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The Benthic Zone

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Floating Offshore Wind: Overcoming Seafloor Challenges

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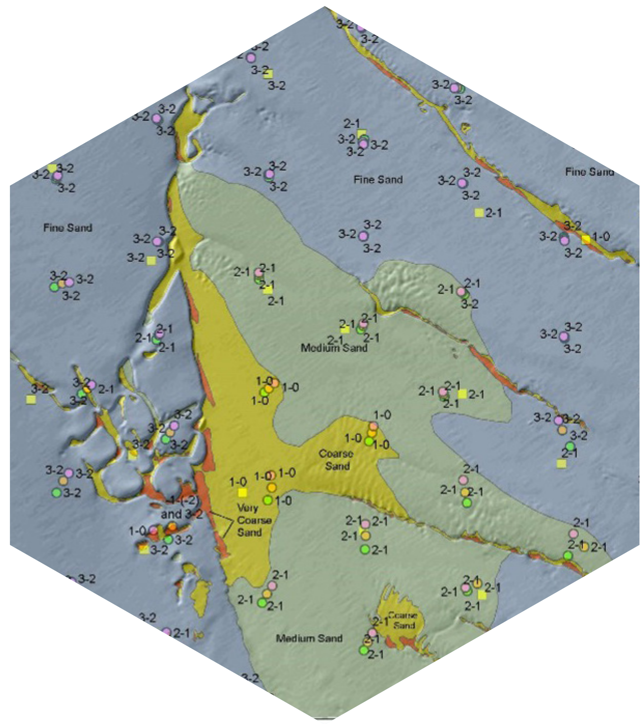
As the world continues the path of decarbonization and renewable energy transformation, the need for additional offshore wind facilities to meet the energy requirements of climate goals has become apparent. Recent lease sales in the waters of the United States by the Bureau of Ocean Energy Management have generated increased domestic interest in resolving the engineering and environmental issues related to both fixed bottom and floating wind power production facilities.

Floating Offshore Wind

Almost all commercial-scale offshore wind turbines to date are installed on foundations fixed to the seafloor in relatively shallow waters (<60 meters). While these facilities have trusted engineering solutions to surviving the rigors of the offshore environment, novel solutions will be required to access the much more expansive deepwater areas. Floating offshore wind projects, like those proposed along the deeper waters of the Pacific and Atlantic coasts, are in active development at present. Deepwater floating offshore wind technology involves wind turbine generators mounted on floating structures that are tethered or anchored in deep waters, typically farther from shore than traditional fixed bottom offshore wind farms. This floating technology enables the harnessing of significant wind energy resources where conventional structures cannot be installed directly into the ocean floor. Electrical cabling is used to transmit the generated power from the turbines to an offshore or onshore substation, ensuring continuous energy transfer.



Where the windfarm foundations and transmission cables interact with the seabed, a series of engineering and environmental challenges arises.

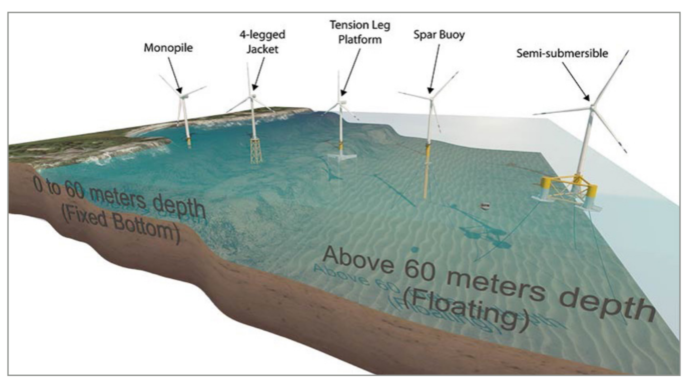


Figure 1. Offshore wind foundation installation methodology is determined by local substrates and geology. Fixed platforms are generally used in shallower waters (<60 meters of water), whereas deeper waters require floating solutions. https://www.nrel.gov/news/program/2020/images/115749-bauer-848.jpg

Subsea Cabling

In large-scale commercial windfarms, energy from each individual turbine is consolidated via a system of array cables at an offshore substation. The electrical current is typically increased in voltage to reduce transmission loss prior to being transferred from the substation to a landfall and an onshore grid interconnection. These export cables can transit tens or hundreds of kilometers and are typically buried under the seafloor.

On the continental shelf, in-water trenching technologies can be used to bury the cables for protection. Installation via these trenching tools works well in soft sediments and can be run directly to the shoreline in some environments. However, it is an inappropriate method for installation in hard or rocky bottoms, or in areas of steep bathymetry. In these areas, cables may be laid on exposed seafloor and subsequently covered or armored with some form of protection or brought to shore using horizontal directional drilling. In regions where cables are trenched or exposed on the seafloor, hazards are identified through traditional geophysical data including multibeam sonar and subbottom profilers. As water depth increases, the resolution of geophysical data decreases, leading to increased uncertainty in seafloor conditions for both engineering and environmental assessment needs. Integral's scientists and engineers address this uncertainty in environmental assessment by utilizing additional technologies to identify, avoid, and mitigate these hazards.

Finding, and Avoiding, Sensitive Benthic Habitats

Offshore benthic habitats are of immense ecological value, hosting diverse marine life and playing a crucial role in the ocean's health. The habitats, made up of varying geoforms, substrate, and biota, can act as crucial breeding and feeding grounds, maintain biodiversity, and contribute to nutrient cycling. However, the installation of offshore infrastructure, such as cabling, can potentially harm these habitats. Potential stressors include physical disturbance from installation activities, alteration of local hydrodynamics, noise, and electromagnetic field emissions.

Integral worked with the U.S. Department of Energy, Oregon State University, and other collaborators at the PacWave South energy test site offshore of Newport, Oregon, to develop a consistent and semiautomated

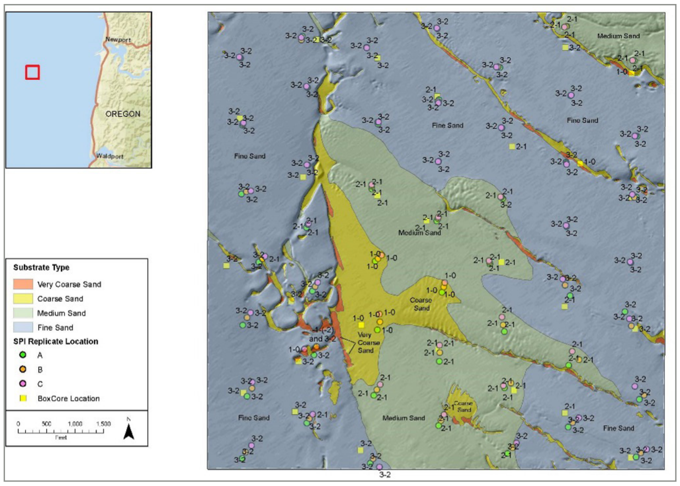


Figure 2. Map generated from Integral's combined multibeam echosounder and SPI–PV mapping efforts (Revelas et al. 2020) that supported the new shrimp population discoveries in Henkel et al. (2022). The mapping illustrates the classification of four distinct CMECS geoforms, potentially indicating areas of sensitive habitat and ecological importance.

method for seafloor surveying by using a combination of traditional geophysical methods (multibeam echosounder) and sediment profile and plan view (SPI–PV) imagery. These studies better characterize benthic habitats in deep waters (Figure 2). The high-resolution benthic habitat maps below prove invaluable for environmental assessments and monitoring of offshore energy sites (Figure 3). Overall, the development of an image processing platform that automatically measures key features represents a step forward in the ability to avoid potentially damaging impacts to sensitive habitats and communities during windfarm construction.

Integral has conducted 22 SPI–PV surveys for offshore wind developers on the U.S. east coast. The resulting highly resolved seafloor habitat maps have allowed developers to design windfarms and cable routes in an environmentally sensitive manner, and have allowed regulators to verify compliance with existing protective measures. Our experience conducting SPI–PV surveys in deepwater habitats, combined with our expertise in data analysis necessary to offshore wind developers, uniquely places Integral in a position to be at the forefront of benthic assessments for floating wind installations.

Protection from Geohazards

Floating offshore wind projects also face a range of geohazards due to the unique geological and oceanographic conditions in deeper waters. For example, the California offshore wind lease areas are characterized

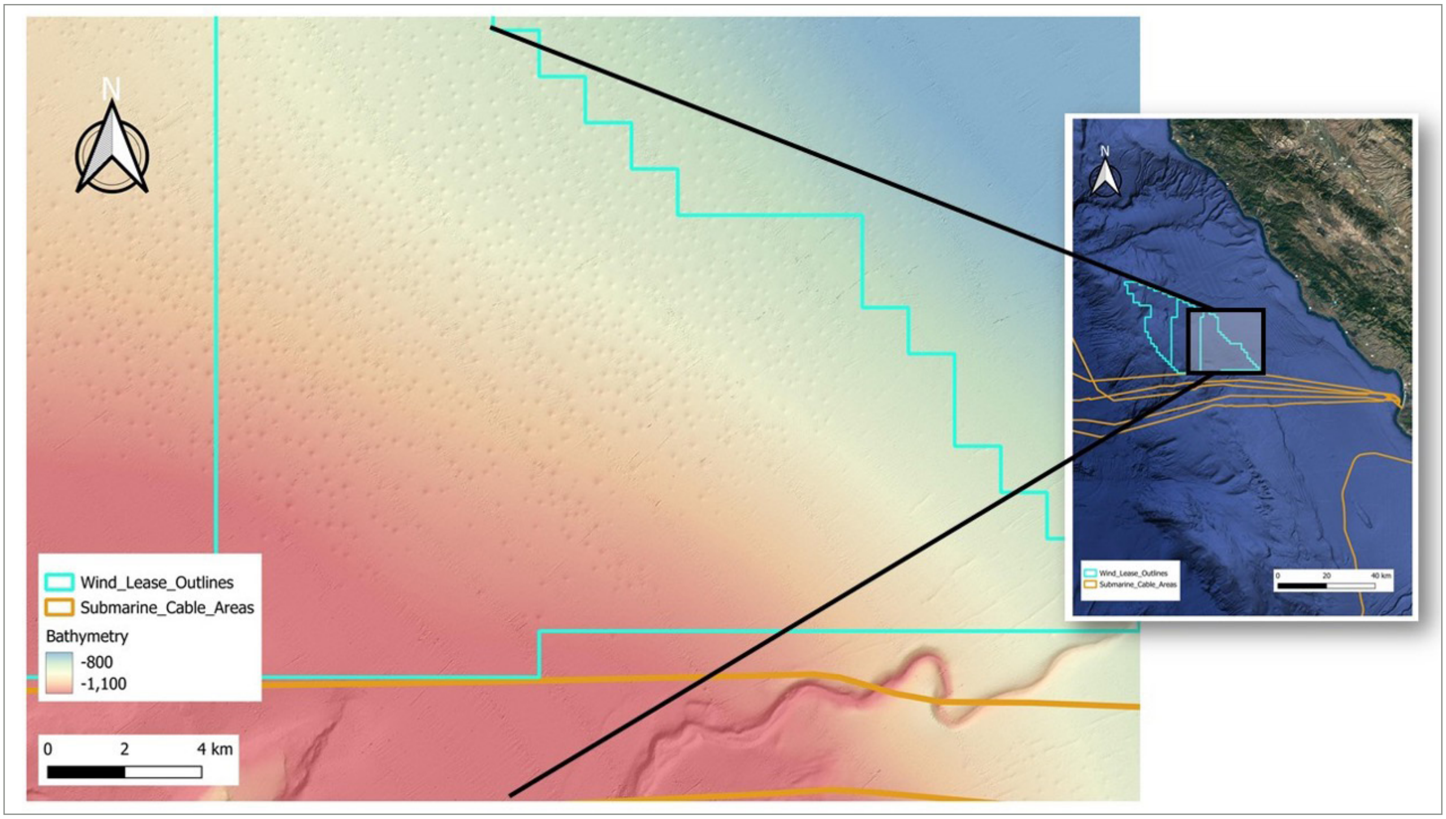


Figure 3. Map of the three offshore wind leases along the central coast of California in approximately 1000 m of water. The zoom shows multibeam bathymetry which illustrates pockmarks that were observed in the surveys (BOEM 2021).

by a complex and varied seafloor topography, including steep submarine slopes and canyons, which can lead to geotechnical challenges such as slope instability and underwater landslides. Careful geotechnical and geological assessments are crucial for site selection and design of offshore wind installations in this region to ensure their resilience against these geohazards.

An example of unique features off Morro Bay are distinctive pockmarks on the seafloor. These pockmarks are essentially craters or depressions on the seabed, varying in size and shape that could pose a challenge for cabling and anchoring of offshore wind turbines. A joint study led by BOEM (2021) used high-resolution geophysical and geological surveys to analyze seafloor and shallow subsurface geology, including fault structure, sedimentary turbidity flows, and active fluid flow in the region (Figure 3). Fortunately, the study found little to no evidence for recent fluid or gas advection in the pockmark field, hazards that could introduce significant risk to seafloor infrastructure. However, evidence of sediment transport and sediment flows in the region need further investigation to minimize and mitigate these potential risks. Similar hazards may exist at other wind development sites yet to be surveyed. Integral's benthic analysis and geohazard identification capabilities will inform marine planning, improve understanding of shallow geologic hazards and sedimentary processes, and better inform future offshore development activities.

The installation of floating wind turbines has the potential to contribute a significant percentage of global renewable energy goals. Doing so in a manner that both protects vital energy infrastructure and minimizes harm to existing habitats and migratory species will require advanced technologies and techniques. Integral provides leading expertise in addressing complex seafloor challenges within the offshore wind industry through a blend of innovative and comprehensive approaches. Our expertise encompasses a broad range of services essential for evaluating seafloor conditions to identify potential hazards, locate sensitive habitats, and minimize risk to both assets and the environment.

Integral is using advanced techniques like multispectral multibeam mapping and SPI–PV imagery, which facilitate the development of highly resolved seafloor maps. Since 2019, Integral has been supporting numerous offshore wind clients with benthic and essential fish habitat mapping services that are underpinned by delivery of SPI–PV imagery and detailed image analysis and reporting/mapping products. These habitat insights are provided to regulators and stakeholders during the permitting and site characterization phase of the offshore wind farm development process. To date, Integral scientists have conducted nearly two dozen SPI–PV surveys for the U.S. offshore wind industry, and Integral is uniquely suited to launch SPI–PV surveys in deeper sites where floating offshore wind platforms are planned.

Integral's services extend to metocean assessments, acoustics, and electromagnetic field assessments; and pioneering automated image analysis tools for seafloor imagery further underscore our capability in delivering quality-controlled data that adhere to regulatory standards. Our holistic and technical approach, combined with a commitment to environmental sustainability, positions Integral at the forefront of solving complex seafloor problems in the constantly developing offshore wind sector.

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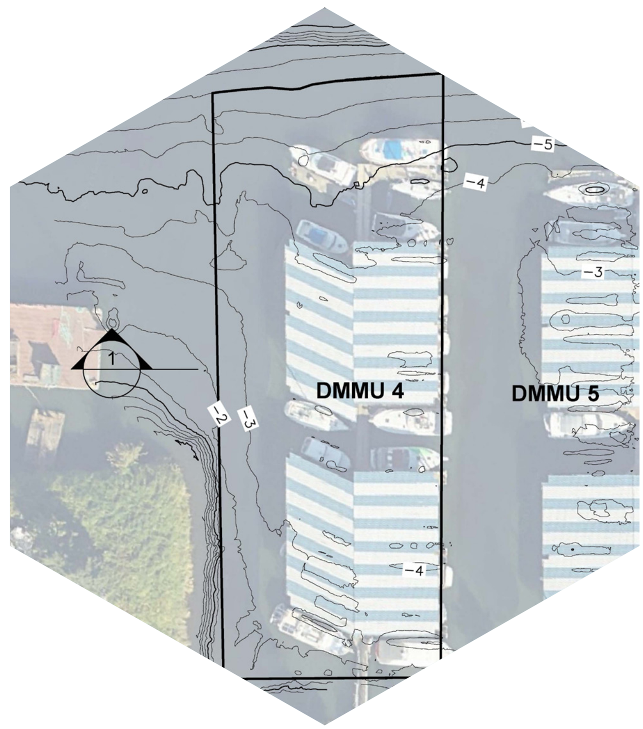
Dredged Material Management Sampling: Considerations for Maintenance Dredging at a Yacht Club on the Lower Duwamish Waterway

By Olivia Hargrave, P.E., *Project Engineer*



When dredging is part of a remediation or maintenance project, managing the dredged material can be expensive and time-consuming. The primary influence on dredging costs is disposal; in-water disposal of dredged material at open-water disposal sites in Washington's Puget Sound is currently $0.75 per cubic yard, which doesn't include the cost of dredging or transportation. By contrast, upland disposal tipping fees at a local nonhazardous landfill can be orders of magnitude greater. So, even if only a portion of the dredged material can be disposed in-water, the potential for reduced project costs is worth evaluating. Chemical constituents in the dredged material should be evaluated early and thoroughly within the project lifecycle.

Characterizing the material to be disposed in open water is a highly regulated process that is dependent upon site history, existing data, hydrodynamic forces, and budget. Dredged material management is typically regulated by a collection of stakeholders. In Washington, disposal decisions are issued by the Dredged Material Management Program (DMMP), which is cooperatively managed by the U.S. Army Corps of Engineers, Seattle District; the U.S. Environmental Protection Agency, Region 10; the Washington State Department of Ecology (Ecology); and the Washington State Department of Natural Resources.

Integral's recent dredged material characterization for the Duwamish Yacht Club (DYC), to support an upcoming maintenance dredging project, provides our case study for the universal challenges of sampling during the management of dredged material. The DYC is a small yacht club in the upper reach of the Lower Duwamish Waterway (LDW), a Superfund site in Seattle, Washington. This article describes the key considerations for dredged material management projects, in general, and uses illustrative examples from the DYC for emphasis.

Dredged Material Context

The first step in characterizing dredged material for its suitability for open-water disposal is to review local (DYC in this example) and surrounding (upper reach of LDW) area history and context. Compiling relevant history includes conducting interviews with knowledgeable persons; reviewing documents, particularly permits; and gathering existing data. These reviews can yield information indicating the potential (or lack thereof) for historical or ongoing contamination of the sediment to be dredged. Context includes ongoing in-water and upland uses and adjacent parcel activities.

At the DYC, dioxin/furan concentrations were of particular concern. In Puget Sound, material to be dredged is tested for dioxins/furans on a case-by-case basis if there is a reason to believe these chemicals may be present, such as proximity to historical sources or existing data showing elevated levels of dioxins/furans. Ecology's Environmental Information Management System (EIMS) contains past DMMP study data, which is used to determine the presence/absence of contaminants in the sediment and point to potential sources. The LDW data sets are also in EIMS, and where these data overlap the planned dredge prism laterally and vertically can provide context about the expected condition of the material to be dredged. The LDW data set is primarily from samples collected less than 2 feet below the sediment surface. Depending on the planned dredge depth and any previous dredging events, existing data may have limited use in developing an understanding of the material to be dredged.

The second step is to combine the known site information with the hydrodynamic information. A recent bathymetric survey of the area to be dredged is critical for calculating the volume of sediment for disposal. In addition, when compared to previously collected bathymetric data, the rate of erosion and/or accretion can be determined. If dredging is to take place months or years after the data collection, the rate of deposition needs to be factored into the sampling design. At the DYC, Integral compared two bathymetric surveys collected 12 years apart to visualize the magnitudes of sediment accumulation and erosion over the past decade. Sufficient timing between bathymetric surveys ensures that a comprehensive understanding of sedimentation rates is gained and that episodic events are not unduly affecting the findings.

The 2011 and 2023 bathymetry surveys, along with a knowledge of DYC history, context, and operations, were used to subdivide the DYC's planned dredged material

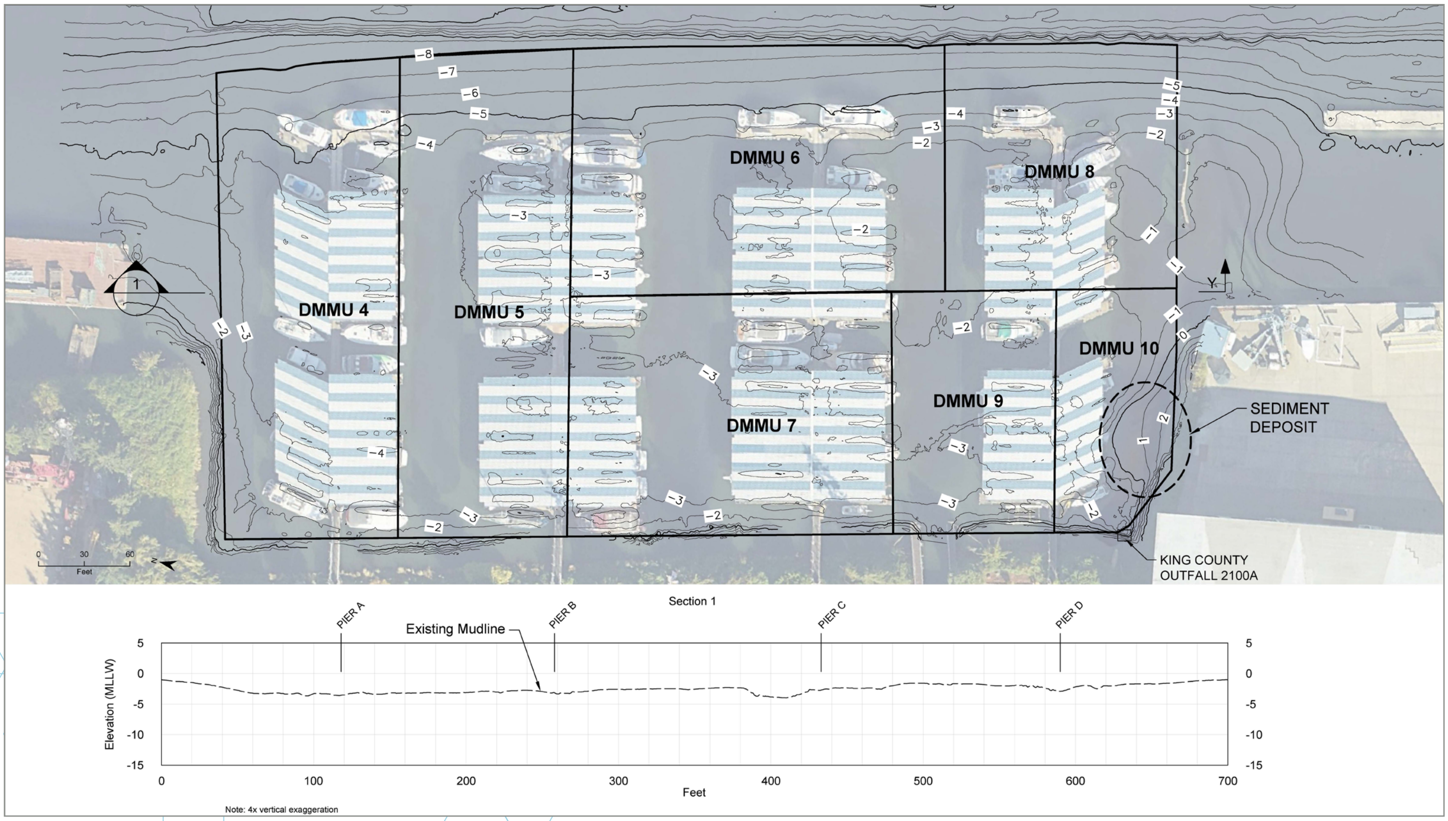


Figure 1. A bathymetric survey revealed an area of sediment deposition near an outfall. DMMU 10 was delineated around the sediment deposit.

into dredged material management units (DMMUs). The sediment affected by an ongoing source was delineated in a separate unit from the rest of the planned dredge area. The bathymetric survey data was the basis for developing a map that showed the change in sediment elevations between 2011 and 2023, which revealed how shoaling near a stormwater outfall of interest had shifted over 12 years, allowing us to draw a DMMU around the area that had been influenced by the outfall since the previous maintenance dredging 24 years ago (DMMU 10 in Figure 1).

Understanding erosion and deposition rates is also crucial to interpreting historical site data. For example, at the DYC, 2013 data from a previous dredged material characterization study is from sediment that has since been buried under an additional 3 feet of accumulated sediment (Figure 2). The bathymetry survey, characterization, and elevation data from a previous disposal study, and knowledge of the DYC's limited sources, meant that in some areas of the yacht club, only the newly deposited 3 feet of sediment needed to be characterized for disposal. The underlying material was adequately characterized by the previous 2013 investigation. This reduced the project complexity at an early stage. Using sample elevations to assess site data is discussed in more detail in the Benthic Zone article by Tufano, Kirkland, and Uselman (2023) titled "Using Accurate Sample Elevations to Characterize Sediment Conditions with 3-Dimensional Modeling."

These data are key to preparing a simple, yet comprehensive, dredged material characterization plan because they reduce uncertainty in the three dimensions of the dredge prism. The dredge prism must be subsectioned into DMMUs that enclose a deliberate portion of the area to be characterized and later dredged in manageable units. The vertical dimension, which includes the z-layer (the leave surface following the planned dredging) is the most difficult of the dimensions to properly characterize, because, due to hydrodynamic forces and the precision of the planned dredging, it is temporally dynamic.

Informed Decisions

Once the subdivision strategy is determined, the sampling and analysis plan is developed in accordance with agency guidance. It is important to engage with the regulatory stakeholders early in the process, to get their input on the sampling strategy. Regulators will approach the project with a wealth of relevant past project

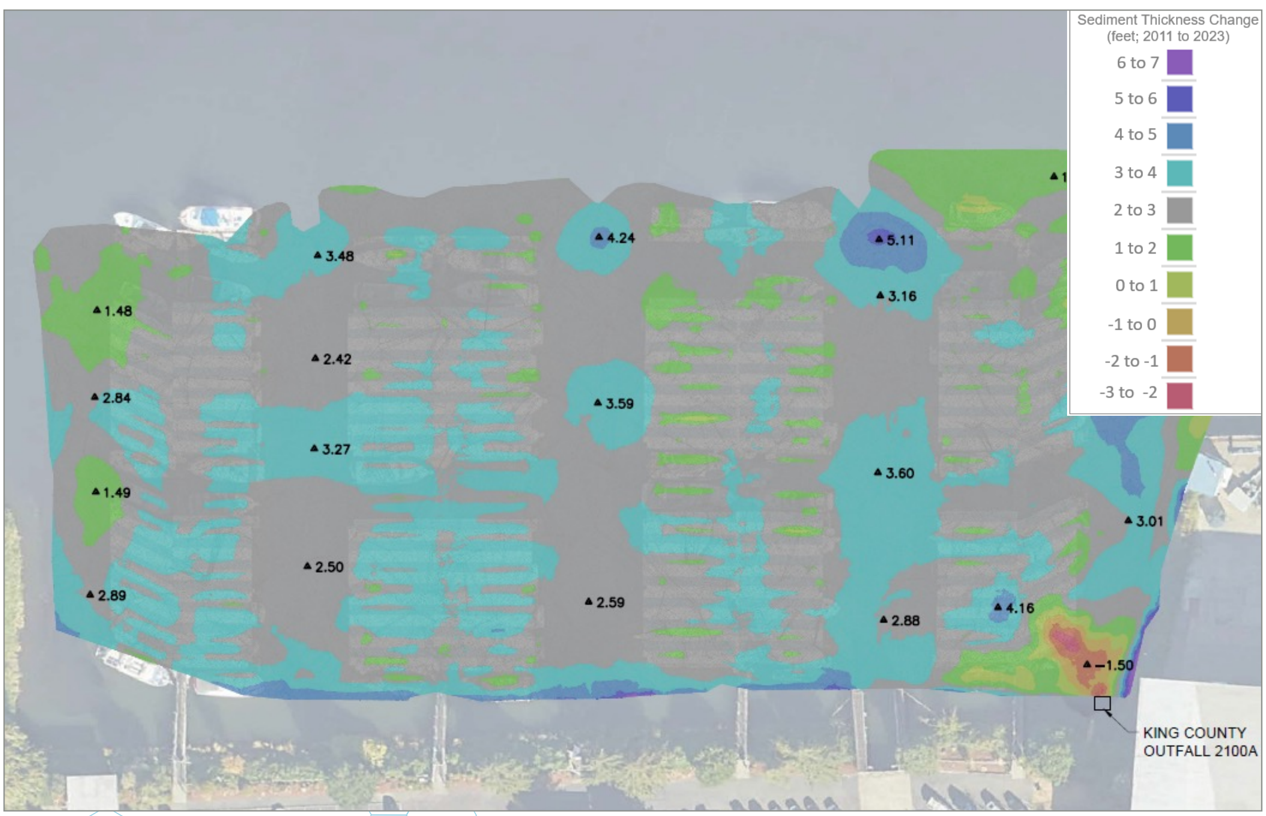


Figure 2. A difference map comparing 2023 to 2011 sediment elevations shows erosion northeast of the outfall. This indicates that the outfall's influence of the sediment is dynamic and has extended further northwest than the sediment deposit in 2023 alone reveals.

knowledge and be able to identify stumbling blocks early on. For example, total chlordanes, a persistent pesticide, had been observed historically in DYC sediment. The Puget Sound DMMP screening level for total chlordanes is sometimes lower than the practical quantitation limit (PQL) using standard analytical methods, which can result in detections of total chlordanes that are below the detection limit but that exceed the DMMP screening level, also referred to as nondetect exceedances (NDEs). Although analytical laboratories in Washington are working toward reducing the PQLs for multiple compounds, including chlordanes, a notable frequency of sample results in dredged material management studies were NDEs. Knowing this and the potential for chlordanes to be present at the DYC, the DYC project used a high-resolution pesticide method to ensure there were no NDEs. The minor increase in the upfront cost for the high-resolution method saved time and reduced the potential for delays. The regulator's knowledge of the analytical limitations with total chlordanes was valuable to the project.

If chemical results were to result in the rejection of a DMMU for open-water disposal, the use of bioaccumulation testing and bioassays is an optional tool to continue the open-water disposal consideration (vs. upland disposal). These tests evaluate the potential ecological impacts of open-water disposal of dredged sediment directly. Bioassay testing measures the chronic and acute toxicity of sediment to benthic organisms. Bioaccumulation tests measure the degree to which sediment causes contaminants to bioaccumulate in benthic species (e.g., bivalves, polychaete worms). Biological testing can override chemistry results, allowing DMMUs that fail the chemistry criteria to still be considered suitable for open-water disposal. The types of chemicals and degree of contamination can influence the decision whether to pursue biological testing or to dispose the material in an upland location.

The advantage to pursuing biological testing is the potential for reduced disposal costs if materials pass such tests, and thus allow failing chemistry results to be overridden. The disadvantages are greater study costs and an extended schedule, as well as no guarantee of a desired outcome. The laboratory costs for biological testing are greater than those for chemical analysis.

Biological testing also requires longer field collection times than those for chemistry testing, due to the greater volume of sediment required. If biological testing is used, it is important to track the volume of sediment as cores are collected in the field. To minimize backtracking during sample collection, field staff should carefully record the volumes collected in each core in real time, factoring in recovery. If additional volume is needed, additional cores can be added to the field effort as it progresses, instead of during an additional sampling equipment and personnel mobilization. Well-prepared field staff make a difference when collecting biological and chemical samples in one mobilization.

Finally, biological analyses take time. Biological testing cannot be started until preliminary chemical data are obtained. Bioaccumulation tests take the longest time of the biological tests at 45 days, with additional time needed for testing the resulting tissues. For those who are prioritizing rapid dredging over potential cost savings, biological testing would not be practical.

Conclusion

Dredged material management sampling is a process that has the potential to lower dredged disposal costs and simplify construction projects. In summary:

- The project's data gaps, costs, and benefits associated with dredged material management should be considered early.
- Reducing site unknowns can start with a review of site history and existing data, and an understanding of the hydrodynamics can inform the plan for dredge characterization sampling.
- Engaging with regulatory agencies early and often can lead to reduced uncertainties.
- Biological testing is a good option for many sites, where upfront investment in testing reduces later project costs.
- Finally, field data collection should emphasize planning and field staff flexibility.

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Authors

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Dr. Nathan Rebuck is an oceanographer with diverse experience in operational oceanography, the offshore wind industry, benthic and essential fish habitat, fisheries, biogeochemistry, and ocean acidification and climate change. He has helped gain regulatory approvals from the U.S. Army Corps of Engineers (USACE), Bureau of Ocean Energy Management (BOEM), and Bureau of Safety and Environmental Enforcement (BSEE) for offshore wind projects and ensured compliance of site investigations activities conducted for Outer Continental Shelf (OCS) leaseholders, including site assessment plan and construction and operations plan surveys for renewable development. He has served as project manager, as well as lead scientist in the field, for offshore environmental surveys of benthic habitat characterization and essential fish habitat. Dr. Rebuck also has extensive experience coordinating and conducting metocean measurement surveys, hydrographic analyses, and water quality sampling in estuarine, coastal, and offshore environments.

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Mr. Daniel Doolittle is a broadly trained marine scientist and senior program manager with more than 25 years of industry, government, academic research, and consulting experience. He specializes in the marine geological, geochemical, and environmental fields and has specific core competencies in the following areas:

- Environmental and exploration consultancy services to the offshore wind, oil and gas, and renewable energy industries
- Expertise in carbonate sedimentology, hydrocarbon seeps exploration, environmental baseline studies, seafloor habitat mapping, and technology development for seafloor remote sensing sensors and systems
- Strategic market and business development, program management, and all phases of project delivery.

Mr. Doolittle's extensive field experience includes projects in multiple frontier offshore basins, remote regions, and most global oceans, including high latitude waters from Antarctica to the Arctic.

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Dr. Craig Jones serves as the managing principal for Integral's Marine, Coastal, Climate, and Technology Services. With more than two decades in the field, he specializes in engineering and scientific projects aimed at understanding challenges at offshore sites for both governmental bodies and private enterprises. His experience spans riverine, lacustrine, estuarine, and coastal processes, delving deep into hydrodynamics, wave dynamics, and sediment and contaminant transport. He is widely recognized for employing cutting-edge field measurements and modeling techniques to deeply understand aquatic systems. He plays an instrumental role in designing field operations and tools to gather information critical to client needs. Furthermore, Dr. Jones excels in assimilating this information into varying analytical frameworks, ranging from empirical to numerical models, ensuring that each project meets the highest quality standards while being efficiently managed. He has testified in federal court and in front of public utility commissions as an expert on environmental issues and regulatory concerns, including sediments and contaminants in support of allocation activities. Dr. Jones continues to work on preparation of materials for various environmental litigation cases in the United States.

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Ms. Diane Achman is an environmental scientist with 15 years of progressive experience in consulting and university research related to a diverse set of water contaminants. She has proven capabilities in planning and implementing QA/QC and data analysis using multiple tools, and she has demonstrated ownership of top-quality work products that meet internal and external client needs. Ms. Achman possesses differentiating strengths in communicating complex concepts in technical writing and in-person presentations to audiences with varied technical background. She is skilled at building and maintaining professional relationships and highly adept at collaborating with a diverse set of team members and clients.

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Ms. Olivia Hargrave is a professional engineer with 5 years of experience in investigation and remediation of environmental systems including sediment, soil, groundwater, and surface water. She has performed alternatives analyses, remedial design, and cost estimation for a range of sites regulated under federal and state programs. Her responsibilities have included feasibility studies, permitting, and litigation/allocation support. She designs and manages environmental sampling programs from planning stages and stakeholder communication to data analysis and reporting. Ms. Hargrave also has experience in natural resource damage assessment and restoration planning.

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