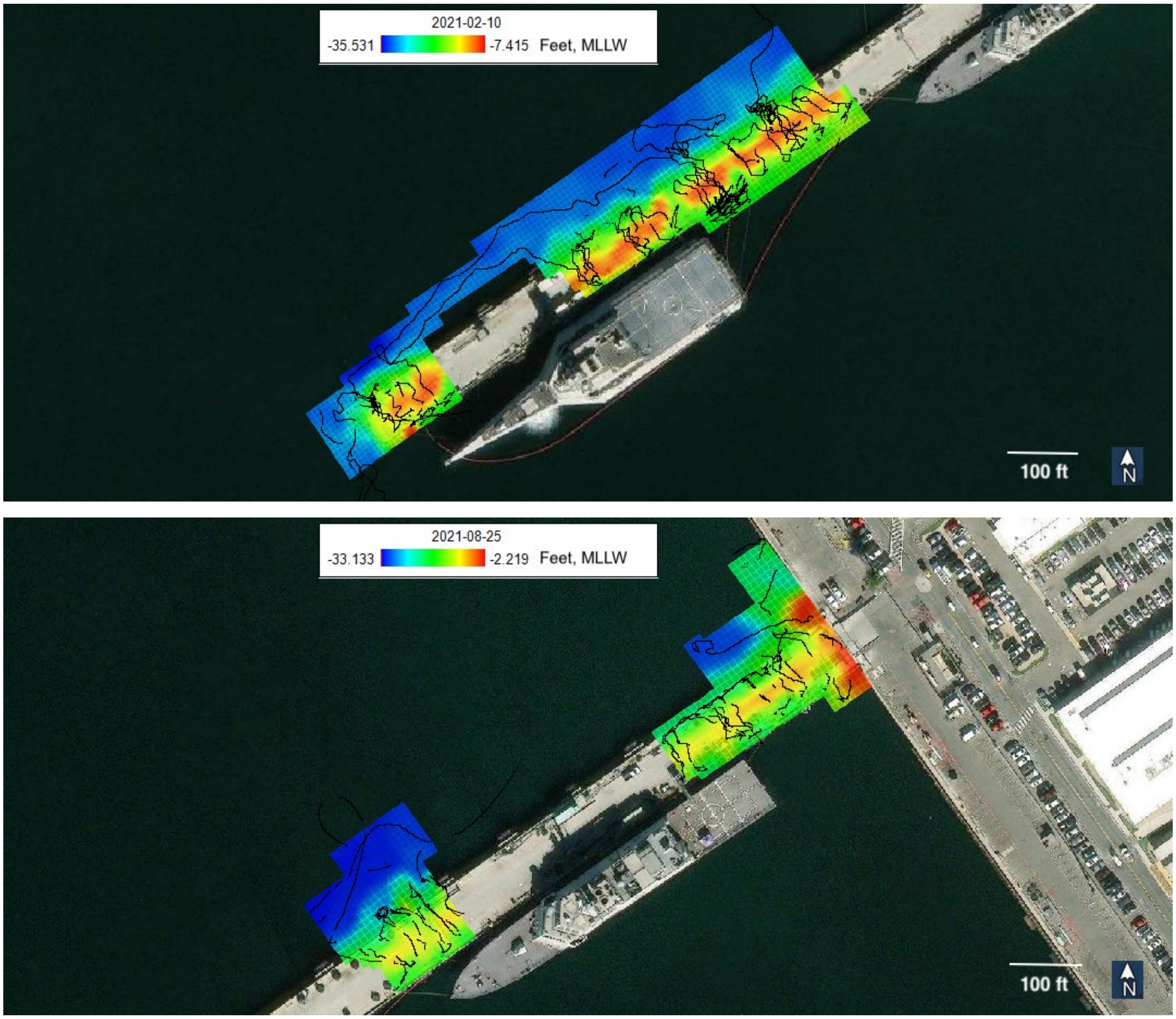
- Imagery from Google Earth.

Figure 22. Seamless bathymetric maps produced from Pier 1 surveys, overlaid on an aerial image of the pier. Black tracks show survey paths and locations of original x,y,z data interpolated to create seamless map.



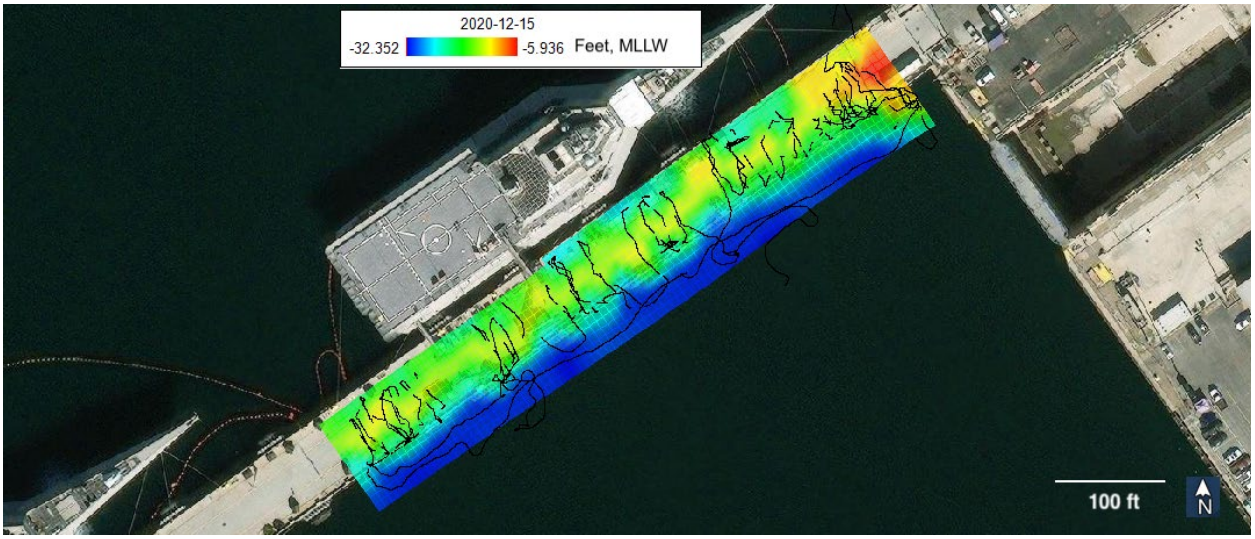
- Imagery from Google Earth.

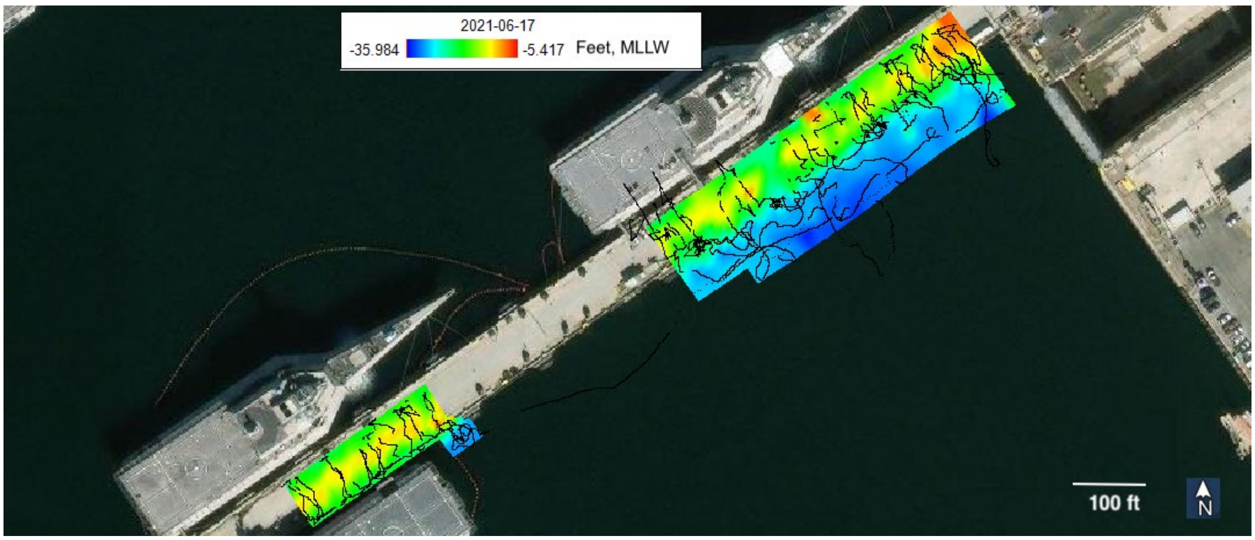
Figure 23. Seamless bathymetric maps from Pier 3 surveys, overlaid on an aerial image of the pier. Black tracks show survey paths and locations of original x,y,z data interpolated to create seamless map.



- Imagery from Google Earth.

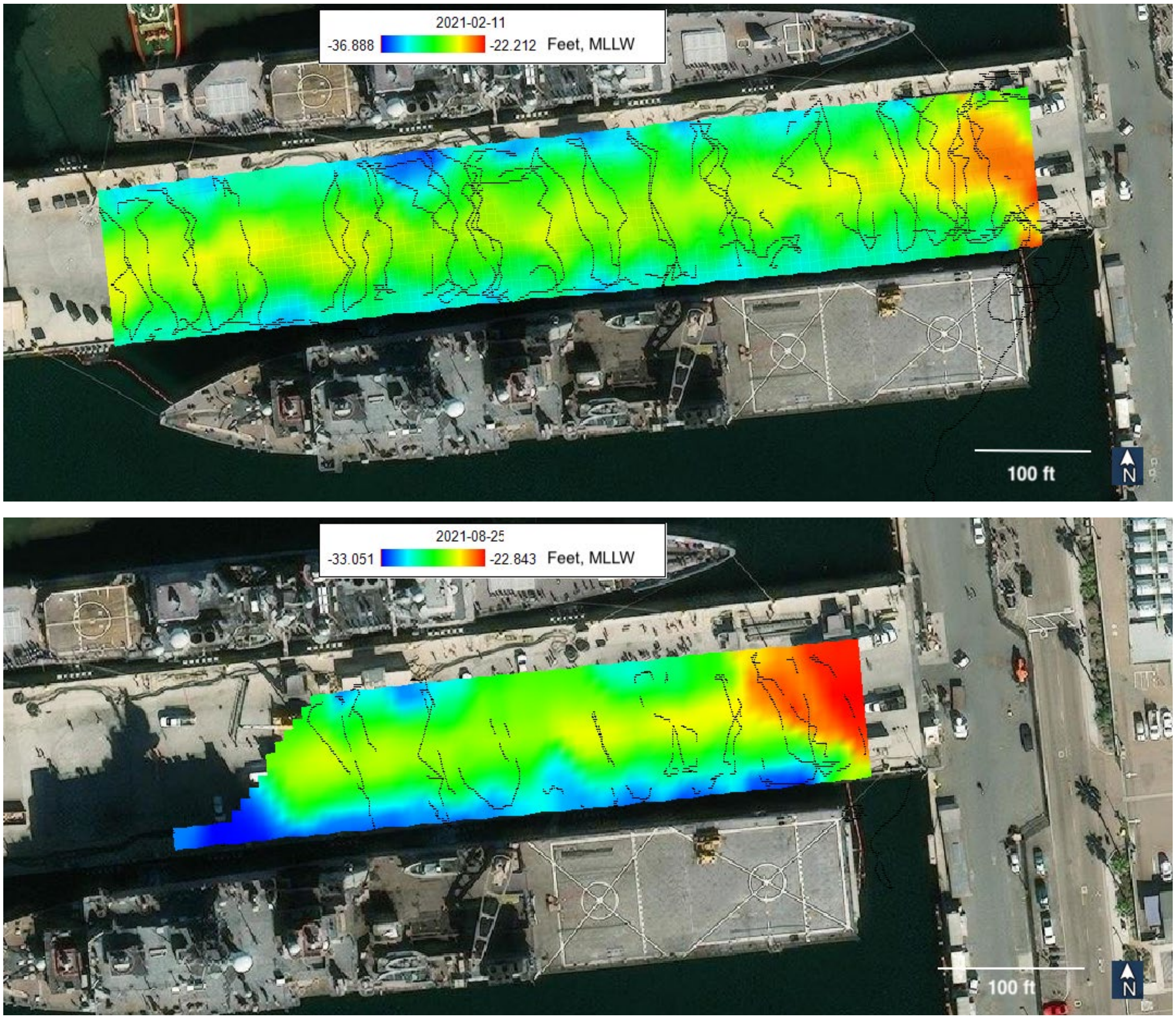
Figure 24. Seamless bathymetric maps from Pier 4 surveys, overlaid on an aerial image of the pier. Black tracks show survey paths and locations of original x,y,z data interpolated to create seamless map.





- Imagery from Google Earth.

Figure 25. Seamless bathymetric maps from Pier 5 surveys, overlaid on an aerial image of the pier. Black tracks show survey paths and locations of original x,y,z data interpolated to create seamless map.



- Black tracks show survey paths and locations of original x,y,z data interpolated to create seamless map.
- Note that for the second Pier 10 survey, the tide was relatively high and the under-pier clearance and visibility was constrained; therefore the Z-boat was not driven as far across under the pier as in the first survey.
- Imagery from Google Earth.

Figure 26. Seamless bathymetric maps from Pier 10 surveys, overlaid on an aerial image of the pier.

The seamless maps created (e.g. Figure 23) did not always appear to match with expectations based upon our understanding of how the sediment piles are shaped under the piers (i.e. from inspecting raw data [Figure 20], contractor soundings, knowledge of how unconsolidated sediments physically behave, etc.). Therefore, an alternative approach to interpolation to create seamless maps spanning the study area was explored. For this approach, each survey area was broken up into single columns in the along-pier direction, and depths were interpolated as with the entire map, thus forcing interpolation to occur along the pier-length axis instead of the across-pier axis. Please see the Bathymetry SOP in Appendix B for more details.

An example of a map produced from this approach is included in Figure 27, and is compared to the map produced using interpolation across the entire model grid instead of using individual along-pier strips. Note that the x,y,z file to produce these test maps was not yet fully processed to correct artifacts.

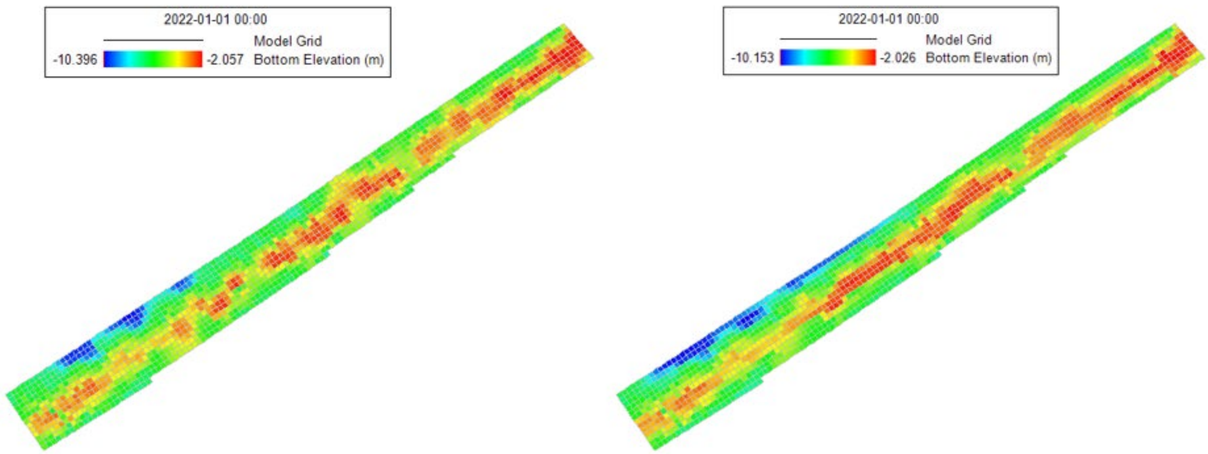


Figure 27. Example seamless bathymetric test maps produced by (left) interpolation across the entire model grid and (right) interpolation only along 1-cell-wide strips of the model grid running lengthwise along the pier.

This along-pier strip-based method seemed to produce somewhat more realistic seamless bathymetric maps, with less along-pier variability; however, the approach was significantly more time-consuming for data processing and was therefore not used for the remainder of the analysis steps.

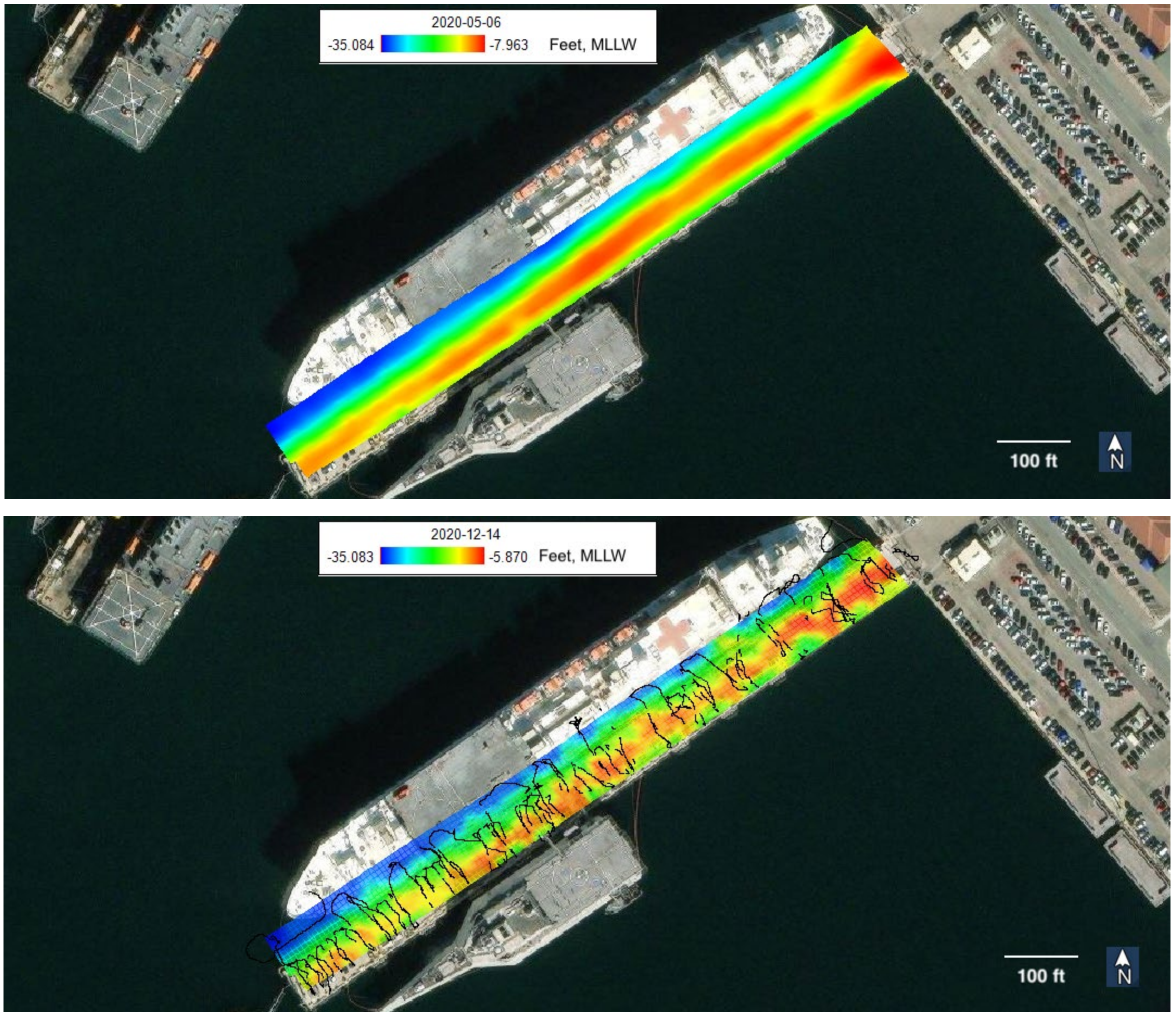
A final semi-quantitative assessment of the mapping accuracy from this demonstration was completed by comparing the results for final seamless maps to expectations. For example, Figure 23 shows two surveys for Pier 3. In the lower map (from the second survey), there are portions of the map that suggest relatively shallow depths outside of the pier on both the north and south sides, where there are no data points collected from outside the pier, because the interpolation algorithm extrapolates the nearest depths, collected underneath the pier, out to fill in the rest of the rectangular survey grid. This causes some portions of the seamless map outside the pier to appear green (~ –22 feet MLLW), and even yellow and orange (~ –12 feet MLLW) in some locations. Realistically, given the depths actually measured by the Z-boat for areas outside the pier during the survey, these seemingly shallow areas are probably similarly deep (i.e. in the range of –40 feet MLLW, and should map as blue). By comparing these too-shallow areas to adjacent map areas with better data coverage, we can estimate there is a strip of grid cells about 3-cells wide that "should" be blue outside the pier, but are not. These grid cells are about 7 feet wide on a side, suggesting a horizontal error of about 21 feet (6.4 m). Similarly, if we expect these grid cells to plot at about –40 feet MLLW, but they are actually plotting at an average of about –20 feet MLLW, this is a vertical error of about 20 feet (6.1 m).

However, these estimates most likely represent worst cases than is likely across most of the bathymetry maps, especially in areas with dense data coverage. For example, the first surveys for pier 3 and pier 10, shown in Figures 23 and 26, respectively, show relatively even survey coverage spanning significant portions of the piers, and similarly even bathymetric map results. In those cases, the accuracy appears closer to the order of ~ 1 grid cell in the x,y direction (~8 feet, 2.4 m) and ~ 6 feet in the z direction (1.8 m).

Therefore, depending on the approach used to evaluate this performance metric, the bathymetric accuracy criterion of better than 3 m error could either be considered to have been achieved, or not achieved. Generally, areas of the maps with more survey tracks are more accurate than sections with sparse coverage. Additional data manipulation, such as constraining the spatial interpolation methods to place greater weights on depths from adjacent cells in the along-pier direction could improve the accuracy of resulting maps in future work.

Considering the accuracy of depths described in section 6.1 and horizontal positions described in section 6.2, we could also estimate the likely approximate accuracy of the resulting bathymetric maps by considering propagation of errors resulting from inaccuracies in the basic x,y,z measurements. However, detailed analysis of this factor is beyond the scope of this work; see Fan et al. [2014] for a detailed analysis of the mathematical analysis required to quantify propagation of errors in DEMs.

For a qualitative comparison of the bathymetric maps created with the methods presented here, the Pier 1 survey 1 grid was populated with depths an x,y,z file provided to NAVFAC Southwest by dredging contractors, based on a pre-dredge side-scan sonar survey. This map is presented in Figure 28, and is generally quite similar to the seamless bathymetric maps produced for this project, also reproduced in Figure 28 for comparison.



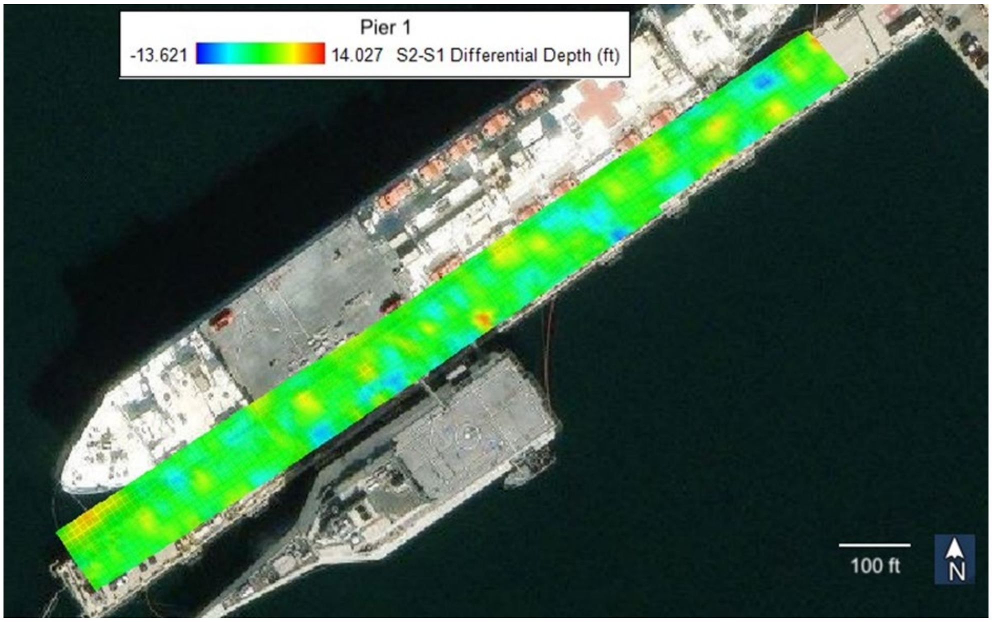
- Imagery from Google Earth.

Figure 28: Seamless bathymetry map (top) using Pier1 survey 1 grid and same methods as above, populated with x,y,z data from side-scan sonar survey from dredge contractor and (bottom) this project.

6.3 EROSION OF UNDER-PIER SEDIMENTS

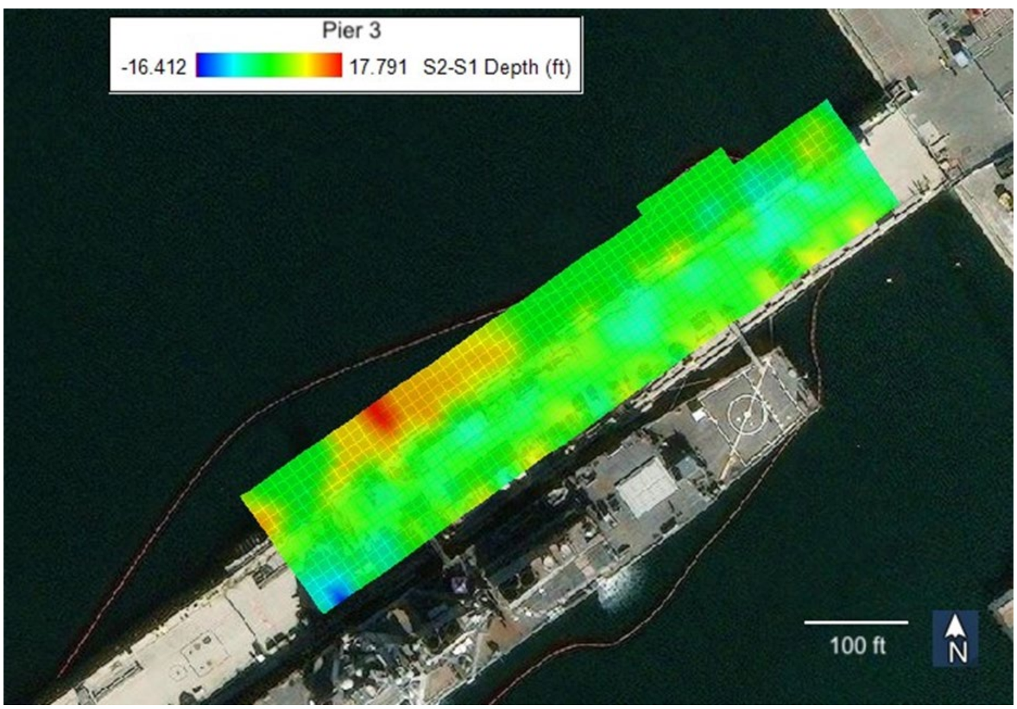
To assess erosion of under-pier sediments, with the goal of determining whether slumping from under piers to the dredge footprints was occurring, the seamless maps from each survey of a given pier were trimmed to only include portions of the map that overlapped in both surveys. The depths for each grid cell from the first survey were then subtracted from those of the second survey to create a grid of differenced depths, where negative values indicate apparent erosion (deeper depths during the second survey) and positive values indicate apparent accretion. This analysis was completed for Pier 1, 3, 5, and 10 and are shown with blue indicating erosion and red indicating accretion in Figure 29 through Figure 32; there were no overlapping areas between the Pier 4 surveys.

The performance criterion associated with erosion of under-pier sediments was to be able to successfully detect erosional footprints on the order of 50 m^3 (65.4 cubic yards, or 1,766 ft^3). Given that the bathymetric map grid cells averaged approximately 4.2 m^2 or about 2 m on a side (45 ft^2 or about 7 ft on a side), in practice this would represent about 10 adjacent cells with a 1 m depth change, or 5 cells with a 2 m change, etc.



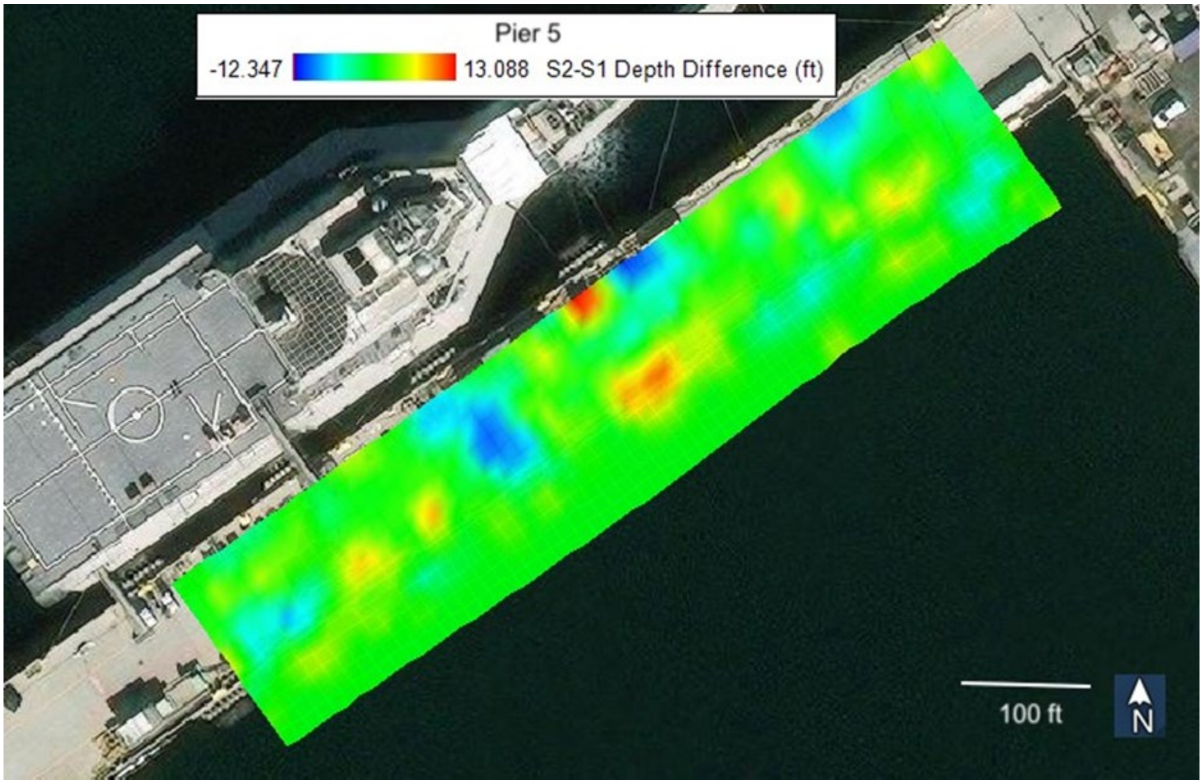
- Imagery from Google Earth.

Figure 29. Apparent difference in depth between first and second survey, Pier 1.



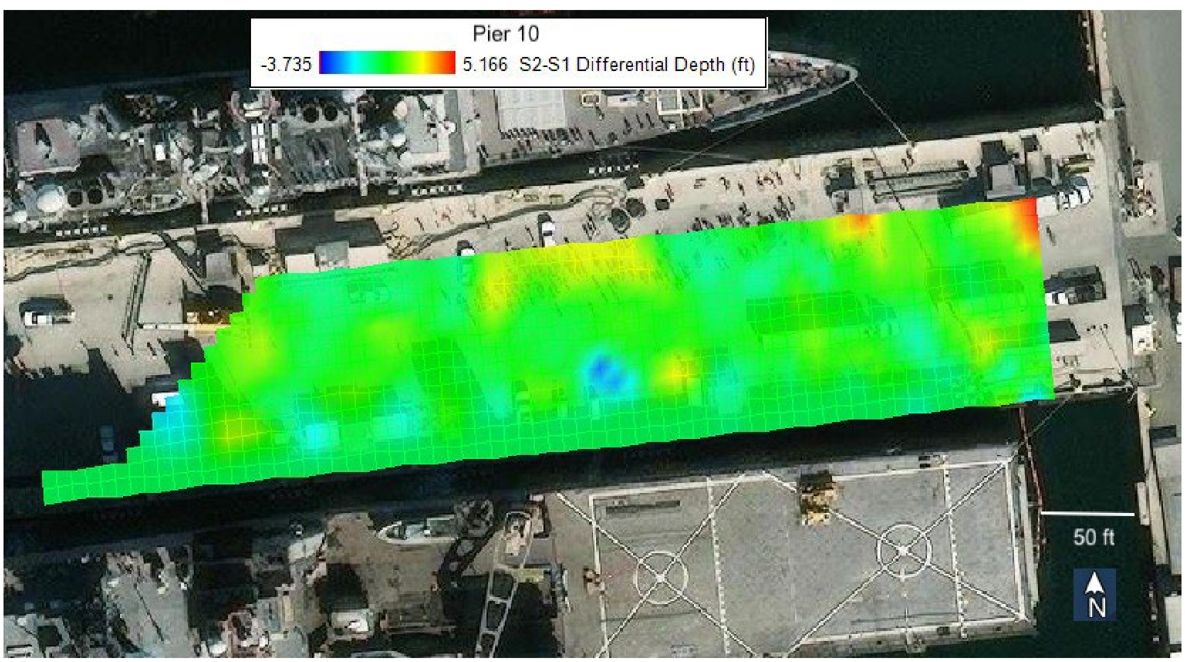
- Imagery from Google Earth.

Figure 30. Apparent difference in depth between first and second survey, Pier 3.



- Imagery from Google Earth.

Figure 31. Apparent difference in depth between first and second survey, Pier 5.



- Imagery from Google Earth.

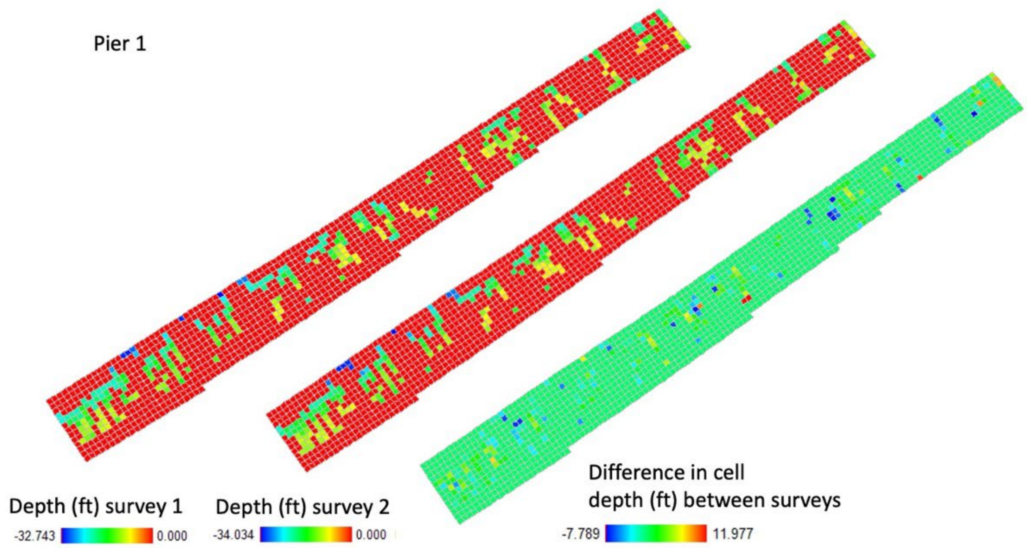
Figure 32. Apparent difference in depth between first and second survey, Pier 10.

Taken at face value, there are apparent change footprints that meet and exceed this magnitude. For example, the Pier 3 change grid (Figure 30) appears to show an area of about 50 adjacent cells that accreted between surveys, with an average depth change of 5.4 m (17.8 ft), and a total apparent increase of about 65,500 m^3 (2,313,000 ft^3 or 85,667 cubic yards) of material. However, inspecting the bathymetry maps with the overlaid Z-boat tracks for Pier 3 (Figure 23) shows that this area contained no datapoints for the second survey and was entirely filled in via interpolation from data points under the pier, where sediment has accumulated with time, and the depths are much shallower. Indeed, this apparent volumetric change exceeds the volume of all of the sediment estimated above the dredge design depth under Pier 3 (see section 6.4), so cannot represent actual change.

To avoid this type of artifact, we inspected the bathymetric maps to identify regions where there was reasonable coverage of survey tracks for both surveys, and estimated apparent erosion/accretion for several of these sections of the maps. In general, this approach showed very little change between surveys; for example near the head of Pier 3, there was an average apparent change of about +0.06 m (+0.2 feet) across an area of 36 grid cells, representing accretion of about 10 m^3 (360 ft^3).

However, given the relatively sparse coverage afforded by single-beam sonar (e.g. typically 5% according to EM 1110-2-1003; in this work, ~20% of grid cells intersected Z-boat tracks), erosion or accretion on the order of 50 m^3 would be rather difficult to accurately capture with this methodology. A 50 m^3 change only represents about 0.1% of the total volume of sediments under a given pier (see section 6.4). Given the sparseness of the data and magnitude of errors in x,y,z positions described above, relatively small volumetric changes of this magnitude are unlikely to be adequately captured with this methodology. Therefore, this performance metric was not achieved.

An additional differencing test was completed for the dataset from Pier 1, in which only the grid cells that had assigned depths (i.e. grid cells that intersected the Z-boat survey track and were assigned a depth based on the average depths (average z) for all positions (x,y) that fell within a given cell boundaries), and that were overlapping in both surveys, were differenced (Figure 33). Within this dataset (283 cells, out of a total 1412 cells covering the entire gridded survey area, ~20% of the total cells), the average depth change was 0.05 m (0.16 ft), the median was 0.01 m (0.02 ft), and the maximum depth change indicating erosion and accretion, respectively, was –2.4 m (–7.8 ft) and +3.7 m (+12 ft). The highest number of adjacent cells that all showed evidence of either erosion or accretion was 4 cells, and suggest a change of approximately 34 ±12.8 m^3. To adequately capture relatively small magnitude changes like this between surveys, different bathymetric survey techniques should be used, such as side-scan sonar collected from a vessel adjacent to the pier.



- Note that the red cells in the left and middle grids indicate cells with no initial data (i.e. survey tracks did not pass through those cells).

Figure 33. Gridded region covered by both (left) survey 1 and (middle) survey 2 at Pier 1 with (right) depth differences between surveys.

Although the bathymetric survey approach presented here was not considered effective for capturing small-scale changes such as slump footprints in sediments under piers, the general shape of the under-pier sediments were considered reasonably accurate. Therefore, the overall stability of the sediments under the piers was assessed by comparing the apparent changes in total volume of material under piers for overlapping portions of the piers for subsequent surveys (see details for volumetric assessment described in section 6.4.1). Note that the Pier 3 analysis is considered flawed, as described above, and there were no overlapping portions of the two Pier 4 surveys.

Table 3. Summary of apparent volumetric change for re-surveyed portions of NBSD piers.

Pier	Apparent volume change between surveys (cubic yards)
1	-216 (0.7% of total volume)
3	*+3,061 (12.7% of total volume)*
5	+534 (1.8% of total volume)
10	+792 (2.2% of total volume)

6.4 RECONTAMINATION SOURCE MAGNITUDE

To quantify the approximate size of recontamination potential represented by the studied under-pier sediments, the volume of sediment material above the dredge design depth of 30 or 37 feet below MLLW (Table 3) was calculated, and this was combined with chemical analysis results from sediment samples collected under the piers.

The volumetric analysis is first described in this section, followed by the chemical analysis, and finally the magnitude of recontamination potential is assessed.

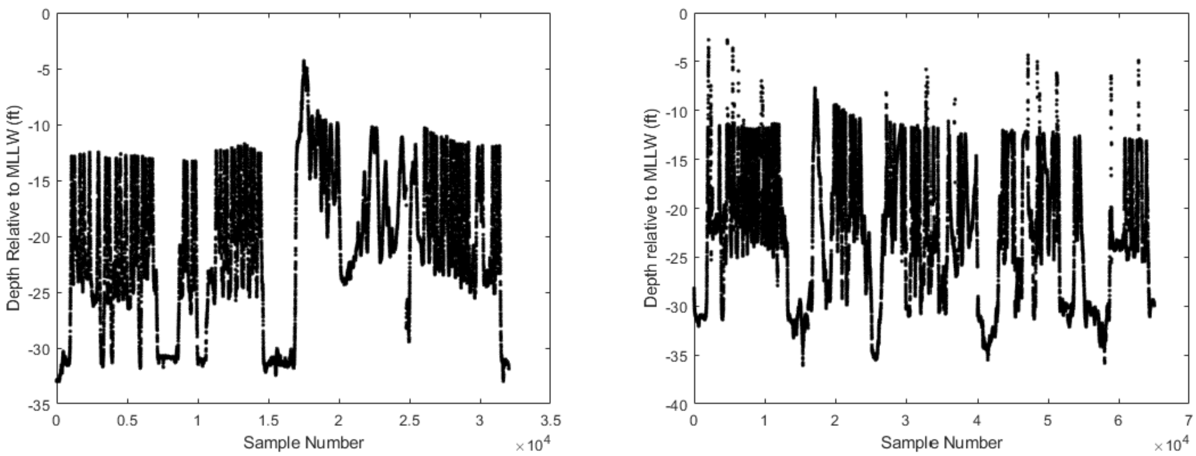
6.4.1 Volume

The volume of sediments that could theoretically slump into adjacent dredged areas from underneath a given pier was calculated by adding the dredge design depth (30 feet or 37 feet, Table 3) to the depth of each grid cell from the final maps in relation to MLLW. For all cells with positive values (i.e. the sediment surface was located above the dredge design depth), this value was multiplied by the size of each grid cell (which ranged between about 35-52 ft^2, depending on the shape of the grid). For all cells in which the sediment surface was located below the dredge design depth, the sediment volume for that grid cell was set to zero. The volume of sediment under a given pier (at the time a given survey was completed, and for the section of the pier that was surveyed) was then calculated by summing all of the volumes above the dredge design depth calculated for each grid cell. For cases where the grid shape and the survey tracks resulted in over-extrapolation and therefore larger volumes of sediment than likely actually exist at a pier (for example, see the northern side of the pier in the second Pier 3 map in Figure 23), the percent of cells with overestimated sediments was estimated and the total volume of sediment was adjusted downwards by this percentage. Finally, the amount of the pier surveyed compared to the entire pier was estimated using polygons drawn in Google Earth, and the amount of sediment that could be expected under the entire pier, had it been surveyed, was estimating by extrapolating the volume for the surveyed portion to the rest of the pier. The results of this analysis are presented in Table 4.

Table 4. Summary of volumetric assessment from under-pier bathymetric maps

Pier	Survey number	Survey date	Area under pier surveyed (of entire under-pier area)	Dredge design depth (ft, MLLW)	Approximate volume of sediment under pier above dredge design depth in surveyed area (cubic yards)	Estimated volume of sediment under entire pier above dredge design depth (cubic yards)
1	1	12/14/2020	96%	30	35,102	36,690
1	2	03/09/2021	81%	30	31,958	38,485
1	Contractor survey	05/06/2020	96% (used Pier 1 survey 1 grid)	30	35,021	36,480
3	1	12/12/2020	84%	37	51,621	61,754
3	2	03/09/2021	47%	37	30,358	64,656
4	1	02/10/2021	42%	30	19,599	46,664
4	2	08/25/2021	32%	30	15,500	48,438
5	1	12/15/2020	33%	30	10,0665	29,672
5	2	06/17/2021	47%	30	16,683	35,730
5	3	08/26/2021	Data unusable – SeaTrac system malfunctioned	30	N/A	N/A
10	1	02/11/2021	61%	37	20,730	33,984
10	2	08/25/2021	32%	37	11,085	34,641

The estimated volumes of sediment under each pair calculated as described above for subsequent surveys generally agreed within ~4% of one another Piers 1, 3, 4, and 10, and the Pier 1 survey 1 volume from this project agreed with that calculated from contractor side-scan sonar based dataset extremely well (~0.6% difference). The differences were larger for Pier 5 (approximately 17%, suggesting a very large amount of accretion which is not realistic), which likely results from an error in the overall volume calculation for the second survey resulting from too-shallow depth artifacts that were not filtered out through our automated data processing steps, and not an actual change (Figure 34). The relatively close agreement in sediment volume between surveys for all piers except Pier 5 indicates that the sediment piles under the piers are not rapidly changing shape over time, and instead are relatively stable. In all cases except Pier 1, the second survey identified slightly larger amounts of sediment under the piers, which is likely to reflect errors in bathymetric maps and volume estimates associated with position uncertainty, relatively sparse data coverage, and interpolation errors.



- Survey 2 had more shallow-scatter than any other survey, which likely contributed to the difference in volume estimation between the two surveys.
- This scatter may have been due to kelp or particulates suspended in the water column that reflected the sonar or due to an instrumentation error.

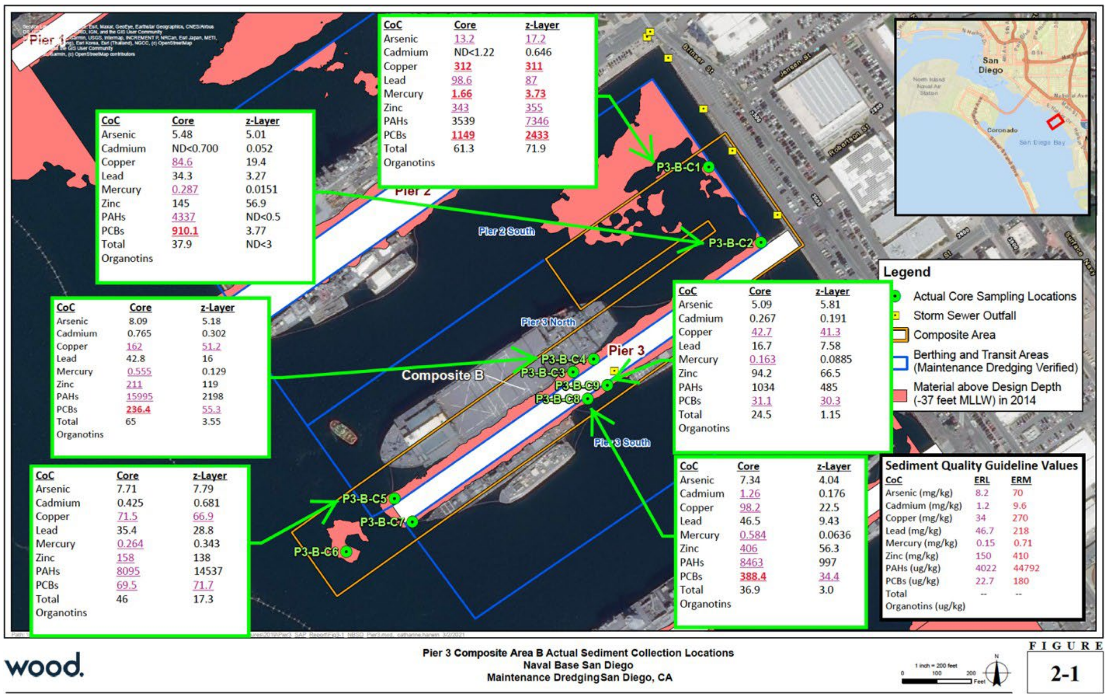
Figure 34. Depth relative to MLLW plotted across the surveys for Pier 5 Survey 1 (left) and Survey 2 (right).

6.4.2 Contaminant concentrations

Sediment samples were collected from underneath piers (Piers 1, 3, 4, 5, and 10) at NBSD to show sediment chemistry that might be present in potentially “slumping” material. Figure 36 shows the locations of the grab and core samples collected for this project. Core samples were sectioned by depth and sent to an external laboratory for analysis. The original hypothesis for this NESDI project was that there might be higher contaminant concentrations in sediments under the piers that could slump down into newly dredged areas along the sides of the piers and thus recontaminate clean dredged areas. The objective of this NESDI project was to determine the potential for recontamination from these undredged sediments under selected piers to the deeper newly dredged areas along the sides of the piers. Since under-pier areas are not normally dredged, these under-pier sediments might represent legacy contaminant levels from earlier time periods when contaminant inputs were higher than at present.

Since normal vibracore-based sampling techniques that can collect longer cores were not possible to conduct under the piers nor from the tops of the piers at NBSD, shorter cores were manually collected (see section 5.3.3 and the Sediment Sampling SOP in Appendix B for more details). For comparison, Figure 35 shows the locations of vibracores taken as part of the recent FY19 maintenance dredging along Pier 3 as an example. Also shown in this figure are the PCB levels (serving as a representative contaminant) averaged over the designed dredge interval as well as levels in the “Z-layer” which represents the material beneath the designed dredge depth that will likely represent the new sediment surface. Comparison of the average dredged material concentrations (removed by dredge project) to the underlying Z-layer (left behind as the new sediment surface) shows that maintenance dredging does a good job of removing contaminated sediments and leaving behind lower sediment concentrations.

Although this result is not the main goal of the periodic maintenance dredging, this side benefit has historically provided significant removal of contaminated sediments from the NBSD pier areas (see Figure 11 for a summary of recent navigational dredging at NBSD).

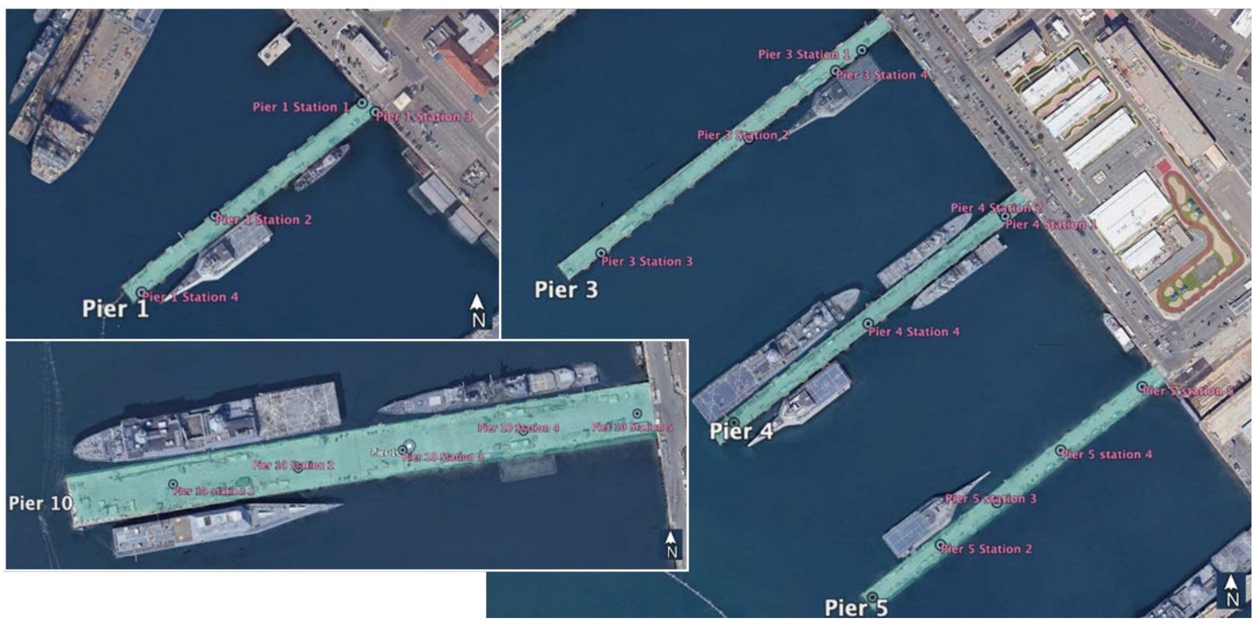


- Purple and red shading of contaminant concentrations indicates concentrations exceeding effects range low (ERL) and effects range median (ERM) concentrations.

Figure 35. Map showing Pier 3 target dredge material (pink shading), locations of vibracore samples (green), and resulting concentrations of various potential contaminants assessed.

Contaminant concentrations were measured for typical metals, PCBs, PAHs, and pesticides, along with additional parameters to aid in the interpretation of sediment geochemistry. Metals included Aluminum (Al), Iron (Fe), Zinc (Zn), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), Selenium (Se), Antimony (Sb), Silver (Ag), and Mercury (Hg). The measured PCBs included the 18 congeners from the NOAA Status and Trends program, with the "total" level calculated as two times the sum of this selected group of 18 congeners (NOAA18). Similarly, for PAHs only the 16 EPA Priority Pollutants (plus an additional two methylated naphthalenes) were measured, and a "total" PAH was calculated as the sum of these 16 priority pollutant polycyclic aromatic hydrocarbons (PPPAH). For pesticides, 21 compounds were measured but the only detections were low levels of dichlorodiphenyltrichloroethane (DDT) or dichlorodiphenyldichloroethylene (DDE) in a few samples. All non-detects were replaced by zero for the summation of totals. Some additional parameters were also measured to aid in interpretation of the results, including the percent total organic carbon (%TOC), and percent solids (%Solids). Most metals and PCBs were measured on all samples, but PAHs, pesticides, %TOC, and Mercury were only measured on a selected subset of samples expected to span the full range of concentrations based on the results from past sampling (i.e. historical sampling around NBSD and elsewhere in San Diego Bay has typically found higher concentrations of contaminants closer to the eastern shoreline, near the quaywall and heads of the piers).

Sediment chemistry parameters often show strong relationships with grain size distributions. More fine-grained sediments have higher surface areas which sorb higher contaminant levels, so even without any additional site sources of contaminants, finer grained samples will show higher contaminant levels. This is also true for other parameters such as %TOC and %Moisture (where %Moisture = 1 - %Solids), which are also elevated in samples with increasing fines content. Therefore, proxy measurements including %Moisture and Aluminum (an element that is relatively elevated in continental rock minerals and often used to indicate relative amounts of land-derived sediments). The %Moisture metric is often used as a proxy for %Fines (which is calculated as the percentage of clay and silt particles compared to all grain sizes in the sample), with their ranges nearly identical since the higher level of fines often retains more moisture when samples are brought into the lab for measurements. Figure 40Pier 10 was replaced relatively recently, and as shown in the bathymetric maps produced from this project, sediments that had accumulated under that pier are now less than at other piers (possibly having been removed by dredging prior to the new pier being installed, or having been redistributed during the pier replacement). Pier 10 samples had generally lower contaminant concentrations than the other piers, and therefore were separated out to act as a “Reference” or “background” concentrations.



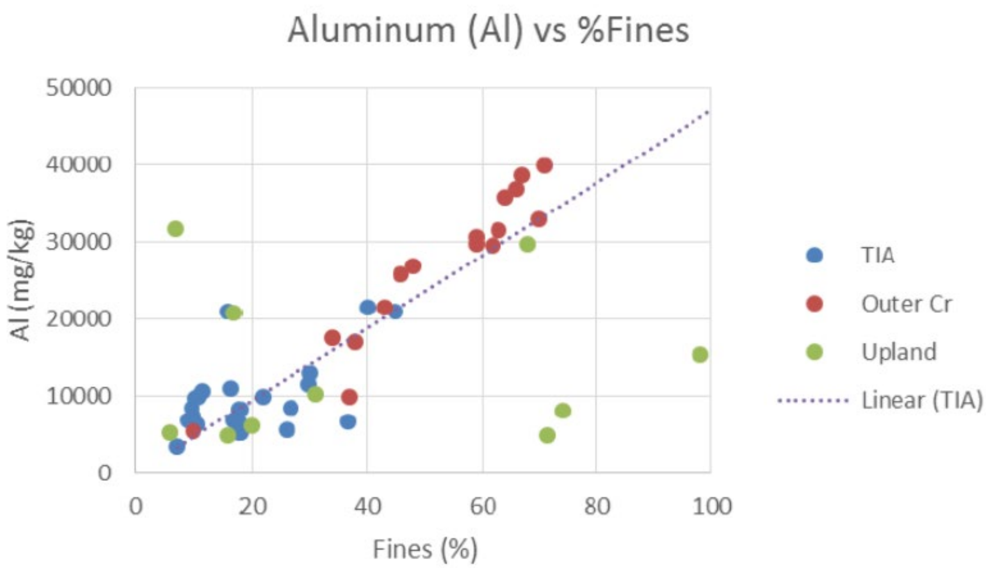
- Imagery from Google Earth.

Figure 36. Maps of sample locations from Piers 1, 3, 4, 5, and 10 (as labeled).

Appendix B (Part 3) shows the samples collected and parameters measured for this project, as described above. Core samples were labeled with pier number, Sample Core number, and Core depth in inches (for example P10-S1-C1-5; which represents Pier 10 Sample Core number 1 from 1 to 5 inches below the sediment surface).

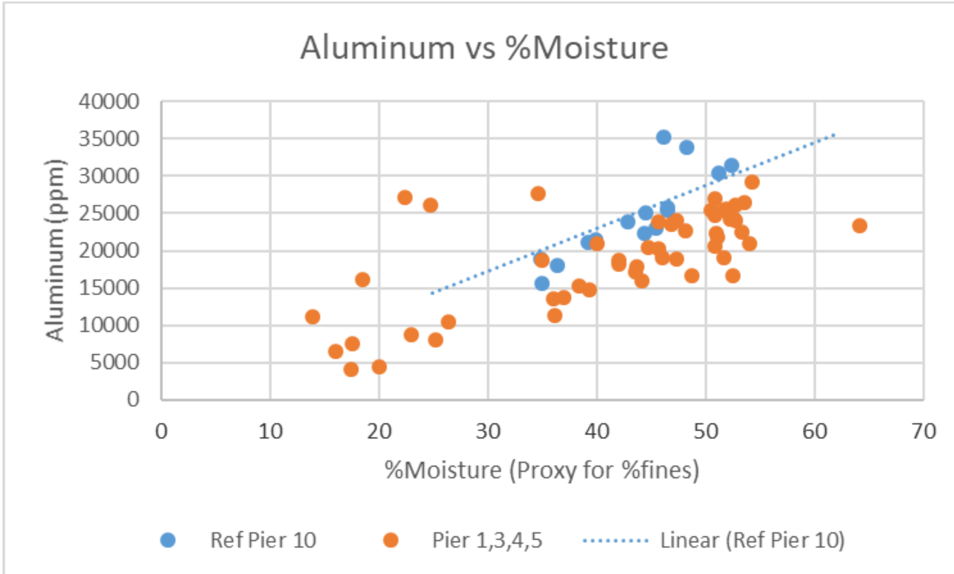
Sediment chemistry parameters often show strong relationships with grain size distributions. More fine-grained sediments have higher surface areas which sorb higher contaminant levels, so even without any additional site sources of contaminants, finer grained samples will show higher contaminant levels. This is also true for other parameters such as %TOC and %Moisture, which are also elevated in samples with increasing fines content.

Although grain size was originally planned to be analyzed in this study, after the other chemistry measurements were completed by the analytical laboratory, insufficient sample volumes remained for analysis. Therefore, proxy measurements including percent moisture (%Moisture = 100 - %Solids) and Aluminum (an element that is relatively elevated in continental rock minerals and often used to indicate relative amounts of land-derived sediments). The %Moisture metric is often used as a proxy for %Fines (sum of clay and silt particles; all particles less than 63 microns in diameter), with their ranges nearly identical since the higher level of fines often retains more moisture when samples are brought into the lab for measurements. Aluminum has also been used as a proxy for grain size in earlier sediment studies around NBSD (Leather et al. 2020) as shown in Figure 37. Figure 38 shows %Moisture has about the same range as %Fines and shows a similar relationship as Figure 37. These relationships suggest that either Aluminum or %Moisture can be used as a proxy for grain size, and both were therefore used to normalize contaminant chemistry for grain size effects for this project.



- Chollas Creek area samples from Tidally Influenced Area (intertidal areas upstream in creek, “TIA”, blue).
- Outer Creek (from shoreline out to end of Pier 1, “Outer Cr”, red).
- Upland areas around the creek thought to act as contaminant sources to creek (green).
- Note most TIA and Outer Cr samples plot along relationship with fine grained samples showing higher Aluminum levels (60% Fines at 30,000 mg/kg [ppm] Aluminum).

Figure 37. Aluminum versus %Fines from Leather, Carilli, and Arias, 2020.



- Pier 10 considered cleaner "Reference" pier for contaminant levels (see discussion).
- Including all the piers would shift linear fit down and approximately match relationship from Figure 37 with %Moisture of 60% showing about 30,000 ppm (mg/kg) Aluminum.

Figure 38. Aluminum versus %Moisture from Under-Pier samples from this study.

Figure 39 shows a plot of Iron versus Aluminum as an example of two sediment parameters with a very strong positive relationship. As grain size becomes finer, more high surface area particles are present that also naturally contain more Iron and Aluminum. An additional site source of Iron is present in three samples that cause the result from those samples to plot above the relationship of the remaining samples. It is these outliers that plot above the trend that indicate there are additional contaminant sources to those particular samples. This plot shows little scatter and few outliers because Aluminum and Iron are very abundant (present in parts per hundred or percent levels) in sediments, compared to much lower (parts per million, ppm levels) of most contaminants; therefore, any very slight additions of Iron from background anthropogenic sources are not observed above the levels in all the other samples. As concentrations in the other parameters drop to ppm and parts per billion (ppb) levels, the scatter in the data becomes greater and picking out these outliers becomes more difficult. Note that 1 ppm is equivalent to 1 mg/kg, and 1 ppb is equivalent to 1 ug/kg.

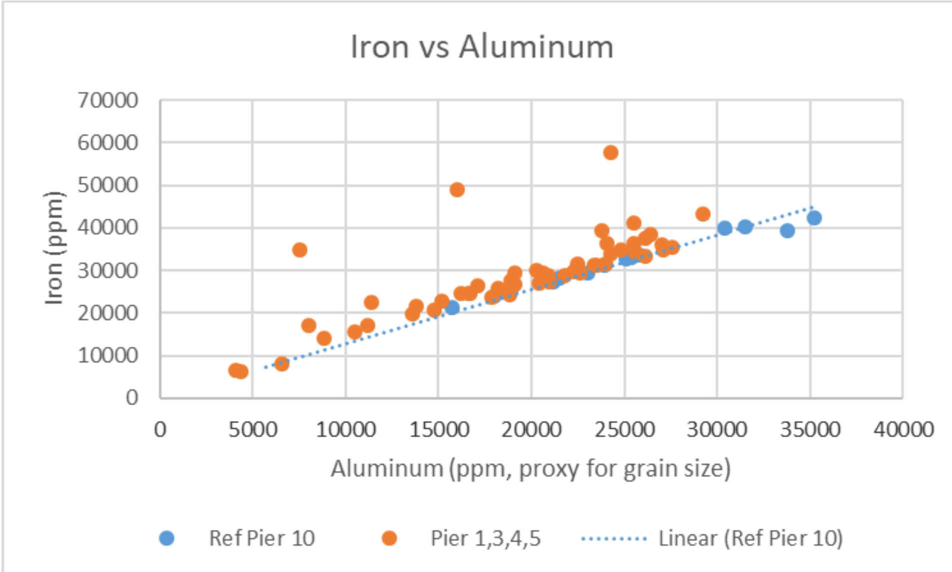
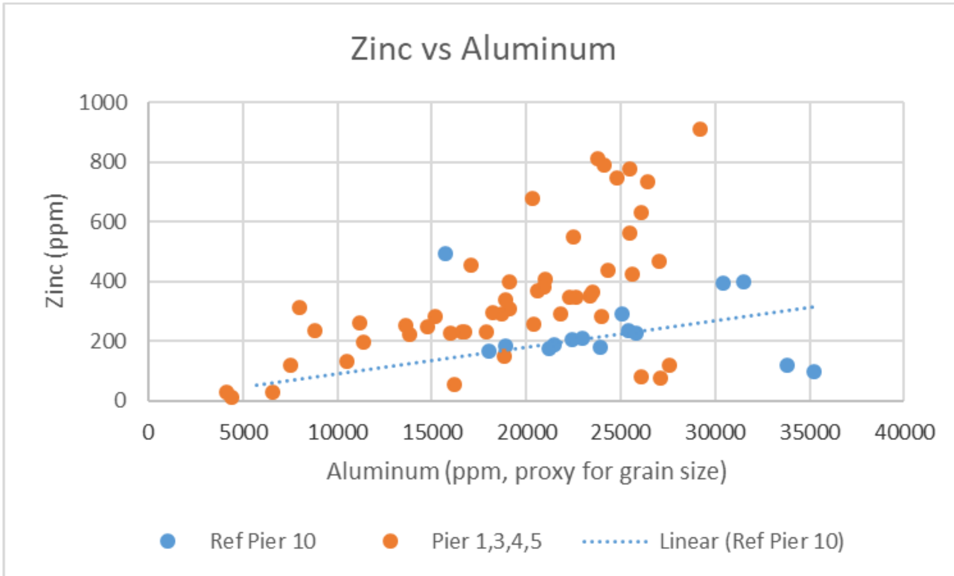


Figure 39. Iron versus Aluminum in Under-Pier samples. Pier 10 to the south is considered as a "reference" pier since it shows lower contaminant levels and is farthest from old sewage outfall at Pier 5.

Figure 40 shows a plot of Zinc versus Aluminum for the NBSD under-pier samples. The included linear trend shows how Zinc concentrations increase with finer grain size in the south NBSD pier area near Pier 10. Samples from Piers 1,3,4, and 5 in the northern NBSD pier area tend to have higher contaminant concentrations and these samples plot above the Pier 10 linear trend. Leather et al. (2020) argued that the former sewage outfall at Pier 5 has resulted in higher contaminant concentrations in the northern NBSD pier areas, but there also could be other legacy contaminant sources in the northern pier areas. Continued resuspension of sediments due to propwash tends to mix deeper sediments back up to the surface so much of the northern pier areas show elevated surface sediment contaminant concentrations, and are unlikely to represent new contamination. Although the Pier 10 sediments are labeled here as a reference site (theoretically not influenced by the local sources of contaminants experienced in the northern NBSD pier area), this local reference level is still elevated (similar to all of the eastern industrial bayfront in San Diego Bay) compared to the true bay wide reference level for sediments located away from the industrial eastern bayfront. For Zinc, the bay wide reference level for fine grain sediments is 192 ppm (CAO R9-2012-0024; SDRWQCB 2012), but the local reference trend intersects the right side of the plot in Figure 40 at about 400 ppm (indicating that the local reference concentration of Zinc is about twice the bay wide reference level). There appears to be one high outlier in the Reference Pier 10 relationship at 493 ppm (P10-S3-C4-8), so there appear to be some additional Zinc sources in the Pier 10 area also contributing to the scatter in the Pier 10 data. There is more scatter in the Zinc data from other piers, with 11 samples with higher concentrations ranging from 500 to 2360 ppm (this highest outlier not shown on plot to preserve scale and readability of plot).



- Zinc shows more scatter due to lower overall concentrations relative to Iron and Aluminum, along with many additional potential local sources of excess (above natural) Zinc in these pier areas.
- High outlier at 2,360 ppm not shown to preserve plot readability.

Figure 40. Zinc versus Aluminum in Under-Pier samples.

Figure 41 shows a plot of Lead versus Aluminum for the pier samples. Again Pier 10 is separated from the results from other piers to show a local reference trend (see plotted linear trend) which also represents trends in many eastern San Diego Bay industrial area sediments. This trend shows local fine-grained sediments have lead levels around 100 ppm (estimated as the concentration at 100% fines level where linear trend intersects the right side of the plot), even when no additional site-specific pier sources are present. This contrasts with the actual bay wide reference value for lead of 53 ppm (CAO R9-2012-0024; SDRWQCB 2012), which was determined from reference sediments located outside of the industrial east side of the bay. Due to resuspension and mixing of multiple legacy contaminant sources, much of the east San Diego Bay industrial areas show sediments with contaminant levels above the bay-wide background levels. Figure 41 indicates there are 4 samples with lead levels from 199 to 279 ppm in the northern pier areas, and even one sample at 337 ppm in the cleaner southern pier areas. These outlier points that plot above the local reference trend line indicate additional sources of lead were present at various times in these locations.

Figure 42 shows a comparison plot from Leather et al. (2020) for Zinc and Lead versus Aluminum for the Chollas Creek area. The linear trend shown for the TIA (upstream in Chollas Creek) was constructed from the mainly sandy samples which plot at the lower Aluminum (lower fines levels) side of the plot. The one TIA outlier sample which suggests there are additional local sources upstream in the creek was not included in the trend. Leather et al. (2020) suggested the linear TIA trend does a good job at predicting the levels in the offshore "Outer Cr" samples (Outer Creek offshore of intertidal creek area out to the end of Pier 1) that contain finer grained sediments and therefore plot on the right side of plot with higher aluminum levels. This suggests the finer sediments offshore do not appear to contain any additional local sources of contaminants from the pier area and all that the contaminant levels could be explained by the sediment contaminant loads entering the area from the upstream creek sources.

The TIA linear trends in Figure 42 are similar to the local background Pier 10 trends shown in earlier plots and support the idea that these levels are in fact local background levels, with samples plotting above these trends indicating additional local contaminant sources from the pier areas.

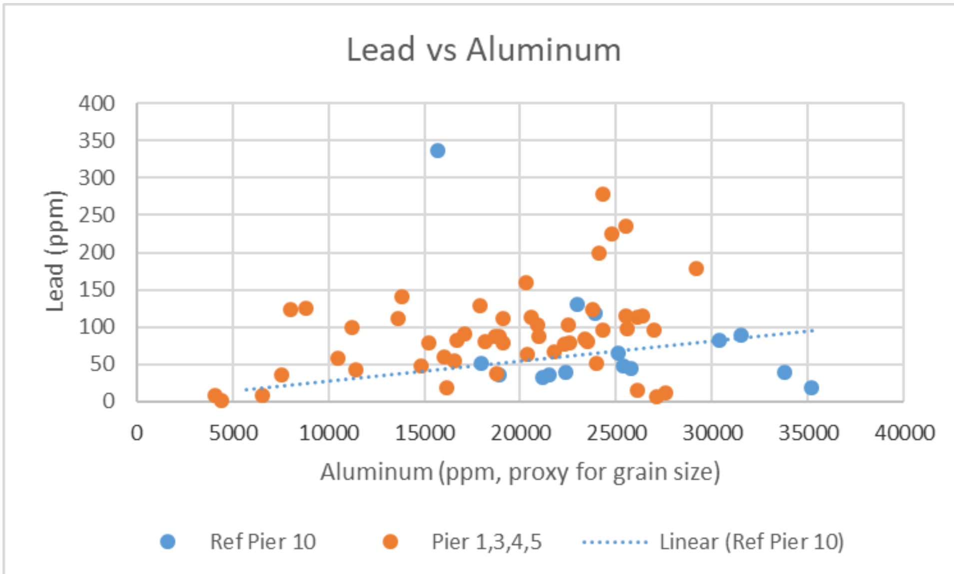


Figure 41. Lead versus Aluminum in Under-Pier samples. Lead shows more scatter due to lower concentrations relative to Zinc, along with many additional potential local sources.

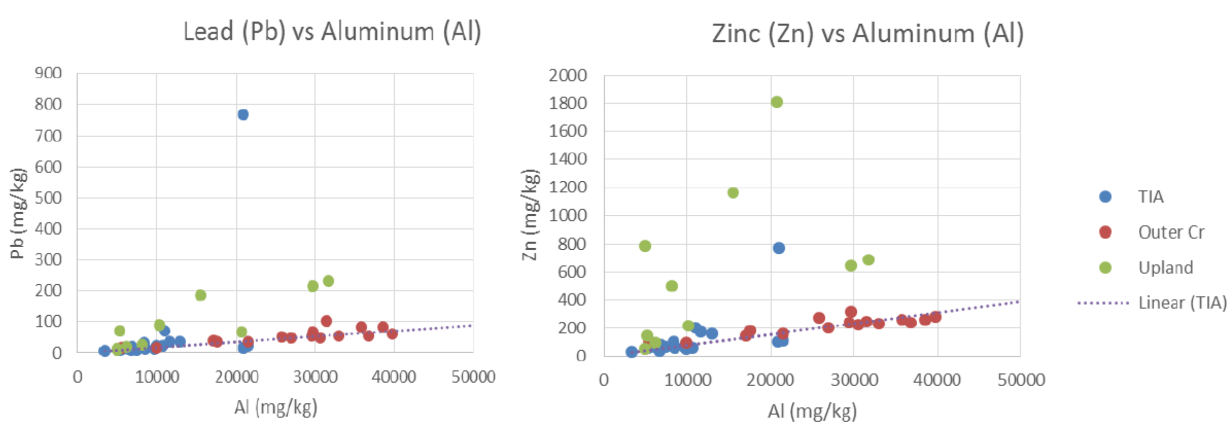


Figure 42. Lead and Zinc versus Aluminum from NBSD areas (not under piers) reported in previous studies (summarized in Leather et al. 2020). Sample labels same as Figure 37.

Figure 43 shows a plot of Copper versus Aluminum for the pier samples in this study. The Pier 10 linear trend shows a fine grain local reference level at about 200 ppm Copper, with most of the northern pier samples plotting above this trend due to ubiquitous copper sources associated with bottom paints. This compares with the actual San Diego Bay reference value for copper of 121 ppm (CAO R9-2012-0024; SDRWQCB 2012) for fine grained sediments located outside of the industrial east side of the bay. The rather subjective selection of outliers plotting above the linear relationship in Figure 43 shows eight samples from 407 to 976 ppm (highest not plotted to preserve plot readability). A more objective criteria for outlier selection could be considered to pick samples that represent a local source of contamination, including placing a 90 or 95% confidence interval around the local reference linear relationship. For the present discussion, outliers were instead selected on a subjective basis, judged when values were about twice the local Pier 10 reference level.

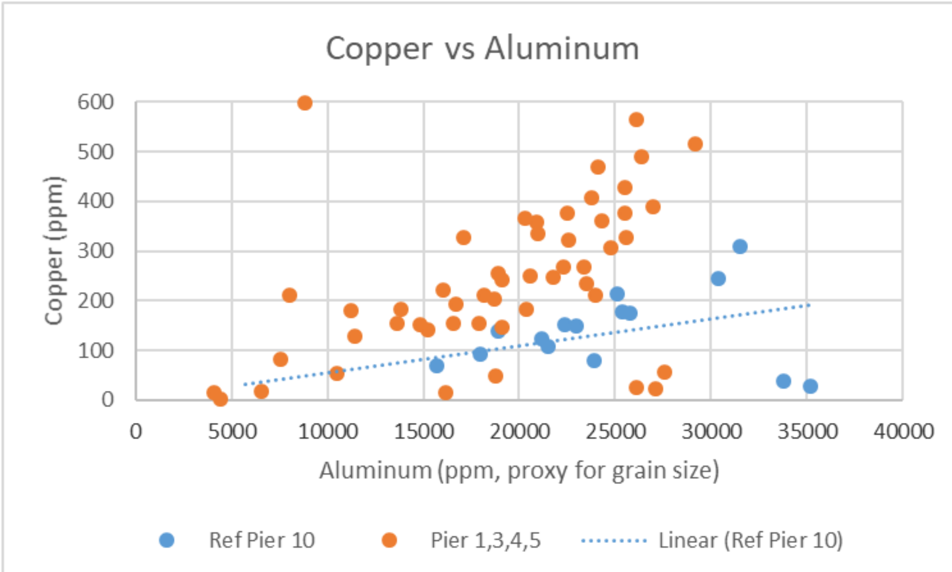


Figure 43. Copper versus Aluminum in Under-Pier samples. Note one outlier at 973 ppm not shown to preserve plot readability.

Figure 44 shows a plot of Mercury versus Aluminum for the Under-Pier samples but note that only a subset of samples were included for mercury analyses in this study. The southern Pier 10 linear trend shows a fine grain local reference level at about 1.5 ppm, but this trend is based on only three samples, so it is highly speculative. Most of the northern pier samples plot above this trend, with two high outlier samples plotting at 2.47 to 3.02 ppm. This contrasts with the actual bay wide reference value for mercury of 0.57 ppm (CAO R9-2012-0024; SDRWQCB 2012), which was determined from sediments located outside of the industrial east side of the bay. Mercury, like Copper, was used in older bottom paint formulations and is a common contaminant found in the NBSD pier areas so mercury is also elevated in the pier areas (Leather et al. 2020).

Figure 45 shows comparison plots from Leather et al (2020) for Copper and Mercury versus Aluminum for the Chollas Creek area. Fine grained sediments from the creek contain Copper and Mercury levels of 100 and 0.25 ppm, respectively (values where trend line crosses right side of plot). Leather et al. (2020) proposed additional contaminant sources from the pier areas were required to bring the contaminant levels in the finer grained samples (the offshore samples closer to Pier 1 that plot to the right in plots) up to the higher levels observed in the plots. Figure 43 and Figure 44 show the Pier 10 local reference levels are about 200 ppm for Copper and 1.5 ppm for Mercury, respectively, so again additional sources for these metals are needed around the NBSD pier areas, since creek sediments alone provide lower concentration sediments.

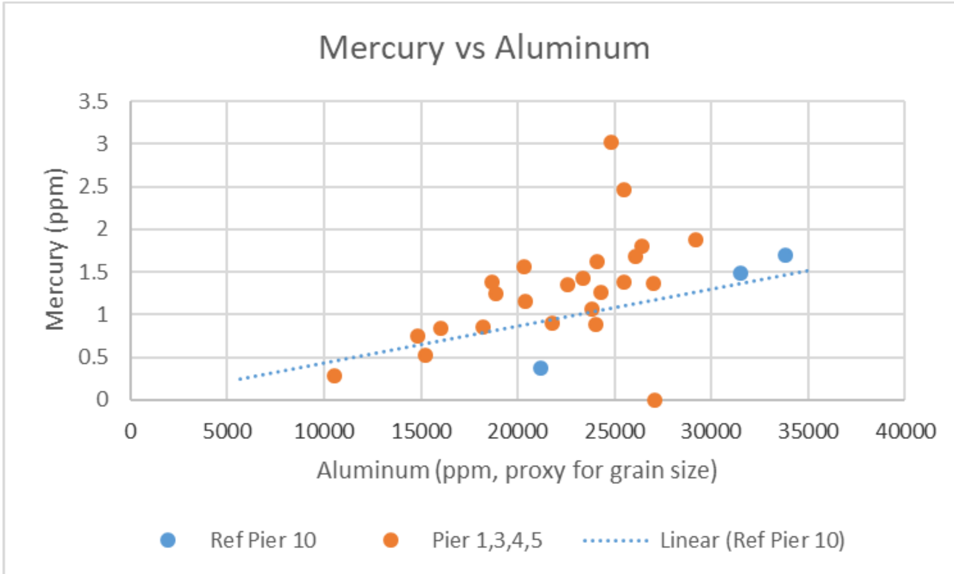


Figure 44. Mercury versus Aluminum in Under-Pier samples. Mercury analyses only conducted on a subset of samples.

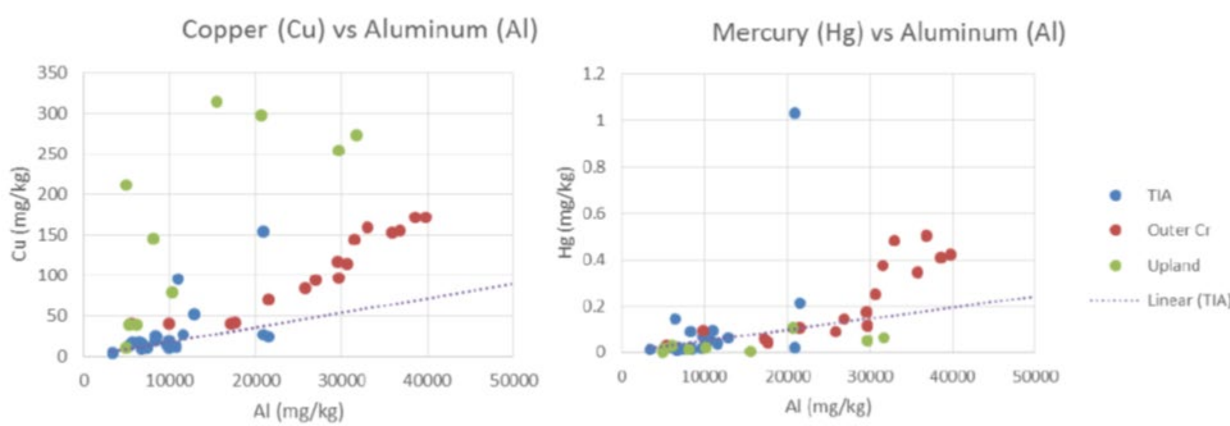


Figure 45. Copper and Mercury versus Aluminum from previous studies at NBSD not under piers (Leather et al. 2020). Sample labels same as Figure 37.

Figure 46 shows a plot for Cadmium versus Aluminum for the NBSD Under-Pier samples. The local reference level found from the Pier 10 linear trend (where it crosses the right side of the plot) is around 1 ppm, but again the scatter around this relationship makes this value questionable. This compares with the actual bay wide reference value for Cadmium of 0.33 ppm (CAO R9-2012-0024; SDRWQCB 2012) for fine grained sediments located outside of the industrial east side of the bay. There are five obvious outliers that plot above the linear trend ranging from 4.03 to 5.65 ppm, and 6 others from 1.6 to 2.09 ppm that might qualify as high outliers; however there are also two "clean" Pier 10 samples at 1.89 and 2.81 ppm that make all these samples questionable high outliers. Along with Zinc, Lead, Copper, and Mercury, Cadmium is a metal that has been found elevated in pier area sediments in past studies (Leather et al. 2020).

Figure 47 shows comparison plots from Leather et al. (2020) for Cadmium versus Aluminum for the Chollas Creek area. Fine grained sediments from the creek contain Cadmium levels of 1 ppm, respectively (values where trend line crosses right side of plot). Leather et al. (2020) proposed that the "Outer Cr" finer grained samples closer to Pier 1 had lower Cadmium concentrations around 0.5 ppm due to dilution with cleaner bay wide reference sediments since their value is closer to 0.33 ppm. The higher outlier samples in Figure 46 show that although the 1 ppm level in the Pier 10 linear trend is about the same as the sediments coming out of Chollas Creek, there are additional sources of cadmium at all pier areas in both the north and south pier areas.

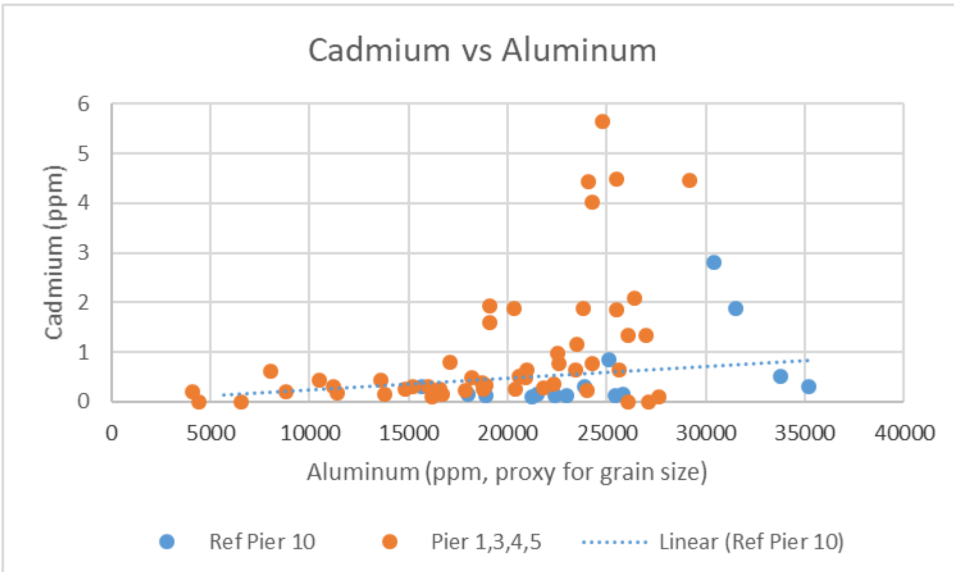


Figure 46. Cadmium versus Aluminum in Under-Pier samples from this study.

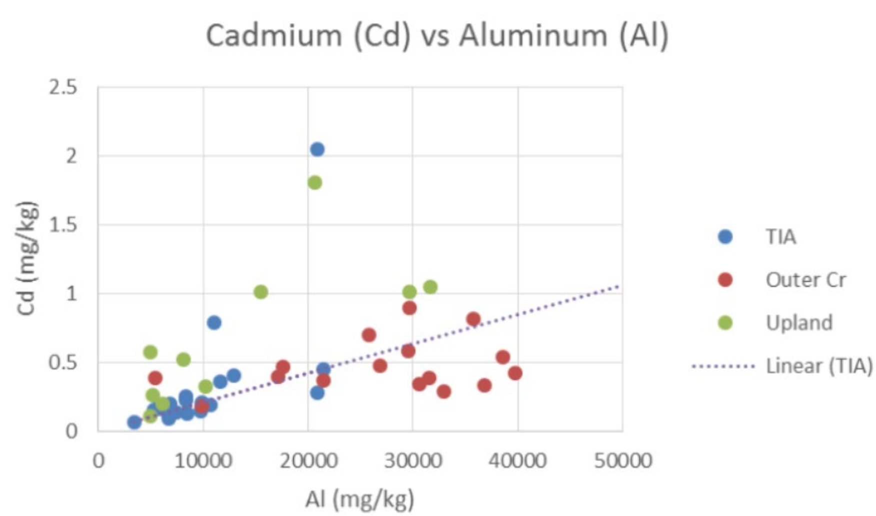


Figure 47. Cadmium versus Aluminum from previous NBSD (not under pier) studies (summarized in Leather et al. 2020). Sample labels same as Figure 37.

For the organic contaminants, PCBs were measured on all the samples, but pesticides and PAHs were only measured on the same subset as Mercury. Since only a few samples showed low levels of DDT or DDE, and other pesticides were not detected or were at low background concentrations, no plots were prepared and there is no further discussion of pesticide results. Total PCBs and PAHs were calculated as discussed earlier. For the metals results presented above, Aluminum was used as a grain size proxy since that variable was analyzed from the same sub-sample fraction as the rest of the metals, so there were no issues related to comparing different splits of the sample (i.e. possible heterogeneity within a sample). Since the organic contaminants required a different subsample of material for extraction and analysis, the organic contaminant results are normalized using %Moisture (equal to 100 - %Solids which was provided for the organic contaminant sample splits) as a proxy for grain size. Since many previous studies also plotted organic contaminants versus %TOC, we include those plots as well for comparisons to previous studies.

Figure 48 shows plots of PCBs versus %Moisture for the pier area samples in this study. Two high outliers at 999 and 3590 ppm were omitted from the plots to preserve readability at the lower levels. There is a large amount of scatter in the Pier 10 linear trend, with samples up to 161 ppb, although most samples are much lower. It is difficult to select high outliers with so much scatter in this relationship, so it might help to select another parameter as a proxy for sediment grain size. %TOC is often used for this, since organic contaminants bind with the TOC on the high surface area fine grained particles (Leather et al. 2020). Figure 49 shows the relationship between total PCBs and %TOC, and all the samples other than the obvious two outliers mentioned earlier appear to show on average a relationship with increasing PCBs with increasing %TOC.

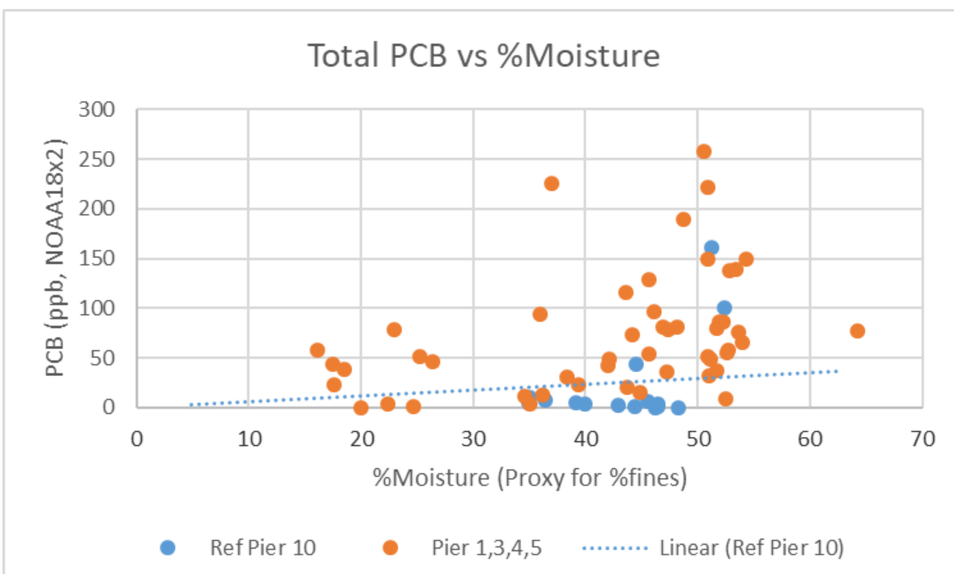
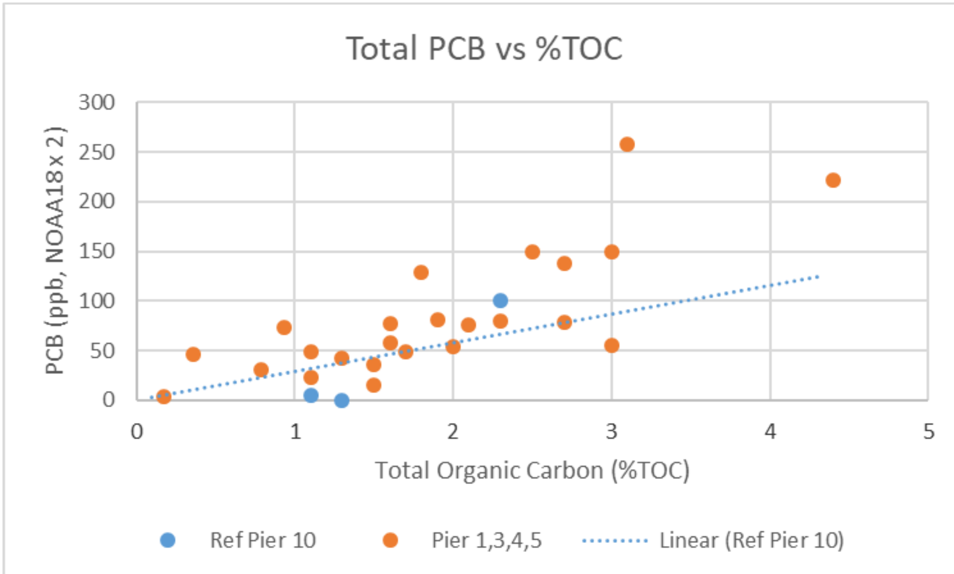
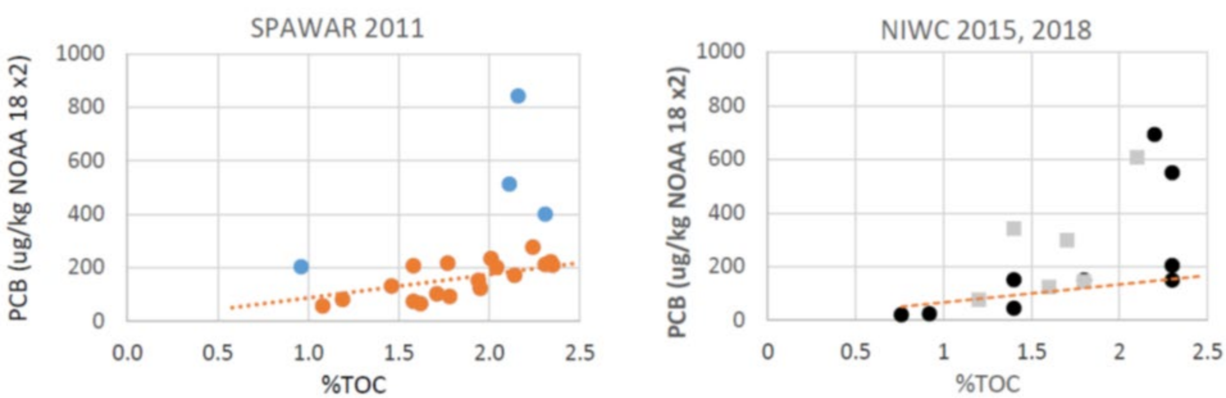


Figure 48. Total PCB versus %Moisture in Under-Pier samples. Two high outliers at 999 and 3590 ppb not shown on plot to preserve readability.



- Two high outliers at 999 and 3590 ppb not plotted here to preserve plot readability.
- TOC was only measured on a subset of samples, so fewer points are plotted than in Figure 48.

Figure 49. Total PCB versus %TOC in Under-Pier samples. Total PCB versus %TOC for pier area samples from this study.



- Linear trends show average PCB levels from 2011 (orange circles), 2015 (black circles), and 2018 (gray squares).
- Outliers over 200 ppb (blue, black, gray) not included in average trend lines.

Figure 50. Total PCB versus %TOC from previous studies (Leather et al. 2020).

Figure 50 shows comparison plots from Leather et al. (2020) for total PCB versus %TOC for the surface sediments in the northern NBSD pier areas. The high outliers for surface sediments in Figure 50 were in the 800 ppb range, otherwise the scatter around the linear trend lines would appear similar to previous Figure 49. Again, due to propwash and other resuspension mixing events, much of the fine-grained surface sediments around the NBSD pier areas reach up to 200 ppb, with some deeper core samples showing PCB values up to the 1000-4000 ppb range (Leather et al. 2020). This compares with the actual bay wide reference value for total PCBs of 84 ppb (CAO R9-2012-0024; SDRWQCB 2012) for fine grained surface sediments located outside of the industrial east side of the bay.

Figure 51 and Figure 52 show similar plots for total PAHs versus %Moisture and %TOC for Under-Pier areas in this study. Local reference values are present up to about 10,000 ppb, with ten high outliers from 18,000 to 46,400 ppb. Figure 53 shows data from previous studies (Leather et al. 2020) with local reference levels up to 3,000 ppb, but our study has deeper core samples with slightly higher local reference values up to about 10,000 ppb. The PAH surface contour map in Figure 46 shows PAHs tend to be higher near the quay wall, which is also seen for most of the other contaminants (Leather et al. 2020).

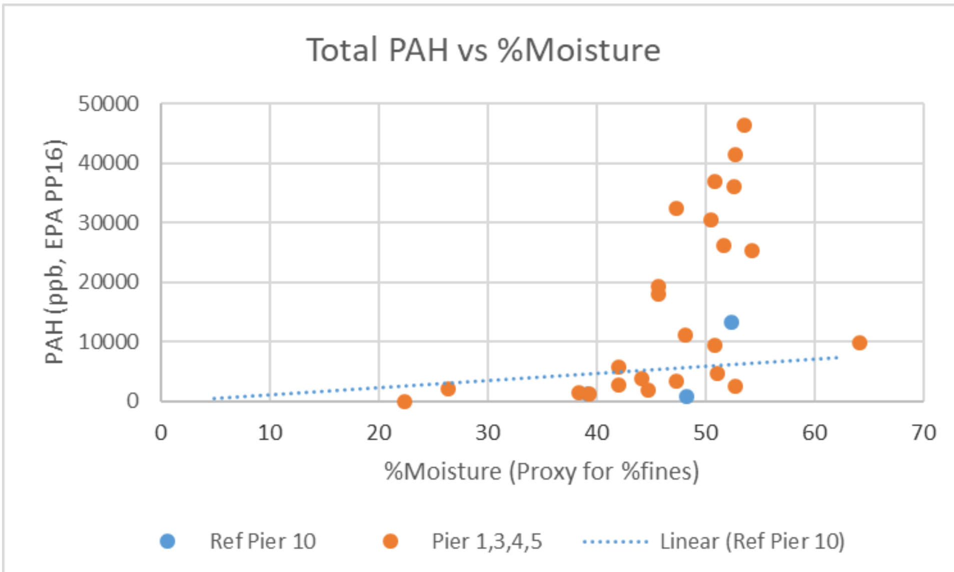


Figure 51. Total PAH versus %Moisture in Under-Pier samples. PAH only measured on subset of samples, so fewer plotted points than in previous figures.

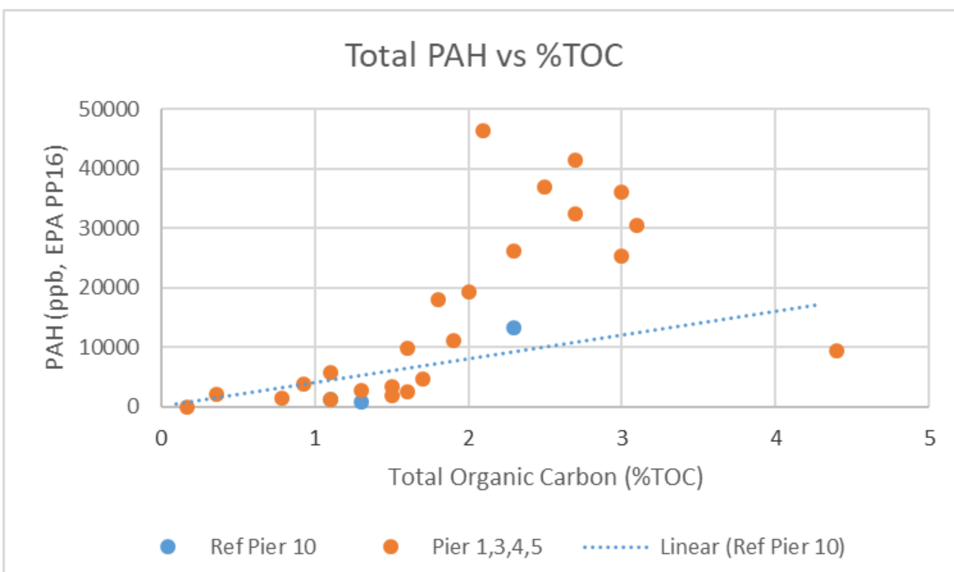


Figure 52. Total PAH versus %TOC in Under-Pier samples. PAH and %TOC only measured on subset of samples, so fewer plotted points than in previous figures.

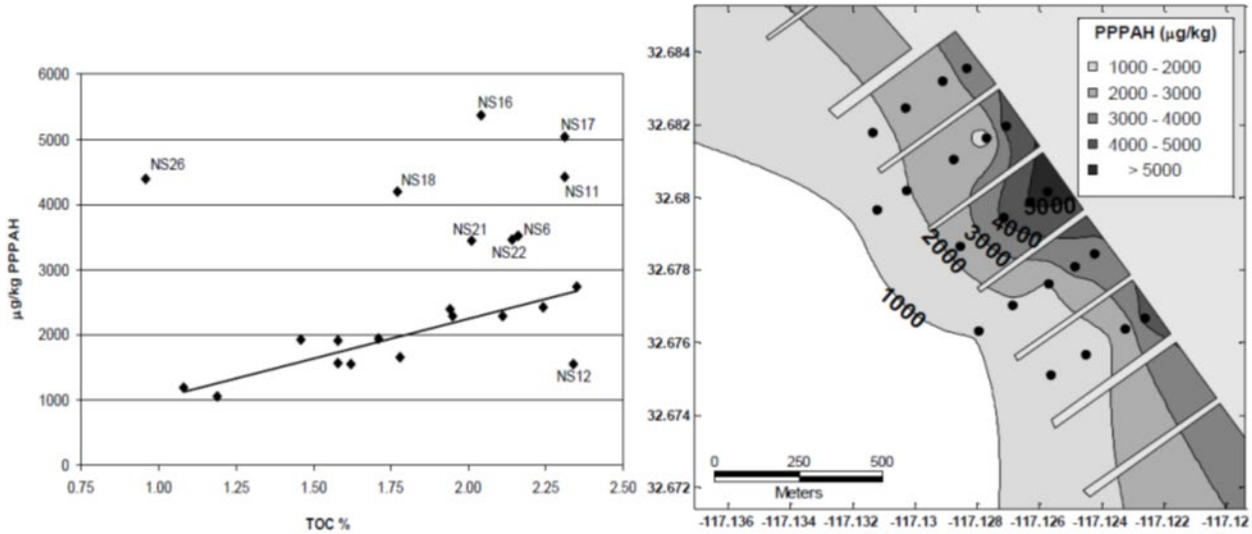


Figure 53. Total PAH versus %TOC from previous studies (Leather et al. 2020). On right is a surface sediment contour map of Priority Pollutant PAH (PPPAH, from EPA 16 PP) from 2011 for northern NBSD area between piers 1-8.

Both PCBs and PAHs often use fingerprinting methods to determine if they originate from the same or different sources. For example, Figure 54 shows some bar chart fingerprints for several samples in the pier area with concentrations in the range of the local background (150 to 250 ppb). These samples show very similar fingerprints supporting a single well mixed source. The three most common congeners are PCB101, PCB138, and PCB153, which suggests a mixture of Aroclors 1254 and 1260. Leather et al. (2020) found this same pattern in most of the pier area samples and suggested that propwash and resuspension of legacy contaminants has resulted in a common pattern in contaminants throughout the pier area. The high concentration outlier at Pier 1 with total PCBs of 3,590 ppb shows a much different pattern with more of the heavier weight congeners suggesting a different source consisting mainly of Aroclor 1260. But overall, the patterns suggest that most of the sediments have a relatively consistent pattern of contamination (although the northern piers have consistently higher concentrations than the southern piers). Whether this is due to a single source of contamination (such as the former sewage outfall at Pier 5) or propwash and other resuspension mixing many sources around the piers is not clear. In either case, for the purposes of this project the concentrations from samples can be averaged to compare to similar results from past surface sediment and deeper maintenance dredge results.

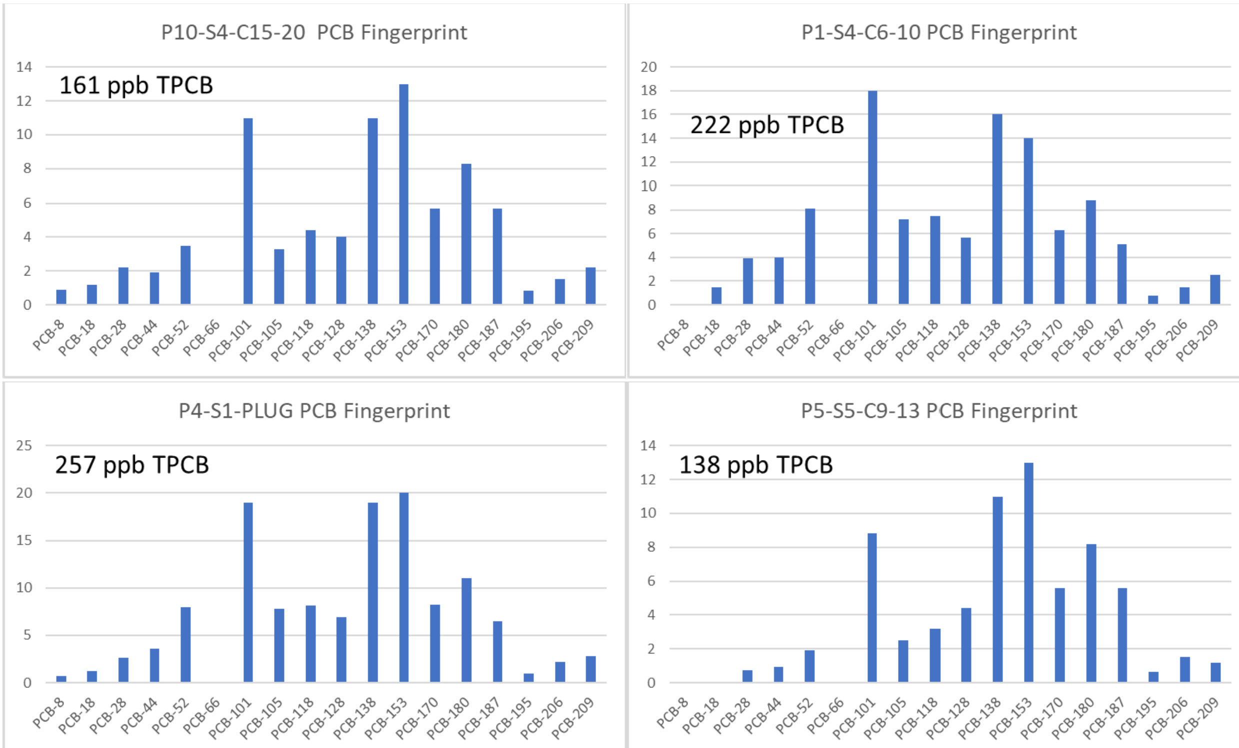


Figure 54. Total PCB (TPCB) bar chart fingerprints for several samples, that reflect local background conditions.

6.4.3 Recontamination magnitude

To assess the overall magnitude of potential recontamination of adjacent dredge footprints from sediments underneath piers at NBSD, the volume of sediments above dredge design depth and average concentration of contaminants in sampled sediments were multiplied together to quantify the total approximate amount of a given contaminant that may occur in that under-pier sediment pile. To put this potential source size into context, the same approach was taken to multiply the volume and average contaminant levels of material removed during navigational dredging to provide an estimate of the total amount of that contaminant that was theoretically removed during dredging. This analysis is summarized in Table 5.

In general, as discussed above in section 6.4.2 and as presented below, the sediments under the sampled piers at NBSD do not appear to contain particularly high concentrations of contaminants. Overall, the volume and contaminant concentrations of sediments under piers are of similar magnitude to sediments removed during navigational dredging, suggesting that sediments underneath and between piers at NBSD are relatively well-mixed (likely due to resuspension from prop wash, storms, and tidal exchange, as well as bioturbation), at least to the depths sampled for this project under piers. Therefore, even if sediments were to slump into adjacent dredged footprints from under the piers, it does not appear that they would result in particularly elevated levels of contaminants in post-dredging monitoring samples, for the studied piers. As well, this study found evidence for relative stability of the sediments under the piers at NBSD based on comparing the under-pier sediment volume captured in subsequent surveys. Indeed, most subsequent surveys seemed to reflect an increase in sediment volume under the pier over time (Table 3). This may be the result of sparse data collection, but overall there was no evidence for large-scale slumping of material from under piers. Therefore, we applied a 0.5% volume change (Table 5) to provide a conservative estimate of the magnitude of the under-pier recontamination potential at NBSD.

Table 5. Summary of magnitude of potential re-contamination represented by under-pier sediments above adjacent navigational dredge design depth.

Pier		Approximate volume of sediment	Average contaminant concentration of sediment (mg/kg for metals, ug/kg for PAHs and PCBs)		Size of entire sediment/ contamination source		Size of recontamination source assuming slumping of 0.5% under pier material
			Under Pier	Dredged	Under Pier	Dredged	
1	Under Pier	39,097 yard³ (29,892 m³, ~29,892x10³ kg)	As *9.67* Cd *7.33* Cr 46.8 Cu *169* Pb *90.3* Hg **1.88** Zn *305* PAHs *5,403* PCBs **496**	As *11.8* Cd *2.43* Cr 73.8 Cu **344.5** Pb *175.6* Hg **2.49** Zn **553** PAHs *25,939* PCBs **758**	289 kg 219 kg 1,399 kg 5,052 kg 2,699 kg 56.2 kg 9,117 kg 162 kg 14.8 kg	247 kg 50.8 kg 1,543 kg 7,202 kg 3,671 kg 52.1 kg 11,562 kg 542 kg 15.8 kg	1.4 kg 1.1 kg 7 kg 25 kg 14 kg 0.3 kg 46 kg 0.8 kg 0.07 kg
	Dredged	27,345 yard³ (20,907 m³, ~20,907x10³ kg)					
3	Under Pier	67,441 yard³ (51,562 m³, ~51,562x10³ kg)	As 4.61 Cd 0.32 Cr 25.8 Cu *76.6* Pb 36.9 Hg *0.41* Zn 135 PAHs 1333 PCBs *120*	As 7.81 Cd 0.77 Cr N/A Cu *128.5* Pb **274.3** Hg *0.586* Zn *226.2* PAHs *6566* PCBs **464.1**	238 kg 16.5 kg 1,330 kg 3,950 kg 1,903 kg 21.1 kg 6,961 kg 68.7 kg 6.2 kg	236 kg 23.3 kg N/A 3,880 kg 8,283 kg 17.7 kg 6,830 kg 198 kg 14.0 kg	1.2 kg 0.8 kg 6.7 kg 20 kg 9.5 kg 0.1 kg 35 kg 0.3 kg 0.03 kg
	Dredged	39,494 yard³ (30,197 m³, ~30,197x10³ kg)					
4	Under Pier	47,551 yard³ (36,355 m³, ~36,355x10³ kg)	As *9.82* Cd *1.27* Cr 66.2 Cu *266* Pb *115* Hg **1.47** Zn **424** PAHs *10,790* PCBs *73.7*	As *11.9* Cd *3.98* Cr *124* Cu **469** Pb **402** Hg **2.32** Zn **895** PAHs *40,369* PCBs **1,447**	357 kg 46.2 kg 2,407 kg 9,670 kg 4,181 kg 53.4 kg 15,415 kg 392 kg 2.7 kg	257 kg 85.9 kg 2,676 kg 10,122 kg 8,676 kg 50.1 kg 19,316 kg 871 kg 31.2 kg	1.8 kg 0.23 kg 12 kg 48 kg 21 kg 0.3 kg 77 kg 2 kg 0.01 kg
	Dredged	28,228 yard³ (21,582 m³, ~21,582x10³ kg)					

- Average concentrations are indicated with blue italic text if the value falls above effects range low (ERL) and red bold text if the value falls above effects range median (ERM).

Table 5. Summary of magnitude of potential re-contamination represented by under-pier sediments above adjacent navigational dredge design depth. (Continued)

Pier		Approximate volume of sediment	Average contaminant concentration of sediment (mg/kg for metals, ug/kg for PAHs and PCBs)		Size of entire sediment/ contamination source		Size of recontamination source assuming slumping of 0.5% under pier material
			Under Pier	Dredged	Under Pier	Dredged	
5	Under Pier	27,786 yard^3 (21,244 m^3, ~21,244x10^3 kg)	As *12.7* Cd *1.48* Cr 68.2 Cu **395**	As *13.0* Cd *1.67* Cr 78.2 Cu **385**	270 kg 31.4 kg 1,448 kg 8,391 kg	176 kg 22.6 kg 1,056 kg 5,199 kg	1.4 kg 0.16 kg 7 kg 42 kg
	Dredged	17,662 yard^3 (13,504 m^3, ~13,504x10^3 kg)	Pb *110* Hg **1.32** Zn **615** PAHs *22,076* PCBs *89.4*	Pb *107* Hg **0.89** Zn **532** PAHs *30,789* PCBs **459**	2,337 kg 28.0 kg 13,065 kg 469 kg 1.9 kg	1,445 kg 12.0 kg 7,184 kg 416 kg 6.2 kg	12 kg 0.14 kg 65 kg 2.3 kg 0.01 kg
10	Under Pier	34,313 yard^3 (26,234 m^3, ~26,234x10^3 kg)	As 6.1 Cd 0.53 Cr 44.8 Cu *140* Pb *77.9* Hg **1.18** Zn *238* PAHs *5,161* PCBs *23.3*	Not available	160 kg 13.9 kg 1,175 kg 3,673 kg 2,044 kg 31.0 kg 6,244 kg 135 kg 0.6 kg	Not available	0.8 kg 0.07 kg 6 kg 18 kg 10 kg 0.15 kg 31 kg 0.7 kg 0.003 kg

- -Average concentrations are indicated with blue italic text if the value falls above ERL and red bold text if the value falls above ERM

As shown above in Table 5, navigational dredging at NBSD has removed significant quantities of contaminants, with sediments and associated contaminants disposed of in upland disposal facilities designed to accept waste with elevated levels of chemicals that could otherwise pose a threat to human health or the environment. Once these sediments are removed, the underlying material (the “Z-layer”) is exposed to the overlying water. The main driver behind this project was to demonstrate a relatively inexpensive and simple method to assess the volume of sediments under Navy piers as well as the contaminant concentrations in those sediments, to help determine whether the under-pier sediments could cause re-contamination of adjacent footprints where navigational dredging occurs. Therefore, another important aspect of the project results is to compare the concentrations of contaminants in under-pier material to those in Z-layer material that would be exposed after navigational dredging. As an example, Table 6 shows that average concentrations of various contaminants analyzed from under-pier sediment cores from Pier 3 were similar to or lower than concentrations of material expected to be exposed in the post-dredge Z-layer.

Table 6. Average sediment concentrations from under-pier sediments compared to adjacent Z-layer sediments measured from pre-dredge cores and expected to be exposed after navigational dredging (from Figure 34).

Pier	Average contaminant concentration of sediment under pier	Average contaminant concentration of Z-layer material exposed after navigational dredging
3	Arsenic 4.61 mg/kg	Arsenic 7.5 mg/kg
	Cadmium 0.32 mg/kg	Cadmium 0.34 mg/kg
	Copper *76.6* mg/kg	Copper *85.4* mg/kg
	Lead 36.9 mg/kg	Lead 25.3 mg/kg
	Mercury *0.41* mg/kg	Mercury **0.73** mg/kg
	Zinc 135 mg/kg	Zinc 112 mg/kg
	PAHs 1333 ug/kg	PAHs *4261* ug/kg
	PCBs *120* ug/kg	PCBs **438** ug/kg

The other main source for recontamination of sediments at NBSD and other locations in San Diego Bay is delivery of new contaminants to the bay from stormwater runoff. For example, runoff from the Chollas Creek watershed at the northern boundary of NBSD contains elevated metals including Copper, Zinc, and Lead from a variety of sources including tire and brake pad wear, and other contaminants such as pesticides, PAHs and PCBs from additional watershed sources such as burning petroleum products and use in commercial and residential developments (City of San Diego and others 2012). A study from the Southern California Coastal Water Research Project used monitoring data and watershed models to estimate the annual discharge of various contaminants from Chollas Creek and Paleta Creek (Schiff and Carter 2007). If we assume that half of this discharge settles out in the NBSD pier area, we can make a rough comparison of the magnitude of re-contamination from stormwater runoff (Table 7) to the magnitude of potential re-contamination associated with slumping of sediments from under the piers, using estimates presented in Table 5 and doubled to account for other piers at NBSD not included in this study. This approach suggests that sediments slumping from under the piers at NBSD would likely contribute less or similarly to adjacent sediment re-contamination compared with new stormwater deposition for Arsenic, Copper, Lead, and Zinc, but that sediment slumping could represent a larger source of re-contamination compared to new stormwater deposition for Mercury, PAHs, and PCBs (Table 7).

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Table 7. Comparison of estimated deposition of contaminants discharged from stormwater vs. slumping from under pier areas at NBSD.

Contaminant	Annual estimated discharge from Chollas and Paleta Creeks (Schiff and Carter 2007)	Annual estimated deposition in NBSD pier areas	Estimated annual slumping contributions to NBSD pier areas (this study)
As	19 kg	10 kg	13 kg
Cu	753 kg	377 kg	306 kg
Pb	476 kg	238 kg	133 kg
Hg	0.16 kg	0.8 kg	2 kg
Zn	4,429 kg	2215 kg	508 kg
PAHs	4.8 kg	2.4 kg	12 kg
PCBs	0.023 kg	0.012 kg	0.25 kg

The comparisons above demonstrate that this performance metric, to estimate and contextualize the magnitude of potential re-contamination represented by under-pier sediments, was achieved by the project. Overall, however, there was significant spatial heterogeneity in the contaminant concentrations of sediments sampled, and therefore movement of sediments from different portions of the piers could have more or less significant impacts to the adjacent sediment quality. However, most of the sampled sediments at NBSD appear well-mixed both under the piers (this study) and adjacent to and between piers (Leather et al. 2020), and stormwater deposition of contaminants is still a significant source of new deposition. Therefore, until additional upstream sources are controlled, remediating under-pier sediments at NBSD is unlikely to result in a meaningful improvement to sediment quality.

6.5 SAMPLING MENU FEEDBACK

The Under-Pier Sediment Sampling Menu (separate technical document approved for public release under RSTI 7088) was delivered to several RPMs associated with the Navy Sediment Workgroup, and feedback was requested to determine whether the document was deemed useful. For example, we inquired whether the document was informative and if it would be referenced by RPMs during contract negotiations for under-pier sediment sampling and assessments. The RPMs that responded with feedback agreed that the document was informative and would be a useful reference for future needs. Therefore, this performance criterion was achieved.

6.6 SAMPLING METHODS UNDER PIERS

Following the sediment sampling methods described in detail in the Under-Pier Sediment Sampling SOP (Appendix B), sampling at each under-pier station at NBSD required approximately 1 hour from start to finish.

For a full day of effort spanning 9-10 hours, which included equipment transport to the site, setup, safety briefing, transit to the piers, sampling, and demobilization/cleanup, approximately 5-6 stations could be sampled each day on dates with very low tides during daylight hours. Note that this rate of sampling also includes time to pre-screen the sediment bed and to screen retrieved samples for potential UXO. This may not be required at other sites.

Overall, the project team successfully used several approaches to retrieve sediment samples under the piers. However, one caveat is that the core samples collected spanned a maximum length of 24”, because of the limitations of the equipment used. The sampling team agreed that had there been the opportunity to use a longer coring device, cores of approximately 36” could have been collected with these methods, but that longer cores would not have been possible to collect because of limited vertical clearance and the need to use completely manual methods for core placement and retrieval. At sites with larger access panels through pier surfaces, longer cores could be collected from the tops of piers, with under-pier support as described in the Under-Pier Sediment Sampling SOP (Appendix B). Overall, the sampling team agreed that the methods developed for this project were appropriate and achievable. The site RPMs also agreed that the results of this work would be valuable for their site investigation work. Therefore, this performance criterion was achieved.

7. COST ASSESSMENT

To allow the results from this demonstration to be transitioned to other Navy sites, it is vital to understand the costs of the method. Table 8 lists cost elements that will be used to assess costs of the demonstrated technology as compared to traditional methods.

Table 8. Cost assessment basis summary. Costs associated with this project (green), costs using different methods (yellow), and costs of remediation due to recontamination (orange).

Cost Element	Data Tracked During Project
Equipment capital costs	Actual costs from purchases during and prior to project, vendor quotes
Field deployment costs a. Bathymetric assessment b. Sediment sampling	Labor, labor rates, other logistical costs such as boat support required for given field effort
Sample analysis	Laboratory costs for sediment sample analysis
Data analysis Bathymetry (DEM) Erosion (DEM differencing) Volumetric assessment Potential for recontamination	Labor, labor rates for each stage and type of data analysis
Estimates for similar effort using bathymetric vessel, field team from contractor agencies	Costs using traditional large-vessel bathymetric assessment and sediment sampling approach
Estimate of additional dredging associated with recontamination from under-pier sediments, if not quantified and controlled	Cost of additional dredging to be estimated based on costs of current dredging program, obtained from RPMs

- Costs associated with this project (green), costs using different methods (yellow), and costs of remediation due to recontamination (orange).

7.1 COST MODEL

The cost model for this analysis uses a per-event cost approach for the Under Pier sediment assessment technology. The cost model incorporates the cost drivers described in the following section and was applied using assumptions regarding the scale of the application. Costs for both a local and a remote effort were estimated, as well as costs to complete an assessment of a single pier, versus a larger study involving five piers.

7.2 COST DRIVERS

The cost drivers associated with this project are largely driven by equipment capital and maintenance costs, labor and overhead costs associated with the field work, logistics costs, consumables, analytical costs associated with the sampling elements, and labor and overhead costs associated with the data analysis and reporting.

Equipment capital costs include costs of the Z-boat system, including computer equipment and software required to use the Z-boat for under-pier bathymetric assessment. Equipment capital costs also include under-pier sediment sampling equipment.

For each type of field effort completed under this demonstration (bathymetric assessments and sediment sampling), costs associated with these efforts were tabulated. Relevant additional factors necessary to scale costs for this technology to be applied at a remote site requiring travel were also included – for example, shipping and travel costs.

Sediment sample analytical costs were included based on costs incurred for this demonstration. Typically, analytical costs are fixed at a per-sample basis, allowing easy scaling of these costs to other sites, if other contaminants are to be assessed at a different site.

Finally, labor costs associated with processing and interpreting the resulting data from field deployments of this technology, and reporting the results, were assessed.

7.3 COST ANALYSIS AND COMPARISON

The focus of the Flexible Under Pier Sediment Assessment technology is to provide one or more relatively inexpensive methods to quantify the volume and contamination levels of sediments that accumulate under Navy Piers, where standard methods for sediment assessment outside of under-pier areas are compromised. In addition, the concept was to provide data that would ideally lead to site managers avoiding costs associated with having to redo site assessment and cleanup work, if under-pier sediments were ignored but did pose a significant recontamination problem. Direct cost comparisons are therefore somewhat challenging, but typical costs for sediment assessment from contractors were used as a comparison to the cost of using this technology, and costs associated with site cleanup were used as an approximate estimate for avoided costs.

7.3.1 Cost Analysis – Under-Pier Technology

Equipment capital costs

The initial equipment costs associated with purchasing the technology used for this demonstration are included in the below tables. However, nearly all equipment used for this demonstration had been previously purchased by NIWC Pacific for other projects. Therefore, the appropriate rental rate for a single deployment effort of the Z-boat and associated equipment was calculated, assuming that the system was used 6 times a year and would need to be replaced after 10 years of use. This is the cost that would need to be charged per use to allow a full replacement system to be purchased in 10 years assuming a 4% inflation rate ($246,120 replacement cost) and also to pay for annual maintenance costs. This was set at 1% of the capital cost based on the maintenance cost assessment also included below. The same approach was completed for the sediment sampling equipment, but assuming a maintenance rate of 10% given the lower overall initial cost and more rugged conditions encountered when using that equipment.

Table 9. Estimate of initial cost for capital and ancillary equipment.

Estimate of Initial Cost for Capital and Ancillary Equipment			
Item			Initial Cost
Z-boat with integrated echosounder			$150,000
SeaTrac USBL system			$20,000
Ancillary - Field Laptop			$1,800
Ancillary - Directional GPS			$3,000
Ancillary - Miscellaneous field gear (pelican cases, etc.)			$1,000
Total Z-boat Under-Pier Bathymetry System			$175,800
Equipment Replacement Cost Estimate			
Inflation Rate	*4%*		
	Years of Use		
	0	5	10
Z-boat Under Pier Bathymetry System & Ancillary Replacement	$175,800	$210,960	$246,120
Estimated Rental Rate Including Inflation and Maintenance			
Maintenance Rate	*1%*		
		Years of use	
Under Pier Bathymetry System & Ancillary	Uses/year	5	10
	3	$14,205	$8,286
	6	$7,102	$4,143
	9	$4,735	$2,762
	12	$3,551	$2,072
	15	$2,841	$1,657
Rental Rate for Cost Analysis			
Under Pier Bathymetry System & Ancillary – per day			$1,657

Table 10. Cost analysis under pier technology, Z-boat maintenance.

Zboat Maintenance Item	Unit Type	Units	Rate	Cost	Frequency
Cleaning	Hours	1	100	$100	1/deployment
Storage	Sq Ft	20	3.5	$70	1/mo
Charge and change batteries	Hours	1	100	$100	1/deployment
Annual maintenance cost (6 deployments/year)				$2,040	

Table 11. Estimate of initial cost for capital and ancillary equipment form 2.

Estimate of Initial Cost for Capital and Ancillary Equipment			
Item			Initial Cost
Manual Sediment Corer System			$3,500
Mini Ponar Grab Sampler System			$1,800
Ancillary - Field Kit			$200
Total Push Pole System			$5,500
Equipment Replacement Cost Estimate			
Inflation Rate	*4%*		
	Years of Use		
	0	5	10
Under Pier Sediment Samplers & Ancillary Replacement	$5,500	$6,600	$7,700
Estimated Rental Rate Including Inflation and Maintenance			
Maintenance Rate	*10%*		
Under Pier Sediment Sampler System & Ancillary		Years of use	
	Uses/year	5	10
	3	$484	$282
	6	$242	$141
	9	$161	$94
	12	$121	$71
	15	$97	$56
Rental Rate for Cost Analysis			
Under Pier Sediment Sampler System – per day			$ 56

Overall project costs

Costs to execute a similar project to the demonstration completed here were estimated to include: (i) field deployment costs, (ii) analytical costs, and (iii) data processing, interpretation, and reporting costs for two different project locations: a local site and a remote site that would require travel by personnel and shipping of equipment. For these two example locations, costs to execute two project sizes were estimated: a project for a single pier and a project encompassing five piers. The sizes of the piers were assumed to be similar to those at NBSD where this demonstration was completed, which informs the level of effort required.

Table 12. Local 1-pier project, part 1.

Local, 1 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	$1,200		0.5	$600	Principal
	Preliminary budget	$1,200		0.5	$600	Principal
	Final budget	$1,200		0.5	$600	Principal
	Contract Agreement	$1,200		1	$1,200	Principal
	Sampling Plan	$1,200		1	$1,200	Principal
	Material Orders	$800		1	$800	Technician
Sub-total					$5,000	
Mobilization Costs	Equipment checkout	$800		0.5	$400	Technician
	Packing for local transit	$800		0.25	$200	Technician
	Shipping	$800		0	$0	Technician
Sub-total					$600	
Field Operating Costs	Roundtrip commute to site (daily)	$2,000		0.4	$800	1 PI & 1 Tech; 1 day each bathy & sampling
	On-site setup/testing (daily)	$2,000		0.25	$500	1 PI & 1 Tech
	Bathy survey completion	$2,000		0.75	$1,500	1 PI & 1 Tech
	Sampling below piers	$2,000		0.75	$1,500	1 PI & 1 Tech
	Sample processing	$2,000		0.5	$1,000	1 PI & 1 Tech
	Vessel support - captain	$1,000		2	$2,000	1 vessel captain
Sub-total					$7,300	
Demobilization Costs	Daily cleanup	$2,000		0.25	$500	1 PI & 1 Tech
	Data download, equipment breakdown	$2,000		0.125	$250	1 PI & 1 Tech
	Packing for local transit	$2,000		0.25	$500	1 PI & 1 Tech
	Shipping	$800		0	$0	Technician
Sub-total					$1,250	

Table 13. Local 1-pier project, part 2.

Local, 1 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Analysis and Reporting	Post-survey data analysis	$1,200		3	$3,600	Principal
	Reporting	$1,200		3	$3,600	Principal
Sub-total					$7,200	
Project Management		$1,200		1.653	$1,983	@ 10% of labor days
Total Labor Costs					**$23,333**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	Bathy equipment rental	$1,657		1	$1,657	Daily rental rate
	Sampling equipment rental	$51		5	$255	Daily rental rate
	Shipping Z-boat, etc.	$500	0		$0	Return shipping
	Boat rental - support vessel	$1,200	1		$1,200	1 day
Sub-total					$3,112	
Materials Costs	Consumables	$10	5		$50	Aluminum foil, kimwipes, gloves, etc.
	Sample containers	$5	10		$50	core tubes, jars
	Log books/sheets	$10	1		$10	
	Fuel	$5	25		$125	For boats and vehicles
Sub-total					$235	
Travel Costs	Airfare	$500	0		$0	
	Per diem and hotel	$400	0		$0	
	Truck/Van	$150	0		$0	
Sub-total					$0	
Analysis Costs	Sediment sample analysis	$500	10		$5,000	Contract
Sub-total					$5,000	
Total non-labor cost					**$8,347**	
Project Sub-total					**$31,680**	
Fee/Markup @ 8%					**$2,534**	
Project Total					**$34,214**	

Table 14. Remote 1-pier project, part 1.

Remote, 1 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	$1,200		0.5	$600	Principal
	Preliminary budget	$1,200		0.5	$600	Principal
	Final budget	$1,200		0.5	$600	Principal
	Contract Agreement	$1,200		1	$1,200	Principal
	Sampling Plan	$1,200		1	$1,200	Principal
	Material Orders	$800		1	$800	Technician
Sub-total					$5,000	
Mobilization Costs	Equipment checkout	$800		0.5	$400	Technician
	Packing	$800		0.5	$400	Technician
	Shipping	$800		0.5	$400	Technician
Sub-total					$1,200	
Field Operating Costs	Travel and return travel	$2,000		2	$4,000	1 PI & 1 Tech; 1 trip
	On-site setup/testing (daily)	$2,000		0.25	$500	1 PI & 1 Tech
	Bathy survey completion	$2,000		0.75	$1,500	1 PI & 1 Tech
	Sampling below piers	$2,000		0.75	$1,500	1 PI & 1 Tech
	Sample processing	$2,000		0.5	$1,000	1 PI & 1 Tech
	Vessel support - captain	$1,000		2	$2,000	1 vessel captain
Sub-total					$10,500	
Demobilization Costs	Daily cleanup	$2,000		0.25	$500	1 PI & 1 Tech
	Data download, equipment breakdown	$2,000		0.125	$250	1 PI & 1 Tech
	Packing	$2,000		0.25	$500	1 PI & 1 Tech
	Shipping	$800		0.5	$400	Technician
Sub-total					$1,650	
Analysis and Reporting	Post-survey data analysis	$1,200		3	$3,600	Principal
	Reporting	$1,200		3	$3,600	Principal
Sub-total					$7,200	
Project Management		$1,200		1.938	$2,325	@ 10% of labor days
Total Labor Costs					**$27,875**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	Bathy equipment rental	$1,657		1	$1,657	Daily rental rate
	Sampling equipment rental	$51		1	$51	Daily rental rate

Table 15. Remote 1-pier project, part 2.

Remote, 1 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
	Shipping Z-boat, etc.	$500	2		$1,000	Return shipping
	Boat rental - support vessel	$1,200	1		$1,200	1 day
Sub-total					$3,908	
Materials Costs	Consumables	$10	5		$50	Aluminum foil, kimwipes, gloves, etc.
	Sample containers	$5	10		$50	core tubes, jars
	Log books/sheets	$10	1		$10	
	Fuel	$5	25		$125	For boats and vehicles
Sub-total					$235	
Travel Costs	Airfare	$500	2		$1,000	2x1 Roundtrip
	Per diem and hotel	$400	6		$2,400	3 days x 2 people
	Truck/Van	$150	3		$450	
Sub-total					$3,850	
Analysis Costs	Sediment sample analysis	$500	10		$5,000	Contract
Sub-total					$5,000	
Total non-labor cost					**$12,993**	
Project Sub-total					**$40,868**	
Fee/Markup @ 8%					**$3,269**	
Project Total					**$44,137**	

Table 16. Local 5-pier project, part 1.

Local, 5 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	$1,200		0.75	$900	Principal
	Preliminary budget	$1,200		0.5	$600	Principal
	Final budget	$1,200		0.75	$900	Principal
	Contract Agreement	$1,200		1	$1,200	Principal
	Sampling Plan	$1,200		2	$2,400	Principal
	Material Orders	$800		1	$800	Technician
Sub-total					$6,800	
Mobilization Costs	Equipment checkout	$800		0.5	$400	Technician
	Packing for local transit	$800		0.25	$200	Technician
	Shipping	$800		0	$0	Technician
Sub-total					$600	

Table 17. Local 5-pier project, part 2.

Local, 5 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Field Operating Costs	Roundtrip commute to site (daily)	$2,000		1.6	$3,200	1 PI & 1 Tech; 3 days bathy, 5 days sampling
	On-site setup/testing (daily)	$2,000		1	$2,000	1 PI & 1 Tech
	Bathy survey completion	$2,000		2.5	$4,500	1 PI & 1 Tech
	Sampling below piers	$2,000		3.75	$7,500	1 PI & 1 Tech
	Sample processing	$2,000		2	$4,000	1 PI & 1 Tech
	Vessel support - captain	$1,000		8	$8,000	1 vessel captain
Sub-total					$29,200	
Demobilization Costs	Post-survey cleanup	$2,000		0.625	$1,250	1 PI & 1 Tech
	Data download, equipment breakdown	$2,000		0.625	$1,250	1 PI & 1 Tech
	Packing for local transit	$2,000		0.25	$500	1 PI & 1 Tech
	Shipping	$800		0	$0	Technician
Sub-total					$3,000	
Analysis and Reporting	Post-survey data analysis	$1,200		9	$10,800	Principal
	Reporting	$1,200		5	$6,000	Principal
Sub-total					$16,800	
Project Management		$1,200		4.5	$5,400	@ 10% of labor days
Total Labor Costs					**$68,100**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	Bathy equipment rental	$1,657		3	$4,971	Daily rental rate
	Sampling equipment rental	$51		5	$255	Daily rental rate
	Shipping Z-boat, etc.	$500	0		$0	Return shipping
	Boat rental - support vessel	$1,200	8		$9,600	8 days
Sub-total					$14,826	
Materials Costs	Consumables	$10	15		$150	Aluminum foil, kimwipes, gloves, etc.
	Sample containers	$5	50		$250	core tubes, jars

Table 18. Local 5-pier project, part 3

Local, 5 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
	Log books/sheets	$10	5		$50	
	Fuel	$5	75		$375	For boats and vehicles
Sub-total					$825	
Travel Costs	Airfare	$500	0		$0	
	Per diem and hotel	$400	0		$0	
	Truck/Van	$150	0		$0	
Sub-total					$0	
Analysis Costs	Sediment sample analysis	$500	50		$25,000	Contract
Sub-total					$25,000	
Total non-labor cost					**$40,651**	
Project Sub-total					**$101,953**	
Fee/Markup @ 8%					**$8,156**	
Project Total					**$110,109**	

Table 19. Remote 5-pier project, part 1.

Remote, 5 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	$1,200		0.75	$900	Principal
	Preliminary budget	$1,200		0.5	$600	Principal
	Final budget	$1,200		0.75	$900	Principal
	Contract Agreement	$1,200		1	$1,200	Principal
	Sampling Plan	$1,200		2	$2,400	Principal
	Material Orders	$800		1	$800	Technician
Sub-total					$6,800	
Mobilization Costs	Equipment checkout	$800		0.5	$400	Technician
	Packing	$800		0.5	$400	Technician
	Shipping	$800		0.5	$400	Technician
Sub-total					$1,200	
Field Operating Costs	Travel and return travel	$2,000		2	$4,000	1 PI & 1 Tech; 1 trip
	On-site setup/testing (daily)	$2,000		1	$2,000	1 PI & 1 Tech
	Bathy survey completion	$2,000		2.25	$4,500	1 PI & 1 Tech
	Sampling below piers	$2,000		5	$10,000	1 PI & 1 Tech

Table 20. Remote 5-pier project, part 2.

Remote, 5 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
	Sample processing	$2,000		2	$4,000	1 PI & 1 Tech
	Vessel support - captain	$1,000		8	$8,000	1 vessel captain
Sub-total					$32,500	
Demobilization Costs	Daily cleanup	$2,000		0.625	$1,250	1 PI & 1 Tech
	Data download, equipment breakdown	$2,000		0.625	$1,250	1 PI & 1 Tech
	Packing	$2,000		0.25	$500	1 PI & 1 Tech
	Shipping	$800		0.5	$400	Technician
Sub-total					$3,400	
Analysis and Reporting	Post-survey data analysis	$1,200		9	$10,800	Principal
	Reporting	$1,200		5	$6,000	Principal
Sub-total					$16,800	
Project Management		$1,200		4.775	$5,730	@ 10% of labor days
Total Labor Costs					**$72,430**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	Bathy equipment rental	$1,657		3	$4,971	Daily rental rate
	Sampling equipment rental	$51		5	$255	Daily rental rate
	Shipping Z-boat, etc.	$500	2		$1,000	Return shipping
	Boat rental - support vessel	$1,200	8		$9,600	8 days
Sub-total					$15,826	
Materials Costs	Consumables	$10	15		$150	Aluminum foil, kimwipes, gloves, etc.
	Sample containers	$5	50		$250	core tubes, jars
	Log books/sheets	$10	5		$50	
	Fuel	$5	75		$375	For boats and vehicles
Sub-total					$825	
Travel Costs	Airfare	$500	2		$1,000	2x1 Roundtrip
	Per diem and hotel	$400	20		$8,000	12 days x 2 people
	Truck/Van	$150	10		$1,500	
Sub-total					$10,500	

Table 21. Remote 5-pier project, part 3

Remote, 5 pier project

Cost Category	Sub Category	Under-Pier Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Analysis Costs	Sediment sample analysis	$500	50		$25,000	Contract
Sub-total					$25,000	
Total non-labor cost					**$52,151**	
Project Sub-total					**$118,101**	
Fee/Markup @ 8%					**$9,448**	
Project Total					**$127,549**	

7.3.2 Cost Comparison

This project focused on demonstrating relatively inexpensive and simple methods to quantify the volume and contaminant concentrations of sediments underneath Navy piers, with the principal aim to help identify whether these sediments could represent a significant source of re-contamination to adjacent dredged areas, which could require further dredging and cleanup.

The cost to dredge and dispose of contaminated material is significant. Based on costs for maintenance dredging and disposal at NBSD and Naval Base Point Loma, the cost of upland disposal of contaminated sediments is approximately $210 per cubic yard of material. This contrasts with material that can be ocean disposed at $20 per cubic yard. Therefore, recontamination in a given dredge footprint by contaminated material could result in subsequent navigational dredging requiring upland disposal instead of ocean disposal, at more than 10 times the cost. For a navigational dredging project on the scale of those completed around the NBSD piers, which ranged from 17,662 to 39,494 cubic yards of material, this could cost an extra $3.4 to $7.5 million if the material must be upland vs. ocean disposed. If this extra cost can be avoided by conducting an under-pier sediment assessment and possible remediation (e.g. by placing activated carbon as an amendment; ~$0.4 million using average costs presented in Kirtay et al. 2017 and references), this could potentially save several millions of dollars at a single pier.

The cost to complete surveys and sediment sampling presented in section 7.3.1 assume rental of equipment at a rate that would fund replacement of the equipment at an expected end of life. However, for owned equipment that is not rented and is not anticipated to require replacement, these costs can be discounted for project execution. Many of the costs associated with a project such as that presented here such as planning, travel, data analysis, etc. are also expected to be similar for the application of these methods compared to more traditional methods for bathymetric surveying and sediment assessment (but note that those methods cannot typically operate in the under-pier environment). The NESDI TICA tool was used to compare the costs of existing technology vs. this technology. Using costs for sediment sampling and side-scan sonar obtained from web searches and site RPMs, approximate costs to complete sediment sampling and a survey of one pier was estimated ($30k and $6.5k, respectively) and compared to estimated costs for completing sediment sampling and bathymetry data collection presented here ($5k and $2.5k). This comparison suggests that the overall cost for an internal Navy bathymetry survey and sediment sample collection using existing equipment is ~2.6 and 6 times less expensive, respectively, compared to typical methods using large vessels and heavy equipment costed by external companies.

8. CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION ISSUES

Overall, this project tested and validated an approach to assess the volume and contaminant levels of sediments underneath Navy piers, to determine whether sediments under the piers should be considered a significant potential source of adjacent re-contamination. The demonstration was executed at the NBSD. Impacts to the project due to the global COVID-19 pandemic prevented the demonstration from being executed at multiple sites; however the variety of pier types, structures, and ages at NBSD allowed the team to test the approach under a variety of conditions. COVID-19 also impacted the project schedule somewhat for a variety of reasons, and impacted the ability of the project team to purchase equipment. However, the project was still able to be accomplished by using existing equipment and materials in creative ways.

This project developed methods for and validated the use of a remotely-operated surface vessel called a Z-boat equipped with an integrated GPS, a survey-grade single beam sonar system, and a USBL diver-tracking device to survey bathymetry underneath Navy piers to provide estimates of the total volume of sediment underneath a given pier. The project found that this methodology was not able to accurately detect small-scale changes in the sediment pile beneath piers such as slumping from the side of the sediment pile into an adjacent dredged footprint. The project team recommends that if detection of relatively small-scale changes are required, a side-scan sonar survey should be completed along the sides of a pier. As well, if a site manager requires a very accurate bathymetric assessment, such as to plan for dredging, sediment amendment placement, or construction, a survey should be contracted by licensed hydrographic professionals. The methods presented here can provide a relatively rough estimate of sediment volume and bathymetry, but should not be relied upon for precise such applications.

This project also developed and validated methods to collect samples of sediment from under-pier areas. Similar to the bathymetric assessment results, these methods were successful in allowing the project team to collect grab and core samples from under-pier areas that would be otherwise inaccessible using standard sediment sampling platforms and approaches. However, the sample sizes were limited to shallower depths than might otherwise be required. For example, if a core were desired from the center of a given pier (the top/shallowest portion of the sediment) to a depth equal to the dredge design depth, this could require cores of approximately 25’ in length, more than 10 times the length of the cores achieved with the methods demonstrated here. Such long cores would require heavy equipment use from the surface of a pier through a wide panel allowing access through the entire pier structure to the water and sediment below, which does not occur at any of the piers sampled for this project and may not occur at any Navy piers. It may be possible to collect long cores from the side of a pier at an angle, but this was not attempted and may also not be realistically feasible. However, this project found that in general the sediments under the studied piers appear relatively physically stable with time, and such long cores may not be realistically very valuable to collect, as the deep sediments beneath piers are unlikely to be exposed in the future except perhaps if a pier is removed/replaced. In that case, long cores can be collected using relatively standard approaches once the top of the old pier is removed (and ideally before the old pilings are removed, if they will be removed and replaced for a given project).

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APPENDIX A: POINTS OF CONTACT

This is a list all the important points of contact (POC) involved in the demonstration, such as co-investigators, sponsors, industry partners, and regulators.

Name	Organization	Phone	E-mail	Role in Project
Jessica Carilli	NIWC PACIFIC 53560 Hull Street San Diego,CA 92152	O: (619) 553-2781 C: (760) 815-2629	jessica.c.carilli.civ@us.navy.mil	Principal Investigator
Regina Guazzo	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	C: (757) 472-0957	regina.a.guazzo.civ@us.navy.mil	Bathymetry Lead
Jim Leather	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	O: (619) 553-6240 C: (858) 354-0376	james.m.leather.civ@us.navy.mil	Sediment Sampling Lead
Bradley Davidson	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	C: (858) 539-3837	iicaptbrad@san.rr.com	Field Support, Vessel Captain (retired as of February 2021)
Ben Whitmore	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	C: (612) 868-5166	benjamin.m.whitmore3.civ@us.navy.mil	Field Support, Vessel Captain
Kevin Carlin	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	C: (714) 878-4545	kevin.p.carlin2.civ@us.navy.mil	Field Support, Vessel Captain
Mario Malfavon	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	C: (760) 807-5255	mario.malfavon.civ@us.navy.mil	Sediment Volume, Erosion Rate Lead

Name	Organization	Phone	E-mail	Role in Project
Angelica Rodriguez	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152	C: (619) 417-4175	angelica.r.rodriguez9.civ@us.navy. mil (obsolete) arodrigu@ucsd.edu (current)	Bathymetry Assistant, Physical Oceanography SME
Joel Guerrero	NIWC PACIFIC 53560 Hull Street San Diego, CA 92152		joel.m.guerrero2.civ@us.navy.mil	Sediment Sampling
Adrian McDonald	CEE Hydrosystems 701 Palomar Airport Road, Suite 300 Carlsbad, CA 92011	O: 760-492-4511	adrian.mcdonald@ceehydrosystems. com	Original source of Z-boat, source for technical input
Lindsay Nehm	Naval Facilities Engineering Systems Command (NAVFAC) SW	O: 619-532-4148	lindsay.nehm@navy.mil	Environmental Restoration, Coastal Division (dredging RPM)
Kari Kohler	NAVFAC SW	O: (619) 532-4163	kari.coler@navy.mil	Environmental Restoration, Coastal division (planner)
Justin Rhoads	Naval Base San Diego (NBSD)	O: 619-556-1566	justin.rhoads@navy.mil	Physical Scientist, NBSD Environmental
David Forbes	NBSD	O: 619-556-6073	david.m.forbes@navy.mil	Physical Security
John Loth	NBSD	O: 619-606-5030	john.loth@navy.mil	Port Operations
Anthony Sims	NBSD		anthony.sims2@navy.mil	Port Operations, Berthing Services
James Mugg	NBSD	O: 619-556-1319	james.mugg@navy.mil	Deputy, Public Works

APPENDIX B: SUPPLEMENTARY DATA AND ANALYSIS

Overview:

This Appendix is comprised of three main parts:

Part 1: Under-Pier Bathymetric Survey and Mapping SOP

Part 2: Under-Pier Sediment Sampling SOP

Part 3: Sediment Analysis Results

APPENDIX B PART 1: UNDER-PIER BATHYMETRIC SURVEY AND MAPPING SOP

Standard Operating Procedures:
Bathymetry Survey and Mapping

Flexible Under Pier Sediment Assessment
NESDI Project Number 572

September 15, 2022

CHECKLIST OF ITEMS REQUIRED FOR UNDER-PIER BATHYMETRY SURVEYS USING REMOTELY OPERATED "Z-BOAT"

Checklist Color/image key:

- Items that are optional, or may not be required for all surveys are *italicized and gray*
- Items integrated/not typically located apart from other items are indicated with a circle

Bathymetry Surveys:

- ❑ Field PC laptop
  - ❑ *The following software is required:*
    - o *HOBO® ware (for level logger; if local tide gauge data are not available)*
    - o *PinPoint by BluePrint Subsea® (for the SeaTrac system)*
    - o *PocketMax 4 (for Hemisphere GPS)*
    - o *CEEPulse® Connect (for changing Z-boat echosounder settings)*
  - ❑ Field laptop power supply
  - ❑ Hemisphere directional GPS unit
  - ❑ Main unit
  - ❑ Hemisphere cord, terminated with:
    - o Hemisphere serial-USB converter
    - o Hemisphere power supply
  - ❑ *Mounting system, if required to secure to vessel while in use*
- ❑ SeaTrac system – contained in waterproof Pelican case
  - ❑ X150 topside beacon
  - ❑ X150 topside cord, terminated with:
    - o X150 topside serial-USB converter
    - o X150 topside power supply
  - ❑ X110 diver beacon(s)
  - ❑ X110 diver beacon battery waterproof container(s)
  - ❑ X110 diver beacon rechargable batteries
  - ❑ X110 diver beacon charger
- ❑ Topside SeaTrac modem boat-mount system
- ❑ Z-boat and accessories
  - ❑ Main boat hull
    - o 1 female omni-directional antenna
    - o 2 male omni-directional antennas
    - o CEE Pulse Echosounder (integrated into boat)
    - o Compass (integrated into boat)
    - o Black GPS data cord
    - o White, disk-shaped GPS antenna
    - o Plastic key for boat
    - o Bow and stern suction-cup lights with batteries
  - ❑ Mount for SeaTrac system (Polyvinyl Chloride [PVC] and ratchet straps)
  - ❑ Cart to transport boat and store while on support vessel

- ❑ Propeller
- ❑ Three battery boat packs (fully charged close to use)
- ❑ Extra batteries for lights (4x AAA for each)

❑ Aurora radio controller in case

- ❑ Two charged battery packs for radio controller

❑ *Handheld GPS to collect groundtruth points, if desired*

❑ Electrical power

- ❑ Power strip large enough to accommodate all three power supplies above
- ❑ Inverter (at least 150W)*
- ❑ Charged marine battery*
- ❑ **Generator can be used instead of these if desired*
- ❑ Extension cord

❑ CTD (Castaway), with spare batteries or similar source to obtain temperature/salinity

❑ *Camera, with appropriate memory storage and waterproof housing (for documenting workflow/etc.)*

❑ Note-taking equipment

- ❑ *Waterproof notebook for data recording and notes*
- ❑ Logsheet for each survey planned
- ❑ Pencils and pens
- ❑ Permanent markers
- ❑ *Printed maps of survey area*

❑ Personal items for each crew member

- ❑ Life vests
- ❑ Safety shoes
- ❑ Water, sunscreen, food, etc. for personal comfort
- ❑ *PPE for coronavirus protection, as required*
- ❑ *Hand sanitizer*
- ❑ *Sanitizing wipes or equivalent for surfaces*

❑ Waterproof bins/containers to organize equipment on boat deck

❑ Pelican case with extra tools, line, cable ties, duct tape, electrical tape, and backup supplies (i.e., extra antennas, etc.) for Z-boat

❑ Bucket and/or container of freshwater for rinsing SeaTrac beacons

❑ Hand towel for drying rinsed equipment

❑ *Kayak and paddle for chasing Z-boat if needed*

❑ List of team and site contacts (see next page)

❑ Health and Safety Plan (printed)

8.1 CONTACTS AND EMERGENCY INFORMATION FOR SURVEYS

FIELD TEAM CONTACTS

Name	Role	Phone

Site contacts

Name	Role	Phone
	Base Environmental	
	Port Operations	
	Physical Security	

BATHYMETRY SURVEY SOP

Instructions for how to set up and breakdown of a Z-boat and associated equipment for Under-Pier bathymetry surveys. Instructions can be printed and laminated, or inserted in a plastic cover. Checked off/information can be entered as indicated below for each survey. Note: Some steps may not need to be completed for subsequent surveys. Instructions assume initial setup of equipment. In addition, some steps are unique to the particular field equipment organization used for this project (for example, the storage containers for equipment groups). These details are included to aid in setting up future surveys, but should be adjusted as needed.

8.1.1 Prior to conducting the survey: charge all batteries

❑ SeaTrac batteries

a. Plug a single battery into charger (the connection may be loose).
b. Connect charger to the outlet.
c. Light on plug changes orange to green when the battery is fully charged (no light is on the battery).

❑ Aurora 9® remote control batteries

a. Connect a single battery to the Aurora 9®, with the remote in the off position.
b. Connect the charger to an outlet and connect it to the charge port on the rear of the remote (to left of battery).
c. The light on the charger plug will turn red (no lights will illuminate on the Aurora 9®).
d. When the battery is fully charged, the charger light should turn off, but does not always.
e. Periodically unplug the charger from the wall outlet and turn on the Aurora 9® to check the battery level; disconnect the battery at 100%. To avoid damaging the batteries, do not over-charge.

❑ Z-Boat batteries

a. Charging instructions are printed on the batteries.
b. Connect the three pairs of translucent connectors (attached to cables labeled Charge) and connect to the red and black wires on the Powerizer chargers.
c. Switches next to those red and black wires should be switched to 1-8A
d. Connect chargers to wall outlet and flip switch on back of Powerizer to start charge.
e. Lights on front of Powerizer will flash and then turn solid red
f. The battery is fully charged when all 3 lights turn green; monitor lights to avoid over-charging batteries.
g. Disconnect each terminal from charger when the light turns green.
h. Put a piece of tape on the batteries and write the latest charge date on each tape label when all 3 terminals are fully charged.

❑ Field PC laptop (Panasonic® Toughbook)

a. Plug in the charger to the laptop.
b. Connect the charger to an outlet.
c. The light on the computer with battery symbol will change to green when the battery is fully charged.
d. Ensure the computer is shut down between uses to avoid battery drain before the survey.

❑ Marine battery to run the inverter

a. Clamp battery booster charge cables to the battery terminals (black to - and red to +; left panel in Figure B-1).
b. Set the top switch on the charger to the two AMP/12 Volt option (middle panel in Figure B-1).

c. Set the lower switch on the charger to the 12 VOLT option (middle panel in Figure B-1).
d. Plug the charger into wall outlet.
e. Note: the Battery is charged when the indicator points to "charged" (right panel in Figure B-1).

Figure B-1. Marine battery being charged (left). Settings for battery charger (middle). Battery charge indicator (right).

8.1.2 Prepare for the Survey in the Field

Once all of the equipment is loaded onto the support vessel and the team members and equipment have transited to the site, follow these instructions to set up the equipment for the field survey.

PHYSICAL SET-UP FOR Z-BOAT:

- ❑ Adjust the Z-boat on the cart to provide enough **vertical clearance** to attach the propeller and SeaTrac system.
- ❑ Push down the **Emergency Stop** button (see Figure B-2, red circle) to prevent the propeller from turning.

Figure B-2. Emergency stop button (circled).

- ❑ Feed the **propeller** through the rings at the stern of the boat and tighten the top ring. Plug the propeller cable into the receptacle in the boat hull (see Figure B-3).

Figure B-3. Detail showing how to plug propeller cable into the receptacle in the boat hull.

- ❑ Ensure the propeller is centered and able to turn in both directions. See alignment example in Figure B-4.

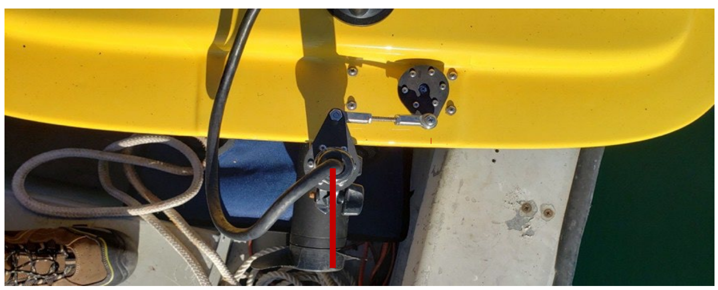


Figure B-4. Centering the propeller.

- ❑ Screw in **one female omni-directional antenna** into the left rear receptacle on the boat hull, see Figure B-5.

Figure B-5. Detail showing one female omni-directional antenna in left rear receptacle.

- ❑ Check that the cable connected to the antenna inside the boat is attached to the port labeled "**Bluetooth**" on the Z-boat computer (red circle, Figure B-6).

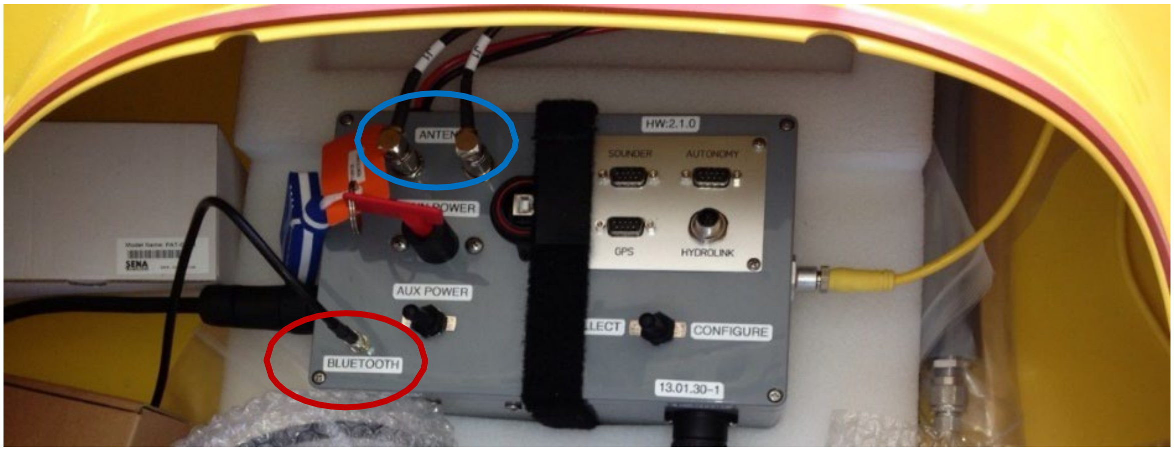


Figure B-6. Antenna (blue oval) and Bluetooth (red oval) connections.

- ❑ Screw in **two male antennas,** one to the front left, and one to the front right port. These antennas receive the signal from the remote controller.
  - ❑ One antenna should be angled **horizontally**,
  - ❑ The other should be angled **vertically** (see Figure B-7; note in this picture, a larger long-range antenna is in use in the vertical position).
  - ❑ Check that interior cables are connected to the ports labeled "**Antenna**" on the Z- boat computer (see Figure B-6, blue selection).

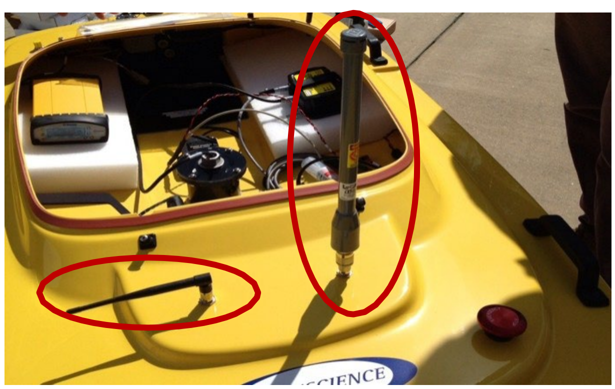


Figure B-7. Antenna examples of horizontal and vertical configurations.

  - ❑ Ensure **CEEPULSE Echosounder** is in the boat (see Figure B-8, left rear, red)

- ❑ Ensure CEEPULSE is connected to the **transducer** (attached to floor of boat) (see Figure B-8, blue).

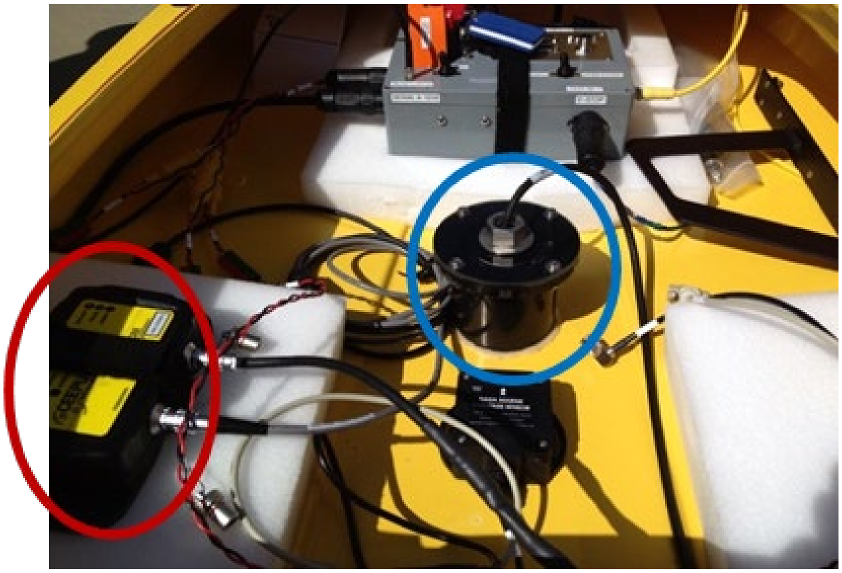


Figure B-8. Red circled area shows the CEEPULSE echosounder; blue circled area shows the CEPULSE transduver.

- ❑ Ensure that the power/data cable is connected from the echosounder to the "**Sounder**" port on the Z-boat computer (see Figure B-9).

Figure B-9. Detail of the "Sounder" port to which the CEEPULSE echosounder power/data cable must be connected.

- ❑ Ensure the **compass** is attached to the Z-boat floor behind the transducer (see Figure B-10).

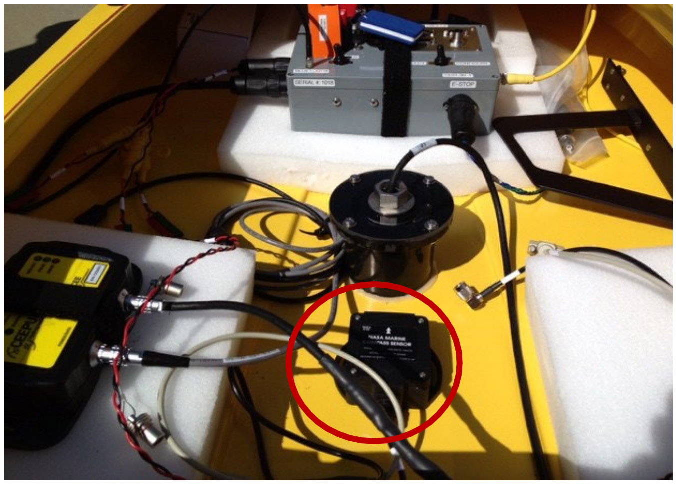


Figure B-10. Detail of the compass attachment to the Z-boat floor (red circle).

- ❑ Check that the compass is connected to the "**Autonomy**" port on the Z-boat control system (see Figure B-11).

Figure B-11. Autonomy port highlighted in red, to which the data cable from the compass must be connected.

- ❑ **Install the battery pack** at the front of the boat and use Velcro® to secure it in place.
- ❑ **Attach Discharge power cables** from the battery pack to three red and black connectors on the Z-boat computer (do not use the translucent charge connectors).
- ❑ Connect the white **GPS antenna** to top of the boat hatch (see Figure B-12).
  - ❑ Connect the **J1 end of the GPS cable** to the white antenna.
  - ❑ Connect the **J2 end of the GPS** cable to rear right port.

Figure B-12. White GPS antenna attached to the top of the boat hatch, with the GPS cable connected to the antenna and rear right port.

- ❑ Ensure the cable is attached to the inside of the rear right port that is connected to the "**GPS**" port on the Z-boat computer.
- ❑ Ensure the **GPS power lines** (red and black that were previously twisted together) are connected to the interior right rear port. Confirm that all of these are connected to the power (Aux 12-Volt out).

❑ Attach the red/green **lights** to the bow of the Z-boat (with the red lights toward port and green lights toward starboard) and the white **light** placed to the stern of the Z-boat with their built in suction cups; see Figure B-13 showing two views detailing the placement.

- ❑ Also tie a **line to each of the lights** (in case the suction cup comes loose).
- ❑ **Check that the lights work**. Replace batteries if needed.

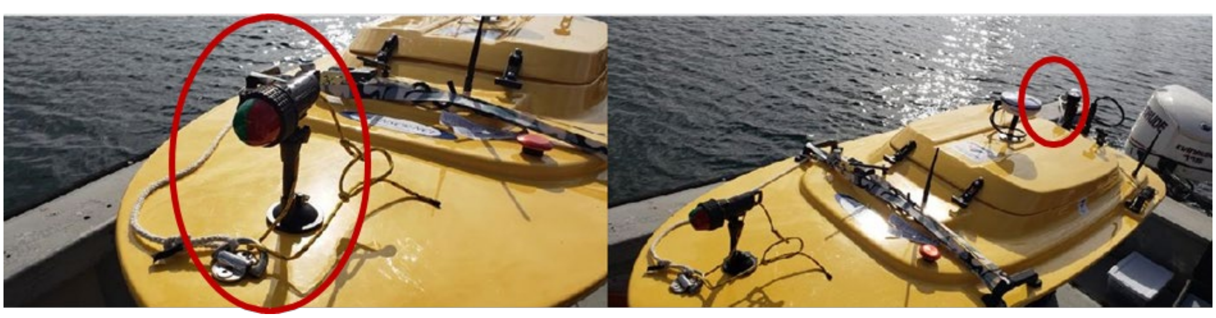


Figure B-13. Detail showing the attachment of red/green lights to the bow of the Z-boat (left), and white light to the stern of the boat (right).

- ❑ Install the battery pack into Aurora 9 radio controller, and close the cover.

SET-UP OF THE SEATRAC ACOUSTIC POSITIONING SYSTEM:

Hemisphere directional GPS:

- ❑ **Clamp inverter** + and – terminals to the marine battery, place it in a dry location in front of large Pelican case used to store the laptop and cables.
- ❑ Set up the **Toughbook** laptop on top of the large pelican case.
- ❑ **Set up the power strip** to the side of the laptop, connect it to the inverter *(use an **extension cord** if needed)*.
- ❑ Place the large directional **Hemisphere GPS** antenna in an appropriate location on the support vessel, with the long axis along the bow-stern of the vessel. Confirm the port connecting to the power/data cord is facing the stern; see the Hemisphere Manual (Appendix D-6) for detailed guidance.
  - ❑ *Mount securely using mounting hardware, zip ties, etc. if needed.*
- ❑ Connect the multi pin side of **Hemisphere cord** to port on the Hemisphere.
- ❑ Plug the **Hemisphere power supply** into power strip.
- ❑ **Connect the Hemisphere GPS to the Toughbook** (or other off-network field laptop) using a USB cable.

The below steps should not be required for subsequent surveys after the initial setup:

- ❑ *To identify which COM port is in use by Hemisphere:*
  - ❑ *Open the Device Manager.*
  - ❑ *Expand the list of Ports.*
  - ❑ *Look for the "USB serial port" and note the port number.*
- ❑ *To set up the Hemisphere GPS to communicate to the computer (only required once):*
  - ❑ *Open the PocketMax4 program.*
  - ❑ *Set the connection type in the software to Serial.*
  - ❑ *Set the Port to COM7 (or another Port if steps above show a different Port).*
  - ❑ *Set the Mode (to AutoBaud to cycle through baud rates and Baud Rate to 19200), as of this writing, 19200 was correct Baud for Hemisphere 103 unit in use for this demonstration.*
  - ❑ *Click Connect.*
  - ❑ *The window should show "Connected! Com 7 @ 19200".*
  - ❑ *Select the configuration method – The Quick Config method is recommended.*
  - ❑ *Change settings if needed:*

- ❑ *Under "PortA[THIS]" tab – set these inputs to 1Hz: GPRMC, GPGLL, GPGGA, GPGSA, GPGSV, GPHDT.*
- ❑ *Click the "x" at the top of the main window to close.*
- ❑ *Select "Save Settings" and Disconnect.*

SeaTrac acoustic tracking system (logs position of Z-boat independently of Z-boat GPS system):

PHYSICAL SETUP:

- ❑ **Mount the topside X150 beacon** (X150 beacon is the larger of the three SeaTrac beacons, see Figure B-14) to the specialized bracket using two stainless steel screws found in the SeaTrac pelican case. Note that the triangular tooth on the bracket without screw-holes should sit on the metal portion of the beacon. This allows the green flashing light on top of the beacon to be viewed from above to confirm that the beacon is working (when plugged in and turned on).

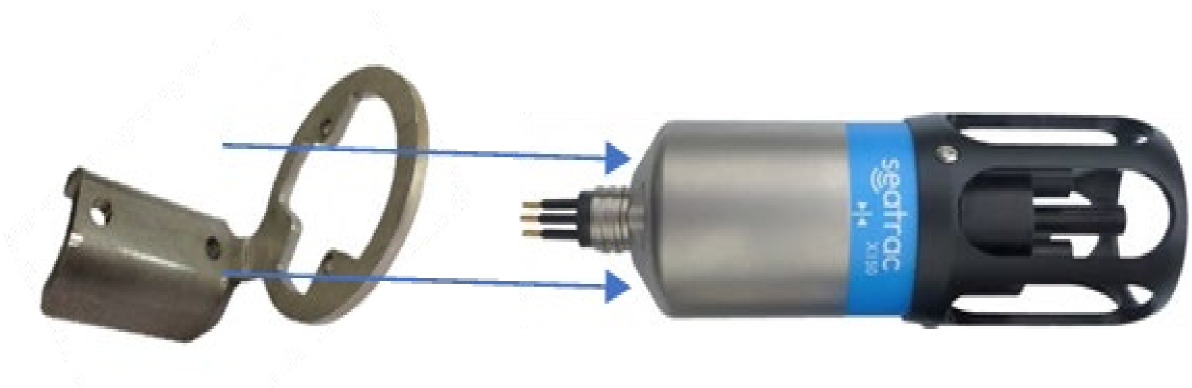


Figure B-14. Detail showing how to mount the topside X150 beacon.

Connect the multipin side of SeaTrac topside cord to the X150 beacon (leave it powered off until ready (beacons are water-cooled and may overheat if left working in the air too long).

- ❑ **Mount the topside SeaTrac beacon-attachment system** (wood, large PVC pipe, metal bracket) to the attachment point on the starboard side of the support vessel using two C- clamps.

- ❑ The PVC pole should be in the **"up" position**, above the water, held up with the bolt through the pole that rests on top of the wood system (see Figure B-15).

Figure B-15. Detail of how to mount the topside SeaTrac beacon-attachment system.

- ❑ Connect the SeaTrac **topside modem to Toughbook computer** using the serial to USB connector (COM5 port on the Toughbook)
- ❑ **Connect the mounting system for the diver beacon (X110)** to underside of Z-boat
  - ❑ Insert a fully-charged **battery into the waterproof pod** and thread the cable from the top of the T-shaped PVC mount out at the bottom.
  - ❑ **Connect the X110 to the cable**. (When connected correctly, a green light will flash on top of the X110.)
  - ❑ **Orient** the X110 with >|< symbol facing the bow of the Z-boat, and the black portion of the beacon X110 facing "downwards" from the bottom of the T shaped mount.
  - ❑ **Insert the battery pod** into the pipe clamp, with the base facing the bow of the Z-boat, and tighten the clamp.

- ❑ Use Duct Tape to secure the X110 beacon so that the **entire black portion** of the beacon sticks out of the PVC T-mount. Do not obscure the black part of the beacon with tape.
  - NOTE that there are two X110 beacons, labelled "2" and "3" with permanent marker. The PinPoint software is currently set to use beacon "2", but can be changed to "3" if needed. *If the permanent marker labels become obscured, the identity of the beacon can be obtained by counting the short green LED blinks on top of the beacon when it is plugged into a battery pack.*

Figure B-16. The X110 beacon.

- ❑ **Secure the beacon mount** to the underside of the Z-boat by threading the straps through the front handles on the Z-boat and tightening with the ratchet, see Figure B-17.

Figure B-17. Detail showing threading the straps through the front handles on the Z-boat and tightening with the ratchet.

- ❑ The gray arms of the mount should be along the bow-stern line of the Z-boat, with the **beacon symbol oriented toward the bow**, see Figure B-18.

Figure B-18. Z-boat beacon mounting system, with the gray stabilizing arms of the mount facing the bow and stern.

MEASURE TEMPERATURE AND SALINITY OF WATER ONCE ONSITE (OR OBTAIN SALINITY FROM ANOTHER SOURCE, SUCH AS NOAA WEBSITE):

- Please reference the manual/quick-start checklist in CastAway-CTD® box for instructions to use.
- CastAway-CTD® should be used to collect salinity and water temperature at several locations (at least 3) through the entire water column around the survey site. Enter below:
  - ❑ Salinity: Temp:
  - ❑ Salinity: Temp:
  - ❑ Salinity: Temp:

These data entries will be used to correct the bathymetric data to account for changes in water density and therefore time-of-travel of acoustic pings.

SEATRAC SOFTWARE SETUP:

❑ **Power on the** Toughbook laptop.

❑ **Open PinPoint software** on the Toughbook ("run as Administrator" is recommended) *The below settings should be remembered by Pinpoint between surveys; if no changes are needed, setup steps can be skipped, see Figure B-19.*

- ❑ *Go into Settings (Note: the gear icon at bottom left, may be slightly cut off on the screen).*
- ❑ *Click the wrench tab (see Figure B-19).*
- ❑ *Set up topside Beacon ("SeaTrac Device"): Baud rate 115200, select appropriate Com port** (COM5 as marked on Toughbook/bin lid organizer).*
- ❑ *If you don't know the COM port, find the port using the "Device Manager".*
- ❑ *Set up incoming NMEA - GPS unit ("Hemisphere"): Baud rate 19200, COM7 (as above, change if needed).*
- ❑ *Set up outgoing NMEA ("NMEA Output Device") to log data - COM15, baud rate 4800.*
- ❑ *Select the checkmark to save your updated settings.*

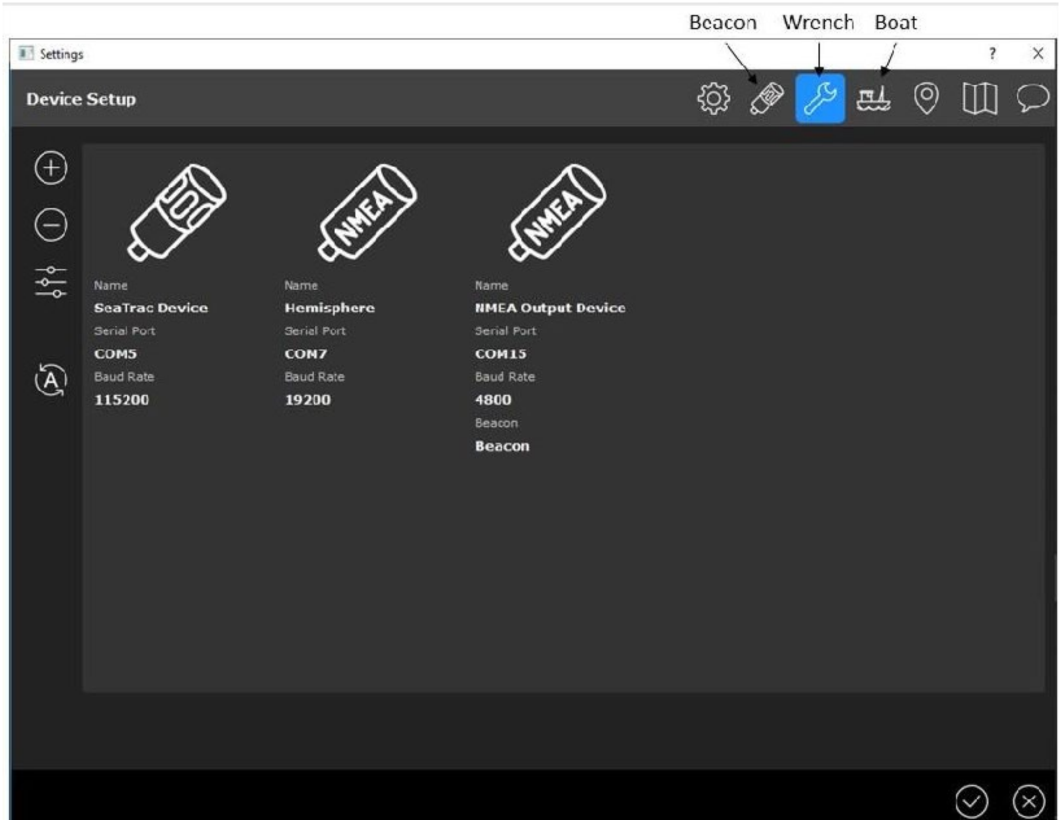


Figure B-19. Configuration settings in the PinPoint software on the Panasonic Toughbook®.

Set Salinity for the survey:

- ❑ **Go into Beacon tab** (Under settings, second icon from left at top; see Figure B-19).
- ❑ **Double-click the local (X150/topside) beacon** to open a settings window (see Figure B-20).
- ❑ **Set the salinity** to match the conditions (from the conductivity-temperature-density [CTD] cast data above, or NOAA website).
- ❑ **Keep the velocity of sound setting to auto**. (The velocity of sound will be calculated using this salinity and the real-time temperature measured by the beacon.)
- ❑ **Click the check mark** to save.

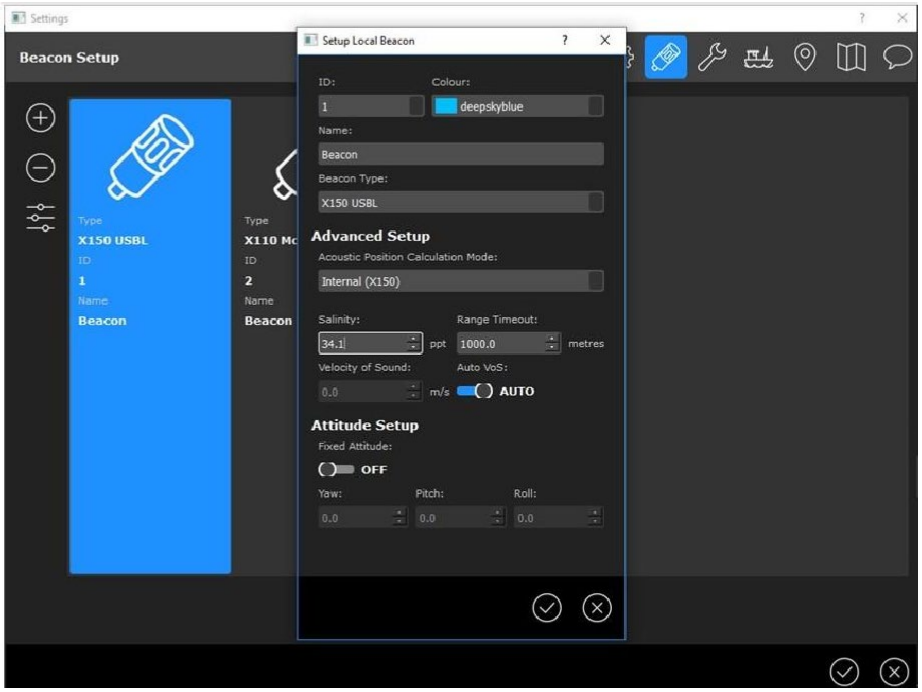


Figure B-20. Configuration settings in the PinPoint software on the Toughbook, example two.

To change beacon ID, if needed:

- ❑ *Double-click the diver beacon (X110) to open a settings window. Select beacon ID 2 or 3 (see the physical mark on the beacon – ensure this matches the ID that is shown with the light-blink sequence when the beacon is powered on; if using 2 beacons for some reason, you will need to add another beacon using the "+" on the left of the main beacon screen).*
- ❑ *Click the check mark to save.*

Set up offset - Hemisphere physical position and topside beacon physical position on boat (if different from past surveys).

- ❑ *Measure the x and y distance between the Hemisphere GPS and the topside Beacon as is shown Fgure B-21. Orientations: x is along the bow-stern axis and y is along the port- starboard axis, see Figure B-21. If you are facing the bow, X-direction is towards bow (+) or stern (-), and Y- direction is towards port (-) or starboard (+). Record these distances on the datasheet.*
- ❑ *Select the boat button on the top of the settings window. Select the satellite button on the left to setup the location of the Hemisphere GNSS receiver in relation to the origin. The Hemisphere position should generally only have an x-value if measurements are conducted as detailed in the diagram in Figure B-21.*

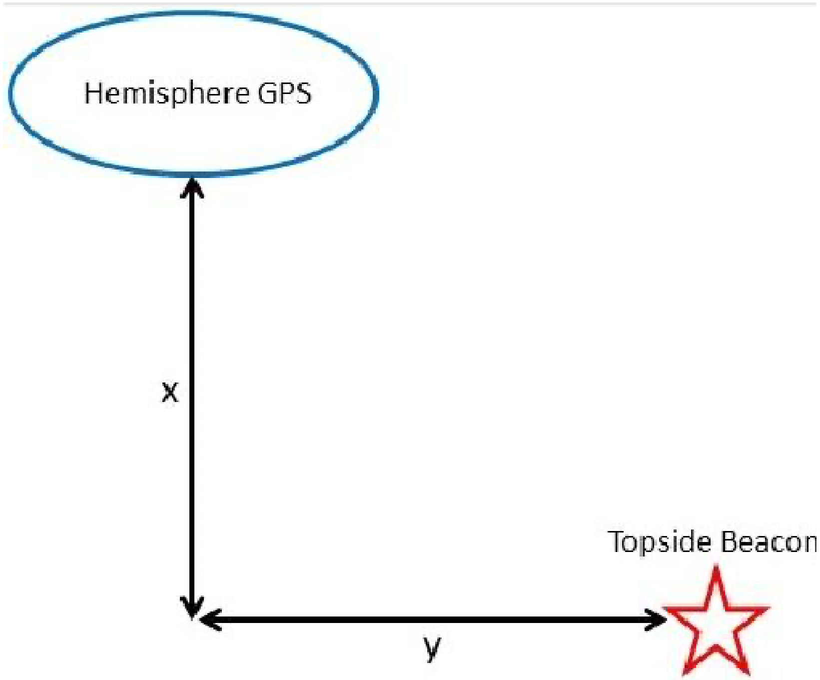


Figure B-21. Detail on the hemisphere position.

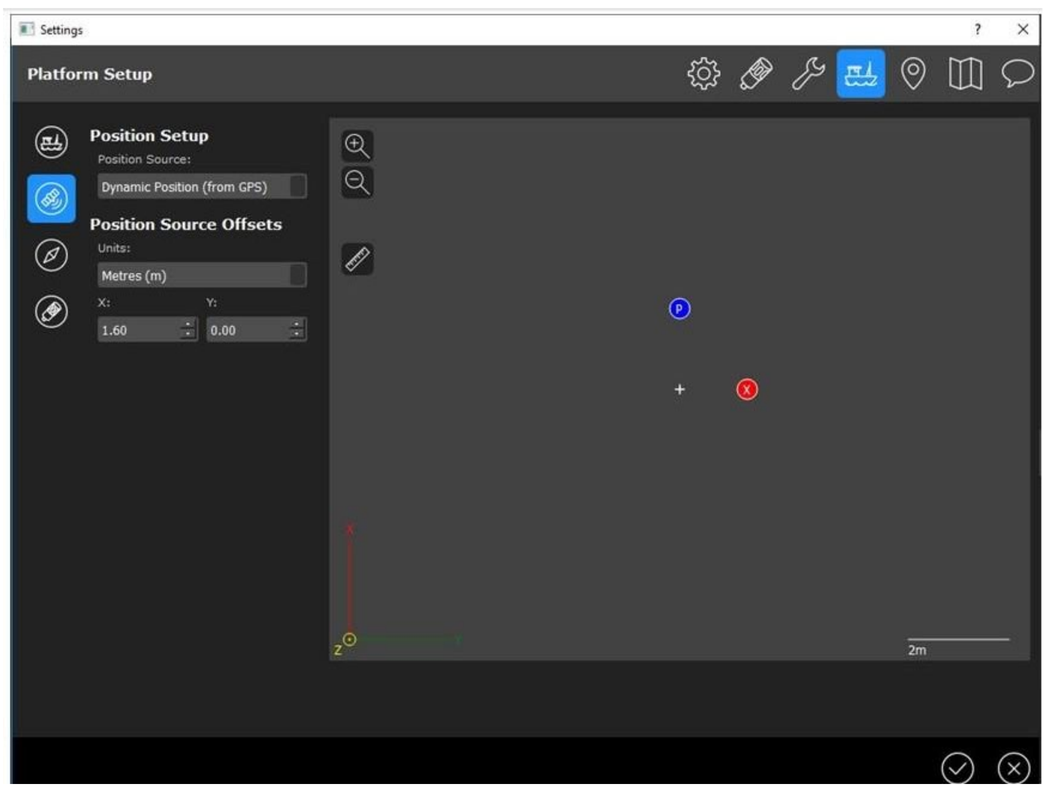


Figure B-22. Configuration settings in the PinPoint software on the Toughbook, showing entry for Hemisphere GPS information.

- ❑ *Select the beacon button on the left (bottom option) to setup the location of the topside modem (X150) in the same way as the setup for the GNSS (Hemisphere). The beacon position should only have a y-value if measurements conducted as shown in Figure B-22.*
- ❑ *Check that the positions of the Hemisphere and Beacon look correct based on their positions on the boat. The blue circle labeled P is the position of the Hemisphere and the red circle labeled X is the position of the topside Beacon, see Figure B-23.*

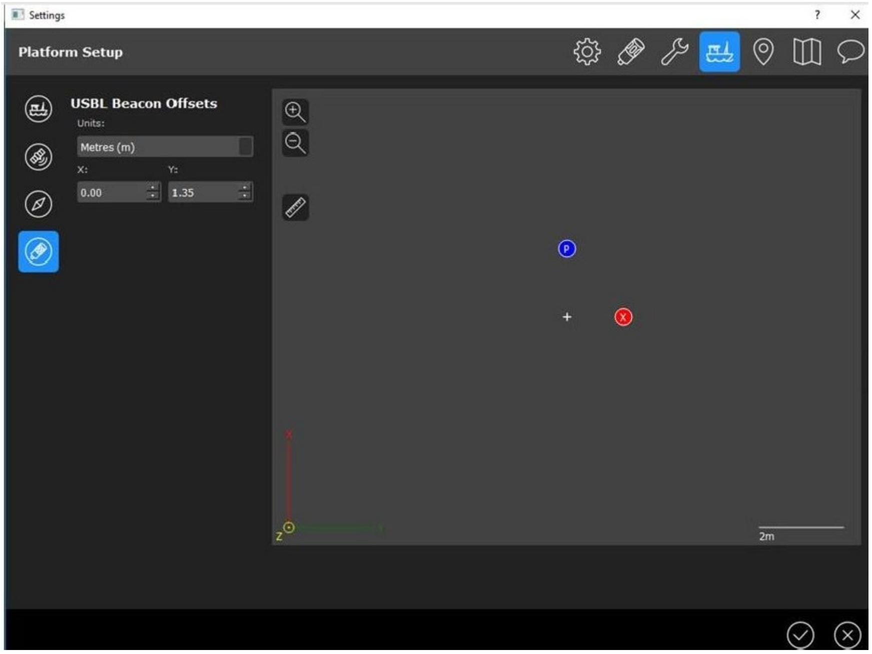


Figure B-23. Configuration settings in the PinPoint software on the Toughbook, showing entry for topside beacon information.

- ❑ *Click checkmark at bottom of settings screen to save and exit settings*

(Note: The GNSS/beacon offset is a little weird and might need to be adjusted/rotated. It may be set up in relation to North and could be affected by the orientation of the Hemisphere unit – this needs to be better tested and refined. As long as correct offset measurements are taken during a survey, this can be adjusted later when the SeaTrac .PPlog files are played back for export.)

- ❑ Once all settings are complete in PinPoint, **click the checkmark** button to close the settings window.

COMPLETE Z-BOAT SETUP:

- ❑ After the above steps are completed, **turn the boat on in the following order (IMPORTANT):**
  - ❑ Switch from **Configure to Collect**
  - ❑ **Turn on the Aurora 9 radio controller,** pushing the central silver slider up.
    - o The left joystick controls steering, while the right controls speed (forward and backward).
    - o Settings should not need to be changed, but reference the manual if needed.

TURN AUX POWER ON

TURN MAIN POWER ON

- o Lights on the CEEPulse® echo sounder should start flashing.
- o Ensure that Active and Bluetooth lights are flashing (see Figure B-24 for location of the lights).
- o If Yellow Standby light is lit, the Z-boat won't collect depth data. Press the mode button until the **Active and Bluetooth lights flash**.
- ❑ **Secure the cover** to the top of the Z-boat

Figure B-24. CEEPulse light configurations: good and bad examples shown.

TURN ON BOW AND STERN LIGHTS

START SURVEY ONCE ONSITE:

- ❑ **Lower the topside beacon into the water**: when onsite for survey: lower the PVC pole holding the X150 into the water, and bolt it in place. NOTE that the >|< symbol on the X150 should face the bow of the support boat. Make sure the PVC pole is oriented correctly.

LAUNCH Z-BOAT

- ❑ Two people, wearing life-vests, should launch the Z-boat from the Whaler using the handles, taking care not to damage the propeller, skeg, or SeaTrac beacon.
- ❑ Once Z-boat is launched and personnel are clear of the propeller, the **Emergency Stop button must be pulled up** to allow the propeller to work.

START SEATRAC POSITIONING

- ❑ Plug in the power to the topside beacon.
- ❑ Click the top left button (that looks like a Wi-Fi signal) in PinPoint to start Pinpoint reading in GPS positions for the support boat, and to start the topside beacon communicating with the diver beacon. If beacons are not in the water and/or GPS is not connected, this will prompt an error message.
- ❑ Click the "folded map" button (left) in PinPoint to monitor the topside and diver beacon data in real-time.
- ❑ Confirm that PinPoint shows the boat/GPS position (blue dot) and Topside beacon (arrowhead symbol) at the expected location on the map (see below)
- ❑ Ensure that the status of Beacon 1 intermittently flashes to "Reply OK #2" and is not constantly flashing "Reply FAIL #2" or "Pinging #2" (see Figure B-25)
- ❑ **Confirm** that the location of the X110 beacon/Z-boat also shows up on the map (as a differently colored arrowhead)
- ❑ **Ensure** that the track of the X110 beacon/Z-boat is being plotted on the map with a "snail trail" (see below) and is in expected position. See note below if this track is not visible.

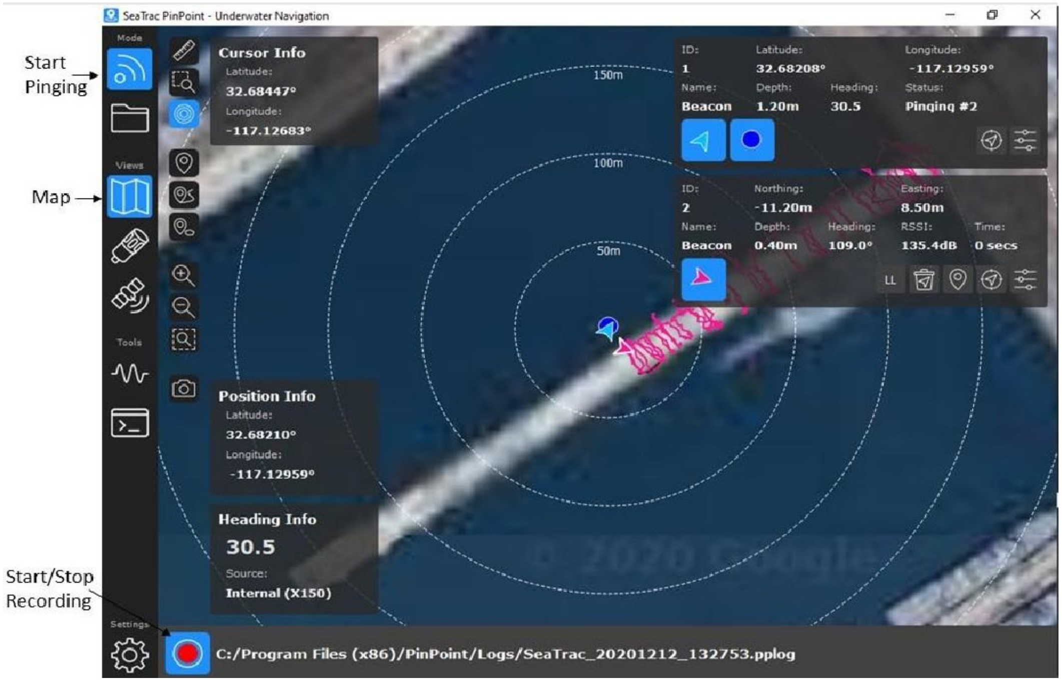


Figure B-25. The status of Beacon 1.

- ❑ Once the above are confirmed, start logging SeaTrac data:
- ❑ **CLICK the red log button** at the bottom of screen just to the right of the settings wheel. NOTE drag the whole screen up if this button is not visible.
- ❑ **Confirm** that the SeaTrac data are recording: look for a filename to the right of the record button with the date/time that the recording started, filetype .pplog (see Figure B-25).
  - o During the survey, the support boat should be oriented such that the topside beacon will face the Z-boat as much as possible during operation, and moves along with the Z-boat as possible. The beacons work by line-of-sight, so obstructions like pilings will prevent them from communicating, and it will be very challenging for the Z-boat operator to drive the boat if they cannot see it well. SeaTrac beacons will continue to communicate underneath camels and oil booms.

Note: If the X110/Z-boat trail is not appearing on screen, ensure the "Maximum Fit Error" option is not set to zero. Open settings, go into the Beacon tab, and select the Remote beacon in use. Under "Position Filtering", check if "Maximum Fit Error" is set to zero, and change this setting to 100 if so.

COLLECTING DATA DURING SURVEY:

- ❑ Try to maneuver the Z-boat **out from under the pier** as often as possible to get a GPS fix.
- ❑ The following information should be **recorded on the datasheet** during the survey:
  - Date and time setup started, time survey starts, time survey ends.
  - Names of survey team involved.
  - Water temperature and salinity from the CTD (read off screen).
  - Weather observations.
  - Times associated with the above setup steps, particularly related to turning on/off data recording equipment.
  - Physical measurements of the support vessel setup (relative location and orientation of Hemisphere, topside SeaTrac beacon, laptop).
  - Physical measurements of the Z-boat setup
    - Vertical distance from water level to bottom of the vessel, where Sounder is located.
    - Horizontal distance between SeaTrac beacon and top-mounted GPS unit.
  - Times the Z-boat was at a position that can be checked against groundtruth information (i.e., edge of pier), and position details describing location.
  - Times the Z-boat is completely under the pier, and times it has sky-view. Figure B-26 shows an example of the Z-boat at the edge of a pier when it may or may not have sufficient sky-view to receive a GPS signal.
  - Drawings/sketches of the survey track completed on a printed map.
  - Any other information the survey team considers may be relevant for data processing and reporting.
- ❑ While conducting a survey, keep an eye on the Z-boat **battery levels** on the screen of the Aurora 9 radio controller so that you do not run out of power. The boat will start being very sluggish when it is low on power (usually around 11 V, see Figure B-27).

Figure B-26. The Z-boat conducting a survey near the edge of a pier.

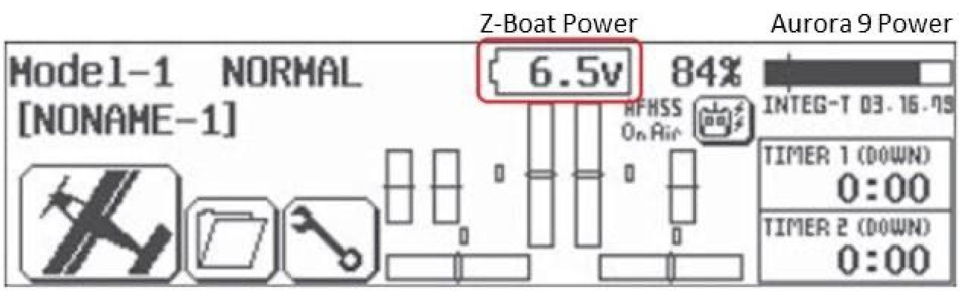


Figure B-27. The battery levels on the screen of the Aurora 9 radio controller shown above.

ENDING SURVEY/BREAKDOWN:

- ❑ **Stop logging dive tracker data** in PinPoint software by clicking Red Record button again.
- ❑ Close the software, **close computer.**
- ❑ **Unplug** USB cords, **turn off power strip.**
- ❑ **Power down inverter**, remove inverter clamps from marine battery.
- ❑ Drive Z-boat **back to main boat.**
- ❑ **Push emergency stop** button on top of boat before retrieving from water.
- ❑ **Retrieve boat** and place on cart.
- ❑ Open hatch, **turn off Aux and main power**, close hatch.

TURN OFF AURORA 9 REMOTE CONTROLLER

REMOVE BEACON MOUNT

- ❑ Remove the **diver beacon and battery pod** from their mount.
- ❑ **Re-plug** in the diver beacon to the battery pod or use a dummy plug to cover the electronic connections, and place in **fresh water** to soak or rinse thoroughly.

PULL UP TOPSIDE X150 SEATRAC BEACON

- ❑ Once removed from mounting pole, **place X150 in fresh water**, (still plugged into the whip) to soak, or rinse thoroughly. Use a hand-towel dampened with freshwater to wipe down the portion of the whip that was submerged/salty, ensuring the plug-ends of the whip stay dry.
- ❑ **Dry beacons** with a hand-towel, then disconnect the whips. Place in a safe location where they will not be damaged and ensure all connector ends are protected from water (by placing in a dry box or using dummy plugs).

UNPLUG HEMISPHERE

- ❑ Carefully **coil and store** SeaTrac whip, Hemisphere whip, power cord, and extension cord in dry box.
- ❑ At end of day, wash and/or sponge off all salt on boat and equipment **with freshwater.**
- ❑ **Make sure the equipment is dry** before it is placed into Pelican cases, etc. for transfer to the lab or storage area.
  - ❑ In the lab or storage area, **leave Pelican cases propped open** for complete drying overnight.
  - ❑ **Download Z-boat data** onto field computer (see steps to do this in "Data download and conversion" section)
  - ❑ **Remove batteries** for recharge and/or storage:
    - ❑ SeaTrac Beacon battery (1)
    - ❑ Aurora 9 batteries (2)
    - ❑ Z-boat batteries (3)

Data download & conversion:

<u>Day of survey</u>

- ❑ Create a **folder** on the field laptop specific to the survey completed. Save all data to this folder.

DOWNLOAD DATA FROM Z-BOAT:

- ❑ Z-boat power should be **off**.
- ❑ Switch from **Collect to Calibrate**
- ❑ Turn Aux Power on and Main Power on

- ❑ Plug **USB-firewire cable** into the computer's USB port and boat's firewire port.
    - ❑ If the computer asks to repair the drive, select **No**.
  - ❑ Navigate to E:// drive.
  - ❑ **Open each of the survey files** starting with the latest one (note that the modified dates will not be correct).
  - ❑ **Check for the date** on lines in file marked "GPZDA" (one type of NMEA sentence that is stored in the files); confirm correct date.
  - ❑ **Copy files** from the correct date to computer from Z-boat
  - ❑ **Eject E:// drive** and then **unplug** cord
  - ❑ **Turn off** Z-boat Aux power and main power (then **remove battery**).

When convenient, using field laptop

- ❑ **Export SeaTrac** files from proprietary .pplog format to NMEA and KML formats:
  - ❑ Open SeaTrac **PinPoint software**, set to map view.
  - ❑ **Click the folder button** on left, navigate to the .pplog file from survey.
  - ❑ **Play** through the **entire file**. You can increase the play speed to 16x, and scrub through most of the file, but *you must let the program play out the last section of the file at least* (you can't scrub all the way to the end; (you must let the last bit play out).
  - ❑ Once done playing, **click the export button** on the bottom, near the right side. Use the window that opens to export the file in **NMEA format** and then do the same for **KML** format, saving into the folder set up in step 1.
  - ❑ *NOTE that if the setup of the Hemisphere/topside beacon relative to the origin was not entered correctly during setup, this can be adjusted, and then the .pplog file can be played through again. This will correct the output files with the adjusted setup information.*
  - ❑ Save any photographs, if collected, from camera onto laptop, see Figure B-28.

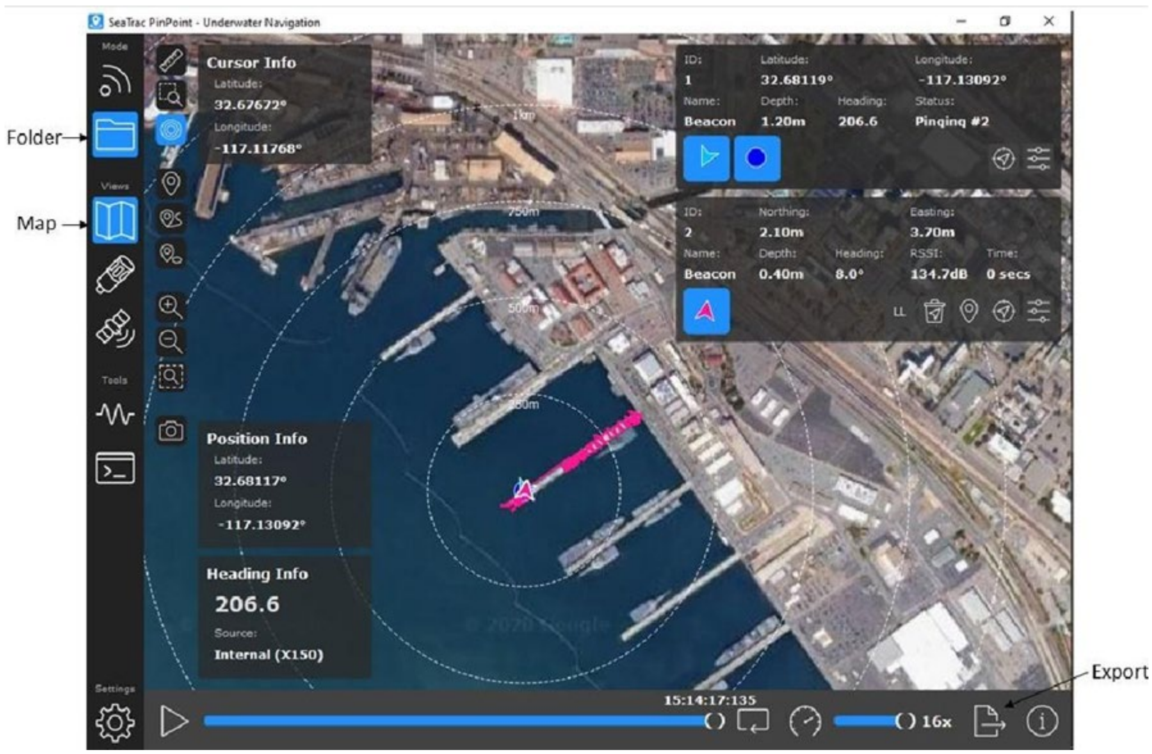


Figure B-28. Output file example.

Z-BOAT AND SEATRAC DATA PROCESSING

Overview

The goal for the bathymetry surveys is to measure depth (z), as related to a fixed vertical datum, as a function of position (x,y). Both the Z-boat and the SeaTrac data, stored in National Marine Electronics Association (NMEA) sentence format, can be combined to relate depth to position. This section will outline the data processing steps conducted to create x,y,z format datasets from which bathymetric maps/DEMs are created. Data was processed using MATLAB® for National Environmental Satellite Data and Information (NESDI) project 572, but other data processing programs such as R could be used as well. The most common projection used in coastal U.S. data is the State Plane system, so position was converted from latitude and longitude (as reported by the Z-boat and SeaTrac systems) to feet easterly and northerly compared to the origin in California (CA) State Plane 6.

NMEA Format

The NMEA-format data files used for this project contain one NMEA sentence per line (row), and each sentence contains multiple pieces of information, separated by commas, after an initial header that indicates the format of the information in the sentence (Table B-1). The files are structured as continuous logs of data that are recorded from the various sensors reporting information; for example, the Z-boat files contain data from the GPS, depth sensor, and compass, interwoven together over the period of the survey as these sensors reported data to the onboard computer. For example, if the depth sensor measured depth at a sampling rate of 10 Hz, the GPS at a rate of 1 Hz, and the compass at a rate of 0.5 Hz, then a 4 second portion of the survey log file might contain:

- GPS position and associated timestamp 1
- Depth measurements 1-10
- GPS position and timestamp 2
- Heading 1
- Depth measurements 11-20
- GPS position and timestamp 3
- Depth measurements 21-30
- GPS position and timestamp 4
- Heading 2
- Depth measurements 31-40

Both the Z-boat data files and the SeaTrac data files contained additional NMEA sentences than those used for this project. To ensure that the correct order was retained for data extracted from the NMEA sentences, the lines of data (rows) were numbered and these values retained during all data processing steps.

Relevant NMEA sentences from Z-boat and SeaTrac outputs are shown in Table B-1.

Table B-1. Relevant NMEA sentences from Z-boat and SeaTrac outputs.

Relevant Metric	NMEA sentence	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8
Z-boat Time, Lat/Lon	$GPGGA	Time position was recorded. Format: hhmmss.ss	Latitude. Format: ddmm.mmmm	N or S for degrees north or south	Longitude. Format: ddmm.mmmm	E or W for degrees east or west	Fix type. 2=DGPS fix		Horizontal Dilution of Precision (HDOP)
Z-boat date and time without location	$GPZDA	Time position was recorded. Format: hhmmss.ss	Day	Month	Year				
Z-boat bottom depths	$SDDBS	Depth in feet	f indicating feet	Depth in meters	M indicating meters	Depth in fathoms	F indicating fathoms		
SeaTrac Time Lat/Lon	$GPRMC	Computer time. Format: hhmmss		Latitude. Format: ddmm.mmmm	N or S for degrees north or south	Longitude. Format: ddmm.mmmm	E or W for degrees east or west		

- Fields are separated by commas in text output file.
- Grayed-out fields indicate other fields not relevant to this project or not used by the NMEA sentence.

Bathymetry file processing

- ❑ Load Z-boat NMEA file into Matlab or program of choice. Reading in the file as a table makes it easy to pull out the relevant data.
- ❑ Remove all lines containing NMEA sentences OTHER THAN $GPGGA, $GPZDA, and $SDDBS. Note that the early lines in each of the surveys do not contain any data in the sentences. When looping through the lines to pull out the data in the following steps, skip any lines that are missing data.
- ❑ Get times from the data.
  - o Find the $GPZDA lines and convert the times to the datenumber format of your choice along with their associated line.
  - o Search for any times that occur before the start or after the end of the survey.
  - o Save a time matrix with only times during the survey and their associated line numbers from the full NMEA file.
- ❑ Extract bottom depth (z) from the data.
  - o Save a depth matrix with the depths in feet (or your chosen units, see Table B-1) and their associated line numbers from the full NMEA file.
  - o Remove all depths from your depth matrix that do not occur during the survey window based on the line numbers of the time data.
  - o Determine times for each depth measurement by linearly interpolating the timestamps using line numbers. In MATLAB®, this looks like:
    DepthTimes=interp1(TimeLines,Times,DepthLines)
  - o Plot a scatter plot of the depths to identify outlier points.
  - o Look at the scatter plot (see Figure B-29) and if there are any clear outliers high above or below the trend of data, set outlier thresholds (Look at the lower part of Figure B-29 where red is used to indicate outlier depth measurements). These thresholds will be unique for each survey. Figure B-29 is an example from Pier 1.
  - o Remove outlier depth measurements.
  - o Correct depths for tides using observed water height measurements (or predicted tides where observed measurements are not available) relative to mean lower low water (MLLW). Be sure to obtain data with the same depth units as selected above from the Z-boat NMEA files.
    - ▪ Download values from a NOAA tide station. At NBSD, NOAA tide station 9410170 was nearby, so we used measured water height from there.

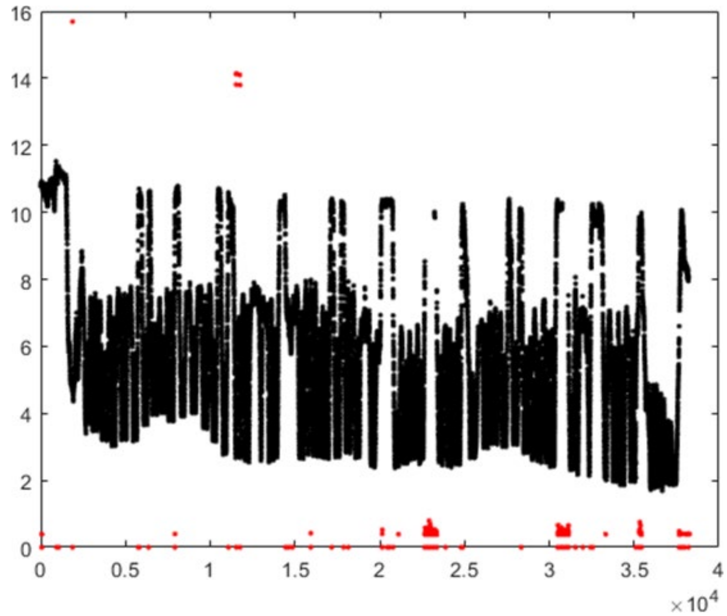


Figure B-29. The scatter plot of raw depth measurements with outliers in red.

- Convert the measured depths from the Z-boat into bottom heights relative to MLLW at the time of each depth measurement. Figure B-30 shows a schematic of how measured depths relate to the fixed vertical datum of MLLW.

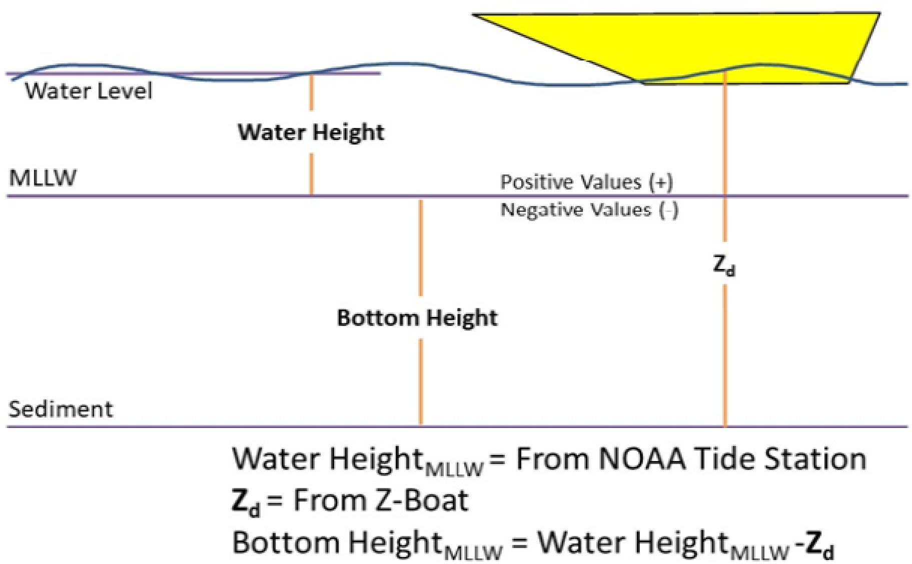


Figure B-30. Water height and bottom height example from Pier 1.

- Plot a scatter plot of depths relative to MLLW to visualize the adjusted data. Example from Pier 1, see Figure B-31.

- To reduce measurement errors, calculate the running average depth for each depth time. Calculate the median of all depth measurements +/- 0.5 s for each depth time.

❑ Get estimated Z-boat locations from the GPS

- The $GPGGA lines contain time of day, (but not the date). Convert the time into a full datenumber
  - Use the start time (without date) of the survey to find the elapsed time since the start of the survey of each GPGGA line.
  - Add the elapsed time to the full datenumber start of the survey to get the full date and time in numerical format of this line.
  - Correct times by adding 1 day if a survey crossed over a UTC date boundary. This can be determined by checking if the timestamp on this line is more than 1 hour before the start of the survey; in that case, these timestamps crossed over into a new day and need to be corrected.

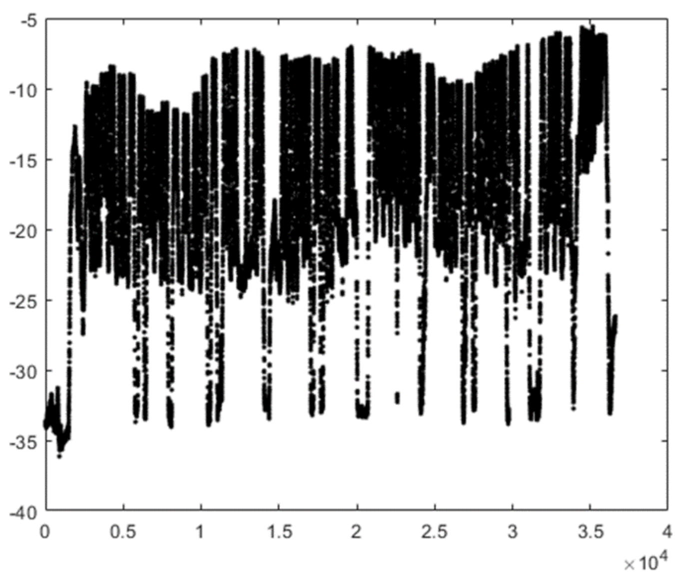


Figure B-31. Scatter plot of depths relative to MLLW.

- Skip any lines that do not contain high-quality GPS positions
  - High-quality positions were selected as those that were determined with differential GPS (DGPS) (Table B-1).
  - High-quality positions were selected as those that also had a horizontal dilution of precision (HDOP) value less than 2 (considered “excellent”) (Table B-1).
- Convert all resulting high-quality positions from latitude and longitude into state plane. NBSD is in CA State Plane 6. Now positions are in x, y and in units of feet.

- Save a matrix comprised of a times, locations, and their associated line numbers from the full original NMEA file.
- Remove all times/locations from the matrix that do not occur during the survey based on the line numbers of the time (ZDA) data.
- Filter the positions based on acceleration to remove inaccurate positions that did not get removed with the above GPS checks.
    - Calculate the speed required to get between subsequent positions.
    - Calculate the difference in subsequent speeds (as a proxy for acceleration). Although different operators may drive the boat at different speeds, and certain piers allow for different speeds depending on obstacles present, the boat does not change speed quickly. Therefore, any high differences in speed are suspicious.
    - Iteratively remove the second set of x,y coordinates that caused the first instance of a speed change of greater than 2 m/s (6.56 ft/s). Recalculate speeds and the difference in speed between points again. Continue to remove problem points until there are no more positions that would require unreasonably high acceleration by the Z-boat to get from one point to another. Note that the best speed difference threshold was determined by trial and error. Plot good positions and their elapsed times since the start of the survey with a colorbar. See Figure B-32 for an example from Pier 1. Observe that there are no good GPS-derived positions underneath the pier (estimated location shown with dashed box) and all points are along the edges of the pier. This is expected, because the concrete pier blocks GPS signal. In this example, the pier is below the plotted points because the boat was unable to exit the pier on the southeastern side.

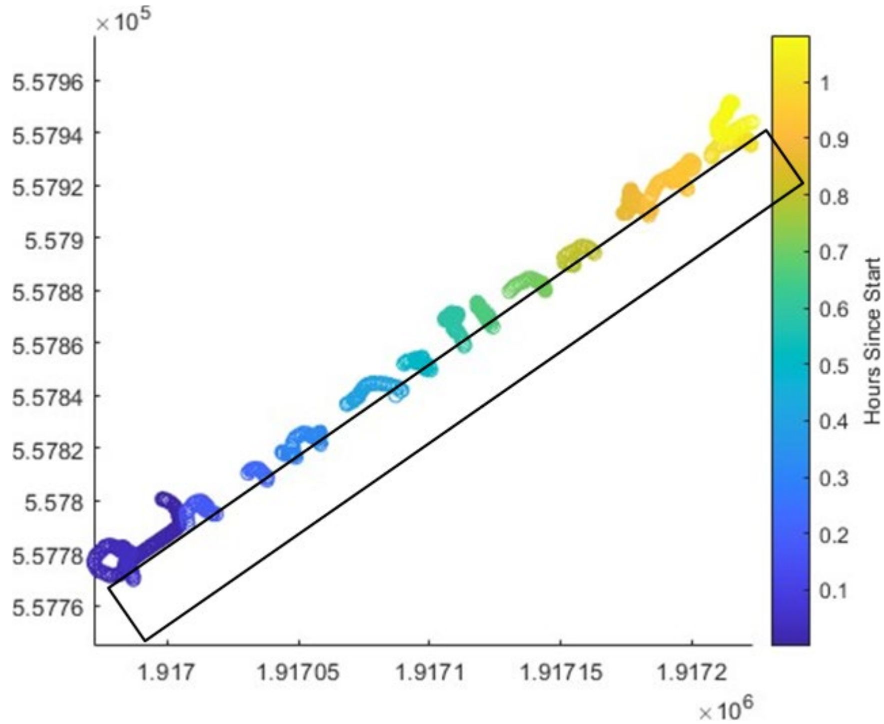


Figure B-32. Plot of good GPS-based positions and their elapsed times since the start of the survey with a colorbar.

- ❑ Use linear interpolation to estimate x,y positions associated with each depth value based on the Z-boat GPS positions only. Here is an example of the code syntax in MATLAB®:
  Depth_y=interp1(PositionTime,Position_y,DepthTime)
  Depth_x=interp1(PositionTime,Position_x,DepthTime)

Note that these interpolated positions for the depth measurements are only used for visualization and are not carried forward to the final dataset.

- o Plot depth with these interpolated positions using a colorbar. Note that because there are so few good GPS positions, there are many more depths than positions, so interpolated positions using GPS-only are very inaccurate. Figure B-33 shows a color bar example from Pier 1:

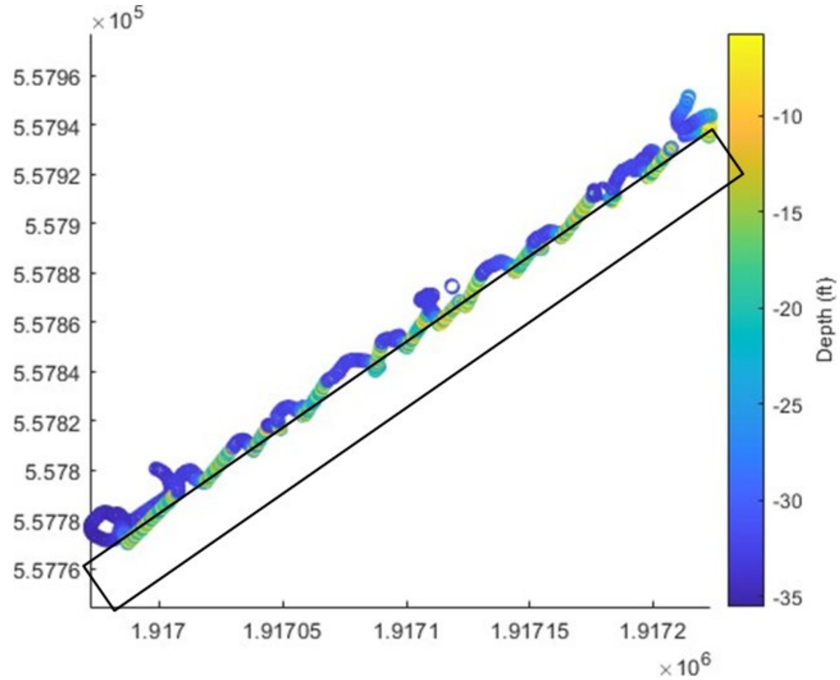


Figure B-33. Interpolated GPS-only-based positions associated with depths (colorbar).

- ❑ Retrieve estimated positions underneath the pier during survey from SeaTrac data.
  - o Load in SeaTrac NMEA in the same way that the Z-boat NMEA was loaded.
  - o Query the indices of all lines containing $GPRMC NMEA sentences.
  - o $GPRMC lines include timestamps but no date. Unlike the Z-boat data, these timestamps are pulled from the clock on the computer that was running the SeaTrac PinPoint software; therefore the timestamps are in local time. Convert the SeaTrac times to UTC so that all timestamps from SeaTrac and Z-boat GPS are comparable. Convert into datenumber format.
    - ▪ **IMPORTANT NOTE:** Since the computer used for these surveys does not continuously obtain an updated time (it was not connected to the internet during the survey), the SeaTrac timestamps needed to be adjusted to account for offsets between the computer clock and the "true" time reported by GPS satellites. This offset differed for each survey, and ranged from 0–25 seconds. The offset was estimated by trial and error (except for the most recent survey, which occurred after a computer update that began saving log files indicating the difference between the computer clock time and GPS time each time the computer was connected to the internet). In the future, to avoid dealing with this offset, the computer should be connected to Wi-Fi and the clock synced immediately before each survey day so that the

drift is minimal, or the software should be altered so that it is using the GPS time instead of the computer time. This second option would be better since the computer is already connected to GPS and this solution has been suggested to the SeaTrac company.

- o Query latitude/longitude position from SeaTrac and convert into State Plane as before. Note that there are no indicators in the SeaTrac datafiles about the quality of the position.
- o Make a matrix that contains the UTC time and x/y positions
- o Remove all lines that did not occur during the survey.
- o Filter the positions based on acceleration in the same way as the Z-boat GPS positions, to remove inaccurate positions.
- o Plot SeaTrac positions and their associated elapsed time since start of the survey with a colorbar. Figure B-34 is an example from Pier 1 (note that the time offset for this survey was –7 seconds):

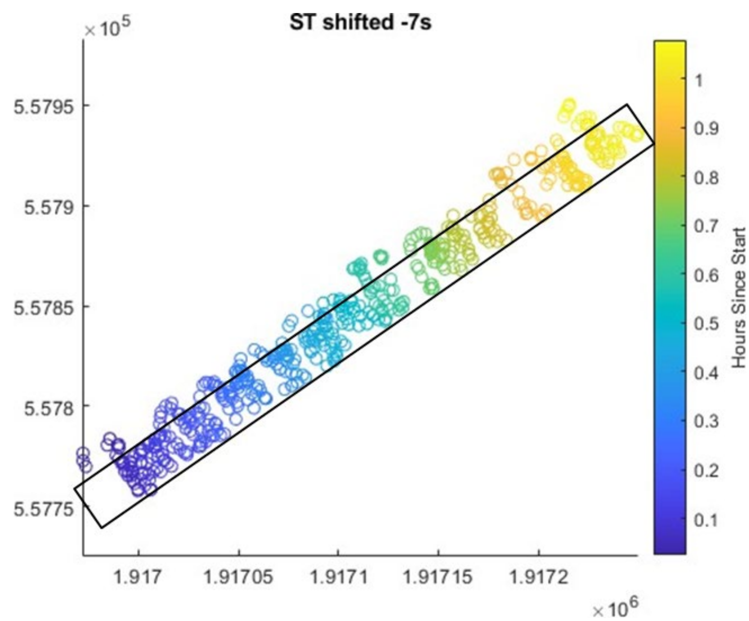


Figure B-34. Plot of SeaTrac-based positions and their elapsed times (with a 7 second adjustment) since the start of an example survey with a colorbar.

- ❑ Add Use linear interpolation to estimate x,y positions for each depth value based on SeaTrac positions only. This is done in the same way as for the GPS positions. Note that these interpolated positions for the depth measurements are only used for visualization and are not carried forward to the final dataset.
  - o Plot depth with SeaTrac-only interpolated positions, with a colorbar, See Figure B-35.

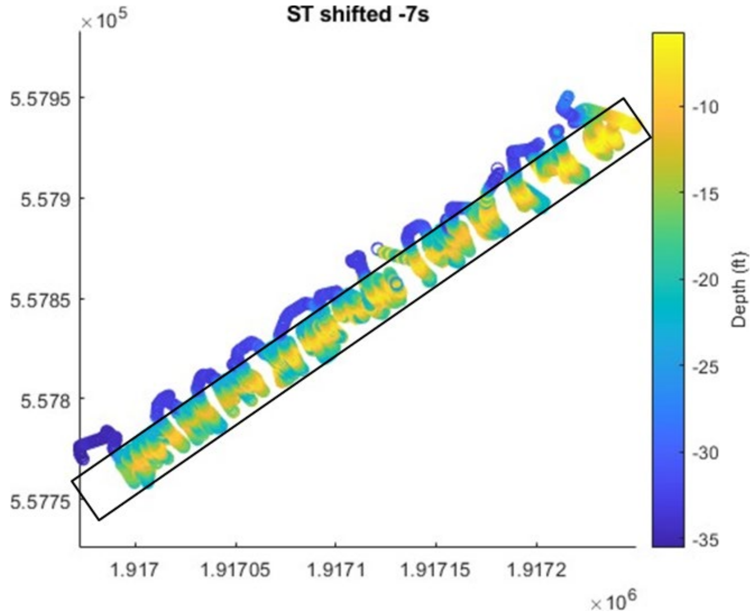


Figure B-35. Example of interpolated SeaTrac-based positions associated with depths recorded 7 seconds after positions, to account for error in SeaTrac timestamps for this survey (colorbar).

- ❑ Combine the locations from the Z-boat GPS and the SeaTrac to assign positions for each depth measurement.
    - o Remove all SeaTrac positions that were within three seconds of a GPS position. We assumed that when GPS was available and passed our quality checks, it should be the more accurate position. The three second threshold was based on trial and error and the fact that the SeaTrac sampling rate is 2 Hz.
    - o Combine the remaining SeaTrac positions and their associated times in a large matrix with the GPS positions and their times.
    - o Filter the combined positions based on acceleration in the same way as before to remove inaccurate positions
- ❑ Use linear interpolation to estimate x,y positions of each depth value based on the combined positions. This is done the same way as before.
- ❑ Remove depths that don't have a position within a certain time cutoff. We used three seconds based on the SeaTrac sampling rate of 3 Hz. This prevents over-interpolating positions to match depth values for periods without very many positions.
- ❑ Plot (1) position and time and (2) position and depth, see Figure B-36.
- ❑ Save the final xyz files as a .txt file. These files contain position (x,y) relative to CA State Plane 6 and depth (z) relative to MLLW. All units are in feet, see Figure B-37.

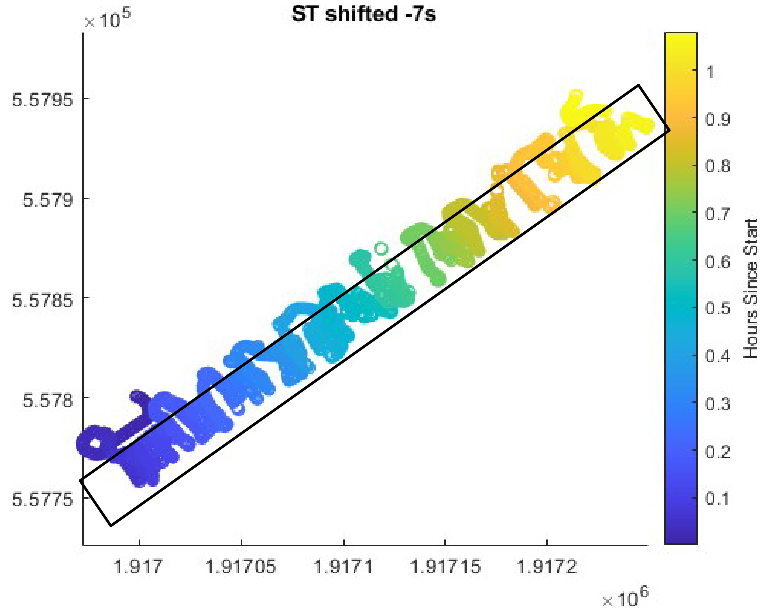


Figure B-36. Plot of combined GPS-based and SeaTrac-based positions (with a 7 second adjustment), colored by their elapsed times since the start of an example survey.

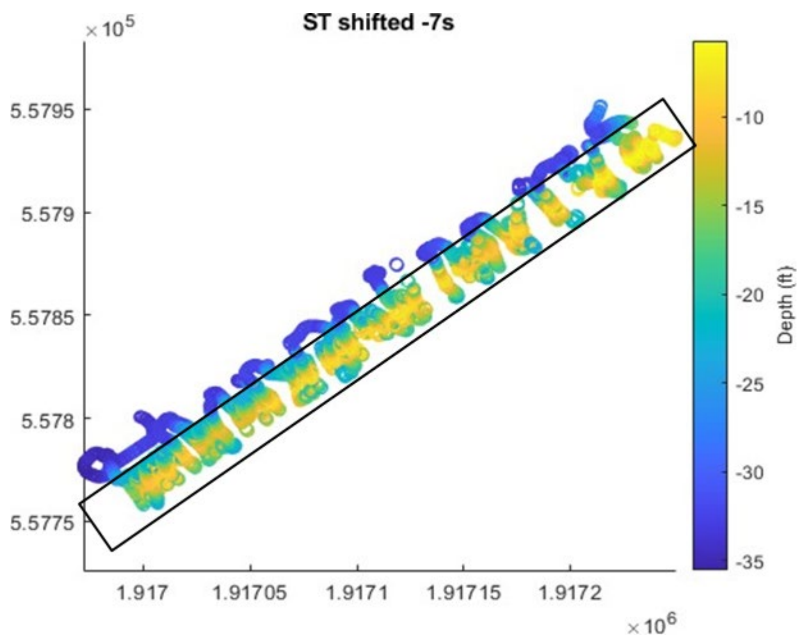


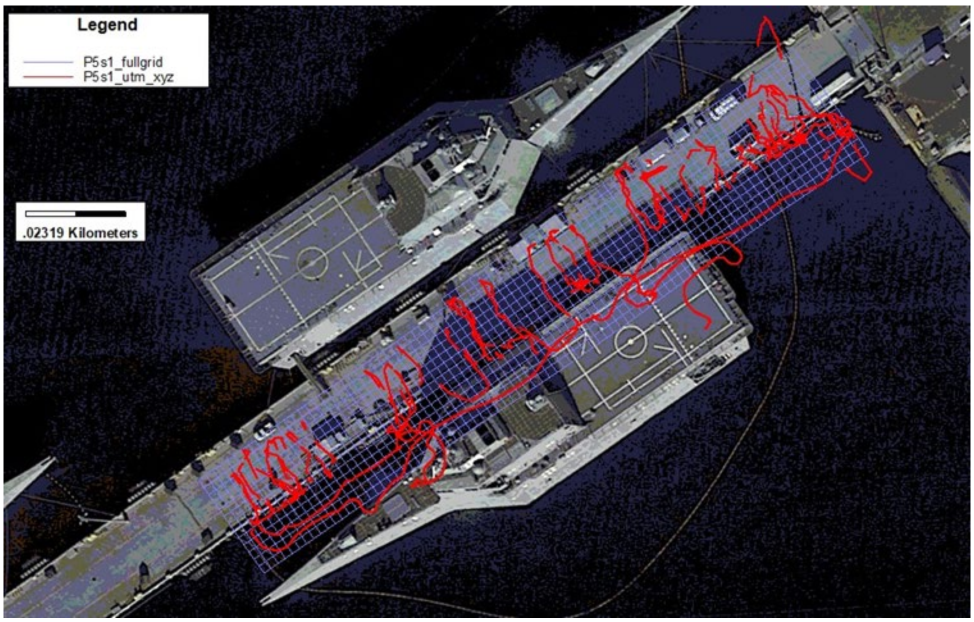
Figure B-37. Final plot showing Z-boat x,y positions using both GPS and SeaTrac positions, colored by associated depth (z) measurements.

BATHYMETRIC MAPPING AND VOLUME/CHANGE ANALYSIS

Bathymetric Maps

For this portion of the analysis, the x,y,z files produced from the above data processing steps are used to create seamless grid-based maps of the portion of the sediment under the piers surveyed. This involves the following steps:

- ❑ Using Environmental Fluid Dynamics Code (EFDC) Explorer Modeling Software (EEMS), generate a geo-referenced curvilinear orthogonal grid that tightly covers the Z-boat track for the survey. An example from Pier 5 is shown in Figure B-38:



- The resulting grids were populated with depth data in two ways.

Figure B-38. A Geo-referenced curvilinear orthogonal grid (blue) that tightly covers the Z- boat track (red).

Full grid interpolation

- ❑ To create seamless bathymetric maps by interpolating based on all existing data from the survey (without preferentially weighting data in the along- vs. across-pier axis; see Single column interpolation, below), generate a centroid data file by assigning depths to all grid cells that intersect the Z-boat survey path by calculating the average depth from all original x,y,z, data that intersect a given grid cell, for the entire multi-column grid.
- ❑ Remove the zero depth values generated (representative of missing data), producing a new x,y,z file with averaged depth for cells containing recorded data, and missing values for empty cells
- ❑ Assign this edited x,y,z file to an empty grid in EEMS.

Next, using inverse distance weight (IDW) interpolation, 3rd order (for the most smoothing) and five nearest neighbors to account for sparse data, assign depths to all grid cells, filling in the empty cells without depths yet assigned.

Single column interpolation

As an alternative approach, a single-column interpolation method was tested to force depths to be interpolated along, and not across, the long axis of the pier.

- The complete grid was separated into individual sub-grids, one cell wide, with the full length of the grid along the pier.
- For each sub-grid, along the length of the pier, import the single column grid in EEMS and assign the corresponding bathymetric depth from the final x,y,z files using average values. This generates centroid data points for the single column grid with depth values within each cell averaged, leaving empty cells where data was not populated.
- An example showing average depths assigned to grid cells (grays) that intersect the Z-boat track (colors) is shown in Figure B-39, for a single 1-cell-wide strip of cells along Pier 1.

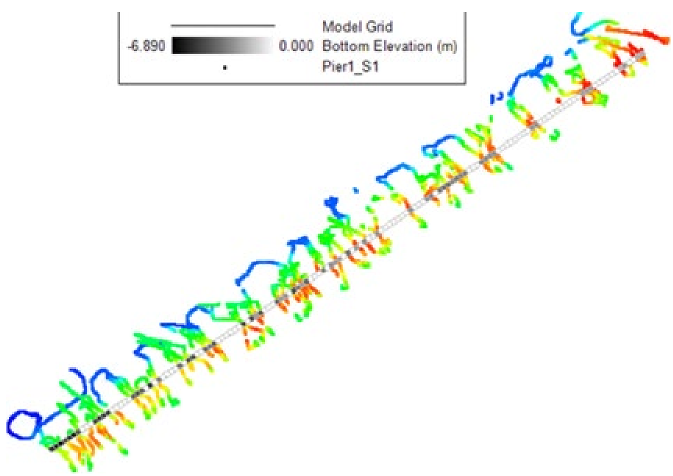


Figure B-39. An example showing average depths assigned to grid cells (grays) that intersect the Z- boat track (colors).

- Remove the zero depth values generated (representative of missing data), producing a new x,y,z file with averaged depth for cells containing recorded data, and missing values for empty cells (still for the same one-grid cell wide column).
- Assign this edited x,y,z file to an empty single column grid in EEMS.
- Assign depths to empty grid cells (that did not intercept the Z-boat track) using IDW interpolation, 3rd order (for the most smoothing), and drawing from the 5 nearest neighbors to account for sparse data. An example for a single 1-grid-cell-wide strip of cells along Pier 1 is shown in Figure B-40.

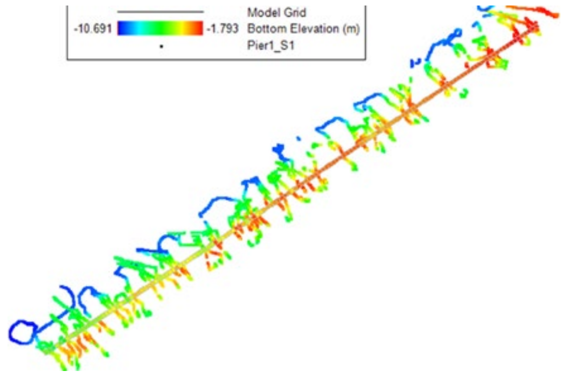


Figure B-40. An example of interpolated depths for a single 1-grid-cell-wide strip of cells along Pier 1.

- ❑ Repeat the above steps for each column of the grid.
- ❑ The resulting single column bathymetry files, now containing data for all cells in a given column (no empty values) are then concatenated into a single x,y,z file containing a single data point for each cell in the original complete grid.
- ❑ An empty original grid is then opened in EEMS and populated with the single cell values from the concatenated file, representing data which has been interpolated only along the pier axis.

For comparison, the completed seamless bathymetry map layers created using both methods described above for one of the surveys is presented below, with the full grid interpolation approach on the left and the single column approach on the right is shown in Figure B-41.

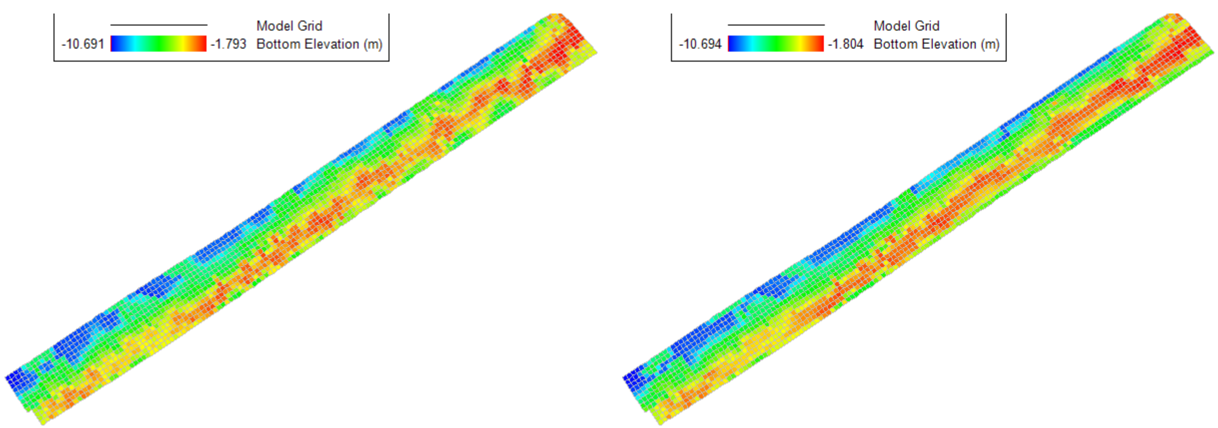


Figure B-41. Bathymetry map comparison using the full grid interpolation (left) versus single column interpolation (right).

Completing the maps

- ❑ To generate completed bathymetry maps, georeferenced aerial images were generated using CVL grid software in conjunction with data from Google Earth. In EEMS, the corresponding georeferenced images were imported to grids populated with the desired bathymetry, described above.
- ❑ Similarly, the original x,y,z data points were again imported as *.txt files in a separate layer in EEMS and colored a neutral color such as gray or black to show the track that the Z-boat took for data collection.
- ❑ Images were then generated by EEMS software to combine the three layers (aerial imagery, seamless bathymetric map, and Z-boat track). An example of a completed map is shown in Figure B-42.

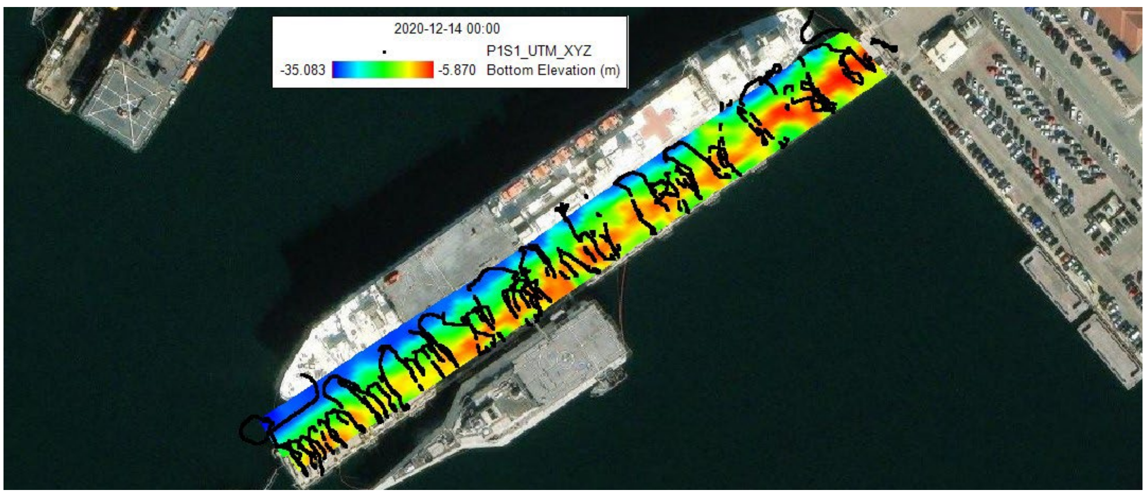


Figure B-42. EEMS software result of combining three layers (aerial imagery, seamless bathymetric map, and Z-boat track).

VOLUME ANALYSIS

For this portion of the analysis, the amount of sediment that could theoretically slump into an adjacent dredged area is estimated. This involves the following steps:

- ❑ Calculate the area of each grid cell that was part of the bathymetric survey
  - o Calculate the area of each bathymetric grid cell from their coordinates **(2A = (x1y2 - x2y1) + (x2y3 - x3y2) + (x3y4 - x4y3) + (x4y1 - x1y4))**
  - o Export the position (relative x,y position within the grid), calculated grid cell area and depth of each grid cell to a spreadsheet.
  - o In the new spreadsheet, add a column and calculate the difference between the depth of the top of the sediment and the dredge design depth, in relation to MLLW. To do this, add the number of feet below MLLW that is the target for the dredge design depth to the depth value of each grid cell. For example,

if the dredge design depth is 30 feet below MLLW, add 30 to the depths of each grid cell. For an example grid cell with a sediment surface at -15 feet below MLLW, the resulting difference will be 15 feet.
  - For grid cells with depths deeper than the dredge design depth, the resulting differences will be negative. Set all negative differenced depths to zero.
  - Multiply the area of each bathymetric grid cell by the differenced depth to calculate the volume of sediment above the dredge design depth for each grid cell in a new column.
- ❑ Sum all of the volumes for all grid cells together. This is the volume of sediment under the portion of the pier surveyed above the dredge design depth.
- ❑ Estimate the proportion (by area) of the pier surveyed, vs. the entire pier area
  - Import the seamless bathymetric map into Google earth and using the polygon drawing tool to estimate the footprint of the map and the entire under-pier area.
  - Divide the area of the bathymetric map by the entire under-pier area.
  - The volume of all of the sediment under the entire pier (including the portion not surveyed) can then be estimated by extrapolating the relative amount of sediment/proportion of pier surveyed across the entire pier area by dividing the total volume of sediment by the proportion of the pier surveyed.
- ❑ Prior to this final step, the total volume of sediment under the pier estimated can be adjusted to roughly account for areas that are most likely over-extrapolated and appear shallower than is likely is reality. This can be done by counting the number of grid cells that fall outside the pier footprint within the overall survey grid but that appear to be shallower than the dredge design depth because of sparse survey coverage. Divide this number by the total number of grid cells in the overall map, and then subtract that amount of sediment from the total volume calculated above. Alternatively, if the volumes are arranged in a spreadsheet spatially, the grid cells that fall outside the pier can simply not be included in the volume calculation.

BATHYMETRIC CHANGE ANALYSIS

The final step for data processing involves differencing bathymetric maps from overlapping portions of each pier to assess whether slumping appears to have occurred between the time periods when each survey was conducted.

- ❑ Trim bathymetric maps from each survey to only include portions of maps that overlap/were created based on areas surveyed during both survey periods. This could either be done to include only grid cells where actual data were collected, or to also include interpolated portions of the maps between survey tracks (given that single-beam sonar only collects data over approximately 5% of the survey area, and for the rest of the area, depth is estimated by interpolation; see Army Corps of Engineers Engineer Manual EM 1110-2-1003).

- Calculate the difference in depths for each grid cell between the first and second survey by subtracting the depths of the first survey from the second survey depths.
- Values in this differenced file that are negative represent grid cells that were deeper during the second survey than the first (indicating erosion), while positive values represent cells that were shallower (indicating deposition).
- Produce a map to visualize the change in bathymetry with a bimodal colorbar, for example blue for negative changes (erosion) and red for positive changes (deposition) in EEMS and overlay on a georeferenced aerial image as described above.
- Visually identify locations in this change map that could represent areas of slumping – these would be most likely to occur near the sides of piers, where multiple adjacent grid cells all indicate erosion. However, be careful to select areas with reasonable data coverage in both surveys (visually assess both original bathymetric maps and the overlaid survey tracks), where changes are more likely to reflect actual change, and not simply differences resulting from interpolation errors where data are sparse.
- Using the area of each grid cell (calculated during the volume analysis step, above), and the depth differences in these apparent slump areas, calculate the total volume of change indicated in these potential slump areas.

APPENDIX B PART 2: UNDER-PIER SEDIMENT SAMPLING SOP

Standard Operating Procedures: Sediment Sampling

Flexible Under Pier Sediment Assessment
NESDI Project Number 572

September 15, 2022

8.2 INTRODUCTION

Sediment that accumulates underneath piers is typically difficult to sample due to the combination of tight spaces with tidal flows impeding the use of traditional oceanic sediment sampling instrumentation and methods. These sediment piles could be important sources of recontamination, and thus disregarding them because of sampling difficulties could be resulting in decreased remediation efficacy and increased costs. This document presents standard operating procedures (SOPs) developed under the NESDI 572 demonstration project "Flexible Under Pier Sediment Assessment" to collect sediment samples under piers using several different approaches. The Sediment Sampling Menu developed for this project provides an overview of sediment sampling methodologies, some of which may be more applicable than those used for this demonstration at other Navy sites, depending on site conditions.

This document presents SOPs developed for the use of two sampling methods, each using two different approaches, under piers at Naval Base San Diego:

Methods described:

1. Grab sampling using a mini ponar sampler
2. Core sampling

Approaches described:

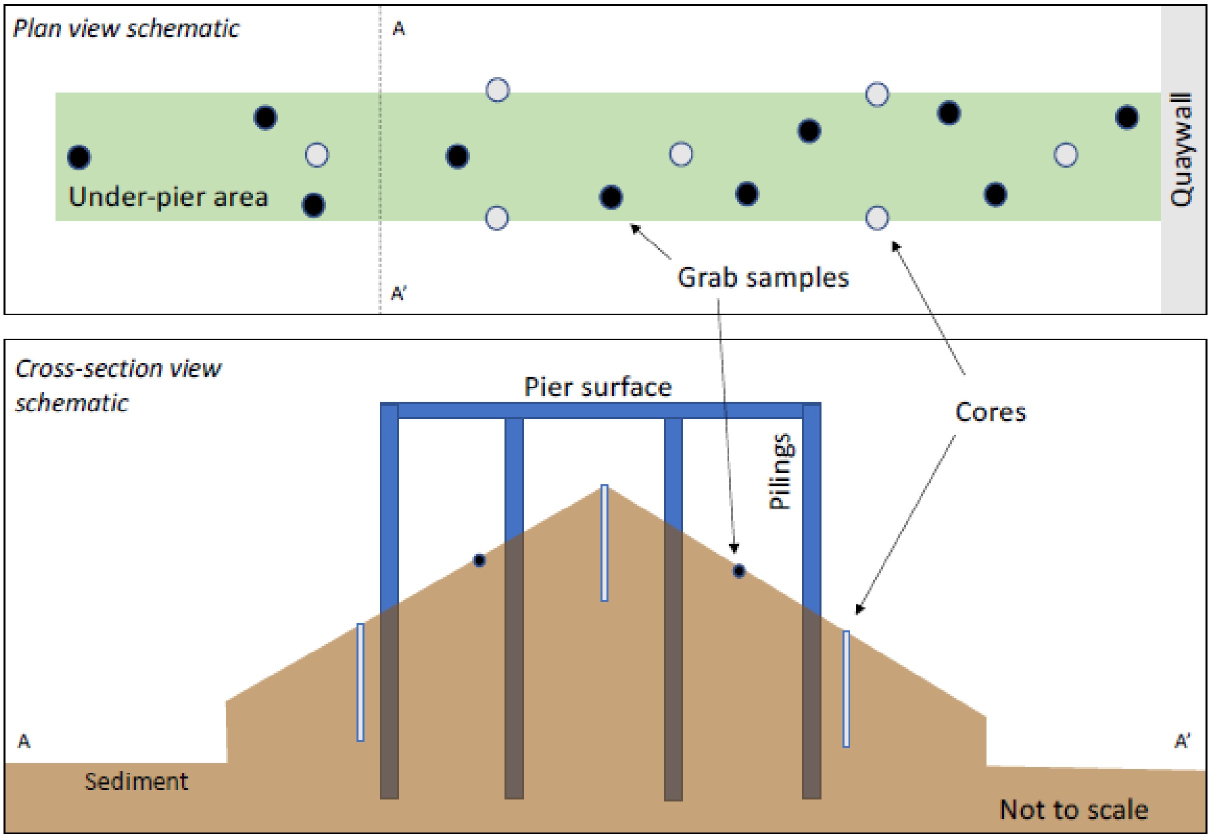
1. Deploying samplers through access panels from the tops of piers, with support from workers in small boats beneath the piers.
2. Deploying samplers from work boats from under the piers only, where access panels through piers were not available.

SAMPLING SCHEMATIC

For the NESDI 572 demonstration project, both core and grab samples were collected under piers at Naval Base San Diego (NBSD). For sampling projects such as this, a target sampling schematic should be developed to guide the in-field sampling and decisions about sample collection locations. The target sampling schematic should be designed following these general guidelines:

1. In cases where specific discharge locations are not suspected, the total number of samples to be collected should be relatively evenly distributed spatially under the pier. If possible, samples should be collected from as close to the central axis of the pier as is feasible, not just around the edges (Figure B-42).
2. Locations of pier through-holes, where sampling equipment can be utilized from the pier surface to collect samples in under-pier sediments can be pre-determined with a survey of the pier surfaces, or by contacting installation facilities personnel.
3. In cases where a specific discharge or hotspot is suspected, additional sample density should be used to delineate the extent of this site.
4. Funding constraints for sample analyses may influence how sample distribution is targeted. In this case, the preparation steps in Section 3.1 and 3.2 should be completed to inform the total number of samples that

should be collected. Schematic views demonstrating sediment sampling approach are shown in Figure B-43.



- From (Top) plan view (with quaywall/land to the right) and (Bottom) cross-section view (with quaywall/land to the back of the figure)..

Figure B-43. Schematics views demonstrating sediment sampling approach.

SAMPLE COLLECTION PREPARATION

The following section describes general steps that should be undertaken to prepare for under-pier sediment sampling and analysis.

Determine analyses to perform

Most sites will have existing sediment quality analyses from locations adjacent to piers associated with dredging projects or sediment investigations. These existing datasets should be reviewed to determine the contaminants of potential concern that should be analyzed in under- pier samples. Contaminants with elevated concentrations from past sampling should be included in the list of analytes for the under-pier sampling. For contaminants such as PCBs, the method of analysis for past samples should be determined so that new datasets can be compared (if desired).

In addition to contaminants, other sediment characteristics should be analyzed as well to allow full evaluation of the resulting dataset. This includes either sediment grain size analysis, or the analysis of metals such as aluminum and iron that vary with and can be used as a proxy for sediment grain size.

Analytical laboratory selection

Before samples are collected, an analytical laboratory (or laboratories) should be identified that will analyze the samples for all chemical and/or physical constituents required. For contaminants such as PCBs, a laboratory that can analyze samples to provide detailed information on individual constituents (congeners) should be selected, if possible, compared to laboratories that provide more generic data (Aroclors).

The testing laboratory selected should be contacted to confirm the amount of sediment required for the completion of all of the desired tests. For reference, Table 1 lists the typical minimum sediment volume needed for various types of analyses. Where possible, sediment should be collected in excess of the minimum stated by the testing laboratory to allow verification of results and/or to provide archive samples. The analytical laboratory should also confirm the appropriate sample container material (i.e. glass, high density polyethylene, etc.), as well as storage and shipping protocols (i.e., whether to freeze or chill the samples, whether the samples must be preserved chemically, etc.).

Table B-2. Typical minimum sediment volume requirements for various sediment analyses from U.S. EPA (2001).

Sediment Analysis	Minimum Sample Volume
Inorganic chemicals	90 mL
Non-petroleum organic chemicals	230 mL
Other chemical parameters (e.g., total organic carbon, moisture content)	300 mL
Particle size	230 mL
Petroleum hydrocarbons[1]	250-1000 mL
Acute and chronic whole sediment toxicity tests[2]	1-2 L
Bioaccumulation tests[3]	15 L
Benthic macroinvertebrate assessments	8-16 L
Pore water extraction	2 L
Elutriate preparation	1 L

1 The maximum volume (1000 mL) is required only for oil and grease analysis; otherwise, 250 mL is sufficient.

2 Amount needed per whole sediment test (i.e., one species) assuming 8 replicates per sample and test volumes specified in USEPA, 2000d

3 Based on an average of 3 L of sediment per test chamber and 5 replicates (USEPA, 2000d).

Sample field data sheet preparation

Field data sheets shall be prepared ahead of each sampling event, designed to collect general information about the site, weather conditions, etc., and specific information about each sample.

The following information will be documented during a given sampling event:

- Type and identification of sampling platform (vessel) used
- Identification of the GPS device

- Names of field team
- Photos and sketches of sampling area, as appropriate
- Ambient weather conditions
    - Wind speed and direction
    - Wave heights
    - Current
    - Tide
    - Air and water temperature
    - Vessel traffic
- Sediment collection devices to be used
- Sampling container preparation steps

Each sample collected will be documented using field sheets that include entries for the following:

- Project title
- Time and date of collection
- Sediment collection type (core/grab) and device
- Sample number, replicate number
- Site name, station number, and GPS coordinates
- Water depth
- Sample penetration depth
- Notes about sample quality including length and appearance of cores or grabs
- Description of sediment
    - Texture and consistency
    - Color
    - Presence of biota or debris
    - Presence of oily sheen
    - Presence and description of smell, if any
    - Sediment characteristics that change with depth, if observed
- Notes about any unusual events which might have affected the sample or deviations from standard operating procedures
- How the sample will be preserved and stored
- Analyses to be completed on the sample

Equipment preparation

All necessary equipment for sample collection must be obtained, either from existing equipment stocks or by purchasing required items.

Determine target sampling stations

Target sampling stations should be identified ahead of any field efforts to collect samples, to guide the fieldwork and maximize efficiency. A tour of pier surfaces can be conducted ahead of any sampling events to identify locations around the pier where access covers can be removed and allow access to the underlying water and thus sediments from the top of the pier.

Other considerations that may drive selection of target sampling sites includes existing datasets from past sediment investigations in nearby areas, or suspected discharge locations that could have been historical sources of contamination. For example, at NBSD, prior sediment assessment work has found higher concentrations of contaminants closer to the quaywall, with concentrations decreasing towards the ends of the piers. Interpolation between samples can result in artificially elevated contaminant concentrations when sampling has limited spatial scope.

Therefore, additional sampling coverage would be desired around locations with elevated concentrations of contaminants. Near real-time field analytical screening procedures can be applied to small sub-samples of each collected sample, to identify locations where additional sampling would be desired. Figure B-44 indicates the piers at NBSD targeted for sediment sampling for this project. Higher-density sampling will thus be targeted closer to the quaywall, to allow better constraint of spatial variability in contaminants, based on expected concentrations.

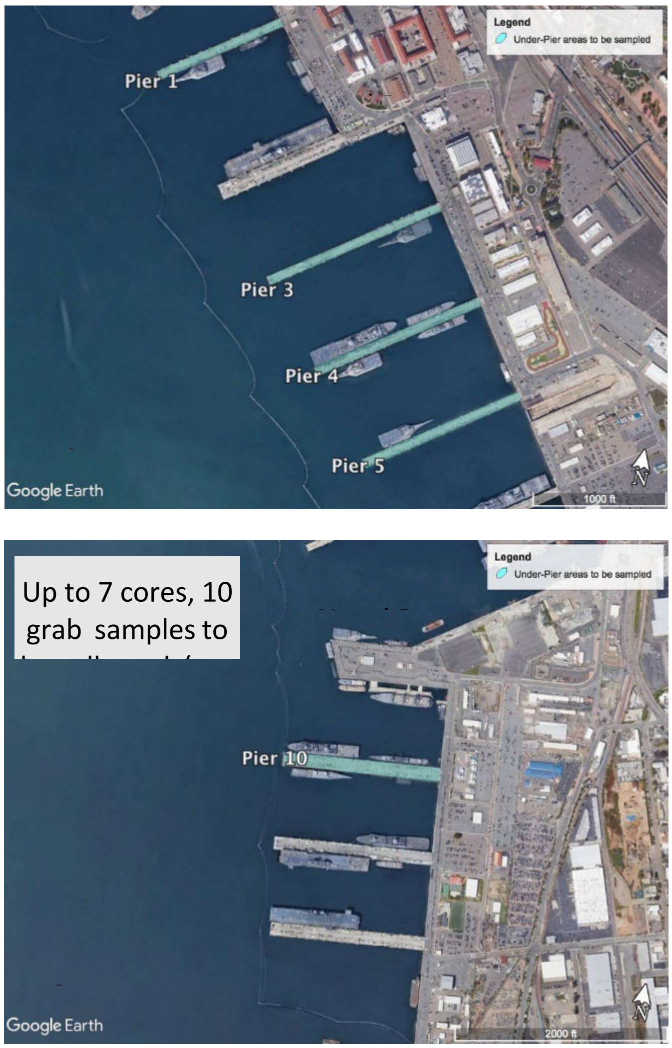


Figure B-44. Target piers for sediment sampling at Naval Base San Diego.

PERSONNEL AND VEHICLES FOR SAMPLING

This section describes the personnel and vehicle requirements to support the two approaches for collecting under pier sediments: (1) using access panels through piers and (2) working completely underneath piers at sites without access panels.

Pier access panel sampling approach

Some Navy piers contain access panels that (a) allow access to equipment underneath piers, such as water infrastructure, from the pier surface, or (b) allow rainwater to drain through pier surfaces. When the diameter of the through-pier hole is large enough, these access panels can be used to allow some of the sampling team members to work on the pier surface, with other team members in work vessels below. This procedure was used successfully at several piers at NBSD.

To use this approach, the sampling team should be comprised of three sub-teams:

(1) The pier-surface team
(2) The under-pier team
(3) The pier-adjacent support team

The pier-surface team

This team should be comprised of two people. A vehicle such as a work truck or van is highly recommended, to transport equipment (see Figure 45 for an example). If a motor vehicle cannot be used on a given pier, a large wheeled cart can be substituted to transport equipment. The pier-surface team will be responsible for selecting the access panels from which sampling will take place, deploying and lifting the sampling equipment, processing samples (see section 5), taking GPS points for the collection sites, and filling in datasheets.

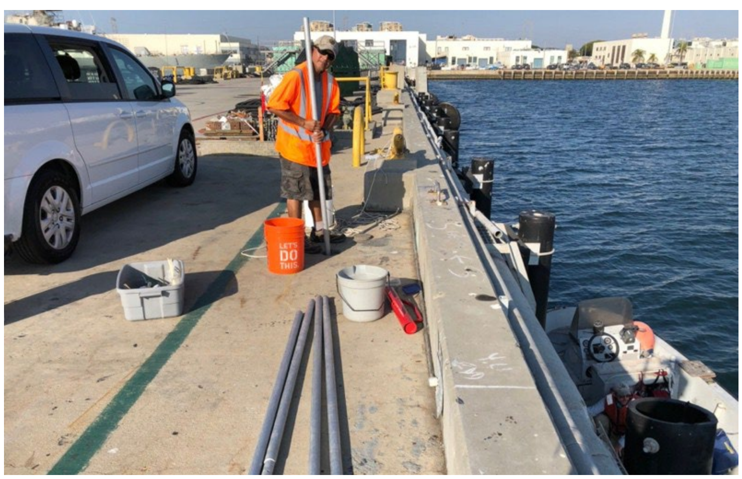
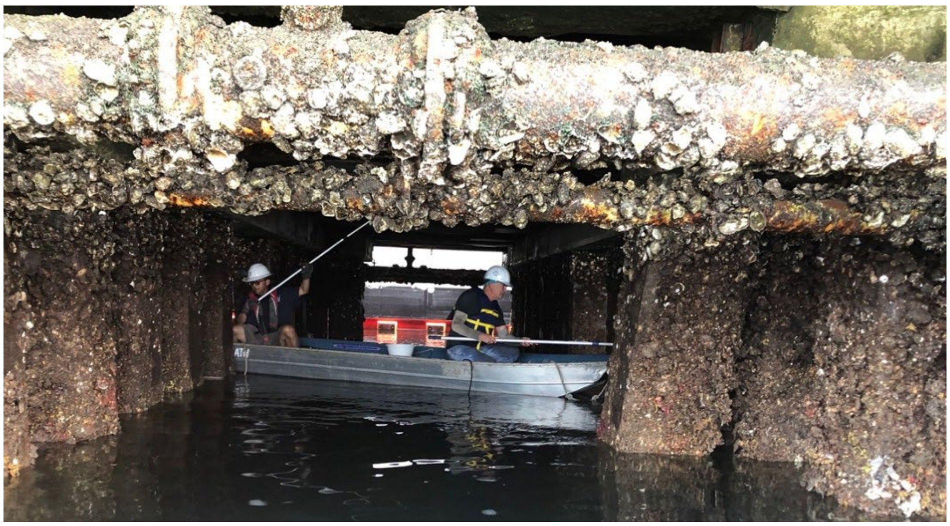


Figure B-45. One member of the pier-surface team, with a work van that was used to transport equipment onto the pier and between stations on the pier. A support boat is also shown adjacent to the pier.

The under-pier team

This team should be comprised of one or two people. They will be maneuvering and working from a small, flat-bottom workboat ("Jon boat") that is small enough to move around underneath the pier, i.e., it is narrow enough to fit between pier pilings and/or between pilings and camels, etc. This team will be responsible for connecting and disconnecting the sampling equipment to the lines and/or poles that the pier-surface team will pass down through the pier access panels, and for initial handling of samples, see Figure B-46. For sites with munitions, the under-pier team will also deploy the magnetometer, overseen by a trained unexploded ordnance safety technician, prior to sample collection.



- Here, the under-pier team is adjusting the position of the workboat using two boat hooks.
- The boat will then be secured to pilings at bow and stern prior to sample collection.

Figure B-46. The under-pier team in a small workboat.

The pier-adjacent team

This team should be comprised of at least one person - the boat captain who will pilot the larger work vessel that will remain adjacent to the pier during sampling. This vessel will transport the workboat and under-pier team to and from the site, and will provide an additional platform for equipment and sample staging. As well, in the case of sites with munitions, this pier-adjacent vessel will provide the work platform for a trained unexploded ordnance safety technician, see Figure B-47.

Figure B-47. The pier-adjacent support vessel and team.

UNDER-PIER SAMPLING APPROACH

For piers without access panels, the sampling team will be comprised of two sub-teams:

(1) The under-pier team
(2) The pier-adjacent support team

The under-pier team

For this approach, this team should be comprised of two people. They will be working from a small, flat-bottom workboat ("Jon boat") that is small enough to move around underneath the pier, i.e. it is narrow enough to fit between pier pilings and/or between pilings and camels, etc. This team will be responsible for deploying and retrieving the sampling equipment (without the assistance of a Pier-surface team) and initial sample handling. For sites with munitions, the under-pier team will also deploy the magnetometer, overseen by a trained unexploded ordnance safety technician, prior to sample collection.

The pier-adjacent team

This team should be comprised of at least two people - the boat captain who will pilot the larger work vessel that will remain adjacent to the pier during sampling, and any additional sampling team members as needed. This vessel will transport the workboat and under-pier team to and from the site, and will provide the main platform for equipment and sample staging and processing. For this approach, the pier-adjacent team will be responsible for processing samples, cleaning sampling equipment, taking GPS points of (locations adjacent to) the collection sites, and filling in datasheets. As well, in the case of sites with munitions, the pier-adjacent vessel will provide the work platform for a trained unexploded ordnance safety technician.

SAMPLE COLLECTION

This section describes both general and specific methods to be used in the field to collect quality sediment samples from under-pier areas. Note that prior to sample collection at NBSD, and at other sites with munitions concerns, the area of seafloor to be sampled must first be cleared by a trained UXO technician by passing a magnetometer over a section of seafloor several feet in diameter around the planned sampling location.

Sample collection: Pier access panel sampling approach

Some piers contain different types of panels that can provide access through a pier to allow some forms of sampling from the pier surface.

Figure B-48 and Figure B-49 show examples of access panels through piers that would either allow samplers to be lowered and retrieved from and back to the pier surface (for larger panels), or would allow poles or lines to be passed through the panels to physically lower and retrieve the samplers, which would be attached and detached from the workboat under the pier (for smaller panels through which samplers cannot fit).

- A round panel removed near the edge of a pier, (center) a square panel removed closer to the midline of a pier (Left).
- View of the water through an access panel with a chain retainer for the panel cover (Right).
- The edge of the workboat and grab sampler are also visible.
- Orange cones mark the locations access panels, visible to the teams in boats, and/or to indicate a hazard to pedestrians or vehicles on the pier surface.

Figure B-48. Examples of some pier access panels that allow sampling of under-pier sediments from the pier surface.

Figure B-49. Additional examples of types of access panels that can provide through-pier access to under-pier areas from the pier surface.

Grab samples

Grab samplers such as a ponar or mini Van Veen grab are set with the sampler jaws open at the surface, held open by the combination of a quick-release pin and upward force provided when the sampler hangs by a line. The sampler is lowered into the water on the line, and when it contacts the bottom, the line slackens, allowing the quick-release pin to be ejected, and the jaws to close around the sediment. The sampler is then recovered to the surface, with the sediment closed inside the sampler jaws.

No access panels were encountered that were large enough to permit the grab sampler to pass through the panel from the top of the pier at Naval Base San Diego. Therefore, on piers with access panels, the following steps were followed:

1. The line used to deploy and retrieve the sampler was passed through the access panel from the team on the pier surface. The bitter end of the line was secured to a fixed object such as a ladder railing on the pier to prevent the line from accidentally being dropped into the water through the pier completely.
2. The sampler was securely attached to the free end of the line under the pier by the workboat team.
3. Once attached, the under-pier team communicated to the pier surface team that the sampler can be lifted. This was accomplished either using walkie-talkies, or by the support boat team passing along verbal requests between the team below and above the pier.
4. The pier surface team then lifted the sampler slowly upwards.
5. Once the sampler was lifted far enough to clear the side gunwale of the workboat, the under-pier team indicated that the pier surface team should pause.
6. The under-pier team would move the workboat out from under the grab sampler, and once clear, would communicate to the pier surface team to lower the sampler into the water.
7. The pier surface team would lower the sampler into the water until the line became slack, indicating bottom contact.
8. The pier surface team would tug sharply on the sampler line several times to ensure the quick-release pin had been released to allow jaw closure, and then pull the sampler backup out of the water. One pier surface team member would

control the lowering and lifting of the sampler, while the other would keep the excess line tidy and assist with communication between the teams.

9. Once the sampler was lifted above the water surface to clear the workboat side gunwale, the under-pier team would indicate that the pier surface team should stop pulling the sampler upwards.
10. The workboat was then shifted back under the grab sampler, and the under-pier team requested that the pier surface team again lower the sampler to allow them to take control of it.
11. The under-pier team checked the sample, and if acceptable would place the sediment into a clean bowl, and then detach the grab sampler from the line.
12. The pier surface team would then recover and stow the line and close the pier access panel.
13. The sample would then be passed from the under-pier team to the pier surface team via the support vessel team, by placing the bowl with sample in it into a bucket lowered from the pier surface to the support vessel. Note that before passing the sample to the pier surface team, for samples collected at sites with possible munitions, the sample would be scanned by a UXO technician.
14. Sample processing and logging was completed on the pier surface, while the under-pier team cleaned the sampling equipment between stations.

Core samples

Core samples are collected by placing a clean, clear polycarbonate core liner into the core barrel, placing a white plastic core catcher into the bottom of the core liner, facing upwards, and then screwing a stainless steel nose-piece onto the bottom of the core barrel. A safety tag-line is tied to the top of the core barrel at a location that will not interfere with the closure of the vent/suction cap. The core barrel is then connected to a 6-foot section of aluminum pipe using a safety locking pin, and lowered into the water, adding additional 6-foot sections of aluminum pipe with locking pins until the core barrel reaches the bottom.

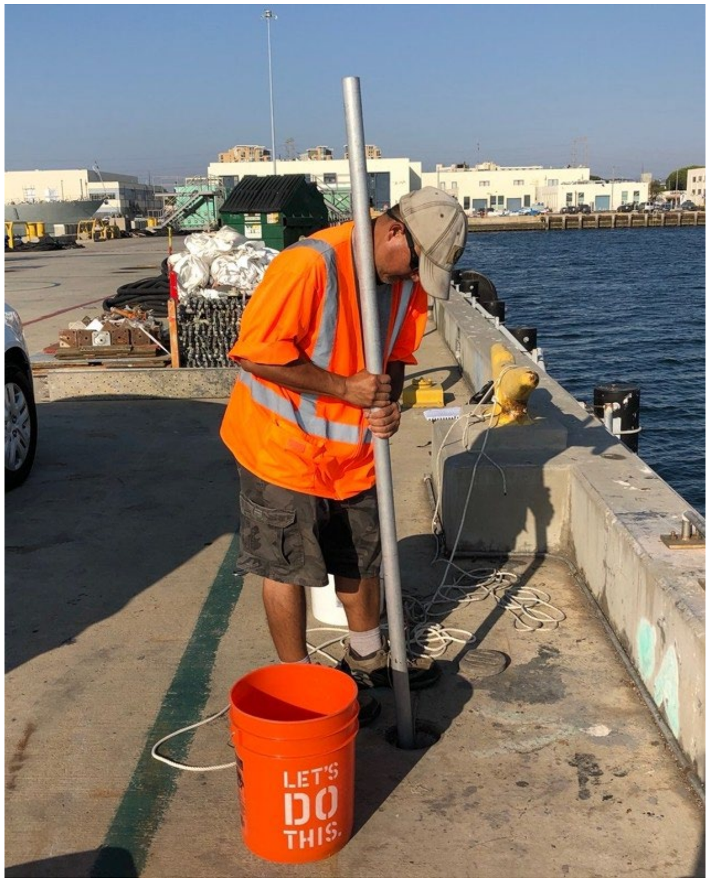
The corer is then driven into the sediment the correct distance (ideally) to fill the core barrel with sediment, without driving the corer beneath the sediment-water interface, which would drive excess sediment out the top of the coring device. It is therefore helpful to mark the location on the aluminum extension poles even with the water or the pier surface when the sampler first touched the bottom, and then to measure and mark the height on the pole above this equal to the length of the core liner. When that next mark reaches the surface of the water or pier surface, this indicates the core barrel is full of sediment and should be retrieved. The core barrel can be driven into the sediment using a downwards vertical force or body weight, or if needed, a slide hammer can be used to hammer the core barrel into harder sediments. If the latter is used, a lexan cap should be inserted into the top of the aluminum extension pipe to protect the pipe from damage from the slide hammer. To recover the core, the extension poles and tag line are pulled vertically from the pier surface.

Some pier access panels were large enough to allow the core sampling equipment to be deployed entirely from the pier surface (Figure B-50). In those cases, the cores were retrieved to the pier surface, logged and processed, and the equipment was cleaned between stations. At sites with munitions concerns, the core was also passed to the UXO technician in the support boat for scanning, in a bucket on a line passed over the side of the pier.

- Equipment for core sampling includes extension poles, a safety tag line organized in a bucket (with the bitter end tied off to a yellow post in the background of the left figure), a red slide hammer, bins containing extra core catchers (white), core caps (orange), blue nitrile gloves, and other necessities.

Figure B-50. Equipment laid out on the pier surface, ready to collect a core sample thorough a pier access panel large enough to accommodate the core sampler.

For locations where access panels were too small to fit the core sampler itself, a similar process was followed to collect cores as was used to collect grab samples, with extension poles and the safety tag line instead of the grab sampler line passed through the access panel (Figure B-51), and then under-pier team working to attach and detach the core sampler instead of the grab sampler.



- Only extension poles and a safety tag line (tied off to a yellow cleat) were lowered through the access panel to the workboat team.
- Workboat team attached and detached the core sampler from the extension pole while under the pier.

Figure B-51. This pier access panel was too small to allow the core sampler to pass through.

Sample collection: Under-pier sampling only

Some piers had no panels that provided access to the water and sediments beneath the pier, such that all samples had to be collected using only teams in the under-pier workboat and support boat outside of the pier.

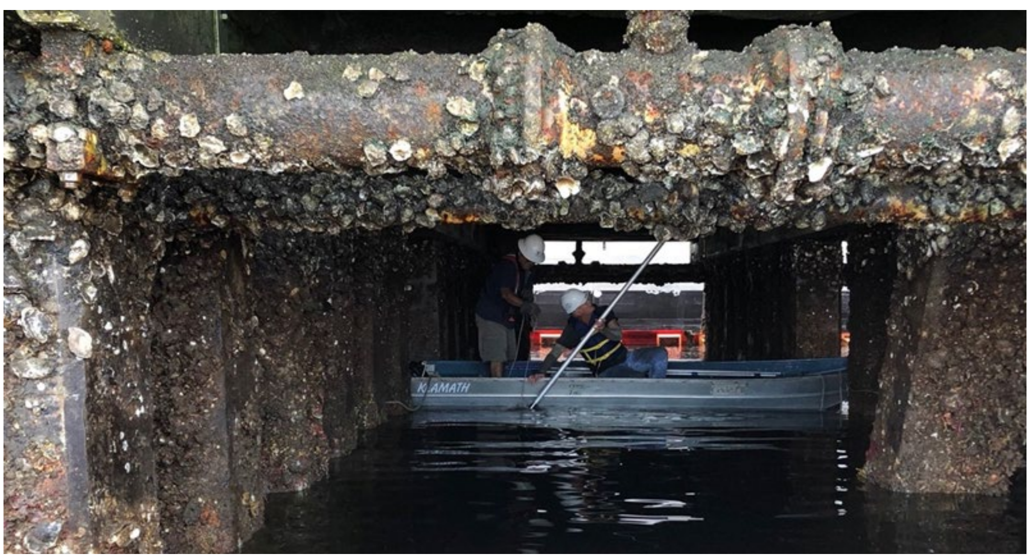
Grab samples

For piers without access panels, the workboat was secured at bow and stern to pier pilings to maintain position. Grab samples were collected by lowering the grab sampler over the side gunwale of the workboat (Figure B-52), ensuring that the bitter end of the line was tied off to the workboat prior to deployment. Samples were then retrieved and processed on the workboat. The advantage to collecting grab samples from the workboat was that any location under the pier could be sampled, not just positions under access panels. However, this method was more physically demanding.

Figure B-52. A member of the under-pier team lowers the grab sampler over the side of the workboat using a line.

Core samples

Collecting core samples from the workboat under the pier without support from a pier-surface team was even more challenging than collecting grab samples from the workboat. The extension pole sections could only be attached with the coring device held in a vertical position when the tide was low enough to provide at least 6 feet of overhead clearance. When this clearance was not available, the coring device had to be held at an angle by one team member, using the safety tag line, and then the other team member had to add an extension pole and install the pin and safety clip (Figure B-53). The corer was then lowered and held vertically to test whether it could contact the bottom and begin collecting samples, or whether another extension pole was needed. Shorter extension poles may have made this procedure easier to complete.



- Extension rods are added at an angle because the overhead clearance is too low to permit the extension pole to be added in a vertical position.

Figure B-53. The under-pier team adds an aluminum extension pole to the coring device at an angle.

Once in contact with the sediment surface, the corer was driven into the sediment and samples were retrieved and processed. However, use of the heavy slide hammer was extremely difficult due to the reduced overhead space.

Cleaning sampling equipment between samples

All sampling equipment should be decontaminated between sampling events to prevent cross-contamination/artifacts. This section describes decontamination procedures that were used to clean sample gear between sampling events to ensure samples are free from cross-contamination. These steps are reproduced from the Sediment Quality Assessment Technical Support Manual (Bay et al. 2014). These steps should be followed, regardless of the particular type of sampling equipment or approach used, to ensure representative samples are collected:

> A method proven effective in cleaning equipment between sampling events includes the following steps:
>
> 1. Rinse equipment to remove all visible sediment.
> 2. Scrub all sampling utensils and mixing bowls with a detergent solution, either in a bucket or by using a spray bottle. Also wash all parts of the grab sampler with the detergent solution.
> 3. Completely rinse the grab, buckets, sampling utensils, and bowls with clean water, making sure they are clear of sediment and detergent residue.
> 4. Rinse items with 10% HCl followed by a rinse with pesticide-grade methanol.
> 5. Completely rinse the grab, buckets, sampling utensils, and bowls with DI water.
> 6. Cover all cleaned items with aluminum foil or plastic until the next use in order to minimize exposure to airborne-particle contaminants. Choice of cover material depends upon the study and analytes being measured (i.e., it should not introduce contaminants that could affect the analyses).
> 7. Rinse all cleaned items with ambient water before use.

To decontaminate sampling equipment between samples collected during a given sampling event, the equipment should be rinsed with ambient water to remove sediments, then rinsed with DI water, then sprayed with pesticide-grade methanol from a squirt bottle.

Depending upon the methods used to collect samples, equipment decontamination may be required on the pier surface or in the workboat. Cleaning can also occur on the support vessel, if needed. Cleaning equipment should therefore be distributed accordingly.

Sample inspection

Samples should be visually inspected to ensure that they are acceptable for use; for example, Figure B-54 indicates appropriate grab sample assessments associated with visual inspection. Coring devices should be inserted vertically into the sediment and should not be tilted upon retrieval, unless the bottom of the core is capped, overlying water is removed, and absorbent material such as florist’s foam is inserted to prevent slumping/mixing within the core. An acceptable core should contain enough sediment to indicate that the desired penetration depth was reached, and show no sign of sediment loss. If a given sample is not acceptable, another replacement core sample should be taken nearby. This will be repeated until an acceptable core sample is collected from a given site. In the event that multiple attempts at sampling fail to produce an acceptable sample (grab or core), for example because of heavy debris accumulation, a different type of sample or different type of sampling device can be used, if available. If no alternative methods are available, or do not result in a quality sample being collected, the site should be abandoned and a different site should be selected.

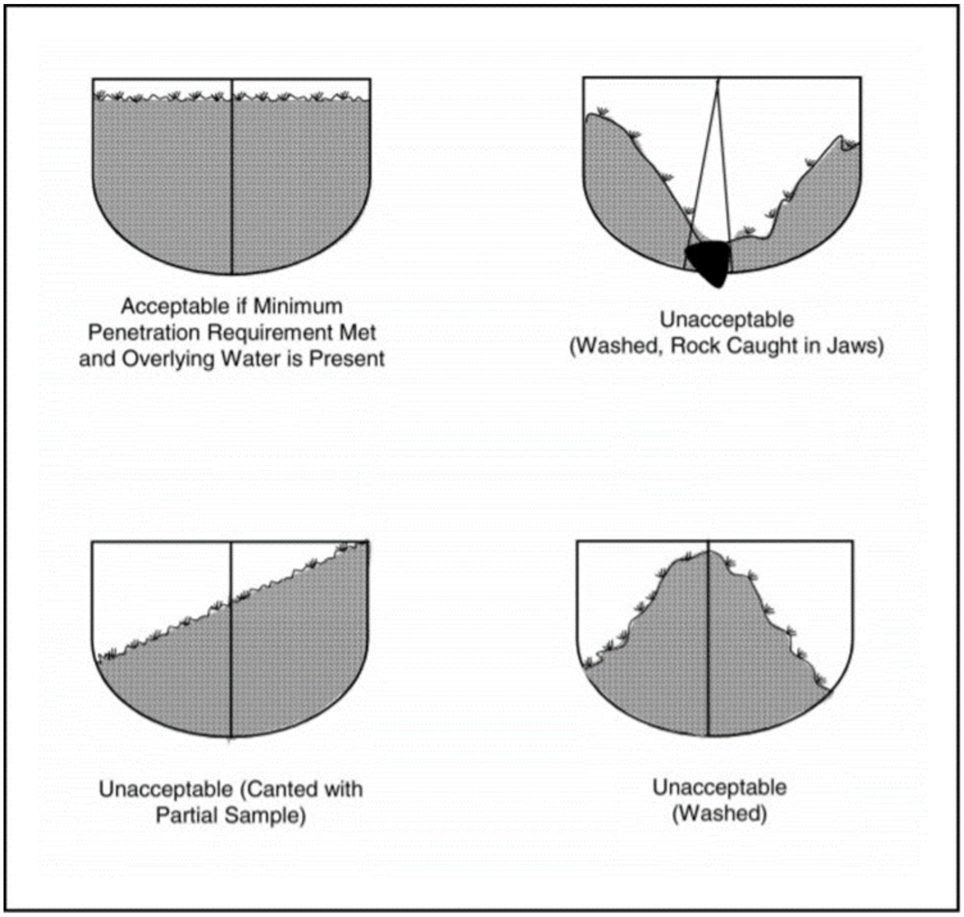


Figure B-54. Diagrams illustrating examples of acceptable (top left) and unacceptable (right, lower left) grab samples. From U.S. EPA (2001).

Sample logging

All samples collected in the field with be logged on appropriate datasheets developed for the project. Samples themselves (jars and/or core sleeves) should be clearly labelled with smudge-proof and waterproof labels. Cores should be kept in a vertical position at all times (see Figure B-55), but should also be labeled to indicate the top of cores in the case they are accidentally tipped horizontally.

Figure B-55. Example of a capped and labelled core positioned upright in a bucket. Blue ice packs surround the lower portion of the core to keep it cold.

SAMPLE PROCESSING

Sediment samples should be processed either in the field immediately after collection (for grab samples) or after collection at an appropriate laboratory (for core samples) to aliquot sediments into appropriate containers for analysis of both organic and inorganic contaminants of concern, following appropriate guidelines (i.e. USEPA, ASTM, etc. standard methods) for each sediment quality metric. Samples should be stored on ice and/or in a refrigerator until they are processed, and stored in a refrigerator following processing until they are shipped to the analytical laboratory in coolers on ice.

Grab sample processing

At sites with potential munitions of explosive concern in the sediments, samples must be screened by a trained unexploded ordnance technician using a magnetometer after collection. In this case, sediment collected in the grab sampler will be emptied into a plastic bowl that has been cleaned between each use, and then screened before the sample is homogenized and aliquoted. At sites without munitions concerns, a stainless steel bowl can be used instead of a plastic bowl. Using a clean stainless steel spoon, the sediment will then be homogenized and aliquoted into clean sample containers. During this procedure, sample characteristics will be recorded on datasheets.

Core sample processing

Core samples in plastic sleeves are removed from the metal sampling device, capped with plastic covers at both ends, and caps are secured using electrical tape. Care should be taken to always maintain core samples in a vertical position. At sites with potential munitions of explosive concern in the sediments, cores must then be screened by a trained unexploded ordnance technician using a magnetometer. Details about each core should be entered on the sampling data sheet, and the cores should be stored upright. A bucket with ice packs works well to store core samples until they are transferred to a refrigerator at the lab.

Single cores from each site will be sectioned and subsampled to provide a surface sample (approximately 0-5cm), and then the remaining material will be subsampled into sections down core.

The length of these sections will be determined based upon core length and visual inspection of the cores. For example, horizons that represent changes in sediment color or texture will be used to delineate core sections. Core subsections should then be homogenized and aliquoted into sampling containers (Figure 14). In the case of cores that are visually homogeneous from top to bottom, sections will be delineated based on depth to achieve approximately equivalent amounts of material for each core section. If particular constituents require significant amounts of sediment for analysis, multiple cores can be collected to provide additional material that can be composited together (see bottom panel of Figure B-56).

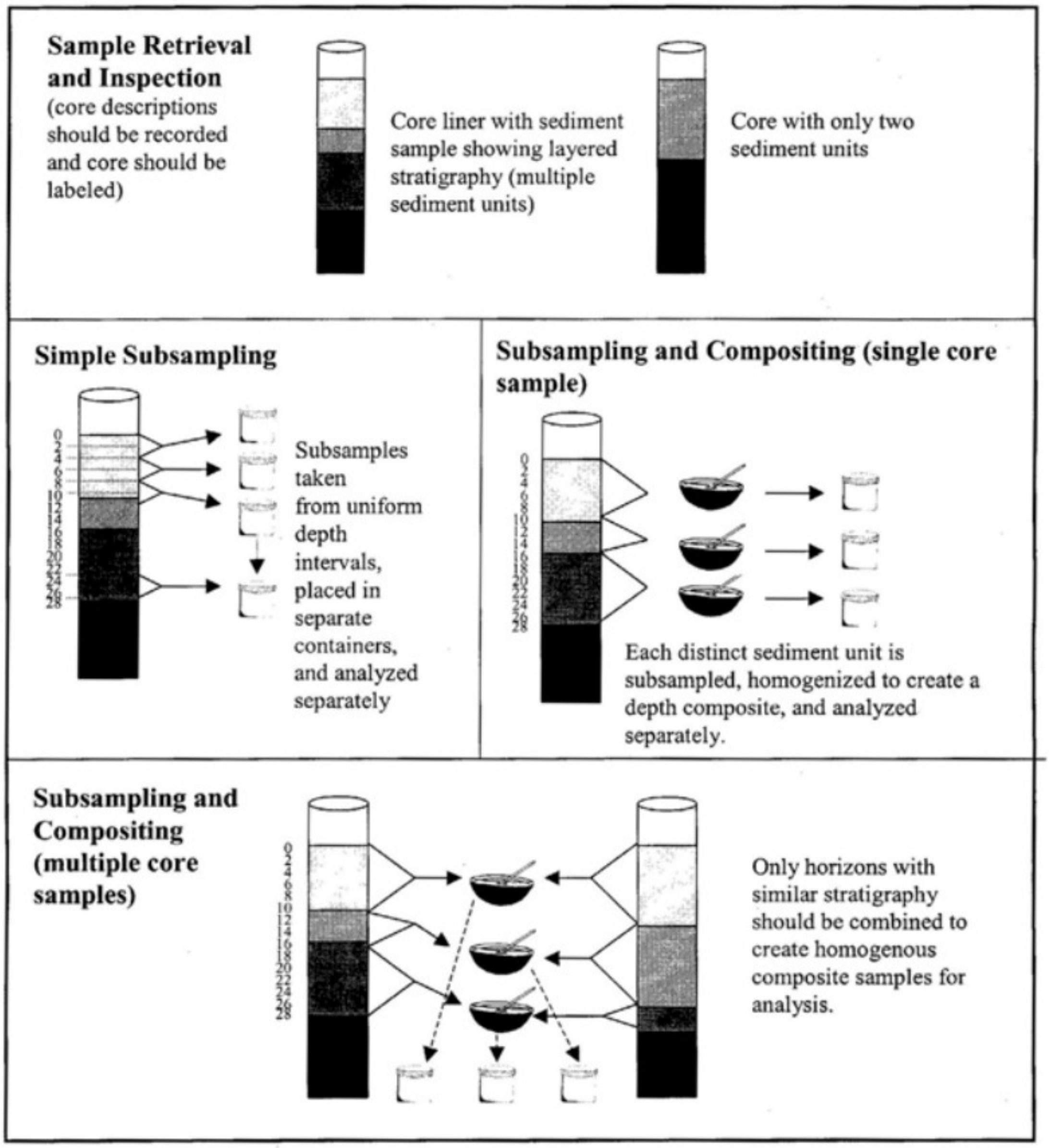


Figure B-56. Options for subsampling and homogenizing sediment core samples. From U.S. EPA (2001).

Aliquots for analysis of chemical/physical constituents

Confirm with the analytical laboratory how the samples should be delivered, including whether samples should be aliquoted for each analysis prior to shipping, or if the laboratory will conduct subsampling for analyses. Be sure to confirm the total sample size needed for all desired analyses from a given sample with the analytical laboratory before collecting and aliquoting samples. As noted above, the collection of multiple cores and/or grab samples may be required to supply sufficient material for all desired analyses.

The following constituents for analysis for samples collected from Naval Base San Diego were selected based on results from prior sediment assessment studies. In some previously collected samples, elevated PCBs, PAHs, Chlorinated pesticides, and several metals (including arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc) were observed. TOC and grain-size measurements provide information on sediment physical characteristics that are typically correlated with contaminant concentrations; organic carbon and fine-grained sediments both tend to sorb contaminants, and thus sediments with higher organic carbon and/or finer grain sizes tend to be enriched in chemical contaminants. Concentrations of aluminum and iron may also be used as a proxy for fine-grained material, if insufficient material is available for grain size analyses, and if these measures have been shown to be correlated with the amount of fine-grained material in samples (as has been shown in previous work from NBSD; Leather et al. 2020). In addition, several samples were selected to analyze coprostanol, a sterol that is a marker for human sewage, to identify whether deeper layers of material enriched in constituents such as PCBs and heavy metals, may be associated with sewage sludge deposits discharged into the Bay by the City of San Diego prior to 1963 (Leather et al. 2020).

(1) Metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc, and aluminum and iron to normalize sediment texture)
(2) PCBs
(3) Other organic contaminants (PAHs and chlorinated pesticides)
(4) Grain size distribution
(5) TOC content
(6) Sewage indicator (coprostanol)

Chain of custody forms

Chain of custody forms will be completed for all samples that are collected and sent to the selected analytical laboratory for analysis. A sample coding procedure will be used to avoid any unintentional bias from the analytical laboratory. On the chain of custody form, the analytes desired for each individual sample (i.e. grab sample or subsampled portion of a core sample) should be indicated.

EQUIPMENT LIST FOR UNDER-PIER SEDIMENT SAMPLING

When using the through-pier access panel sampling approach, Items to be used by the pier-surface team are indicated with *

Items to be used by the under-pier team are indicated with •
Items to be used by all teams are indicated with #

Administrative and sample tracking items:

- ☐ Vehicle permit (to access pier gate/areas as needed) *
- ☐ Photography pass #

- ◻ Common Access Card, NIWC Pacific badge #
- ◻ Site sampling plan #
- ◻ Health & Safety Plan (HASP) #
- ◻ Maps and directions to worksite #
- ◻ Logbook ⋆
- ◻ Data sheets ⋆
- ◻ Pens, pencils, permanent markers #
- ◻ GPS unit (charged) ⋆
- ◻ Analytical laboratory chain of custody forms and shipping airbills ⋆
- ◻ Labelling tape #

Sample storage:

- ◻ Sample bottles (glass, wide-mouth 16 oz supplied by analytical laboratory) ⋆
- ◻ Ice chest ⋆
- ◻ Frozen ice packs ⋆
- ◻ Bucket to transport cores upright ⋆
- ◻ Ziplock bags ⋆

Sampling equipment:

Handheld coring device for use through pier openings or from work boat under pier

- ◻ Stainless steel core barrels (20" length) [2 total] •
- ◻ Core barrel end screw cap [2 total] to hold core liner & core catcher in place •
- ◻ T-connectors for core barrels [2 total] •
- ◻ Polycarbonate core liners (20" length) [15-20] •
- ◻ Eggshell core catchers, 1 per core liner [15-20] •
- ◻ Core caps, 2 per core liner [30-40] •
- ◻ Electrical tape •
- ◻ Stainless steel custom adapter for core barrel-to-extension poles [1] •
- ◻ Aluminum extension poles, long [10] ⋆
- ◻ Aluminum extension pole, short [1] ⋆
- ◻ Cotter pins to connect extension poles [10] ⋆
- ◻ Delron cap for slide hammer use with poles [1] ⋆
- ◻ Slide hammer [1] ⋆
- ◻ Tag line in bucket, 50 ft. length [1] ⋆

Mini ponar/Van Veen for grab samples

- ◻ Stainless steel Mini ponar/Van Veen grab sampler [1] •
- ◻ Mini ponar/Van Veen release pin with spring [2 total, 1 attached to sampler] •
- ◻ Spare parts for mini ponar/Van Veen sampler •
- ◻ Non-stretch sampling line, 50 ft. length [1] ⋆

Sample processing and decontamination equipment:

- ◻ Bowls for homogenizing grab samples; plastic if samples must be screened for presence of munitions of explosive concern with magnetometer [2 or more] •
- ◻ Large stainless steel spoons to homogenize samples [2 or more] #
- ◻ Paper towels #
- ◻ Carboy of DI water *
- ◻ Squirt bottle of DI water *
- ◻ Squirt bottle of methanol *
- ◻ Nitrile gloves, powderless (multiple sizes) #
- ◻ Bucket with trash bags and/or bucket liners for waste #
- ◻ Steel wool *
- ◻ Wire brushes *

Other equipment and supplies:

- ◻ Zipties (small, medium, large, heavy-duty) #
- ◻ Duct tape [1 roll] *
- ◻ Teflon tape [1 roll] *
- ◻ Crowbar [1-2] *
- ◻ Grate openers [1-2] *
- ◻ Long/large flathead screwdrivers [1-2] *
- ◻ Measuring tape *
- ◻ Depth gauge or lead line to measure water depth •
- ◻ Extra buckets #
- ◻ Orange cones for pier surface demarcation *
- ◻ NIWC Pacific placard for pier area equipment identification *
- ◻ Toolbox with various tools: wrenches (14 mm and adjustable), pliers, nippers, screwdrivers, box cutters, etc. *

Personal equipment:

- ◻ Work gloves [1 per person] #
- ◻ Hardhats [at least 1 for each person working under pier] •
- ◻ Personal floatation devices [at least 1 for each person] #
- ◻ Fluorescent vests [1 for each person working on pier surface] *
- ◻ Safety shoes/boots #
- ◻ Face masks/hand sanitizer for COVID protection #
- ◻ Food, water, sunscreen, hat, insect repellant, etc. #

APPENDIX B PART 3: SEDIMENT ANALYSIS RESULTS

Sediment analysis results are presented in tables using the following shorthand indicators: Pier number is indicated by P#, for example Pier 1 is P1. Stations at a given pier are similarly numbered, for example Station 1 is S1. All results are from core samples, indicated with a C and followed by a range of numbers that indicates the depth below the surface in centimeters; for example a sample from a core spanning the top 1-6 cm of material in the core is indicated C1-6. Blank cells indicate that a particular analyte was not measured in a given sample. Sediment samples are detailed in the tables shown in this Section: Table B-3 to B-23.

Table B-3. NBSD metal concentrations (mg/kg) in sediment core samples underneath Pier 1 (P1).

P1		**S1**		**S2**		**S3**		**S4**	
Units for Sediment: **mg/Kg**		**C1-6**	**C6-8**	**C1-6**	**C6-12**	**C1-6**	**C6-8**	**C1-6**	**C6-10**
Pier ID#		1	1	1	1	1	1	1	1
Matrix:		Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **Metals**		Site 1		Site 2		Site 3		Site 4	
Aluminum	Al	11200	8010	14800	18800	11400	7540	19100	24800
Iron	Fe	17100	17000	20600	24400	22400	34900	26600	34800
Zinc	Zn	263	314	249	150	198	121	401	746
Arsenic	As	6.53	29.4	6.57	5.35	5.95	4.4	8.17	11
Cadmium	Cd	0.296	0.626	0.247	0.262	0.176	49.50	1.92	5.65
Chromium	Cr	32.3	49.6	33.7	29.9	27.2	20.4	58.4	123
Copper	Cu	181	212	151	49.8	129	83.3	242	307
Lead	Pb	98.9	124	47.1	37.3	42.8	35.6	112	225
Nickel	Ni	82.7	53.6	12	9.9	10.6	6.31	16.9	28.9
Selenium	Se	1.3	0.873	1.58	1.26	1.55	0.831	3.27	3
Antimony	Sb	0.502	1.29	0.459	0.27	0.25	0.245	0.579	2.34
Silver	Ag	0.776	0.831	0.581	0.387	0.453	0.281	2.19	9.08
Mercury	Hg			0.743					3.02

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-4. NBSD metal concentrations in sediment core samples underneath Pier 3 (P3).

P3		S1		S2				S3			S4	
Units for Sediment: **mg/Kg**		**C1-3**	**C3-6**	**C1-5**	**C5-10**	**C10-17**	**C17-19**	**C1-3**	**C3-8**	**C8-10**	**C1-5**	**C5-7**
Pier ID#		3	3	3	3	3	3	3	3	3	3	3
Matrix:		Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **Metals**		Site 1		Site 2				Site 3			Site 4	
Aluminum	Al	21000	16200	15200	10500	4400	4110	27600	27100	26100	13600	6550
Iron	Fe	27200	24600	22700	15700	6210	6430	35600	34900	33500	19900	8020
Zinc	Zn	407	55.8	282	134	10.7	30.8	120	77.3	80.5	254	31.4
Arsenic	As	9.06	1.99	6.46	5.37	2.18	6.02	5.29	2.38	2.35	6.4	3.18
Cadmium	Cd	0.648	0.107	0.308	0.442	0.00	0.2	0.0929	0.00	0.00	0.425	0.00
Chromium	Cr	43.1	26.9	39.6	23.5	5.54	8.22	30.6	28.6	27.2	39	11.8
Copper	Cu	336	16.3	141	54.3	3.36	14	56	23.5	25.9	154	18.2
Lead	Pb	86.8	18.5	79	58.3	1.09	8.45	12.2	7.02	15.1	111	8.35
Nickel	Ni	16.3	7.53	12.6	7.52	2.79	3.22	14.1	12	11.4	9.66	3.59
Selenium	Se	2.45	0.195	1.28	0.688	0.218	0.278	0.632	0.306	0.319	1.51	0.172
Antimony	Sb	0.359	0.106	0.427	0.356	0.000	0.107	0.166	0.0823	0.127	0.307	0.093
Silver	Ag	1.11	0.14	0.68	0.427	0.000	0.164	0.192	0.00	0.0977	0.76	0.109
Mercury	Hg			0.531	0.289							

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-5. NBSD metal concentrations (mg/kg) in sediment core samples underneath Pier 4 (P4).

P4		S1				S2		S3			S4		
Units for Sediment: mg/Kg		C1-6	C6-12	C12-18	PLUG	C1-5	C5-10	C1-4	C4-8	C8-13	C1-5	C5-9	C9-13
Pier ID#		4	4	4	4	4	4	4	4	4	4	4	4
Matrix:		Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: Metals		Site 1				Site 2		Site 3			Site 4		
Aluminum	Al	18900	20300	24100	25500	20600	17100	16600	17900	23500	20400	18700	18200
Iron	Fe	27500	29900	36400	41300	29500	26300	24500	23700	31200	27100	25300	25700
Zinc	Zn	339	677	790	778	371	454	232	232	366	257	292	296
Arsenic	As	8.32	13.7	21.2	11.3	9.02	11	7.44	6.15	9.08	6.6	7.02	7
Cadmium	Cd	0.34	1.89	4.44	4.48	0.505	0.795	0.245	0.23	1.15	0.259	0.389	0.49
Chromium	Cr	62.1	73.5	101	136	68.6	61.6	41.8	40.5	59.7	49.3	47.9	52.5
Copper	Cu	255	367	470	377	249	328	155	155	234	184	204	211
Lead	Pb	88.2	160	199	236	113	90.4	55	129	80.8	64.2	87.4	81
Nickel	Ni	15.6	15.9	22.7	22.8	14.6	18.1	12.5	11.6	14.2	11.8	11.4	11.5
Selenium	Se	2.2	1.91	2.61	2.48	2.43	2.02	2.23	1.82	1.62	2.44	2.01	1.89
Antimony	Sb	0.51	2.07	2.1	1.5	0.768	0.979	0.27	0.199	0.526	0.252	0.293	0.405
Silver	Ag	1.36	3.22	3.56	4.05	1.36	1.91	0.772	0.64	2.09	0.865	0.961	1.08
Mercury	Hg	1.25	1.56	1.63	2.47						1.15	1.38	0.857

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-6. NBSD metal concentrations (mg/kg) in sediment core samples underneath Pier 5 (P5).

P5		S1	S2		S3				S4				S5				S5DUP		
Units for Sediment mg/Kg		C1-5	C1-5	C5-10	C1-5	C5-10	C10-15	C15-20	C1-5	C5-10	C10-15	C15-20	C1-5	C5-9	C9-13	C13-17	C1-5	C5-9	C9-13
Pier ID#		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Matrix:		Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **Metals**		Site 1	Site 2		Site 3				Site 4				Site 5				Site 5 - Field Duplicate		
Aluminum	Al	19100	16000	23800	24000	23400	22600	27000	21800	25500	24300	29200	20900	22500	26100	26400	22300	25600	24300
Iron	Fe	29300	48900	39500	31700	31200	29400	36100	28900	36300	57600	43200	28800	31700	37700	38400	29700	34200	33900
Zinc	Zn	308	227	814	281	354	349	468	290	563	2360	911	383	551	632	733	346	426	440
Arsenic	As	7.25	6.93	16.6	7.43	8.41	9.45	11.8	7.6	13.5	32.8	16.3	9.6	13.3	14.5	15.3	8.41	10.8	10.6
Cadmium	Cd	1.6	0.293	1.87	0.216	0.632	0.78	1.33	0.274	1.86	4.03	4.46	0.484	0.988	1.35	2.09	0.354	0.643	0.78
Chromium	Cr	53.7	72.9	70.7	54.6	60	62.3	74.3	51.7	76.7	77.9	87.3	56.9	68.5	81.5	73.3	58.8	63.3	70.3
Copper	Cu	147	222	407	210	267	321	390	247	429	976	515	358	377	565	489	268	327	361
Lead	Pb	78.4	59.6	124	51	84.4	79.6	96.6	66.4	115	279	178	103	103	113	115	77.6	97.3	96.4
Nickel	Ni	15.5	34.3	18.1	12.8	13.9	14.8	16.9	12.9	18.1	26.2	21	13.9	17.2	18.2	17.6	13.8	14	16.2
Selenium	Se	2.37	2.01	2.47	2.48	2.42	2.51	2.61	2.39	2.47	3.6	3.32	2.68	2.75	2.98	2.9	2.88	2.89	3.02
Antimony	Sb	0.386	0.412	1.35	0.223	0.454	0.562	0.698	0.368	0.867	4.83	1.79	0.526	1.11	0.832	1.12	0.513	0.526	0.508
Silver	Ag	1.78	1.08	2.11	1.06	2.1	2.20	3	1.17	2.66	3.13	3.63	1.51	2.27	3.18	3.02	1.46	2.33	2.45
Mercury	Hg		0.834	1.07	0.881	1.43	1.35	1.36	0.898	1.38	1.26	1.88			1.68	1.81			

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-7. NBSD metal concentrations (mg/kg) in sediment core samples underneath Pier 10 (P10).

P10		S1				S2		S3		S4				S5		
Units for Sediment **mg/Kg**		C1-5	C5-10	C10-15	C15-20	C1-5	C5-9	C1-4	C4-8	C1-5	C5-10	C10-15	C15-20	C1-4	C4-8	C8-12
Pier ID#		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Matrix:		Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **Metals**		Site 1				Site 2		Site 3		Site 4				Site 5		
Aluminum	Al	23000	23900	33800	35200	25400	21500	21200	15700	25800	25100	31500	30400	22400	18900	18000
Iron	Fe	29500	31400	39500	42500	33100	28300	27300	21200	33800	32800	40400	39900	29700	25500	24100
Zinc	Zn	210	179	120	96.4	234	187	177	493	229	291	399	394	207	185	165
Arsenic	As	5.83	5.59	6.23	5.39	6.44	5.24	4.65	4.43	6.15	7.71	9.73	8.56	6.11	5.02	4.35
Cadmium	Cd	0.123	0.296	0.516	0.3	0.123	0.15	0.0913	0.31	0.154	0.856	1.89	2.81	0.118	0.128	0.15
Chromium	Cr	40.5	38.3	40.7	36.2	43.9	38.2	34	27.6	44.1	58.7	79.9	81.5	40.1	35.3	32.4
Copper	Cu	149	78.4	37.7	27.8	178	107	123	69.8	175	213	309	245	153	138	93.4
Lead	Pb	131	119	39.1	18.7	48.5	36.5	31.8	337	44.5	65.3	88.3	82.9	38.8	35.4	52.1
Nickel	Ni	11.8	11.1	13.3	14.2	12.9	10.7	9.86	8.06	12.2	13.3	17.3	18.6	11	9.85	8.65
Selenium	Se	2.39	1.85	2.01	1.93	2.64	1.79	1.8	1.24	2.41	2.01	2.59	2.61	2.15	1.53	1.75
Antimony	Sb	0.115	0.18	0.125	0.0947	0.153	0.147	0.12	0.163	0.156	0.335	0.545	0.718	0.166	0.137	0.123
Silver	Ag	0.51	0.67	0.515	0.286	0.549	0.566	0.448	0.457	0.668	1.76	2.94	2.93	0.611	0.521	0.534
Mercury	Hg			1.7				0.371				1.48				

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-8. NBSD metal concentrations (mg/kg) in sediment core samples at the quay wall (QW) between Piers 3 and 4 (P3/P4).

P3/P4		QW	QW	QW
Units for Sediment: **mg/Kg**		C1-4	C4-8	G
Pier ID#		3/4	3/4	3/4
Matrix:		Sediment	Sediment	Sediment
Analyte: **Metals**		Quay Wall		
Aluminum	Al	13800	8810	16700
Iron	Fe	21700	14000	24500
Zinc	Zn	221	234	230
Arsenic	As	7.24	9.01	7.09
Cadmium	Cd	0.162	0.19	0.15
Chromium	Cr	35.3	19.8	39
Copper	Cu	182	598	192
Lead	Pb	140	125	82.6
Nickel	Ni	9.24	6.98	10.1
Selenium	Se	1.89	0.89	2.39
Antimony	Sb	0.287	0.297	1.07
Silver	Ag	0.706	0.416	0.707
Mercury	Hg			

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)
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Table B-9. NBSD PCB congener concentrations (mg/kg) in sediment core samples underneath Pier 1 (P1).

P1	S1		S2		S3		S4	
Units for Sediment: **mg/Kg**	C1-6	C6-8	C1-6	C6-12	C1-6	C6-8	C1-6	C6-10
Pier ID#	1	1	1	1	1	1	1	1
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PCB Congener**	Site 1		Site 2		Site 3		Site 4	
PCB-8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
PCB-28	0.0	0.95	0.0	0.0	0.0	0.0	0.73	3.9
PCB-44	0.0	0.74	0.0	0.0	0.0	0.0	0.55	4
PCB-52	0.0	1.7	0.8	0.0	0.5	0.59	1.2	8.1
PCB-66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-101	94	4.9	1.8	0.53	0.99	1.9	2.9	18
PCB-105	0.0	1.3	0.59	0.0	0.0	0.0	0.96	7.2
PCB-118	0.0	1.6	0.76	0.0	0	0.71	1.1	7.5
PCB-128	180	1.4	0.66	0.0	0.41	0.72	1	5.7
PCB-138	110	4.4	2.1	0.55	1.3	2.2	2.7	16
PCB-153	440	4	2.3	0.65	1.5	2.70	3.1	14.00
PCB-170	270	1.5	0.82	0.0	0.51	0.73	1.3	6.3
PCB-180	430	2.2	1.1	0.0	0.67	1.2	1.8	8.8
PCB-187	210	1.3	0.79	0.0	0.55	0.99	1.3	5.1
PCB-195	45	0.00	0.00	0.0	0.0	0.0	0.0	0.79
PCB-206	17	0.00	0.00	0.0	0.0	0.0	0.0	1.5
PCB-209	0.0	0.00	0.00	0.0	0.0	0.0	0.0	2.5
NOAA18	1796	25.99	11.72	1.73	6.43	11.74	18.64	110.89
TPCB (2xNOAA)	3592	51.98	23.44	3.46	12.86	23.48	37.28	221.78

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm
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Table B-10. NBSD PCB congener concentrations (mg/kg) in sediment core samples underneath Pier 3 (P3).

P3	S1		S2				S3			S4	
Units for Sediment: mg/Kg	C1-3	C3-6	C1-5	C5-10	C10-17	C17-19	C1-3	C3-8	C8-10	C1-5	C5-7
Pier ID#	3	3	3	3	3	3	3	3	3	3	3
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PCB Congener**	Site 1		Site 2				Site 3			Site 4	
PCB-8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-18	7.3	0.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
PCB-28	6.3	0.49	0.0	0.53	0.0	0.58	0.0	0.0	0.0	0.53	0.0
PCB-44	21	0.82	0.44	0.62	0.0	0.77	0.0	0.0	0.0	1.2	0.89
PCB-52	61	3.4	1.3	1.4	0.0	1.6	0.44	0	0.0	4.3	3.4
PCB-66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-101	110	3.9	2.7	3.7	0.0	3.5	0.87	0.36	0.35	7.6	6.3
PCB-105	40	0.76	0.8	1.4	0.0	1.2	0.0	0.0	0.0	2.1	1.6
PCB-118	43	1.5	1.1	1.7	0.0	1.3	0.0	0.0	0.0	3.1	2.5
PCB-128	25	0.71	0.8	1.1	0.0	1.2	0.33	0.0	0.0	2.4	1.3
PCB-138	83	2.5	2.5	4	0.0	3	1.1	0.4	0.0	6.4	4.4
PCB-153	64	2.7	2.7	3.6	0.0	2.9	1.1	0.52	0.0	6.5	4.50
PCB-170	14	0.74	0.92	1.2	0.0	1.5	0.97	0.32	0.0	3	1.1
PCB-180	16	0.67	1.2	1.7	0.0	1.9	0.76	0.0	0.0	2.9	1.4
PCB-187	7.2	0.4	0.87	1.5	0.0	1.2	0.43	0.0	0.0	3	0.84
PCB-195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-206	0.0	0.0	0.0	0.6	0.0	0.67	0.0	0.0	0.0	2.3	0.0
PCB-209	0.0	0.0	0.0	0.0	0.0	0.62	0.0	0.0	0.0	0.95	0.55
NOAA18	499.4	19.23	15.33	23.05	0.0	21.94	6	1.60	0.35	46.78	28.78
TPCB (2xNOAA)	998.8	38.46	30.66	46.1	0.0	43.88	12	3.2	0.7	93.56	57.56

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-11. NBSD PCB congener concentrations (mg/kg) in sediment core samples underneath Pier 4 (P4).

P4	**S1**				**S2**		**S3**			**S4**		
Units for Sediment: **mg/Kg**	**C1-6**	**C6-12**	**C12-18**	**PLUG**	**C1-5**	**C5-10**	**C1-4**	**C4-8**	**C8-13**	**C1-5**	**C5-9**	**C9-13**
Pier ID#	4	4	4	4	4	4	4	4	4	4	4	4
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PCB Congener**	Site 1				Site 2		Site 3			Site 4		
PCB-8	0.0	0.37	0.58	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-18	0.0	0.92	1.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-28	0.0	1.8	1.1	2.6	0	0.84	0.0	0.0	0	0.0	0.0	0.0
PCB-44	0.0	1.5	1.6	3.6	0.51	1.1	0.0	0.0	0.73	0.0	0.0	0.63
PCB-52	0.0	3.2	3.5	8	1.5	2.9	0.0	0.0	1.6	0.47	1.1	1.7
PCB-66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-101	2.9	8.6	5.7	19	4.1	8.6	1.1	1.6	5.5	1.4	3.3	5
PCB-105	0	2.4	1.6	7.8	1	2	0.0	0.0	1.7	0.0	0.62	1.3
PCB-118	1.1	3.4	2	8.1	1.7	3.2	0.0	0.0	2.1	0.0	1.1	1.9
PCB-128	1.1	3.7	2	6.9	1.5	3.2	0.0	0.69	2.5	0.5	1.2	1.3
PCB-138	3.1	9.2	5	19	4.5	8.3	0.99	1.9	6.2	1.5	3.2	4.2
PCB-153	4.2	10	5.7	20	5.1	9.9	1.5	2.70	7.60	1.8	4.4	4.20
PCB-170	1.6	4.7	2.6	8.2	1.7	4.2	0.0	0.94	3.3	0.62	1.9	1.4
PCB-180	2.3	6.8	3.9	11	2.4	5.9	0.65	1.3	4.6	0.85	2.3	1.9
PCB-187	1.8	3.8	2.2	6.5	1.7	3.9	0.0	1	3.1	0.67	1.7	1.1
PCB-195	0.0	0.63	0.0	0.97	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
PCB-206	0.0	1.4	0.53	2.2	0.0	1.1	0.0	0.0	0.73	0.0	0.54	0.0
PCB-209	0.0	1.8	0.0	2.8	0.0	2	0.0	0.0	0.81	0.0	0.0	0.0
NOAA18	18.1	64.22	39.11	128.57	25.71	57.64	4.24	10.13	40.47	7.8	21.36	24.63
TPCB (2xNOAA)	36.2	128.44	78.22	257.14	51.42	115.28	8.48	20.26	80.94	15.6	42.72	49.26

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-12. NBSD PCB congener concentrations (mg/kg) in sediment core samples underneath Pier 5 (P5).

P5	S1	S2		S3				S4				S5				S5DUP		
Units for Sediment **mg/Kg**	C1-5	C1-5	C5-10	C1-5	C5-10	C10-15	C15-20	C1-5	C5-10	C10-15	C15-20	C1-5	C5-9	C9-13	C13-17	C1-5	C5-9	C9-13
Pier ID#	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PCB Congener**	Site 1	Site 2		Site 3				Site 4				Site 5				Site 5 - Field Duplicate		
PCB-8	0.0	0.0	0.0	0.8	0.0	0.0	0.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-18	0.95	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-28	1.9	0.71	0.0	1.8	0.0	0.66	1	0.0	0.93	0.0	1.4	0.0	0.0	0.74	0.59	0.0	0.0	0.0
PCB-44	1.5	0.54	0.0	0.65	0.0	0.79	1.3	0.0	0.64	0.53	1.9	0.63	0.62	0.93	0.74	0.0	0.0	0.74
PCB-52	2.7	1.4	0.6	1.2	1.6	2.1	2.5	1	1.4	1.7	3.7	1.4	1.4	1.9	1.3	0.63	1.7	1.6
PCB-66	3.9	0.0	0.0	0	0.0	0.0	0.0	0.0	3	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-101	6.6	4.3	2.9	3.1	5.5	6.2	8.8	3.3	4.9	5.5	10	4.6	5.9	8.8	5	2.2	5.8	5.8
PCB-105	2.2	1.3	1.4	1.1	1.3	1.6	3.2	0.87	1.5	1.1	3.8	1.1	1.2	2.5	1.7	0.0	1.3	1.5
PCB-118	2.7	1.7	1.5	1.3	2	2.3	3.7	1.3	1.9	1.3	4.2	1.7	3.7	3.2	2	0.89	2.1	2.2
PCB-128	2.3	2.3	1.8	1.4	2.2	2.4	4.5	1.5	2.1	1.4	4.4	1.9	3.8	4.4	2.2	1	2.7	2.7
PCB-138	6.5	5.2	4.6	3.8	6	6.1	12	4.1	5.6	3.7	11	4.9	6	11	6	2.7	6.3	7
PCB-153	6.6	6.7	4.5	4.6	7.3	7.40	13.00	5	6.2	4.20	12.00	6.1	10	13	6.60	3.5	7.7	7.90
PCB-170	2.8	3.2	2.5	1.9	3	2.8	6.4	1.9	2.6	1.7	5.6	2.5	5.4	5.6	3	1.7	4	3.3
PCB-180	3.8	4.6	3.5	2.5	4.3	4	8.8	2.7	3.8	2.7	8.3	3.7	5	8.2	4.3	2.2	5.7	4.8
PCB-187	2.3	2.9	1.9	1.8	3.1	2.8	5.4	2	2.5	1.7	5	2.6	19	5.6	2.7	1.5	3.6	3.3
PCB-195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.96	0.64	0.0	0.0	0.0	0.0
PCB-206	0.8	0.94	0.77	0.68	1.1	1	1.7	0.63	0.8	0.0	1.8	0.96	5.1	1.5	0.85	0.0	1.1	0.86
PCB-209	0.76	1	0.97	1.1	1.3	0.6	1.7	0.0	0.88	0.0	1.5	1	1.3	1.2	0.9	0.0	1.3	1.1
NOAA18	48.31	36.79	26.94	29.13	38.7	40.75	74.45	24.3	39.68	27.53	74.6	33.09	69.38	69.21	37.88	16.32	43.3	42.8
TPCB (2xNOAA)	96.62	73.58	53.88	58.26	77.4	81.5	148.9	48.6	79.36	55.06	149.2	66.18	138.76	138.42	75.76	32.64	86.6	85.6

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-13. NBSD PCB congener concentrations (mg/kg) in sediment core samples underneath Pier 10 (P10).

P10	S1				S2		S3		S4				S5		
Units for Sediment **mg/Kg**	C1-5	C5-10	C10-15	C15-20	C1-5	C5-9	C1-4	C4-8	C1-5	C5-10	C10-15	C15-20	C1-4	C4-8	C8-12
Pier ID#	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PCB Congener**	Site 1				Site 2		Site 3		Site 4				Site 5		
PCB-8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.69	0.9	0.0	0.0	0.33
PCB-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
PCB-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	2.2	0.0	0.0	0.0
PCB-44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	1.9	0.0	0.0	0.0
PCB-52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.96	1.9	3.5	0.0	0.0	0.0
PCB-66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PCB-101	0.74	0.41	0.0	0.0	0.41	0.48	0.54	0.92	0.55	3.6	7.7	11	0.32	0.68	0.83
PCB-105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.95	1.8	3.3	0.0	0.0	0.0
PCB-118	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	2.6	4.4	0.0	0.0	0.0
PCB-128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.5	4	0.0	0.0	0.0
PCB-138	1	0.41	0.0	0.0	0.0	0.49	0.67	0.86	0.59	3.6	7.2	11	0.0	0.66	0.77
PCB-153	1.3	0.63	0.0	0.0	0.0	0.77	0.96	1.40	0.92	4	8.5	13.00	0.0	1	1.20
PCB-170	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.55	0.0	1.5	3.6	5.7	0.0	0.0	0.0
PCB-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.55	0.0	2.1	5.3	8.3	0.0	0.0	0.5
PCB-187	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.55	0.0	1.5	3.6	5.7	0.0	0.0	0.0
PCB-195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.82	0.0	0.0	0.0
PCB-206	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.76	1.1	1.5	0.0	0.0	0.0
PCB-209	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.2	0.0	0.0	0.0
NOAA18	3.04	1.45	0.0	0.0	0.41	1.74	2.17	4.83	2.06	21.57	50.19	80.62	0.32	2.34	3.63
TPCB (2xNOAA)	6.08	2.9	0.0	0.0	0.82	3.48	4.34	9.66	4.12	43.14	100.38	161.24	0.64	4.68	7.26

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-14. NBSD PCB congener concentrations (mg/kg) in sediment core samples at the Quay Wall (QW) between Piers 3 and 4 (P3/P4).

P3/P4	QW	QW	QW
Units for Sediment: **mg/Kg**	**C1-4**	**C4-8**	**G**
Pier ID#	3/4	3/4	3/4
Matrix:	Sediment	Sediment	Sediment
Analyte: **PCB Congener**	Quay Wall		
PCB-8	0.31	0.0	0.0
PCB-18	3	1.9	3.3
PCB-28	2.1	1.1	2.3
PCB-44	2.5	1.7	4
PCB-52	13	6.1	14
PCB-66	0.0	0.0	0.0
PCB-101	20	7.9	18
PCB-105	7.1	1.4	4.9
PCB-118	10	2.9	7.3
PCB-128	6	1.4	4.1
PCB-138	20	4.5	13
PCB-153	17	5.1	13.00
PCB-170	4	1.3	3.3
PCB-180	4.8	1.7	4.3
PCB-187	2.4	1.1	2.6
PCB-195	0.0	0.0	0.0
PCB-206	0.45	0.0	0.58
PCB-209	0.0	0.82	0.0
NOAA18	112.66	38.92	94.68
TPCB (2xNOAA)	225.32	77.84	189.36

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-15. NBSD Organochlorine (OC) pesticide concentrations (mg/kg) in sediment core samples underneath Pier 1 (P1), Pier 3 (P3), and Pier 10 (P10).

P3	S2		S3
Units for Sediment: mg/Kg	C1-5	C5-10	C3-8
Pier ID#	3	3	3
Matrix:	Sediment	Sediment	Sediment
Analyte: **OC Pesticides**	Site 2		Site 3
4,4'-DDD	0.0	0.0	0.0
4,4'-DDE	1.88	2.37	0.0
4,4'-DDT	0.0	0.0	0.0
Aldrin	0.0	0.0	0.0
alpha-BHC	0.0	0.0	0.0
alpha-Chlordane	0.0	0.0	0.0
beta-BHC	0.0	0.0	0.0
delta-BHC	0.0	0.0	0.0
Dieldrin	0.0	0.0	0.0
Endosulfan I	0.0	0.0	0.0
Endosulfan II	0.0	0.0	0.0
Endosulfan sulfate	0.0	0.0	0.0
Endrin	0.0	0.0	0.0
Endrin aldehyde	0.0	0.0	0.0
Endrin ketone	0.0	0.0	0.0
gamma-BHC Lindane	0.0	0.0	0.0
gamma-Chlordane	0.0	0.0	0.0
Heptachlor	0.0	0.0	0.0
Heptachlor epoxide	0.0	0.0	0.0
Methoxychlor	0.0	0.0	0.0
Toxaphene	0.0	0.0	0.0

P1	S2	S4
Units for Sediment: mg/Kg	C1-6	C6-10
Pier ID#	1	1
Matrix:	Sediment	Sediment
Analyte: **OC Pesticides**	Site 2	Site 4
4,4'-DDD	0.0	0.0
4,4'-DDE	2.18	33.7
4,4'-DDT	0.0	0.0
Aldrin	0.0	0.0
alpha-BHC	0.0	0.0
alpha-Chlordane	0.0	0.0
beta-BHC	0.0	0.0
delta-BHC	0.0	0.0
Dieldrin	0.0	0.0
Endosulfan I	0.0	0.0
Endosulfan II	0.0	0.0
Endosulfan sulfate	0.0	0.0
Endrin	0.0	0.0
Endrin aldehyde	0.0	0.0
Endrin ketone	0.0	0.0
gamma-BHC Lindane	0.0	0.0
gamma-Chlordane	0.0	0.0
Heptachlor	0.0	0.0
Heptachlor epoxide	0.0	0.0
Methoxychlor	0.0	2.05
Toxaphene	0.0	0.0

P10	S1	S3	S4
Units for Sediment mg/Kg	C10-15	C1-4	C10-15
Pier ID#	10	10	10
Matrix:	Sediment	Sediment	Sediment
Analyte: **OC Pesticides**	Site 1	Site 3	Site 4
4,4'-DDD	0.0	0.0	0.0
4,4'-DDE	0.84	1.53	5.49
4,4'-DDT	0.0	0.0	0
Aldrin	0.0	0.0	0.0
alpha-BHC	0.0	0.0	0.0
alpha-Chlordane	0.0	0.0	0.0
beta-BHC	0.0	0.0	0.0
delta-BHC	0.0	0.0	0.0
Dieldrin	0.0	0.0	0.0
Endosulfan I	0.0	0.0	0.0
Endosulfan II	0.0	0.0	0.0
Endosulfan sulfate	0.0	0.0	0.0
Endrin	0.0	0.0	0.0
Endrin aldehyde	0.0	0.0	0.0
Endrin ketone	0.0	0.0	0.0
gamma-BHC Lindane	0.0	0.0	0.0
gamma-Chlordane	0.0	0.0	0.0
Heptachlor	0.0	0.0	0.0
Heptachlor epoxide	0.0	0.0	0.0
Methoxychlor	0.0	0.0	0.0
Toxaphene	0.0	0.0	0.0

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-16. NBSD organochlorine (OC) pesticide concentrations (mg/kg) in sediment core samples underneath Pier 4 (P4).

P4	**S1**				**S2**		**S3**			**S4**		
Units for Sediment: **mg/Kg**	**C1-6**	**C6-12**	**C12-18**	**PLUG**	**C1-5**	**C5-10**	**C1-4**	**C4-8**	**C8-13**	**C1-5**	**C5-9**	**C9-13**
Pier ID#	4	4	4	4	4	4	4	4	4	4	4	4
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **OC Pesticides**	Site 1				Site 2		Site 3			Site 4		
4,4'-DDD	3.38	6.98	14.3	25.6						2.45	2.59	3.44
4,4'-DDE	0.0	0.0	0.0	0.0						9.71	21.3	0.0
4,4'-DDT	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Aldrin	0.0	0.0	0.0	0.0						0.0	0.0	0.0
alpha-BHC	0.0	0.0	0.0	0.0						0.0	0.0	0.0
alpha-Chlordane	0.0	0.0	0.0	0.0						0.0	0.0	0.0
beta-BHC	0.0	0.0	0.0	0.0						0.0	0.0	0.0
delta-BHC	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Dieldrin	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Endosulfan I	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Endosulfan II	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Endosulfan sulfate	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Endrin	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Endrin aldehyde	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Endrin ketone	0.0	0.0	0.0	0.0						0.0	0.0	0.0
gamma-BHC Lindane	0.0	0.0	0.0	0.0						0.0	0.0	0.0
gamma-Chlordane	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Heptachlor	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Heptachlor epoxide	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Methoxychlor	0.0	0.0	0.0	0.0						0.0	0.0	0.0
Toxaphene	0.0	1.8	0.0	2.8	0.0	2.0	0.0	0.0	0.81	0.0	0.0	0.0

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-17. NBSD Organochlorine (OC) pesticide concentrations (mg/kg) in sediment core samples underneath Pier 5 (P5).

P5	**S1**	**S2**		**S3**				**S4**				**S5**				**S5DUP**		
Units for Sediment **mg/Kg**	**C1-5**	**C1-5**	**C5-10**	**C1-5**	**C5-10**	**C10-15**	**C15-20**	**C1-5**	**C5-10**	**C10-15**	**C15-20**	**C1-5**	**C5-9**	**C9-13**	**C13-17**	**C1-5**	**C5-9**	**C9-13**
Pier ID#	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **OC Pesticides**	Site 1	Site 2		Site 3				Site 4				Site 5				Site 5 - Field Duplicate		
4,4'-DDD		3.16	6.62	2.93	4.98	4.38	6.87	3.28	6.00	9.01	15.30			8.68	8.59			
4,4'-DDE		25.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
4,4'-DDT		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Aldrin		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
alpha-BHC		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
alpha-Chlordane		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
beta-BHC		0.0	0.0	0.0	0.0	0.86	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
delta-BHC		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Dieldrin		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Endosulfan I		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Endosulfan II		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Endosulfan sulfate		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Endrin		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Endrin aldehyde		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Endrin ketone		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
gamma-BHC Lindane		0.0	0.0	0.0	0.0	5.44	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
gamma-Chlordane		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Heptachlor		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Heptachlor epoxide		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Methoxychlor		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Toxaphene	0.76	1.0	0.97	1.1	1.3	0.6	1.7	0.0	0.88	0.0	1.5	1.0	1.3	1.2	0.9	0.0	1.3	1.1

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-18. NBSD PAHs concentrations (mg/kg) in sediment core samples underneath Pier 1 (P1), Pier 3 (P3), and Pier 10 (P10).

P1	S2	S4
Units for Sediment: mg/Kg	C1-6	C6-10
Pier ID#	1	1
Matrix:	Sediment	Sediment
Analyte: **PAHs**	Site 2	Site 4
Naphthalene	3.7	10.6
2-Methylnaphthalene	2.2	6.6
1-Methylnaphthalene	1.2	2.75
Acenaphthylene	2.0	16.5
Acenaphthene	1.35	9.83
Fluorene	2.4	12.9
Phenanthrene	25.2	109
Anthracene	11.6	105
Fluoranthene	65.7	552
Pyrene	95.1	1790
Benzo (a) anthracene	49.6	437
Chrysene	80.8	976.00
Benzo (k) fluoranthene	156	1140
Dibenz (a,h) anthracene	36	192
Benzo (g,h,i) perylene	140	620
Benzo (b) fluoranthene	166.00	1200
Benzo (a) pyrene	166.00	1360
Indeno (1,2,3-cd) pyrene	193.00	918
TPAH (Σ16PAH)	1194.43	9448.83

P3	S2		S3
Units for Sediment: mg/Kg	C1-5	C5-10	C3-8
Pier ID#	3	3	3
Matrix:	Sediment	Sediment	Sediment
Analyte: **PAHs**	Site 2		Site 3
Naphthalene	2.8	1.7	1.1
2-Methylnaphthalene	1.5	1.1	0.0
1-Methylnaphthalene	0.9	0	0.0
Acenaphthylene	1.41	3.25	0.0
Acenaphthene	1.11	0.0	0.0
Fluorene	1.8	1.1	0.0
Phenanthrene	18.7	9.86	1.48
Anthracene	12.7	12.3	0.0
Fluoranthene	86.7	61.2	1.0
Pyrene	151	177	2.3
Benzo (a) anthracene	67.8	90.6	0.0
Chrysene	99.2	123	1.28
Benzo (k) fluoranthene	231	369	3.5
Dibenz (a,h) anthracene	48.1	63.4	0.0
Benzo (g,h,i) perylene	142	161	6.6
Benzo (b) fluoranthene	271.0	406.0	4.8
Benzo (a) pyrene	235.0	411	3.9
Indeno (1,2,3-cd) pyrene	204.0	271.0	3.8
TPAH (Σ16PAH)	1574.31	2161.39	29.59

P10	S1	S3	S4
Units for Sediment mg/Kg	C10-15	C1-4	C10-15
Pier ID#	10	10	10
Matrix:	Sediment	Sediment	Sediment
Analyte: **PAHs**	Site 1	Site 3	Site 4
Naphthalene	4.6	3.4	7.4
2-Methylnaphthalene	1.7	2.0	4.9
1-Methylnaphthalene	0.0	0.0	2.1
Acenaphthylene	2.7	5.8	48.1
Acenaphthene	0.0	1.6	3.93
Fluorene	0.0	2.3	0.0
Phenanthrene	21.6	25.4	41
Anthracene	4.9	13.6	69.7
Fluoranthene	70.9	63.9	131
Pyrene	83.1	74.1	143
Benzo (a) anthracene	29.7	45.7	175
Chrysene	33.7	67.7	453
Benzo (k) fluoranthene	64.2	143.0	2550
Dibenz (a,h) anthracene	15.6	36.3	340
Benzo (g,h,i) perylene	141.0	130.0	1260
Benzo (b) fluoranthene	96.8	188.0	2940.0
Benzo (a) pyrene	115.0	160.0	3030
Indeno (1,2,3-cd) pyrene	150.0	188.0	2060
TPAH (Σ16PAH)	833.8	1148.92	13252.13

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-19. NBSD PAHs concentrations (mg/kg) in sediment core samples underneath Pier 4 (P4).

P4	S1				S4		
Units for Sediment: **mg/Kg**	C1-6	C6-12	C12-18	PLUG	C1-5	C5-9	C9-13
Pier ID#	4	4	4	4	4	4	4
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PAHs**	Site 1				Site 4		
Naphthalene	5.4	8.56	8.11	12.9	3.8	4.1	5.7
2-Methylnaphthalene	3.5	6.7	6.14	11.1	2.6	3.0	4.4
1-Methylnaphthalene	1.9	3.62	3.07	5.31	1.0	1.3	2.0
Acenaphthylene	11.8	38.8	81	51.1	10.4	15.6	31
Acenaphthene	4.2	9.65	21.2	21	1.04	1.68	3.08
Fluorene	5.3	19.1	0.0	19.6	2.4	0.0	3.2
Phenanthrene	46.3	110	72.5	89.6	19	27.7	39.4
Anthracene	29.4	138	98.7	194	19.4	27.4	63.6
Fluoranthene	134	318	23.8	348	98.9	107	184
Pyrene	294	2010	13400	11300	147.0	150	265
Benzo (a) anthracene	104	350	551	707	72.7	84.4	177
Chrysene	182	773	953	1490	113	152	323.00
Benzo (k) fluoranthene	511	3270	4690	4030	288	447	914
Dibenz (a,h) anthracene	112	320	357	567	60.6	80.6	182
Benzo (g,h,i) perylene	312	1150	1400	1340	184	250	489
Benzo (b) fluoranthene	663	4030	4130	3980	301	534	1170
Benzo (a) pyrene	561	3470	4470	4060	284	476	1060
Indeno (1,2,3-cd) pyrene	485	2000	2210	2340	259	350	781
TPAH (Σ16PAH)	3460.35	18015.1	32466.3	30550.2	1864.16	2707.47	5690.99

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-20. NBSD PAHs concentrations (mg/kg) in sediment core samples underneath Pier 5 (P5).

P5	S2		S3				S4				S5	
Units for Sediment **mg/Kg**	C1-5	C5-10	C1-5	C5-10	C10-15	C15-20	C1-5	C5-10	C10-15	C15-20	C9-13	C13-17
Pier ID#	5	5	5	5	5	5	5	5	5	5	5	5
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Analyte: **PAHs**	Site 2		Site 3				Site 4				Site 5	
Naphthalene	10.7	10.2	4.83	11.5	5.9	6.98	5.3	7.7	11.7	11.1	10.1	18.7
2-Methylnaphthalene	6.0	7.8	2.81	6.3	4.4	5.4	4.3	6.63	18.0	9.7	11.1	12.8
1-Methylnaphthalene	2.09	3.7	0.0	2.9	1.87	2.3	2.8	4.01	16.1	5.68	6.3	7.4
Acenaphthylene	13	22.2	13.9	42.8	19.8	89.2	10.3	95.9	52.7	42.2	138	139
Acenaphthene	2.3	5.75	1.52	9.53	4.55	11.4	16.4	12.2	44.8	18	20.8	23.9
Fluorene	4.5	0.0	0.0	10.8	0.0	24.6	15.1	19.4	96.3	19.5	23.7	0.0
Phenanthrene	27.1	51.4	23.3	73.1	68.4	101	161	88.7	918	95.9	110	141
Anthracene	30	68.8	25.6	80.9	82.5	259	49.3	110	430	73	271	258
Fluoranthene	72.3	11.8	104	180	189	868	294	341	1320	336	697	641
Pyrene	1120	5200	162	597	726	12300	385	4970	8030	8900	10700	17900
Benzo (a) anthracene	79.6	337	72	232	258	912	138	410	1010	522	824	1070
Chrysene	146	584	111	418	493.00	1440.00	257	622	1180.00	521.00	1290	1690.00
Benzo (k) fluoranthene	479	3100	368	1600	1860	4790	658	4370	5270	3400	5820	5660
Dibenz (a,h) anthracene	80.9	299	77.3	236	246	148	125	456	498	349	700	571
Benzo (g,h,i) perylene	263	1060	268	862	912	1590	435	1510	1770	1210	2370	1950
Benzo (b) fluoranthene	591	3540	467	2270	2410	5930	861	5720	6630	4280	7780	6820
Benzo (a) pyrene	532	3360	396	1930	2080	5460	767	4960	5780.0	3660	6920	6290
Indeno (1,2,3-cd) pyrene	380	1650	380	1250	1690	2970	611	2500	3080	1990	3730	3260
TPAH (Σ16PAH)	3831.4	19300.2	2474.45	9803.63	11045.1	36900.2	4788.41	26192.9	36121.5	25427.7	41404.6	46432.6

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-21. NBSD %Moisture, %TOC, and %Solids data in sediment core sample. underneath Pier 1 (P1), Pier 3 (P3), and Pier 4 (P4).

P1	S1		S2		S3		S4	
Units for Sediment: %	C1-6	C6-8	C1-6	C6-12	C1-6	C6-8	C1-6	C6-10
Pier ID#	1	1	1	1	1	1	1	1
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Parameter:	Site 1		Site 2		Site 3		Site 4	
Percent (%) Moisture	13.9	25.2	39.4	35	36.2	17.6	51.7	50.9
Percent (%) TOC			1.1					4.4
Percent (%) Solids	86.1	74.8	60.6	65	63.8	82.4	48.3	49.1

P3	S1		S2				S3			S4	
Units for Sediment: %	C1-3	C3-6	C1-5	C5-10	C10-17	C17-19	C1-3	C3-8	C8-10	C1-5	C5-7
Pier ID#	3	3	3	3	3	3	3	3	3	3	3
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Parameter:	Site 1		Site 2				Site 3			Site 4	
Percent (%) Moisture	40.1	18.5	38.4	26.4	20.0	17.5	34.6	22.4	24.7	36.0	16.1
Percent (%) TOC			0.8	0.4				0.2			
Percent (%) Solids	59.9	81.5	61.6	73.6	80.0	82.5	65.4	77.6	75.3	64.0	83.9

P4	S1				S2		S3			S4		
Units for Sediment: %	C1-6	C6-12	C12-18	PLUG	C1-5	C5-10	C1-4	C4-8	C8-13	C1-5	C5-9	C9-13
Pier ID#	4	4	4	4	4	4	4	4	4	4	4	4
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Parameter:	Site 1				Site 2		Site 3			Site 4		
Percent (%) Moisture	47.3	45.7	47.4	50.5	50.9	43.6	52.5	43.7	46.9	44.8	42.0	42.1
Percent (%) TOC	1.5	1.8	2.7	3.1						1.5	1.3	1.1
Percent (%) Solids	52.7	54.3	52.6	49.5	49.1	56.4	47.5	56.3	53.1	55.2	58.0	57.9

- "S" indicates "site"
- "C" indicates "core"; numbers after "C" indicate depth of core section analyzed (in cm)

Table B-22. NBSD percent (%Moisture, %TOC, and %Solids data in sediment core samples underneath Pier 5.

P5	S1	S2		S3				S4				S5				S5DUP		
Units for Sediment: %	C1-5	C1-5	C5-10	C1-5	C5-10	C10-15	C15-20	C1-5	C5-10	C10-15	C15-20	C1-5	C5-9	C9-13	C13-17	C1-5	C5-9	C9-13
Pier ID#	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Parameter:	Site 1	Site 2		Site 3				Site 4				Site 5				Site 5 - Field Duplicate		
Percent (%) Moisture	46.1	44.2	45.7	52.7	64.2	48.2	50.9	51.1	51.7	52.6	54.3	54.0	53.4	52.8	53.6	51.0	51.9	52.3
Percent (%) TOC		0.9	2.0	1.6	1.6	1.9	2.5	1.7	2.3	3.0	3.0			2.7	2.1			
Percent (%) Solids	53.9	55.8	54.3	47.3	35.8	51.8	49.1	48.9	48.3	47.4	45.7	46.0	46.6	47.2	46.4	49.0	48.1	47.7

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

Table B-23. NBSD %Moisture, %TOC, and %Solids data in sediment core samples underneath Pier 10 (P10) and at the Quay Wall (QW) between Piers 3 and 4 (P3/P4).

P10	S1				S2		S3		S4				S5		
Units for Sediment: %	C1-5	C5-10	C10-15	C15-20	C1-5	C5-9	C1-4	C4-8	C1-5	C5-10	C10-15	C15-20	C1-4	C4-8	C8-12
Pier ID#	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Parameter:	Site 1				Site 2		Site 3		Site 4				Site 5		
Percent (%) Moisture	45.5	42.9	48.3	46.2	46.5	39.9	39.2	35.0	46.5	44.5	52.4	51.2	44.4	34.9	36.4
Percent (%) TOC			1.3				1.1				2.3				
Percent (%) Solids	54.5	57.1	51.7	53.8	53.5	60.1	60.8	65.0	53.5	55.5	47.6	48.8	55.6	65.1	63.6

P3/P4	QW	QW	QW
Units for Sediment: %	C1-4	C4-8	G
Pier ID#	3/4	3/4	3/4
Matrix:	Sediment	Sediment	Sediment
Parameter:	Quay Wall		
Percent (%) Moisture	37.0	23.0	48.7
Percent (%) TOC			
Percent (%) Solids	63.0	77.0	51.3

- “S” indicates “site”
- “C” indicates “core”; numbers after “C” indicate depth of core section analyzed (in cm)

APPENDIX B: REFERENCES

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APPENDIX C: CORRESPONDENCE

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT
5900 LA PLACE COURT, SUITE 100
CARLSBAD CA, 92008

August 11, 2021

SUBJECT: Determination of Need for Department of the Army Permit

Jessica Carilli
Naval Information Warfare Center Pacific
43475 Strothe Road
San Diego, California 92152

Dear Ms. Carilli:

I am responding to your pre-construction notification dated March 17, 2021 for clarification whether a Department of the Army Permit is required for your proposed project, NBSD Flexible-Under-Pier Sediment Assessment (File No. SPL-2021-00192-MER). The proposed project is located in within the San Diego Bay at Naval Base San Diego, San Diego County, California (Latitude 32.679°, Longitude -117.127°).

The proposed project would include conducting sediment surveys as part as a preliminary site investigation to detect munition constituents and contaminated sediments, underneath Naval Base San Diego (NBSD) Piers 1, 3, 4, 5, and 10, within the Munitions Response Site 100. Based upon the information you provided in your email correspondence on May 19, 2021 and July 7, 2021, the proposed project has been determined to be undertaken by the Defense Environmental Restoration Program (DERP) established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Superfund Amendments and Reauthorization Act (SARA). In accordance with Executive Order 12580, the Department of Defense (DoD) is the delegated the authority under CERCLA at DoD Installations. Pursuant to CERCLA Section 121 (e)(1), NBSD is not required to obtain permits under Section 404 of the Clean Water Act or Section 10 of the Rivers and Harbors Act for the proposed project.

If you have any questions, please contact Max Roseman at 760-602-4832 or via email at Please help me to evaluate and improve the regulatory experience for others by completing the customer survey form at https://regulatory.ops.usace.army.mil/customer-service-survey/.

Sincerely,

Date: 2021.08.11 16:07:28 -07'00'

Michael LaDouceur
Acting Section Chief
San Diego and Imperial Counties Section

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6. AUTHORS

Jessica Carilli
Regina Guazzo
James Leather
NIWC Pacific

Mario Malfavon
Joel Guerrero
Benjamin Whitmore
NIWC Pacific

Kevin Carlin
Angelica Rodriguez
Bradley Davidson
NIWC Pacific

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

NIWC Pacific
53560 Hull Street
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Navy Environmental Sustainability Development to Integration (NESDI) Program
Avenida de la Provincia, 2B, 03440 Ibi, Alicante, España

Chief of Naval Operations Energy and Environmental Readiness Division (CNO N45)
1200 Navy Pentagon, Washington, DC

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14. ABSTRACT

This project was conducted in response to NESDI need N-1196-18 submitted by Len Sinfield of the Naval Facilities Engineering Systems Command (NAVFAC) Southwest. Remediating contaminated sediments in Navy harbors is estimated to be a $2 billion problem. Recontamination of previously remediated sites can compound these costs, requiring further cleanup and monitoring efforts than originally planned. One potential source of recontamination is sediment built up underneath Navy piers, where sediment assessment and dredging typically do not occur. These sediments may contain legacy contaminants such as heavy metals, polychlorinated biphenyls (PCBs), and pesticides; the specific types and quantities of potential contaminants of concern vary by site. This report details our results of our testing validating and assessing the volume and contaminant levels of sediments underneath Navy piers. The goal of the testing was to determine whether sediments under the piers should be considered a significant potential source of adjacent re-contamination. The project has demonstrated and validated the use of three (3) main technologies to quantify the volume and potential contaminant loads of under-pier sediments:
1. Under-pier bathymetry using a small unmanned platform.
2. Sediment volume and erosion assessment.
3. Quantifying contaminant concentrations.
The goal of this report was to create a simple and cost-effective solution to quantify the volume and contaminant loads of under-pier sediments. This challenging environment is constrained by tides, ship movements, varying pier architectures, and sporadic or non-existent GPS signals.

15. SUBJECT TERMS

pre-dredge; core, sediment; bathymetric assessment; sediment contamination; sediment erosion

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Jessica Carilli
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