Western Dredging Association

DREDGING READINESS: NAVIGATING SHARED NEEDS

PROCEEDINGS OF THE

2026 DREDGING

SUMMIT & EXPOSITION

July 20 - 23, 2026

Montreal, Quebec Canada

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of the

2026 DREDGING SUMMIT & EXPO

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Edited by

Donald F. Hayes, Ph.D., P.E., BCEE, F. ASCE

and

Madeline Lemings

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FOREWORD

The Western Dredging Association (WEDA) organized the 2026 Dredging Summit & Expo in Montreal, Quebec, Canada during July 20-23, 2026. This document contains 54 Technical Papers and Extended Abstracts that served as the basis for presentations at the conference from a spectrum of professionals that encompasses the dredging industry. Manuscripts cover almost every aspect of dredging, dredged material management, beneficial use, equipment innovations, contaminated sediment management, and environmental compliance. These papers describe successful projects and important research results. These proceedings focus on the readiness of the dredging industry to fulfill our shared goals and objectives of successful and sustainable projects.

These high-quality manuscripts result from hard work and a dedication to excellence by the authors. Their willingness to contribute to continuous improvement in the dredging profession by sharing their knowledge and expertise is acknowledged with deep appreciation.

The papers in these proceedings were reviewed by the WEDA Technical Papers Committee, chaired by Mr. Connor Tennant of Manson Construction. A complete list of committee membership is provided below. WEDA appreciates the dedication of Technical Paper Committee members and the many hours volunteered to ensure the highest quality proceedings possible.

These proceedings are provided to the public without charge as part of WEDA's educational mission and commitment to excellence in the dredging industry. We also hope the manuscripts inspire others to share their work at future WEDA conferences and publish rigorously reviewed manuscripts in the WEDA Journal of Dredging

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ENGAGING WEDA TO ADVANCE DREDGING-RELATED INNOVATION

D. F. Hayes[1] and R. K. Mohan[2]

EXTENDED ABSTRACT

Continual innovation is the lifeblood of any industry, and the dredging industry is no different. Significant innovation is evident in smaller projects, particularly those related to sediment remediation or high-profile beneficial use opportunities. However, high financial risks, slim profit margins, and a preponderance of low-bid contracts associated with US navigational dredging produce a unique environment that does not encourage industry-wide innovation. Certainly, large dredging companies innovate continuously to compete with smaller contractors that have less overhead. Those technological advancements are held close to maintain a competitive advantage. The US Army Corps of Engineers is interested in fostering innovation to produce higher quality and more effective projects, particularly increasing the sustainability of managing dredged sediments. Yet, their role as the consumer of dredging services based on low-bid contracts puts them in a tricky position. Combined, these results in a perception that the US dredging industry is technologically behind their international competitors who operate in different business environments.

The desire to significantly increase beneficial use of dredged materials in the US has served as a catalyst to inspire dredging and dredged material management related innovation in recent years. Tyler *et. al* (2024) and Ousley *et. al* (2024) describe obstacles to increasing beneficial use of dredged sediments. Identified obstacles include risk, uncertainty, funding policies, maintenance costs, and communication issues. Hayes *et. al* (2024) and Mohan *et. al* (2026) discuss areas of potential innovation that might improve project efficiency, cost effectiveness, reduce risk, or increase the certainty of positive outcomes. Not surprisingly, there was significant synergy between these publications. A few areas most cited were:

1. Integrating site characterization methods to reduce project risk
2. Advances in dredge automation to improve sediment removal efficiency
3. Sustainable sediment management approaches to improve outcome and reduce uncertainty
4. Contracting methods that might encourage innovation

These topics, and others, will provide significant fodder for discussion during this panel session. The primary focus, however, will be on how WEDA can help foster an environment more conducive to innovation, including, but not limited to the following specific questions:

1. How can WEDA facilitate a dredging innovation forum, as part of national and chapter meetings, or other avenues?
2. Can WEDA co-sponsor and encourage industry challenge programs to stimulate innovation?
3. Can WEDA create or sponsor innovation testbeds by working with membership and their projects?
4. What can WEDA do to strengthen BUDM leadership and practice?

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[1] The Dredging Professor, LLC, Meridian, MS; 337-212-0127, don@thedredgingprofessor.com

[2] Sr. Partner, Anchor QEA, Inc. (Horsham, PA), and Professor of Practice, University of Georgia (Athens, GA); 215-756-5030; rmohan@anchorqea.com

5. How can WEDA work with the dredging industry, federal/resource agencies, and universities to foster innovation?

The panel will consist of the two authors plus:

- Dr. Alan Kennedy, Environmental Laboratory, U.S. Army Engineer Research and Development Center
- Mr. Duncan McTaggart, Director, Applications Engineering, Ellicott Dredge Enterprises
- Mr. Conner Tennant, Production Manager, Manson Construction Co.
- Mr. Michael Beton, Senior Director, Integrated Operations and Production, GLDD

These panelists should provide a broad spectrum of viewpoints that span the dredging industry. The authors will summarize the key panel discussion points into a technical note following the conference for possible publication in the WEDA Journal of Dredging.

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PANEL DISCUSSION GROUP: FROM REACTIVE REMOVAL TO DESIGN-INTEGRATED SEDIMENT MANAGEMENT

L. Gehrmann[1] and T. Groß[2]

ABSTRACT

Reservoir sedimentation increasingly threatens storage reliability, flood protection, hydropower generation, and downstream river morphology. Dredging remains a critical and often unavoidable tool for restoring reservoir capacity and ensuring operational safety. However, it is frequently applied as a reactive measure once sedimentation has already reached critical levels, rather than as part of a long-term, system-oriented sediment management strategy.

This panel brings together experts from consulting, dredging contracting, reservoir ownership and operation, as well as design and innovation, to discuss how dredging can be better embedded into integrated sediment management. The discussion will explore when conventional dredging and disposal are necessary, where their limitations lie, and how design- and operation-oriented approaches can reduce long-term dependence on emergency interventions.

Key topics include performance and risk drivers for dredging projects, downtime constraints for operators, permitting and environmental acceptance, and the role of monitoring and data-driven decision criteria. Particular attention is given to emerging approaches that move beyond “dredge-and-dispose”, such as sediment routing, controlled downstream transfer, and hybrid concepts that reconnect upstream and downstream sediment fluxes while remaining compatible with dam safety and regular reservoir operation.

The panel will further address how reservoirs and sediment management systems can be designed from the outset to be “sediment-ready”, integrating accessibility, monitoring, and operational flexibility into long-term planning. The session aims to identify practical decision criteria, readiness levels of new approaches, and concrete recommendations for aligning design, contracting, and operation toward resilient, sediment-aware reservoir systems.

Keywords: reservoir sedimentation, dredging, sediment routing, integrated sediment management, design for sediment, adaptive operation

Invited Panelists:
Dr. Martin Teal (Westconsutants) - confirmed
Gregory Smith (J.F Brennan) - confirmed
Jennifer Bountry (BoR) - confirmed

INTRODUCTION

Dredging remains a central and often unavoidable tool in reservoir and waterway sediment management. In practice, however, dredging is frequently implemented under limited flexibility, and constrained decision space—often once sedimentation has already reached a critical level. This reactive application increases project risks, restricts available options, and places both contractors and operators under significant economic and operational stress.

[1] Project Manager, Hülskens Sediments GmbH, Hafenstr. 3, 46483 Wesel, Germany
[2] Directive Manager, Hülskens Sediments GmbH, Hafenstr. 3, 46483 Wesel, Germany

This panel addresses how dredging can be better embedded into integrated sediment management strategies without challenging its fundamental relevance. Rather than positioning dredging against alternative measures such as sediment routing or adaptive operation, the discussion focuses on hybrid approaches that combine dredging with routing concepts and monitoring-based decision logic over the lifecycle of a project.

A central premise of the panel is that hybrid sediment management does not require entirely new technologies, but a different way of structuring projects over time. In many cases, dredging can play a strategic role in enabling subsequent measures, stabilizing system conditions, or maintaining operational flexibility, rather than serving solely as an emergency response. Sediment routing, sluicing, venting, or bypass systems are therefore discussed not as replacements for dredging, but as complementary elements whose practical applicability depends on timing, data availability, and realistic operational constraints.

The panel brings together perspectives from dredging contractors, designers and consultants, and technology providers, with the shared goal of grounding hybrid sediment management concepts in real project experience. Particular attention is given to:
how hybrid approaches can be implemented stepwise across multiple intervention phases,
which types of monitoring are realistically needed to support operational decisions,
and how early involvement of dredging expertise can improve project robustness and reduce downstream risk.

Environmental and regulatory requirements are acknowledged as boundary conditions, but the discussion deliberately remains focused on implementation logic, project structure, and economic feasibility. Future developments are addressed only insofar as they can be linked to current dredging practice and near-term decision making.

The session is aimed at practitioners in the dredging and sediment management field who are interested in moving from reactive interventions toward more resilient, better integrated project strategies—while keeping dredging firmly at the core of practical sediment management.

BLOCK 0 – WHY SEDIMENT MANAGEMENT HAS BECOME A CORE ISSUE FOR RESERVOIR OPERATION

Reservoirs are a cornerstone of water infrastructure worldwide, providing storage for flood protection, water supply, hydropower generation, and operational regulation of river systems. Their long-term performance, however, is increasingly constrained by sedimentation. As rivers enter impoundments, reduced flow velocities cause transported sediments to deposit within the reservoir, progressively reducing effective storage volume and altering hydraulic conditions. This process is slow, cumulative, and often underestimated in day-to-day operation, yet its consequences directly affect safety, reliability, and economic performance of reservoir systems.

Loss of storage capacity due to sediment accumulation compromises core reservoir functions. For flood control, reduced volume can lead to higher operating water levels and increased flood risk if outdated design assumptions are applied. For hydropower and water supply, sediment deposits can interfere with intakes, gates, and outlets, reducing operational flexibility and increasing maintenance requirements. At the same time, many reservoirs were originally designed with a defined dead storage volume intended to accommodate gradual sediment infilling, yet the actual service life of dams and their continued use often extends well beyond this sediment design life. Preserving the functionality of existing assets has therefore become a primary engineering and operational challenge.
Sediment management is no longer a purely environmental or long-term planning topic but a practical

necessity for maintaining reservoir performance. Dredging, sediment routing, flushing, and related measures are widely recognized tools to address sedimentation, yet in practice they are often applied reactively, once sedimentation has already reached critical levels. This reactive approach typically reduces available options, increases time and cost pressure, and limits the feasibility of combining multiple management measures.

Against this background, the necessity of sediment management lies not in selecting a single "best" technique, but in understanding how different measures interact over time and how they can be structured into robust project strategies. Dredging remains a central and proven solution, but its effectiveness and efficiency strongly depend on timing, project setup, and integration with complementary measures. Recognizing sediment as a dynamic, system-wide factor in reservoir operation is therefore the starting point for moving from emergency interventions toward more resilient, integrated sediment management approaches.

BLOCK 1 – REALITY CHECK FROM PRACTICE

In day-to-day reservoir sedimentation rarely presents itself as a sudden failure, but rather as an accumulating constraint that gradually reduces operational flexibility. Decisions on sediment management are therefore often postponed until clear operational impacts occur—such as loss of storage volume, reduced flood buffering capacity, or interference with intakes and outlets. By the time these issues become unavoidable, project options are typically limited, schedules are tight, and interventions must be implemented under significant constraints. In many cases, conventional dredging and off-site disposal then become the practical last resort—often mobilized under time pressure and with limited flexibility—resulting in disproportionately high costs. Practical experience shows that this late response increases costs and risks, irrespective of the specific sediment management method ultimately applied.

This situation is not driven by a lack of available techniques. Dredging, routing, and monitoring tools are well established and widely understood in the profession. Instead, the challenge lies in how sediment issues are framed within projects and over time. When sediment management is treated as an isolated or deferred task rather than an integral operational consideration, dredging and related measures are forced into reactive roles. This panel starts from that shared reality and uses it as a basis to explore where earlier structuring, phased approaches, and better integration could expand the solution space for practitioners—without questioning the central role of dredging itself

Q1 – Opening Reality Check

Which operational indicators tell you most reliably that sediment is starting to affect performance—water levels, intake behavior, turbidity, maintenance frequency, something else?

Q2 – Is This Really a Technical Problem?

Looking back, would you say most sediment-related challenges arise from missing technology—or from how sediment issues are framed and sequenced within operation?

Q3 – Dredging's Position in Today's Reality

In today's reservoir operation, is dredging more often a planned management tool—or still primarily an emergency response? And what changes when it is forced into the latter role?

Q4 – Consequences of Late Reaction

When sediment management decisions come late, what are the first constraints you encounter in practice—time, access, cost, or available technical options?

BLOCK 2 – DREDGING UNDER PRESSURE: REACTIVE INTERVENTION AS THE DOMINANT REALITY

In many reservoir projects, dredging is not introduced as a planned management activity but as a response to an operational constraint that can no longer be accommodated. Once sediment accumulation interferes with flood retention, intake performance, navigation, or dam safety requirements, dredging is often mobilized under tight schedules and limited degrees of freedom. At this stage, water levels, access routes, disposal options, and operational windows are already constrained, leaving little room to optimize scope, sequencing, or cost.

This reactive context does not reflect a limitation of dredging as a technique. On the contrary, dredging is a proven and adaptable tool for removing deposited sediment and restoring functionality in reservoirs. However, when implemented as a reactive or near-emergency measure, its role becomes predominantly corrective rather than strategic. Project teams must prioritize immediate risk reduction, often accepting higher costs, simplified layouts, or reduced operational efficiency to meet urgent requirements.

Experience from practice shows that such situations are rarely caused by an absence of dredging expertise or equipment. Instead, they result from how sedimentation is addressed within the overall project timeline. When sediment management is treated as a deferred issue, dredging is pushed into a compressed intervention phase, where coordination with operations, routing measures, or monitoring systems is difficult or no longer possible. As a result, dredging is frequently perceived as a last resort, even though earlier integration could have expanded the available solution space.

This block recognizes dredging as the central response mechanism and uses this reality as a starting point to question how projects might evolve if dredging were planned earlier and combined with complementary measures. Understanding why dredging so often operates in a reactive mode is essential before exploring how hybrid sediment management approaches can reduce pressure, improve predictability, and maintain dredging's effectiveness within more resilient project structures.

Q1 – When Dredging Enters the Project

In most reservoir projects, when does dredging realistically enter the decision process—early as part of a long-term plan, or later when operational constraints become clearer?

Q4 – Planned vs. Stand-Alone Dredging

From your experience, how different does dredging look when it is planned as one element in a broader sediment management sequence, instead of a stand-alone intervention?

Q5 – Why Dredging Feels 'Late'

Would you agree that dredging often feels 'late' not because it is wrong, but because other sediment management elements were never structured around it in the first place?

Transition Block 3

Block 2 is not about dredging as an emergency solution, but about understanding why it so often operates under constrained conditions—and what that means for project outcomes.

BLOCK 3 – SEDIMENT MANAGEMENT AS A SYSTEM, AND THE ROLE OF HYBRID APPROACHES

Sediment management in reservoirs encompasses a broad range of measures that address sediment dynamics at different spatial and temporal scales. These include upstream sediment yield reduction, operational strategies such as flushing or drawdown, sediment routing and bypass systems, and the

removal of deposited material through dredging. In practice, no single measure can address sedimentation on its own, particularly in reservoirs that must simultaneously meet requirements for flood control, water supply, hydropower generation, and operational safety.

As sedimentation progresses, reservoir systems increasingly operate under multiple, sometimes competing constraints. The challenge is therefore not to identify an optimal standalone solution, but to structure sediment management as a coordinated sequence of complementary measures that preserves flexibility over time. Within this broader framework, dredging represents a proven and indispensable intervention for restoring capacity and maintaining functionality, while other measures influence how, when, and under which conditions sediment is mobilized or transferred.

Hybrid approaches emerge from this system perspective. Rather than replacing dredging, they combine dredging with sediment routing concepts and monitoring-based decision logic to manage sediment more adaptively. Dredging may stabilize reservoir conditions or recover lost capacity, sediment routing may selectively pass sediments during suitable hydraulic conditions, and monitoring provides the information needed to adjust timing and scale. The effectiveness of such approaches depends less on individual technologies than on how clearly the interfaces between measures are defined and how well they are aligned with operational constraints.

A key element of hybrid sediment management is the project timeline. When sediment is managed through a sequence of coordinated interventions rather than isolated actions, integrated sediment management strategies can be applied—regarding access, reservoir levels, coordination with operations, and compatibility with routing or flushing measures. This does not diminish the role of dredging; instead, it reinforces its value as a central component within a more resilient and predictable sediment management strategy.

By framing dredging within the wider context of sediment management systems, this block sets the stage for discussing how hybrid approaches can improve project robustness and long-term performance, while keeping dredging firmly at the core of practical reservoir sediment management.

Q1 – Opening the System Perspective

If we step back for a moment: sediment management in reservoirs includes many tools. Which other sediment management strategies are applied in projects where you have been involved?

Q2 – Why Single Measures Are Rarely Enough

Where do you see the limits of relying on a single sediment management measure—whether dredging, routing, or operational changes—on its own?

Q3 – Introducing Hybrid Approaches

In practice, how often do sediment management solutions end up being a combination of measures applied over time, rather than a single, stand-alone intervention?

Q4 – Where Dredging Fits into Hybrid Sequences

In these combined approaches, where does dredging typically play its strongest role—stabilizing conditions, restoring capacity, enabling other measures, or all of the above?

Q5 – Time and Sequencing as the Key Differentiator

Would you agree that what really distinguishes successful hybrid approaches is not the technology, but how sediment management measures are sequenced over the project timeline?

Q6 – Role of Dredging Contractors in Hybrid Concepts

From your perspective, at what point should dredging contractors be involved in developing these combined sediment management strategies?

Q7 – Transition to Block 4 (Monitoring & Decisions)

If sediment management is understood as a coordinated system, what minimum information do operators and project teams need to actually make these combined approaches work?

Block 3 is not about choosing between dredging and other measures, but about understanding how dredging works best when it is embedded in a broader, coordinated sediment management system.

BLOCK 4 – MONITORING AND DECISION-MAKING: TURNING DATA INTO OPERATIONAL CHOICES

If sediment management is understood as a coordinated system rather than a sequence of isolated measures, the role of monitoring shifts fundamentally. Monitoring is not an end in itself, nor a question of collecting as much data as possible, but a means to support timely and proportionate operational decisions. In reservoir sediment management, the key challenge is therefore not measurement, but interpretation and use.

In practice, many projects rely on limited or infrequent information about sediment accumulation and river behaviour. As a result, sediment management decisions—whether to dredge, route sediment, or adjust operations—are often triggered only once constraints become visible. By that stage, choices are reduced and coordination between measures becomes more difficult. This is not due to a lack of monitoring technologies, but to the absence of clearly defined decision logic that links observed conditions to specific actions.

Within integrated and hybrid sediment management approaches, monitoring serves a different purpose. Rather than documenting conditions after the fact, it provides early indication of trends, supports the identification of suitable operational windows, and helps determine the scale and timing of interventions. Simple, targeted information—such as the location of sediment bodies, changes in reservoir bathymetry, or event-driven sediment inputs—can be sufficient if it is directly tied to predefined decision criteria.

From this perspective, monitoring enables dredging and routing measures to be planned with greater flexibility. It allows sediment management to be scheduled proactively, combined with other measures where appropriate, and aligned with reservoir operation rather than competing with it. The emphasis is therefore on monitoring that reduces uncertainty, not on monitoring that increases complexity.

This block focuses on how monitoring and data interpretation can realistically support sediment management decisions in reservoirs. By linking measurement to action, monitoring becomes a practical tool that helps expand the degrees of freedom identified in earlier blocks, strengthening dredging as a central component of coordinated sediment management strategies.

Q1 – What Information Actually Matters

From a practical standpoint, what is the minimum information you need to make informed decisions on timing and scope of sediment interventions?

Q3 – Monitoring as an Enabler for Dredging

How can monitoring help dredging move from a fixed response toward a more flexible, better-timed intervention?

Q4 – Linking Data to Action

At what point does monitoring stop being informative and start being operational? In other words, when does data actually trigger a decision?

Q5 – Avoiding Monitoring Overload

Where do you see monitoring becoming counterproductive—adding complexity without improving decisions?

Q7 – Transition Question (Block 4 → Block 5)

If monitoring helps reduce uncertainty, what changes does that enable in how sediment management projects are designed and coordinated over time?

BLOCK 5 – WHAT NEEDS TO CHANGE: PRACTICAL TAKEAWAYS FOR FUTURE PROJECTS

The preceding discussion highlights that the challenges associated with reservoir sedimentation are not rooted in a lack of tools or experience. Dredging, sediment routing, and monitoring are all established elements of professional practice. The decisive factor is how these elements are brought together within projects and across time.

Moving forward, more resilient sediment management will depend on earlier structuring and clearer definition of roles and interfaces. When sediment management is addressed only once constraints are fully visible, degrees of freedom are inevitably reduced. When it is considered as an ongoing operational topic, dredging and related measures can be planned and combined in ways that preserve flexibility, improve predictability, and reduce overall project pressure.

For practitioners, this implies a shift in perspective rather than a shift in responsibility. Dredging contractors are not asked to replace designers or operators, but to contribute their practical expertise earlier, where sequencing, access, and feasibility are still open questions. Designers and consultants, in turn, benefit from grounding sediment management concepts in execution reality. Operators gain from monitoring strategies that support decisions rather than merely documenting conditions.

The key takeaway is that integrated sediment management does not require abandoning established practices. Instead, it requires aligning them more deliberately. By treating sediment management as a coordinated system—rather than a series of isolated interventions—dredging remains a strong and reliable core measure, operating with greater degrees of freedom and within more robust project frameworks.

This closing block therefore emphasizes actionable change: clearer integration, better timing, and closer collaboration. These adjustments, while incremental, offer a realistic pathway toward sediment management strategies that are both operationally effective and compatible with the practical realities of dredging practice.

Q1 – Stepping Back

Looking across everything we discussed today, what do you see as the main bottleneck that currently limits effective sediment management in reservoirs?

Q2 – Prioritizing Change

Which change would have the biggest immediate impact—changing when decisions are made, who is involved, or how measures are coordinated?

Q3 – Reality Check

What is one change that is realistic to implement in ongoing or upcoming projects—not in the next decade, but starting now?

CLOSING

Today's discussion has shown that reservoir sediment management is not about choosing one solution over another. It is about how proven measures—dredging, routing, and monitoring—are structured and coordinated over time.

Dredging remains a robust and indispensable tool. What determines its effectiveness is not urgency or scale, but timing, integration, and clarity of roles within a broader sediment management system.

What we heard repeatedly is that better outcomes do not require entirely new technologies, but earlier thinking, clearer sequencing, and closer collaboration between planners, operators, and dredging professionals.

If sediment management is treated as an ongoing operational responsibility rather than a series of isolated interventions, dredging can operate with greater flexibility and deliver stronger, more predictable results.

With that, I would like to thank our panelists for sharing their experience and insights, and thank the audience for engaging in this important discussion.

CITATION

Gerhmann. L, and Groß, T. "Panel Discussion: From Reactive Removal to Design Integrated Sediment Management," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

ADVANCING BENEFICIAL USE OF CONTAMINATED SEDIMENT THROUGH HYDROCYCLONE SEPARATION

J. Wiens[1], H. Raddemann[2], C. White[3] and H. Williams[4]

EXTENDED ABSTRACT

Background/Objectives. A hydrocyclone-based sand separation and washing treatability study was conducted to characterize the performance of mechanical particle-size separation in reducing contaminant concentrations on dredged sediment from the Milwaukee Estuary Area of Concern (MKE AOC). The study assessed whether coarse-grained fractions (sieve #4–#100) generated during hydraulic dredging could be reliably separated and washed to meet physical and chemical criteria suitable for beneficial reuse as residual management cover (RMC), backfill, or capping layer material for the project. Composite sediments collected from the Milwaukee River Downtown and Kinnickinnic (KK) River Upper reaches—areas exhibiting elevated concentrations of PAHs, metals, and PCBs—were selected to evaluate through the separation process.

Approach/Activities. Three homogenized bulk sediment composites were developed based on particle-size distribution and contaminant thresholds exceeding cleanup criteria. Baseline geotechnical characterization (moisture content, organic content, and particle-size distribution) and comprehensive chemical analyses (metals, mercury, PAHs, PCB Aroclors, PFAS, dioxins/furans, nutrients, phenolics, and oil and grease) were performed prior to slurry generation. Slurries were mixed to solids concentrations representative of hydraulic dredge pipeline transport and processed through a scalping stage, hydrocyclone separation, and subsequent screening and wet-washing using sieve sizes selected from the baseline geotechnical properties. Separated fractions were analyzed to quantify contaminants and evaluate removal efficiency.

Results/Lessons Learned. Sediments in all studied reaches were predominantly coarse-grained (56–70% sand), with organic content present (5.0–6.6%). Hydrocyclone separation effectively concentrated fine-grained and organic material in the overflow, while producing a coarse underflow fraction with substantially reduced contaminant loads. Analytical results for the retained sieve fractions demonstrated PCB, PAH, and metal concentrations below both project cleanup goals and Probable Effect Concentrations. Mass-balance estimates indicate that separation and reuse of the #4–#100 fraction would reduce the volume requiring placement in the Dredged Material Management Facility (DMMF) by approximately 300,000 CY, improving facility capacity management and providing operational contingency. Hydrocyclone separation and washing represent a technically feasible, high-throughput solids management process capable of producing coarse fractions that satisfy both physical and chemical criteria for beneficial use in the MKE AOC. The process consistently removed fine-grained and higher-contaminant sediment fractions while generating a reusable sand fraction

[1] Senior Technologist, Jacobs, 1050 Wilshire Drive Ste 155, Troy, Michigan 48084, USA, T: 269-744-2565, Email: jtannar.wiens@Jacobs.com
[2] Project Manager, Jacobs, 1610 N 2nd St Ste 201, Milwaukee, Wisconsin, 53212, USA, T: 262-323-1848, huck.raddemann@jacobs.com. (corresponding author).
[3,4] Project Manager, USEPA, 77 W Jackson Blvd Ste 1600, Chicago, Illinois, 60604, USA (corresponding author)

suitable for RMC, backfill or engineered cap construction. Integration of hydrocyclone-based separation into the remedial dredging workflow is recommended to reduce DMMF capacity demands to stay within the allotted capacity for the project and decrease project costs by minimizing imported material required for the project.

Keywords: Dredging, dredged material processing, PFAS removal, PCB removal.

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Wiens, J., Raddemann, H., White, C., and Williams, H. "Advancing Beneficial Use of Contaminated Sediment Through Hydrocyclone Separation," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

OPTIMAL PLANNING FOR WATERWAY NETWORK MAINTENANCE DREDGING

T. J. N. Perera[1], M. Hanowsky[2], K. N. Mitchell[3], K. Kothari[4]

EXTENDED ABSTRACT

The availability of a network of navigable channels and waterways across a geographical region is a prerequisite for the waterborne transportation of goods that contributes to the sustainability and growth of a regional economy. However, to achieve these benefits, the network must be maintained. Channels and waterways are subject to recurring sedimentation, which reduces their navigable depths and availability for use. To restore depths, the channels must be periodically dredged, a capital-intensive process that physically removes the accumulated sediments. Due to its capital requirements, dredging is often subject to multi-year planning and budget cycles. We present the application of a mixed-integer mathematical programming (MIP) model to optimize strategic planning of waterway network maintenance dredging and demonstrate how a cost-optimized dredging program utilizes advanced maintenance to reduce dredging costs and improve the availability and efficiency of channels for navigation.

A MIP model has been developed to solve for the optimal dredging decisions, which are defined as when, to what navigable depths, and which waterways in a portfolio should be dredged to minimize cost and/or maximize the availability of the network for vessels. The design of the model reflects the decision frameworks developed by Mitchell et al. (2013) and extended by Loney et al. (2019). Specifically, there exists:

- A waterway network sub-divided into programmatic management units and further sub-divided into waterway segments or reaches.
- A series of consecutive time periods, during which sedimentation, dredging, and use of the network may occur concurrently.
- A sedimentation forecast for each reach, conditional on the navigable depth of the reach.
- A choice to dredge (maintain or deepen the navigable depth) of each reach for which there is both a fixed mobilization cost and variable unit cost.
- A set of routes that represents the demand for use of the waterway network. Each route consists of a set of reaches, or path; required depth; and value.

[1] Research Scientist, Woolpert, 4454 Idea Center Boulevard, Dayton, Ohio 45430, USA, T: 530-219-0737, Email: thomas.perera@woolpert.com.
[2] Director of Transportation Analytics, Woolpert, 4454 Idea Center Boulevard, Dayton, Ohio 45430, USA, T: 312-371-6649, Email: michael.hanowsky@woolpert.com.
[3] Principal Researcher, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, T: 601-634-2022, email: kenneth.n.mitchell@usace.army.mil.
[4] Research Scientist, Woolpert, 4454 Idea Center Boulevard, Dayton, Ohio 45430, USA, T: 510-717-4051, Email: keshav.kothari@woolpert.com.

The MIP model may be solved for either of two objective functions. The first solves for the minimum cost to maintain the network such that all demand is met at all depths. The second, solves for the set of dredging decisions (corresponding reaches and depths), that maximizes the total value of routes that may transit the network. In each case, a route is considered undisrupted if and only if all reaches in the route path meet the required depth. The model was applied to a realistic problem similar to that periodically solved by the US Army Corps of Engineers (USACE); a waterway network of roughly 2,400 interconnected coastal reaches with annual dredging decisions over an 8-year period. Two scenarios are presented.

In scenario 1, the model was used to solve two optimized minimum cost dredging plans. The first is a simultaneous solution that solves for minimum total cost across all 8 years. The second solves for 8 sequential annual plans that minimizes the cost of each year individually. Both solutions show large costs in the first year, which represents the decision to return all reaches to their fully maintained state. However, a solution that optimizes for all years simultaneously invests even more, which dredges some reaches deeper than necessary in the first year. The deeper dredging results in cost savings in years 2-8. These results suggest that cost savings can be achieved in the management of a dredging portfolio through the use of advanced maintenance.

In scenario 2, the model was used to solve an 8-year dredging program that maximizes the total cargo tonnage on routes that are not disrupted ("enabled") at different budget levels. The solutions were post-processed to identify dredging activities that are deeper than necessary to enable the available cargo tonnage in the immediate year. In these cases, the optimal solution is to perform "advanced maintenance", whose benefits are achieved in later years and compares the relative cost of advanced maintenance work for the second scenario. Advanced maintenance is observed to increase both in time and with budget level, which suggests that the optimal dredging program is to establish a steady state and then identify strategic dredging projects with benefits that are realized over a longer time horizon. Additionally, advanced maintenance falls to zero in year 8, because the model does not consider tonnage after this time and therefore, there is no benefit to advanced maintenance.

In conclusion, the model solves for an optimized dredging program and allows comparative results between scenarios, which allows for the identification and measurement of advanced maintenance. When combined, these findings showcase the substantial operational impact of advanced maintenance dredging and demonstrate the utility of the model as a decision support tool in evaluating tradeoffs in dredging planning, and budgeting.

Keywords: Mixed-Integer Programming, Optimization, Shoaling, Budgeting, Capital Implementation.

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DISCUSSION OF MEASUREMENT AND PAYMENT FOR HYDRAULIC DREDGING WITH GEOTEXTILE TUBE DEWATERING ON SEDIMENT MANAGEMENT PROJECTS

D.S. Kennedy[1]

ABSTRACT

This paper discusses the structure of the Bid Form Schedule of Quantities and Prices (Bid Form) and content of the measurement and payment (M&P) specifications section for hydraulic dredging with geotextile tube dewatering on sediment management projects. Detailed analysis is also provided on how the Bid Form and M&P specifications section may impact the design and bidding process, construction costs and schedule, and construction management responsibilities. The content is applicable to both clean and contaminated sediment management projects, private- and public-sector clients, and, generally, projects relatively short in duration (i.e. less than 3 years). This paper provides (1) background and understanding of the bid package; (2) discussion of differences and impacts between private- and public-sector client requirements; (3) suggested formats for Bid Forms, as well as contents and use; and (4) recommendations for M&P of hydraulic dredging and geotextile tube dewatering work. The impact of project location, dredging and dewatering technology and equipment, and sediment placement and disposal requirements is also addressed. Project-specific examples, lessons learned, and successes of environmental and remedial dredging and geotextile tube dewatering design and construction projects are included to facilitate discussion.

Keywords: Environmental engineering, bid package, sediment remediation, risk, construction cost.

INTRODUCTION

This paper discusses the structure of the Bid Form and content of the M&P specifications section for hydraulic dredging with geotextile tube dewatering on sediment management projects and how the Bid Form and M&P specifications section may impact the design and bidding process, construction costs and schedule, and construction management responsibilities. While the focus of this paper is on hydraulic dredging and sediment dewatering projects, the content is applicable to other earthwork environmental engineering projects with construction scopes that may include:

- Excavation of soil in dry or partially dry conditions
- Mechanical dredging of sediment
- Mechanical dewatering of sediment
- Backfilling, placement, grading, and compaction of fill and/or treatment media
- Soil and sediment covering and capping
- Material stockpiling, handling, and management
- In-situ deep and shallow soil mixing, solidification, and stabilization (ISS)
- River, stream, and creek bank stabilization and restoration

[1] Environmental Engineering V, AECOM, 401 West A Street, Suite 1200, San Diego, California, USA 92109, T: 857-248-0302, Email: darrell.kennedy@aecom.com.

- Excavation and structural support
- Pile installation and driving
- Mechanically stabilized earth embankments and retaining walls
- Demolition of structures, concrete, and pavement
- Utility removal, restoration, and retrofitting
- Soil erosion and sediment control
- Water management
- Temporary water treatment system (WTS)
- Off-site waste transportation and disposal (T&D)
- Paving, landscaping, planting, and general restoration
- Short- and long-term operations and maintenance (O&M) and monitoring

BACKGROUND AND UNDERSTANDING

For earthwork environmental engineering projects, when a project goes out to bid for construction, a series of contract documents are included in the issued for bid (IFB) package along with the design drawings and technical specifications to define contract requirements and obtain information from the bidder. These contract documents include 'front-end' documents, bid form schedules, division 0 and 1 specifications sections, and supplemental information. Of these documents, the Bid Form and M&P specifications section are among the most critical.

This section provides a brief definition and description of bid schedules and contract specifications sections. The nomenclature and numbering used herein generally align with industry standards; however, variation in bid schedule and contract specifications section nomenclature and numbering may be observed between projects based on the market sector and client(s), consultant(s), stakeholder(s), and government entity(ies) involved.

Bid Schedules

Bid schedules are used to exchange information with the bidder, define contact requirements, obtain pricing, and help the engineer and client understand technical approach. A list of common bid schedules used in private contracts is provided below. Each client and contracting entity will have additional bid schedules and attachments submitted as part of the front-end documentation and contract entity requirements.

- Schedule A – Schedule of Quantities and Prices
- Schedule B – List of Addenda
- Schedule C – Schedule of Materials
- Schedule D – List of Subcontractors
- Schedule E – List of Equipment
- Schedule F – Construction Milestones
- Schedule G – List of Personnel
- Schedule H – Sustainability Best Management Practices

Schedule A – Schedule of Quantities and Prices

Schedule A – Schedule of Quantities and Prices: This schedule is used to provide quantities to and obtain pricing from the bidder for each bid line item. This schedule may also be referred to as the Unit Price Schedule or Schedule of Values. This schedule is referred to as the Bid Form in this document. The Bid

Form is developed and partially filled out prior to solicitation by the client or engineer, typically between the 60% to 90% design level. The scope of the construction is broken out into separate bid line items each with definable components of work. Units and an estimated quantity are included for each bid line item filled out by the engineer, and the bidder populates the unit price and total cost for each bid line item. Often, the engineer develops a construction cost estimate or opinion of probable construction cost that follows the Bid Form structure that can be used for client funding projection estimates and as a tool for comparison against the received commercial bids. While the headings and content of the Bid Form are consistent across most projects, the detail and structure of the Bid Form will vary based on the scope, complexity, and scale of the project and the client-specific requirements.

Bid items are established to cover the entire contractor's scope defined with the contract documents, design drawings and specifications, and project plans and permits; and must be measurable either quantitatively or qualitatively. Bid items are established for administrative, bonding, and general condition requirements, and the remaining bid items are established to capture scope and costs for mobilization, temporary facilities and controls, surveying, site preparation activities, operations, restoration activities, and demobilization. Expendables, consumables, and alternate bid items may be established as needed, which will be discussed in greater detail in the Discussion section. Particular to dredging and dewatering projects, the type of dredging (mechanical versus hydraulic), approach to dewatering (stockpiling, geotextile tubes, mechanical dewatering, or drying and solidification), and sediment disposal/placement location(s) will influence the establishment of bid items pertaining to the dredging and dewatering setup, operations, and breakdown.

Example Bid Forms from five different hydraulic dredging and geotextile tube dewatering projects are provided as Tables 1 through 5 below and are referenced in the Discussion section. Bid Item Descriptions have been revised for discretion and confidentiality requirements. Change orders that were incurred during construction are not shown on the Bid Forms. Given the length of the Table 3 Bid Form, the in-line version of Table 3 in this section is abbreviated to present the bid items specific to the hydraulic dredging and geotextile tube dewatering work; the full version is included in Appendix A. A description of each project's scope is included in the Discussion section below.

Table 1. Project 1 - Bid Form from Clean Small Design-Build, Private Project.

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
1	General Conditions	LS	1	$	$
2	Survey and Controls	LS	1	$	$
3	Staging and Sediment Dewatering Area Construction	LS	1	$	$
4	Turbidity Curtain	LS	1	$	$
5	Dredge Intake Channel	CY	560	$	$
6	Dredge Intake Pipe and Caisson	Day	5	$	$
7	Sediment Management	Day	5	$	$
8	Upland Restoration	LS	1	$	$
9	100% Performance Bond	LS	1	$	$
				Grand Total Cost	$

Table 2. Project 2 - Bid Form from Contaminated Design-Build Pilot Test, Private Project.

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
1	Mobilization	LS	1	$	$
2	Temporary Facilities and Controls	LS	1	$	$
3	Engineering Consulting	Hr	120	$	$
4	Perimeter Sheen Containment System				
4A	Mobilization and Demobilization	LS	1	$	$
4B	Operation	Day	40	$	$
5	Hydraulic Dredging and 6” Sand Cap Each Day				
5A1	Operation – Hourly (Dredge and Cap Equipment/Labor)	Hr	100	$	$
5A2	Operation – Daily (Dredge and Cap Equipment/Labor)	Day	10	$	$
5B1	Relocation and/or Downtime – Hourly (Dredge and Cap Equipment/Labor)	Hr	100	$	$
5B2	Relocation and/or Downtime – Daily (Dredge and Cap Equipment/Labor)	Day	10	$	$
6	Sediment Management				
6A	Filter Press	Day	20	$	$
6B	Geotextile Tube	Day	20	$	$
7	Decant Water Management	Day	20	$	$
8	Transportation				
8A	Sediment: Facility 1	Ton	2,888	$	$
8B	Debris: Landfill	Ton	463	$	$
9	Disposal				
9A	Sediment: Facility 1	Ton	2,888	$	$
9B	Debris: Landfill	Ton	463	$	$
10	Backfill Placement				
10A1	Operation – Hourly Mechanical Submerged Release	Hr	10	$	$
10A3	Operation – Daily Hydraulic Submerged Release	Day	5	$	$
11	Sand and Gravel Backfill Material Import				
11A	Clean Sand	CY	1000	$	$
11B	Gravel and Aggregate	CY	1000	$	$
12	Expendables				
12A1	Geotextile Tube 1	Ea	2	$	$
12A2	Geotextile Tube 2	Ea	2	$	$
12B	Absorbent Booms	Pallet	90	$	$
12C1	Bioremediation Agent Concentrate 1	Gal	1,000	$	$
12C2	Bioremediation Agent Concentrate 2	Gal	500	$	$
12C3	Odor Suppressant Foam	Gal	100	$	$
12D1	Polymer Concentrate 1	Gal	150	$	$
12D2	Polymer Concentrate 2	Gal	50	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
12D3	Polymer Concentrate 3	Gal	50	$	$
12D3	Polymer Concentrate 4	Gal	50	$	$
13	Demobilization	LS	1	$	$
				Grand Total Cost	$

Table 3. Project 3 - Abbreviated Bid Form from Contaminated Large, Remote Public Project.

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
31 05 19.14-1	Supply of Geotextile Tubes	Ea	22	$	$
31 05 19.14-2	Installation of Geotextile Tubes	Ea	19	$	$
35 20 24.01-1	Sediment Removal	m3	89,100	$	$
				Grand Total Cost	$

Table 4. Project 4 - Bid Form from Contaminated Large, Private Project.

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
1	Mobilization and Demobilization				
1A	Pre-Mobilization Activities	LS	1	$	$
1B	General Mobilization and Demobilization	LS	1	$	$
1C	Season 1 Hydraulic Dredge Mobilization and Demobilization	LS	1	$	$
1D	Season 2 Hydraulic Dredge Mobilization and Demobilization	LS	1	$	$
2	Temporary Facilities and Controls				
2A	Project Management and Coordination	Wk	52	$	$
2B	General Conditions	LS	1	$	$
2C	SDA – Temporary Controls, Facilities, Access, and Laydown	LS	1	$	$
2D	Traffic Control by Contractor	LS	1	$	$
2E	Site Security	LS	1	$	$
2F	Health and Safety	LS	1	$	$
2G	Surveying	LS	1	$	$
2H	Noise, Vibration, and Structural Inspections and Monitoring	LS	1	$	$
3	SDA Cell Construction				
3A	Cell Grading and Earthwork	CY	21,046	$	$
3B	Install Cell Geotextiles and Geomembrane	SF	138,395	$	$
3C	Install Cell Drainage Stone	Ton	21,839	$	$
3D	Geotextile Tube Dewatering System Install and Removal	LS	1	$	$
3E	Operations and Maintenance of SDA	CY	159,127	$	$
4	Lake Dredging				

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
4A	Pipe and Pump Install and Removal	LS	1	$	$
4B	Pipe and Pump Operations and Maintenance	LS	1	$	$
4C	Hydraulic Dredging	CY	159,127	$	$
4D	Dam Stabilization	LS	1	$	$
4E	Dock Relocation or Removal and Restoration	LS	1	$	$
5	Water Management and Treatment				
5A	SDA Water Treatment System Mobilization, Install, and Demobilization	LS	1	$	$
5B	SDA Water Management, Treatment, and Disposal	LS	1	$	$
6	Waste Transportation				
6A	Non-Hazardous Waste – Facility 1	Ton	37,099	$	$
6B	Non-Hazardous Waste – Facility 2	Ton	55,649	$	$
6C	Non-Hazardous Waste – Facility 3	Ton	37,099	$	$
6D	Non-Hazardous Waste – Facility 4	Ton	28	$	$
6E	Non-Hazardous Waste – Facility 5	Ton	55,649	$	$
7	Waste Disposal				
7A	C&D Debris	Ton	1,208	$	$
7B	Vegetation, Phragmites, and Tree Recycling/Mulching	Ton	2,427	$	$
7C	Aggregate, Stone, and Concrete Recycling	Ton	22,160	$	$
8	Performance and Payment Bond	LS	1	$	$
	Grand Total Costs (Bid Item No. 1 through 8)				**$**
	Alternate Bid Items				
ALT1	Traffic Control by Police	Hr	250	$	$
ALT2	Hydraulic Dredge, SDA, and WTS Standby and Shutdown				
ALT2A	Hydraulic Dredge, SDA, and WTS Standby	Hr	80	$	$
ALT2B	Hydraulic Dredge, SDA, and WTS Standby	Day	5	$	$
ALT2C	Hydraulic Dredge, SDA, and WTS Shutdown	Day	100	$	$
ALT3	Odor Suppressants				
ALT3A	Foam Equipment Mobilization and Demobilization	LS	1	$	$
ALT3B	Foam Operations	Day	200	$	$
ALT3C	Short Duration Foam	Gal	9,167	$	$
ALT3D	Long Duration Foam	Gal	1,833	$	$
ALT3E	Hydrocarbon Mitigation Agent 1	Gal	2,750	$	$
ALT3F	Hydrocarbon Mitigation Agent 2	Gal	2,750	$	$
ALT4	SDA WTS Carbon Change Out	lb	10,000	$	$

Table 5. Project 5 - Bid Form from Clean Large, Public Project

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
015000.01	SMF Temporary Facilities and Controls	Mo	14	$	$
015000.02	SMF Temporary Facilities and Controls During Winter Shutdown	Wk	15	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
015000.03	Off-Site Area 1 Temporary Facilities and Controls	Mo	5	$	$
015000.04	Peninsula Temporary Facilities and Controls	Mo	13	$	$
015000.05	Peninsula Temporary Facilities and Controls During Winter Shutdown	Wk	15	$	$
015000.06	Off-Site Area 2 Temporary Facilities and Controls	Mo	13	$	$
015000.07	Off-Site Area 2 Temporary Facilities and Controls During Winter Shutdown	Wk	15	$	$
015000.08	Stabilized Construction Entrance	Ea	2	$	$
015000.09	8-oz/SY Non-Woven Geotextile and Dense-Graded Aggregate (DGA)	SF	60,950	$	$
015000.10	18” Diameter Compost Filter Sock	LF	5,430	$	$
015000.11	24” Diameter Compost Filter Sock	LF	3,425	$	$
015000.12	Storm Drain Inlet Protection	Ea	6	$	$
017200.01	Pre-Construction Upland Surveying	Ea	1	$	$
017200.02	Progress Upland Survey and Layout	Ea	1	$	$
017200.03	As-Built Upland Surveying	Ea	1	$	$
017200.04	Pre-Construction In-Water Surveying	Ea	1	$	$
017200.05	Progress In-Water Survey and Positioning	Ea	1	$	$
017200.06	As-Built In-Water Surveying	Ea	1	$	$
021200.01	C&D Debris T&D	Ton	200	$	$
021200.02	Dredge Debris T&D	Ton	7,300	$	$
021200.03	Vegetation, Hydrilla, and Organic Debris T&D	Ton	140	$	$
022300.01	Phase 1 Pipe and Pump Installation	Ea	1	$	$
022300.02	Phase 2 Pipe and Pump Installation	Ea	1	$	$
022300.03	Phase 3 Pipe and Pump Installation	Ea	1	$	$
022300.04	Phase 4 Pipe and Pump Installation	Ea	1	$	$
022300.05	Phase 1 Pipe and Pump Removal	Ea	1	$	$
022300.06	Phase 2 Pipe and Pump Removal	Ea	1	$	$
022300.07	Phase 3 Pipe and Pump Removal	Ea	1	$	$
022300.08	Phase 4 Pipe and Pump Removal	Ea	1	$	$
022300.09	Pipe and Pump Operations and Maintenance	CY	207,000	$	$
022425.01	Treatability Testing	Ea	1	$	$
022425.02	SMF Dewatering System Installation	Ea	1	$	$
022425.03	SMF Dewatering System Removal	Ea	1	$	$
022425.04	SMF Operation and Maintenance	CY	207,000	$	$
022700.01	Pre-Dredge Debris Removal Mobilization	Ea	1	$	$
022700.02	Pre-Dredge Debris Removal Demobilization	Ea	1	$	$
022700.03	Phase 1 Hydraulic Dredge Mobilization	Ea	1	$	$
022700.04	Phase 2 Hydraulic Dredge Mobilization	Ea	1	$	$
022700.05	Phase 3 Hydraulic Dredge Mobilization	Ea	1	$	$
022700.06	Phase 1 Hydraulic Dredge Demobilization	Ea	1	$	$
022700.07	Phase 2 Hydraulic Dredge Demobilization	Ea	1	$	$
022700.08	Phase 3 Hydraulic Dredge Demobilization	Ea	1	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
022700.09	Pre-Dredge Debris Removal, Management, and Transloading	Ton	7,300	$	$
022700.10	Hydraulic Dredging	CY	207,000	$	$
023313.01	Utility Clearance and Surveying	Ea	1	$	$
310000.10	Staging Area Restoration	SF	12,151	$	$
				Grand Total Costs	$

Schedule B – List of Addenda

Schedule B – List of Addenda is a placeholder for bid addenda obtained following the solicitation (e.g., question and clarifications) that then become part of the contract documents to the awarded bidder.

Schedule C – Schedule of Materials

Schedule C – Schedule of Materials is filled out by the bidder to identify any variations from the specified materials and to list the vendor, supplier, and source of each material required and identified in the drawings and specifications.

Schedule D – List of Subcontractors

Schedule D – List of Subcontractors is filled out by the bidder to identify each subcontractor, the type of work to be performed, contact information, approximate value of the work, and any company designation relevant to the contract (e.g., Disadvantaged Business Enterprise). For larger projects, typically the subcontractors that represent more than a certain percentage (e.g., 15%) of the total contract value are requested to be listed.

Schedule E – List of Equipment

Schedule E – List of Equipment is filled out by the bidder to identify equipment description and unit rates (e.g., daily, weekly, monthly). The rates in this schedule then become part of the contract documents for establishing and verifying rates for time and material (T&M) work performed by the contractor.

Schedule F – Construction Milestones

Schedule F – Construction Milestones is filled out by the engineer and provides a list of specific construction milestone dates that the bidder's initial progress schedule should be developed to achieve. The contract may include negative cost implications if the contractor does not achieve these milestone dates during construction. Construction milestones dates are adjusted based on force majeure events or regulatory actions that are not a result of the contractor's work and are not within the contractor's control.

Schedule G – List of Personnel

Schedule G – List of Personnel is filled out by the bidder to identify administrative personnel, laborer, and operator positions, titles, and hourly rates. The rates in this schedule then become part of the contract documents for establishing and verifying rates for T&M work performed by the contractor.

Schedule H – Sustainability Best Management Practices

Schedule H – Sustainability Best Management Practices is filled out by the bidder to identify the sustainability best management practices (BMPs) expected to be performed by the contractor as part of the

project. To facilitate the bidder in identifying opportunities, the list is partially filled out by the client or the engineer to include a table of required sustainability requirements and encouraged opportunities available in the design. This schedule is new and emerging within bid packages because of the emphasis the industry has put on sustainable construction practices over the past decade.

Contract Specifications Sections

Contract specifications sections provide the requirements for administrative, contractual, and cost components within the contract documents. A short list of contract specifications sections is provided below using number and nomenclature adapted and derived from the Construction Specifications Institute® Masterformat™ (CSI 2026). Federal and state government clients usually have their own standard specifications sections for contracting. For example, construction services for United States (U.S.) military programs utilize the Unified Facilities Guidance Specifications (UFGS) (DoD 2026), while state clients such as the New York State Office of General Services (NYSOGS) utilize their own, i.e., NYSOGS Master Specifications (MF24) (NYSOGS 2024). Most federal and state programs do not allow for modification to contractual specifications within division 0 and 1 of the specifications sections, and the templates are updated at the discretion of the government. However, private sector clients often allow for adaptations, modifications, and revisions at the discretion of the engineer and subject to the client's acceptance. Flexibility to modify the specifications sections and bid schedules adds value through risk reduction and sharing, as discussed further in the Discussion section below.

Contract specifications sections can include:

- 012500 Contract Modification Procedures: This specifications section includes procedures for changes in the work, i.e., requests for information (RFIs), field orders, change orders, and change directives. Liquidated damages may be detailed in this section if not included in the contractual agreement between the contractor and the client.
- 012700 Measurement and Payment: This specification section generally includes a detailed description of the work included in each bid item and provisions for M&P of bid line items, assessment of non-conforming work, and eliminated items. This specification section is critical to understanding the Bid Form. On some government projects, the M&P descriptions for each bid line item are included in the respective technical specifications' sections, e.g, M&P for dredge work would be in the front part of the specifications section for dredging as opposed to including it in the separate M&P specifications section.
- 012900 Payment Procedures: This specifications section includes requirements and procedures for applications for payment, invoices, substantiating data, and certification for payment.
- 013100 Project Management and Coordination: This specifications section includes requirements for staffing, meetings, and coordination of work.
- 013200 Construction Progress Documentation: This specifications section includes requirements for documenting construction progress, including construction milestones, baseline schedules, work breakdown structure reporting, progress scheduling, earned value reporting, cost reporting, daily construction reporting, health and safety reporting, record documents, and schedule reviews.
- 017700 Closeout Procedures: This specifications section includes requirements for final cleanup and contract closeout procedures.

DISCUSSION

This section discusses the Bid Form and M&P differences for Projects 1 through 5 and the impacts those differences have on the projects. Each project includes hydraulic dredging and geotextile tube dewatering activities. Risk sharing and reduction is a key concern addressed in the Bid Form and M&P and is discussed throughout the section.

Bid Forms vary in length and detail, typically correlating to scope, size, and complexity of the project. Client-specific procurement, contractual, and cost management requirements are primary factors to consider when developing the Bid Form because there is little to no ability to develop the Bid Form outside of those requirements. Other factors that impact the Bid Form include, but are not limited to:

- Geography, location, and availability and allocation of resources
- Project objectives and purpose
- Urgency (i.e., emergency action or not)
- Funding mechanism and available funds
- Degree of stakeholder involvement
- Construction start date and duration and schedule and seasonal restrictions
- Permitting and regulatory constraints and requirements
- Design development (i.e., design-build versus design-bid-build) and level and content of the design in the IFB package
- Performance versus prescriptive designs requirements
- Constructability, implementability, and precedence
- Safety risk and requirements
- Bidders and contractors considered and utilized
- Coordination with other consultants
- Accuracy in estimated quantities
- Ability to measure and document completed work
- Innovation, technology, and software involved

Example of Client and Sector Requirements Impacts to the Bid Form

This section uses Project 5 as an example of how public-sector and client influenced the number of bid items, bid item units, design effort, bid pricing, and construction costs and schedule.

Public- and private-sector clients have different requirements for documents, forms, and attachments that are included in the bid documents. In the public sector, the bid documents are determined by rules, laws, and ordinances established by the government entity funding the contract. In the private sector, while bid documents are established by the client's policy, there is more flexibility for how the work is structured, contracted, and managed compared to the public-sector jobs.

Client and sector (public vs. private) requirements dictate permissible level of detail and scope to be included within each bid item. Using Project 5 as an example, the mobilization and demobilization of the hydraulic dredge equipment and the installation and removal of the pipe and pump operations were split into discrete phases associated with defined dredge areas because this public-sector client does not allow partial payment on lump sum items. The public-sector client also required the work to be awarded to the lowest bidder. With this requirement, larger contractors with higher overhead and operating costs, though they may be technically more competent and qualified, were likely not to be awarded the project due to

submission of a higher commercial bid than the smaller firms that are willing to operate on lower margins to win the work. Since partial payment on lump sum items was not allowed, bid items that would typically be consolidated, and partially paid based on percent complete, were separated at the time of Bid Form development. Combining the mobilization and demobilization into one line item, would force the contractor to hold the charges for multiple months or years until the work is completed. However, separating the mobilization from the demobilization work and then further separating the work into phases allows the contractor to timely get paid for the portion of the work that has been completed. Furthermore, the ability for the contractor to get paid in a timely manner, reduces the likelihood of firms declining to bid, increasing the total bids received for consideration and resulting in a more competitive bidding process.

Conversely, this more prescriptive approach increases the design and planning effort, the likelihood of receiving higher overall bids, and the occurrence of change orders during construction. The phases for Project 5 were defined based on estimated production rates by the engineer, the feasibility for the contractor to complete the dredging work within that reach during the allowable work period, and with the assumption that more or alternate equipment (e.g., larger dredges, more booster pumps and pipe) would be required as the work progresses further from the sediment management facility (SMF). The contractor is forced to assume three separate mobilizations and structure their schedule, costs, and bids accordingly. Presenting the mobilization and demobilization as one single line item for the entire job and allowing for partial payment enables a performance-based operation, simultaneous work, higher dredge production, and schedule reduction. Additionally, if more than one mobilization is required to complete the work within a particular phase for reasons outside of the contractor's control (e.g., late notice to proceed, regulator/permit restrictions, community requirements, inaccurate engineer planning estimates, early winter), then the contractor may submit a change notice to recoup the additional costs incurred that were not assumed or included within the bid proposal.

Project Type, Scope, and Resources

This section discusses how the project type, scope, and resources are additional factors that differentiate the development of the Bid Form and M&P specifications section between projects. Project type herein refers to design-build or design-bid-build; scope includes definable work components and project objectives; and resources refer to a broad range of topics from contractors able to perform the work to availability of technologies, equipment, labor, and materials needed and project location and time of execution.

Project Type

Projects 1 and 2 are design-bid projects for which AECOM was the engineer, construction manager, and general contractor. The design component of these projects included the development of select drawings, specifications, and plans as needed to obtain regulatory acceptance and permits, procure bids, and manage the construction. The projects did not include the typical 30%, 60%, 90%, and 100% design process with complete drawing sets, specification sections, and comprehensive plans. Instead, two primary packages were developed, IFB (for pre-bid and permitting) and Issued for Construction (IFC) (after contract award), and the packages were largely performance based. Both projects solicited bids from selected contractors that specialized in the scope of work in the package. While the engineer developed the initial Bid Form, the final Bid Form used for M&P was a coordinated effort that included suggestions and preferences from the contractor that were more in-line with how the contractor priced the work and the costs that the contractor would incur.

However, because design-build projects have less developed designs, depending on the scope, there is greater uncertainty in the estimated quantities. As shown in Table 2, aside from bid item numbers 1, 2, and 4A, all other bid items were unit price (i.e., T&M). T&M was also used for Project 2 because the project was a pilot test, as discussed in the paragraph below. Lessons learned from these projects are the design-build coordinated effort between the engineer and contractor, use of unit price line items, and flexibility that the private clients allowed for the development of the Bid Form and M&P specifications section reduced risk, which resulted in a reduced base contract price, fewer change orders, and a positive teaming environment throughout construction that ultimately increased client satisfaction.

Scope of Example Projects 1 through 5

The Bid Form must capture the entire scope of the project. For context and discussion, the general scope of Projects 1 through 5 is listed below.

- Project 1 included removing approximately 534 in situ CY of sediment within a 5-day work window in front of an intake pipe (machine dredge) and within a caisson (diver dredge) and managing the sediment in geotextile tubes within an upland area prepared prior to the start of dredging. There was no T&D of filter cake and no temporary water treatment and discharge.
- Project 2 was a full-scale pilot test to evaluate the use of hydraulic dredging to productively remove non-aqueous phase liquid–impacted sediments, contain sheen, and dewater the dredged sediment using geotextile tube and filter press technology on barges. Off-site T&D was included, and temporary water treatment and discharge was done under separate contract using existing infrastructure (not shown on Table 2 Bid Form).
- Project 3 involved building access to the remote site, building and operating a camp, constructing a confined disposal facility (CDF), hydraulically dredging approximately 89,100 in situ m^3 of sediment and managing the sediment in geotextile tubes within the CDF, temporary water treatment and discharge, placing other contaminated waste material within the CDF, closing the CDF, and final site restoration.
- Project 4 involves constructing a sediment dewatering area (SDA), hydraulically dredging approximately 159,130 in situ CY of sediment and dewatering the sediment in geotextile tubes, temporary water treatment, off-site T&D of filter cake, and removal and restoration of the SDA. The upland area available for dewatering is limited; therefore, the SDA is being filled and excavated multiple times to complete the dredging.
- Project 5 involves hydraulically dredging approximately 207,000 in situ CY of sediment and dewatering the sediment in an existing SMF. Off-site T&D of filter cake and temporary water treatment is not included.

Project Scope Discussion

There are several takeaways from review of the scope of Projects 1 through 5:

- As evident in Tables 1 through 5, the number of bid items increases with the project scope.
- Unit price work tends to be more favorable to projects with greater risk and quantity uncertainty. For example, Project 1 was very low volume, and the duration was defined by the facility shutdown period of 1 week. The material quantities needed to prepare the sediment management area could be accurately estimated; therefore, the use of lump sum was low risk.
- While the machine hydraulic dredge operations could have been measured using T&M because the operating period was fixed, the contractor preferred using unit price per in situ CY to increase

production to get paid more. The client agreed on the unit price work for machine dredging because, ultimately, the client wanted as much sediment removed in front of the intake as possible within the fixed shutdown period, but if the dredge contractor failed to produce, the client paid less. Here, the unit price structure aligned the client and contractor objectives.

- The diver dredge contractor and the sediment management contractor both preferred to reduce risk by using time-based units of measure; therefore, if the client requested that dredging continue for days 6 and 7, the contractors would be paid for the labor, fuel, polymer, equipment rentals, and other direct costs for those additional 2 days.
- On this project, the as-built dredge volume was less than the estimated dredge volume. Because Bid Item Number 5 was unit price per CY dredged, the client paid less per CY for the as-built volume of material removed than they would have if they used a daily rate or lump sum price for dredging work. Therefore, the Project 1 Bid Form structure successfully shared risk with the performance based, unit price approach.

Unit Price Preference for Sediment Removal

In-situ volume is the most common and preferred approach for dredging projects regardless of technology because of the precision variability in estimated sediment volume to be removed, which is based on available data. Projects 3, 4, and 5 all use in-situ volume as the M&P unit for hydraulic dredging work; however, they differ in the approach for M&P sediment management work because each provides unique shared risks driven by the project conditions. The hydraulic dredging objective for Projects 3 and 4 was to remove all soft sediment; the volume was estimated by performing investigations to determine the bottom of the soft sediment elevations by coring and probing and top of soft sediment elevations from bathymetric surveying. By contrast, the Project 5 dredge prism design objective was to remove approximately 207,000 in-situ CY using target elevations using the surveyed existing top of sediment elevation data. Measurement of the completed dredge work was through comparison of pre-dredge to post-dredge survey data.

Most waterbodies are open systems, and the sediment volume calculations and estimates can change between survey events due to sedimentation, scour, and differences in bathymetric survey technology utilized. Assuming there are no restrictions at the sediment management area beyond the contractor's control, the dredge production is determined solely by the contractor's capability, and the client is not paying more if dredge production is low; therefore the risk is shared equally between client and contractor when the dredging M&P is per unit volume, which was observed in the Project 1 example above. The difference in the M&P for managing the sediment for these project examples is discussed below.

Project Location and Resource Availability

The Project 3 site is remote, and material import to the site that requires truck transportation is limited to a brief period during the winter when an ice road is constructed and maintained. Hydraulic dredging occurs during the summer work season and, since geotextile tubes cannot be imported as the dredge work progresses, the estimated number of geotextile tubes to manage the dredge volume were imported to the site prior to the start of the dredge work. A separate line item was included for geotextile tube installation and filling operations per tube. This is a suitable method for the geotextile tube dewatering M&P when the specifications include defined in-situ and ex-situ sediment volume per tube, dewatering time constraints, and required verification measures to confirm in-situ and ex-situ volumes, such as bathymetric survey of the dredge area, topographic survey of the tube field, and filter cake percent solids and density testing.

Performance Versus Prescriptive Designs Requirements

Project 4 provides a good example of a minimum requirement, performance-based approach to a complete hydraulic dredge project from pre-mobilization and site preparation through restoration and demobilization. Starting with bid item 1, pre-mobilization activities are included as a lump sum unit that includes the contractor treatability testing and reporting to evaluate geotextile tube dewatering and filter cake drying and solidification, which provides the contractor an opportunity to verify the design by the engineer and revise the technical execution plan prior to mobilization. Requiring the contractor to collect sediment material and perform a treatability test prior to mobilization has successfully been implemented on projects involving performance-based sediment dewatering work which has resulted in fewer RFIs, change notices/orders, and design changes throughout construction.

Hydraulic dredge mobilization and demobilization was split into two seasons with a winter shutdown in-between, which facilitated price comparison for the client and engineer at bid and measuring work completion during construction by the construction manager for prompt and fair payment.

The bid items under temporary facilities and controls are lump sum except for Bid Item Number 2A, Project Management and Coordination, which is per unit of time. While the requirements of bid item 2 are definable within the specifications and must be provided during construction, the total duration of the services and how the requirements are met are determined by the contractor, which provides a high-risk, high-reward opportunity for the contractor. Week(s) was used as the unit of measure for project management coordination so that those services could be utilized during the pre-mobilization planning and post-construction reporting periods; this also aids the bidders in understanding project duration expectations. Using a measure of time for contractor project management and coordination services has been particularly successful on design-build projects where the contractor is often consulted by the engineer for constructability and cost evaluations during the panning phase.

Bid Item Numbers 3A, 3B, and 3C, SDA Cell Construction, include unit price items for the earthwork and material required to construction the SDA cell, which is defined by the design and footprint shown on the drawings (i.e., prescriptive). These quantities are measurable through survey and material import tickets. Bid Item Number 3D, Geotextile Tube Dewatering System Install and Removal, is lump sum because the contractor is responsible for designing and providing its own unique system to meet the minimum performance requirements for geotextile tube dewatering in accordance with the specifications.

The most critical item on the Project 4 Bid Form is Bid Line Item 3E, Operations and Maintenance of the SDA. This line item is unit price, and the estimated quantity and measurement method is equal to Bid Line Item 4C, Hydraulic Dredging. This line item includes, but is not limited to, the following:

- Operation and maintenance of geotextile tube dewatering system and SDA cells during hydraulic dredging and sediment dewatering, drying, management, and loadout work
- Geotextile tube filling and stacking
- Geotextile tube dewatering, spoils management, drying, mixing and drying, excavating geotextile tubes, and loadout of material
- Swatting and management of geotextile tubes
- Maintenance of sumps, drainage, swales, and diversion structures for water and filtrate management
- Tarping and covering of exposed soils, sediments, and stockpiles in the SDA cells
- Maintenance and repairs to any materials, equipment, or software for geotextile tube dewatering

- Removal of spoils, residuals, and other liquids and debris from the SDA cells
- Preparing the cell for and performing turnovers
- Management of the dedicated geotextile tube for backwash from the water treatment system
- Water supply for chemical conditioning
- Purchase, storage, handling, and use of chemicals and polymers for chemical conditioning of the dredged slurry
- Polymer dosage efficacy testing, measurement, and monitoring
- Coordination with hydraulic dredging, WTS, loadout, and import operations
- Off-site T&D of unused or improperly stored polymers and chemicals for dewatering
- Performance of free-liquid and geotechnical tests on filter cake
- Purchase, delivery, storage, and handling of geotextile tubes
- Providing geotextile tube submittal information, certificates, and warranties
- Purchase, delivery, storage, and handling of drying reagents for dewatering and drying of hydraulically dredged sediments and contents of the geotextile tubes

The costs in the list above are largely derived from labor, rental equipment, and consumables. The quantity of fuel, polymer, drying reagent, and geotextile tube materials used, the labor hours spent, and the duration the equipment remains on-site is based on the contractor's ability to perform. Therefore, the contractor holds most of the risk. In addition, this unit price line item allows the bidders to differ from one another in their commercial pricing because the estimated quantity for this line item is so large that it can swing the overall price.

The final items for discussion within this subsection are Bid Items 4A, Pipe and Pump Install and Removal, and 4B, Pipe and Pump Operations, which are both lump sum. Like Bid Line Item Number 3D, this work is largely dependent on the contractor's technical approach and proposed equipment. An approximate pipeline alignment is shown on the drawings, allowing the contractor to estimate pumping distance and elevation change. However, the final upland pipe alignment; amount of floating pipe; pipe diameter; booster pumps type, quantity, and location; operational parameters; and standby equipment is determined by the contractor. This provides another high-risk, high-reward opportunity for the contractor and an easy-to-measure payment item for the construction manager and client.

Alternate Bid Items

Alternate bid items are not included, needed, and/or permitted on every Bid Form. Alternate bid items include work components that may not be executed during construction due to certain unknowns at the time of IFB. Including alternate line items provides transparency, eliminates the need to go through the formal change notice process to obtain pricing post-award, reduces T&M ticket disputes and price gouging, and facilitates the bid review and funding estimates by the engineer and client. A common example of an alternative bid item for hydraulic dredging and geotextile tube dewatering projects is standby and shutdown, as shown with Alternate Bid Item ALT 2 on Table 4. The contractor should not be liable for standby and shutdown that occurs from events that are out of the contractor's control, such as force majeure, regulatory shutdowns, and other unforeseen events. Because standby and shutdown occurrences and periods are unknown, acquiring hourly and daily rates for standby that include the contractor's labor and personnel on-site and daily and weekly shutdown costs for equipment only without labor present is recommended.

This approach for including alternate bid items on the Bid Form has been successful on hydraulic dredging and geotextile tube projects in expediting change, reducing construction management effort, and preventing

cost disputes associated with scope items ranging from dredge standby/shutdown to construction of sediment dewatering areas at alternate locations and introducing different polymers and/or drying reagents to evaluate dewatering and drying efficacy at full-scale.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the Bid Form and M&P specifications section are some of the most powerful tools within the design and bid process and influential documents during construction. Indeed, concepts in developing the Bid Form and M&P specifications section can be shared across projects; however, each project will have a unique Bid Form and M&P specification section based on the client and sector requirements and project type, scope, and resources.

- When developing the Bid Form and M&P specifications section, first identify the client requirements and restrictions on formatting, structure, and payment procedures.
- Based on the project type (design-build versus design-bid-build), design requirements (performance versus prescriptive), urgency (i.e., emergency action or not), and objective, determine the level of acceptable risk, which entity should hold more of the risk, and how to balance the risk between bid items.
- When determining the unit, consider the ability to measure and monitor the work and whether it is a qualitative determination or a quantitative measurement.
- Ensure there are sufficient requirements within the technical specifications for documentation, frequency of measurements, and verification of work to estimate quantities for progress and final payments.
- Seek opportunities to incentivize performance-based operations by balancing the distribution of unit price and lump sum work. For lump sum items with costs derived from and proportional to project schedule assumptions, consider adding project milestones dates with associated liquidated damages tied to the project milestone dates to ensure expeditious work.
- Utilize unit price items, when possible, on large, complex projects and when investigation data are limited, design is not detailed, and/or estimates on quantities may fluctuate.
- Determine whether separate line items should be included for expendables and consumables based on availability of resources and precision in estimated quantities.
- Coordinate with the bidder and contractor when the project allows to modify the Bid Form prior to the start of construction to reduce unnecessary risk, limit change order potential, and facilitate a better relationship between all parties.
- For hydraulic dredging and geotextile tube dewatering projects, T&M consumption for geotextile tube dewatering operations is proportional to the hydraulic dredge volume. Include polymers, geotextile tubes, and other consumables within the geotextile tube dewatering operational unit price item and set the estimated quantity and measurement method equal to the hydraulic dredging unit price item.
- If the project scope includes excavation and off-site T&D of the filter cake, also include drying reagents within the geotextile tube dewatering operations unit price.
- To limit the probability of change orders due to a change of conditions prior to mobilization, require the contractor to collect project sediment and water at locations, depths, and quantities of their choosing and have the contractor perform a treatability study to identify the preferred chemical conditioning program and drying reagents, evaluate dewatering and drying efficacy, and treat the resultant filtrate.

- Ensure there are sufficient requirements within the M&P specification section and technical specifications to verify and report the in-situ and ex-situ sediment volumes and the filter cake percent solids, density, strength, and other geotechnical properties; include the costs for that work within the bid items.
- Each contractor in the hydraulic dredging and geotextile tube dewatering industry has different preferences, systems, equipment, software packages, and technologies to install, operate, and perform the work. Utilize the Bid Form, M&P specifications section, and other design documents to incentivize contractor innovation, creativity, progress, and production.

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CITATION

Kennedy, D.S. "Discussion of Measurement and Payment for Hydraulic Dredging with Geotextile Tube Dewatering on Sediment Management Projects," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20–23, 2026.

DATA AVAILABILITY

All data, models, and code generated or used during the study are proprietary or confidential. This data may be provided upon request with restrictions on republication and use.

ACKNOWLEDGEMENTS

This paper was peer reviewed by Kristine Carbonneau and Micheal J. Gardner. Thank you.

NOMENCLATURE

Table 6. Abbreviations and Acronyms

Abbreviation or Acronym	Definition
ACM	Asbestos Containing Material
Bid Form	Bid Form Schedule of Quantities and Prices
BMP	Best Management Practice
C&D	Construction and Demolition
CDF	Confined Disposal Facility
CY	Cubic Yard
Day	Workday
DGA	Dense Graded Aggregate
DR	Department Representative
Ea	Each

Abbreviation or Acronym	Definition
Gal	U.S. Gallon
HASP	Health and Safety Plan
HDPE	High-Density Polyethylene
Hr	Hour
IFB	Issued for Bid (also known as Issued for Tender)
IFC	Issued for Construction
ISS	In-Situ Stabilization
kg	Kilogram
lb	U.S. Pound
LF	Linear Feet
LS	Lump Sum
M&P	Measurement and Payment
m2	Square Meter
m3 or m^3	Cubic Meters
MF24	NYSOGS Master Specifications
Mo	Work Month
No.	Number
NYSOGS	New York State Office of General Services
O&M	Operations and Maintenance
oz	Ounces
PWTP	Process Water Treatment Plant
SDA	Sediment Dewatering Area
SF	Square Feet (Foot)
SMF	Sediment Management Facility
SY	Square Yard
T&D	Transportation and Disposal
T&M	Time and Material
TCA	Tailings Containment Area
Ton	U.S. Short Ton (2,000 pounds)
U.S. and/or USA	United States of America
UFGS	Unified Facilities Guidance Specifications
Wk	Work Week
WTS	Water Treatment System

APPENDIX A – COMPLETE TABLE 3

Table 3. Project 3 - Bid Form from Large and Remote Public Project

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
012983-1	Packaging, Handling, and Transport of DR's Samples to Analytical Laboratory	kg	1,500	$	$
013119-3	Inter-Season Meeting	Ea	3	$	$
013119-5	Month Progress Meetings	Ea	40	$	$
013119-6	Community Meetings	Ea	4	$	$
013529.13-2	Wildlife Monitors	Day	710	$	$
015200-2	Operations and Maintenance of Camp Services	Wk	101	$	$
015200-3	DR and Authorized Personnel Room and Board	Person-Day	1,414	$	$
015200-4	Casual Meals – Authorized Visitors	Ea	75	$	$
015200-5	DR Return Transportation to Site	Person–Return Trip	215	$	$
015200-6	Communications Links	Wk	101	$	$
015200-7	DR's Field Lab	Wk	101	$	$
017100-2	Supply and Installation of Survey Monuments	Ea	3	$	$
017113-4	Camp Start Up	Ea	4	$	$
017113-5	Camp Winterization	Ea	3	$	$
024123-1	Surface Debris Removal – Site 1	Ton	55	$	$
024123-2	Surface Debris Removal – Site 2	Ton	50	$	$
024123-3	Surface Debris Removal – Site 3	Ton	6	$	$
024123-4	Surface Debris Removal – Site 4	Ton	3	$	$
024123-5	Power Pole Removal – Site 4	Per Pole	55	$	$
024123-7	Surface Debris Removal – Site 5, 6, and 7	Ton	2	$	$
025000-1	Excavation and Relocation of Contaminated Material – Site 3	m3	35	$	$
025000-2	Excavation and Relocation of Contaminated Material – Site 1	m3	30,820	$	$
025000-3	Excavation and Relocation of Contaminated Material – Site 2 (BP1, BP2, BP3, BP4, and MISC.)	m3	20	$	$
025000-4	Excavation and Relocation of Contaminated Material – Site 2 (WR1, WR2, and WR3 Stockpiles)	m3	1,500	$	$
025000-6	Supply of Contaminated Material Containers	m3	50	$	$
025000-7	Excavation and Relocation of Contaminated Material – Site 8	m3	5	$	$
028100-1	Hazardous Material Removal – Site 1	Ton	50	$	$
028100-3	Supply of Hazardous Material Containers	Ea	5	$	$
030511-1	Engineered Caps – Site 1 – Vents	Ea	5	$	$
030511-2	Engineered Cap – Site 2 – Shaft	Ea	1	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
030511-3	Engineered Site Protection Slab – Site 9	m2	32	$	$
030511-4	Engineered Site Protection Slabs – Site 2 – BP1, BP2, BP3, BP4, and BP5	m2	280	$	$
310519.11-1	Supply and Installation of Geocomposites	m2	23,090	$	$
310519.14-1	Supply of Geotextile Tubes	Ea	22	$	$
310519.14-2	Installation of Geotextile Tubes	Ea	19	$	$
312213-1.1	Excavation – Site 1 – Lake Basin Soils	m3	3,400	$	$
312213-1.2	Excavation – Site 1 – Lake Cove – Over-Excavation to Bedrock	m3	2,400	$	$
312213-1.3	Excavation – Site 1 – Overburden Excavation and Topsoil Stripping	m3	200	$	$
312213-1.4	Excavation – Site 2 – Topsoil Stripping	m3	140	$	$
312213-2	Type A Granular Fill – Supply and Placement – Site 1: CDF Construction	m3	8,890	$	$
312213-3	Type B Granular Fill – Supply and Placement – Site 1: CDF Construction	m3	20,570	$	$
312213-4	Type C Granular Fill – Supply and Placement – Site 1: CDF Construction	m3	4,500	$	$
312213-5	Cohesive Soil – Supply and Placement – Site 1: CDF Adjacent Slope Cover	m3	1,700	$	$
312213-6	Type A Granular Fill – Supply and Placement – Site 1; TCA Repairs	m3	200	$	$
312213-7	Cohesive Soil – Supply and Placement: TCA Repairs	m3	2,900	$	$
312213-8	Cohesive Soil Stockpiles – Supply and Placement – Site 1: Stockpiles (For Future Repairs)	Ea	3	$	$
312213-9	Type A Granular Stockpiles – Supply and Placement – Site 1: Stockpiles (For Future Repairs)	Ea	2	$	$
312213-10	Type A Granular Fill – Supply and Placement – Site 2: Waste Rock (WR1) Cover	m3	800	$	$
312213-11	Type C Granular Fill – Supply and Placement – Satellite Site 2: Waste Rock (WR1) Cover	m3	520	$	$
312213-14	Riprap – Supply and Install – Site 1	m3	15	$	$
312316.26-1	Rock Excavation and Blasting – Site 1 – Lake Drainage Channel	m3	4,300	$	$
312316.26-2	Rock Excavation and Blasting – Site 1 – CDF Construction Area	m3	29,800	$	$
312316.26-3	Rock Excavation and Blasting – Site 1 – Borrow Area #3	m3	9,000	$	$
313219.10-1.1	Non-Woven Geotextiles – Supply and Installation – Site 1: CDF Construction	m2	29,430	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
313219.10-1.2	Non-Woven Geotextiles – Supply and Installation – Site 2: Waste Rock (WR1) Cover	m2	3,500	$	$
313219.10-2	Erosion Control Blankets – Supply and Installation – Site 1 – Lake Reclamation and TCA Repairs	m2	96,720	$	$
313219.15-1	Geosynthetic Clay Liners – Supply and Install – Site 1, CDF Base Sump and Trench	m2	800	$	$
313219.20-1	Bituminous Geomembrane – Supply and Install – Site 1, CDF Base, WTP Pad and Cover System	m2	26,510	$	$
313219.20-2	Bituminous Geomembrane – Supply and Install – Site 2 – Waste Rock Cover	m2	1,800	$	$
313219.20-3	HDPE Passive Vent Pipes – Supply and Install – Site 1 – CDF Cover	Ea.	6	$	$
313219.20-4	HDPE Passive Vent Pipes – Supply and Install – Site 2 – Waste Rock Cover	Ea.	3	$	$
329219.16-1	Biotic Soil Media – Supply and Placement – Site 1	m2	96,720	$	$
329219.16-2	Wet Seed Mix – Supply and Placement – Site 1	m2	7,500	$	$
329219.16-3	Dry Seed Mix – Supply and Placement – Site 1	m2	89,220	$	$
334616.10-1	HDPE Piping – Inspection and Withdrawal Riser Site 1– CDF	m	42	$	$
334616.10-2	HDPE Piping – Cleanout Riser Site 1 – CDF	m	28	$	$
334616.10-3	HDPE Piping – Perforated Collection and Conveyance Piping Site 1 – CDF	m	84	$	$
352024.01-1	Sediment Removal	m3	89,100	$	$
444113-4	Process Water Treatment	LS	320,000	$	$
BOPC	Profit, Overhead, Training, etc.	LS	1	$	$
BOPC	Submittal Procedures	LS	1	$	$
BOPC	Mobilization Year 1	LS	1	$	$
BOPC	Mobilization Year 2	LS	1	$	$
BOPC	Mobilization Year 3	LS	1	$	$
BOPC	Demobilization Year 4	LS	1	$	$
011100-1	Workers Orientation Seminar	LS	1	$	$
011100-2	CDF Construction Plan	LS	1	$	$
011100-3	Site 2 Waste Rock Cover Construction Plan	LS	1	$	$
012983-2	Contractor’s Testing Requirements Including Sampling, Transportation, and Analysis at an Accredited Laboratory	LS	1	$	$
013119-1	Pre-Construction Meeting	LS	1	$	$
013119-2	Pre-Mobilization Site Visit	LS	1	$	$
013119-4	Post Construction Meeting	LS	1	$	$
013529.13-1	Site-Specific HASP	LS	1	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
013543-1	Wildlife and Wildlife Habitat Management and Monitoring Plan	LS	1	$	$
013543-2	Sediment Erosion and Control Plan	LS	1	$	$
013543-3	Spill Contingency Plan	LS	1	$	$
013543-4	Waste Management Plan	LS	1	$	$
013543-5	Quarry Management Plan	LS	1	$	$
013543-6	Environmental Protection Supplies	LS	1	$	$
015200-1	Camp Supply and Start-Up	LS	1	$	$
017100-1	Survey	LS	1	$	$
017113-1	Mobilization and Demobilization Plan	LS	1	$	$
017113-2	Mobilization – Site 1	LS	1	$	$
017113-3	Mobilization – Site 2	LS	1	$	$
017113-6	Demobilization – Site 1	LS	1	$	$
017113-7	Demobilization – Site 2	LS	1	$	$
017113-8	Mobilization and Demobilization – Site 9 and Site 3	LS	1	$	$
017113-9	Mobilization and Demobilization – Site 5, Site 6, and Site 7	LS	1	$	$
017700-1	Post-Demobilization Inspection	LS	1	$	$
017800-1	Project Record Documents	LS	1	$	$
020000-1	Winter Road Track Survey	LS	1	$	$
020000-2	Upgrade of Legacy Winter Road	LS	1	$	$
020000-3	Winter Road Construction	LS	1	$	$
020000-4	Winter Road Maintenance	LS	1	$	$
020000-5	Installation and Maintenance of River Crossing	LS	1	$	$
020000-6	Decommissioning of River Crossing	LS	1	$	$
024116-1	Removal and Onsite Disposal of Concrete Foundations	LS	1	$	$
024123-6	Unknown Debris Area Sweep	LS	1	$	$
025000-5	Excavation and Relocation of Contaminated Material – Site 9 (Drill Cores)	LS	1	$	$
028100-2	Hazardous Material Removal – Site 3	LS	1	$	$
028100-4	Hazardous Material Removal – Site 8, Site 5, and Site 7 (ACMs)	LS	1	$	$
311100-1	Clearing and Grubbing – Site 1 – Cohesive Soil Borrow Areas	LS	1	$	$
311100-2	Clearing and Grubbing – Site 1 - Lake	LS	1	$	$
311100-3	Clearing and Grubbing – Site 2 – Construction Area of WR1 Waste Rock Cover	LS	1	$	$
311100-4	Clearing and Grubbing – Miscellaneous	LS	1	$	$
312213-12.1	Reclamation of Proposed Borrow Areas – Site 1: BA-01, BA-02, VA-03, and BA-04	LS	1	$	$

Bid Item No.	Bid Item Description	Unit	Estimated Quantity	Unit Price	Total Cost
312213-12.2	Reclamation of Existing Historic Borrow Areas – Site 1: Former Airstrip Borrow Area and Waste Storage Borrow Area	LS	1	$	$
312213-13.1	Access Road Construction and Maintenance	LS	1	$	$
312213-13.2	Access Road Removal and Closure	LS	1	$	$
444113-1	PWTP Design and Construction Plan	LS	1	$	$
444113-2	PWTP Operations and Maintenance Plan	LS	1	$	$
444113-3	PWTP Commissioning and Maintenance and Decommissioning Plan	LS	1	$	$
				Grand Total Cost	$

COST AND BENEFITS OF INNOVATIVE BENEFICIAL USE OF DREDGED SEDIMENT FROM NAVIGATION PROJECTS IN COASTAL NEW JERSEY, 2014-2025

W. Scott Douglas[1]

ABSTRACT

Over the past decade the NJ Dept of Transportation's Office of Maritime Resources has dredged over 2.3 million cubic yards (1.76 million m^3) of sediment from the State's navigation channels in the Atlantic coastal zone, restoring safe navigation to over 125 miles (201 km) of recreational and light commercial channels. Much of this dredging was necessitated by the sediment that was washed into the channels by Superstorm Sandy in 2012. Historically, dredged material had been managed mostly upland into confined disposal facilities that were located along the 200-mile system. However, in the years leading up to Superstorm Sandy, many of these CDFs were either filled to capacity or had been converted to wildlife habitat or residential development, leaving much of the system without viable dredged material management. To supplement the existing disposal capacity and to accomplish the needed dredging, the Office of Maritime Resources embarked on an ambitious program of innovative beneficial use including marsh platform elevation, benthic habitat enhancement, shoreline stabilization, and upland beneficial use. These techniques were effective but proved to be more time-consuming to design and permit, took longer to construct and were more costly than traditional upland disposal. However, considerable valuable benefits are derived from innovative beneficial use as these techniques often increase resiliency, enhance habitat for wildlife and fisheries, and provide construction fill for beaches, landfills and habitat restoration projects. A summary of cost, timelines and benefits as well as recommendations for future work will be presented.

Keywords: dredged material management, marsh enhancement, shoreline stabilization, benthic enhancement, confined disposal

INTRODUCTION

In 2012 the coastline of New Jersey's Atlantic shore was ravaged by Superstorm Sandy. Considerable overwash of sediment and remixing of internal backbay sediments resulted in 1.5 -2 million cubic yards of sediment being deposited in the network of 200 nautical miles (322 km) of shallow draft navigation channels used by commercial and recreational boaters and fishermen. The State of New Jersey applied for support from the Federal Emergency Management Agency (FEMA) in order to restore the system to navigability. Over the next decade, NJDOT's Office of Maritime Resources (NJDOT/OMR) worked to return the system to a state of good repair.

When the system was originally built, most sediments were either sidecast into the adjacent marshes or placed onto nearby beaches. In more recent years, fine grained material was restricted to confined upland disposal in CDFs. Over the years many of these CDFs were either filled, abandoned or developed into residential homes. When the recovery effort began, there was insufficient capacity to handle all the

[1]Dredging Program Manager - retired, NJ Department of Transportation, 3450 Rt 212, Riegelsville, PA, 18077, USA, T: 484-357-5249, Email: scott@acdcpa.com.

material. Innovative beneficial use options were explored including excavation of existing CDFs, marsh platform elevation, shoreline stabilization, benthic enhancement and active dewatering with geotextile bags and belt filter presses. These efforts have been seen as positive from the environmental management perspective as they largely maintain sediment in the coastal zone.

Rarely are there enough diverse projects in one area over a short period of time where cost benefit data can be analyzed and where engineering, permitting and construction constraints are similar enough to not to confound the analysis. While actual cost and benefits in this analysis are specific to New Jersey, the relative costs and benefits of various techniques and strategies should be transferable to other parts of the country.

METHODOLOGY

Cost data for all phases of the work were collected on each project conducted by NJDOT between 2014 and 2024. This included the cost of engineering and permitting, oversight, monitoring (if required) and internal management. Cost of FEMA reimbursement administration was not included. Both storm recovery and maintenance projects are included. If multiple management strategies were employed, for example using both beach replenishment and a confined disposal facility, then costs were separated by technique to the extent possible. Median costs were utilized for analysis rather than averages to avoid biasing the data toward very small projects. Only those projects utilizing small dredges (18 inches (45.7 cm) or less) were considered in the analysis, to avoid biasing the data toward large projects.

RESULTS

Dredging Cost by Technique

By far the least expensive dredging techniques will involve placing material directly into the water, either at a confined or unconfined site. This is because this technique allows for the largest equipment to be used and operated in the most efficient way. As the dredging becomes more restricted either by the size of the equipment or the type of management strategy employed, the cost per cubic yard increases, often dramatically (Table 1, Figure 1).

Table 1. Costs associated with dredging techniques used by small dredges in NJDOT Back-bay projects between 2012-2024.

	n	Volume Dredged CY (m^3) 2012-2024	Median Cost and Range/CY
In water hydraulic	5	198,952 (152,110)	$61 (31-195)
Confined upland hydraulic	12	801,109 (612,492)	$58 (19-142)
Semi confined upland hydraulic	18	568,375 (434,554)	$57 (21-396)
In water/upland mechanical	5	319,114 (243,980)	$79 (56-111)
Hydraulic to belt filter or geotextile bags	7	464,544 (359,169)	$127 (95-142)

Dredging Cost by Management Strategy

The management strategy utilized will also affect the cost of the project. The least expensive strategy is beach replenishment, followed closely by benthic enhancement. These techniques are routinely used,

relatively easy to permit, and often use direct in-water placement techniques with little if no impact on dredge efficiency. The most expensive projects involve extensive engineering and/or permitting and often require careful monitoring and adaptive management that slows dredging efficiency (Table 2, Figure 2).

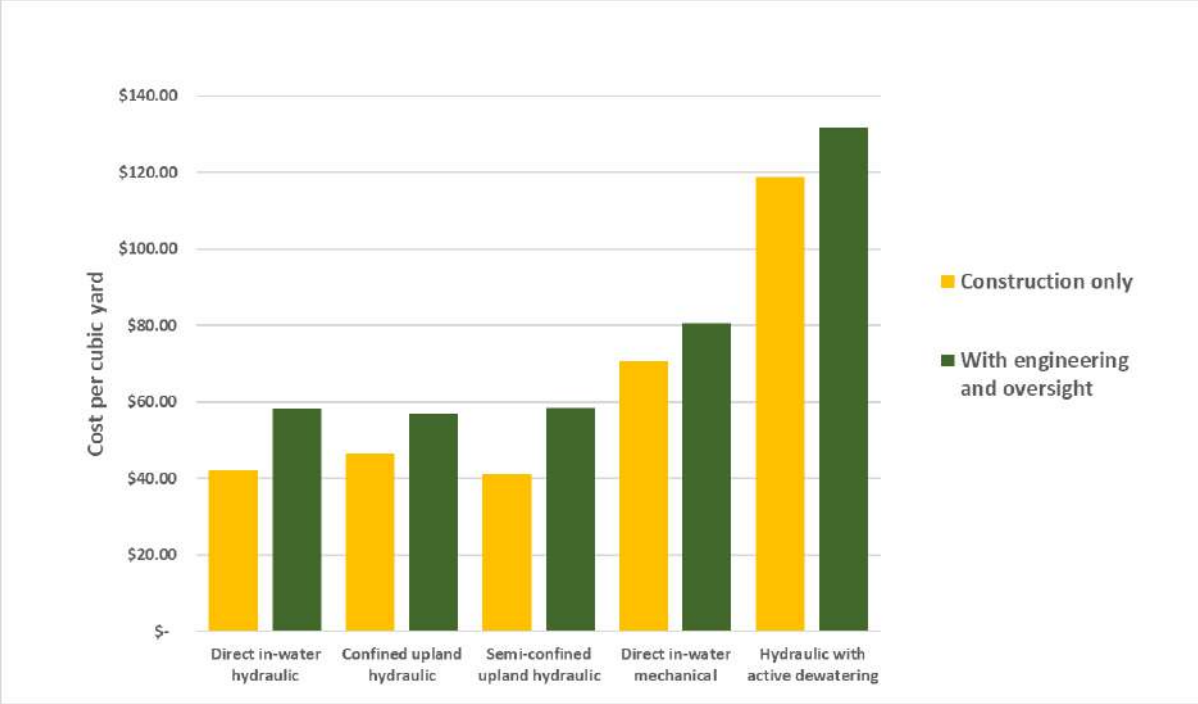

Figure 1. Costs associated with dredging techniques used in dredging NJDOT Back-bay projects with small dredges between 2012-2024.

Table 2. Costs associated with utilization of innovative management strategies in NJDOT Back bay dredging projects with small dredges between 2012-2024.

	n	Volume Placed CY (m^3) 2012-2024	Median Cost and Range/CY
Benthic enhancement	6	473,668 (362,145)	$64 (31-79)
Shoreline stabilization	2	53,542 (40,936)	$76 (61-92)
Beach nourishment	19	598,244 (457,390)	$56 (21-396)
Confined Upland Disposal	15	1,010,395 (772,502)	$89 (19-195)
Upland beneficial use	8	415,281 (317,505)	$115 (60-247)
Marsh enhancement	2	14,5291 (11,089)	$298 (251-346)

Some of the key issues driving up the cost of innovative management strategies are:

- **Complexity**: Most innovative strategies are more complicated to design than traditional methods such as CDFs or beach placement. Extensive, multi-seasonal evaluations may be required to obtain data needed for permitting and/or design.

- **Experience:** The use of non-traditional methods increases the risk to all parties. Contractors will charge more for these projects to protect themselves from loss.
- **Regulation/permitting**: Projects utilizing innovative strategies often take longer to permit than traditional placement methods, again due to increased risk.
- **Size:** Small demonstration level projects, while less risky environmentally, are much more expensive (per cubic yard) to implement.
- **Schedule*:*** Design and permitting often take longer, sometimes much longer than traditional management methods. Construction times are often longer due to lower dredging rates.
- **Adaptive management and monitoring**: Site evaluations and monitoring of project conditions before, during, and following construction adds costs not usually incurred when using traditional methods.

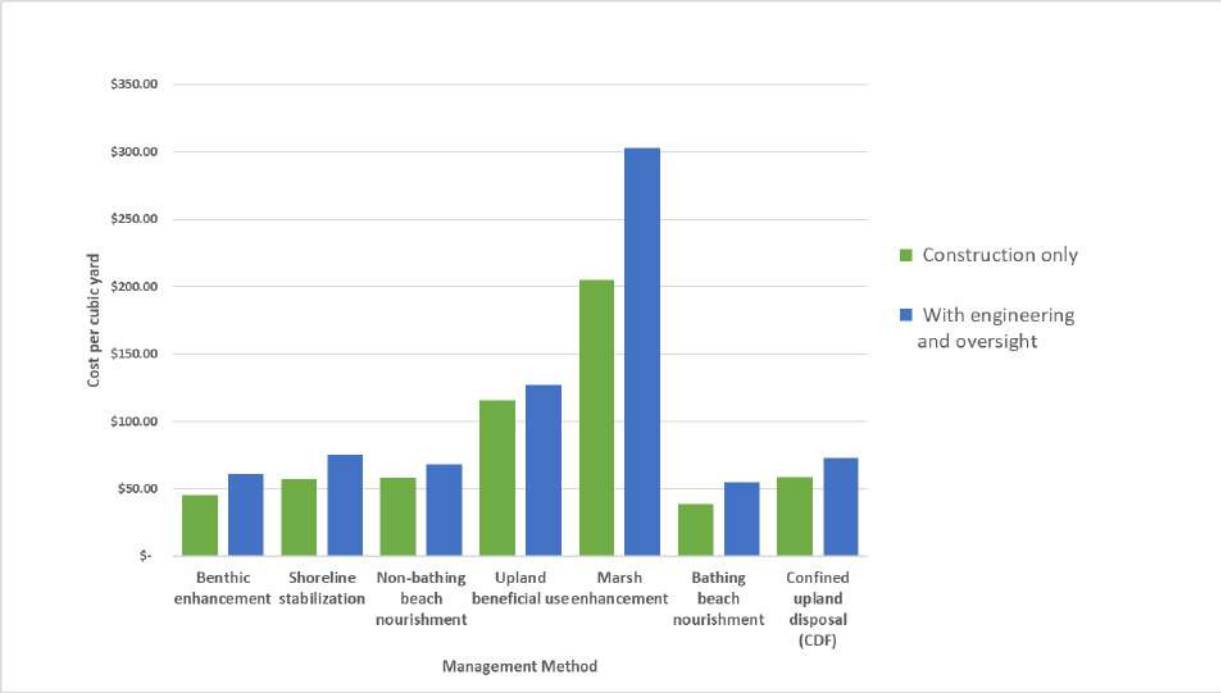

Figure 2. Costs associated with innovative management strategies on NJDOT Back bay dredging projects with small hydraulic dredges between 2012-2024.

Schedule

The time required to design, permit and construct a dredging project will vary depending on the type of equipment used, the techniques employed, and the placement strategy chosen.

Experience in New Jersey back bays between 2012 and 2024 indicates that traditional methods are usually quicker to design and permit than innovative methods (Figure 3). Some of this is simply a result of unfamiliarity, but mostly it is due to the more extensive data collection needs for design and permitting, which can take more than a year. From a permitting perspective, the most demanding are in-water restoration projects, which often require multi-seasonal monitoring of existing conditions as well as a longer permitting review and final design considerations (Figure 4).

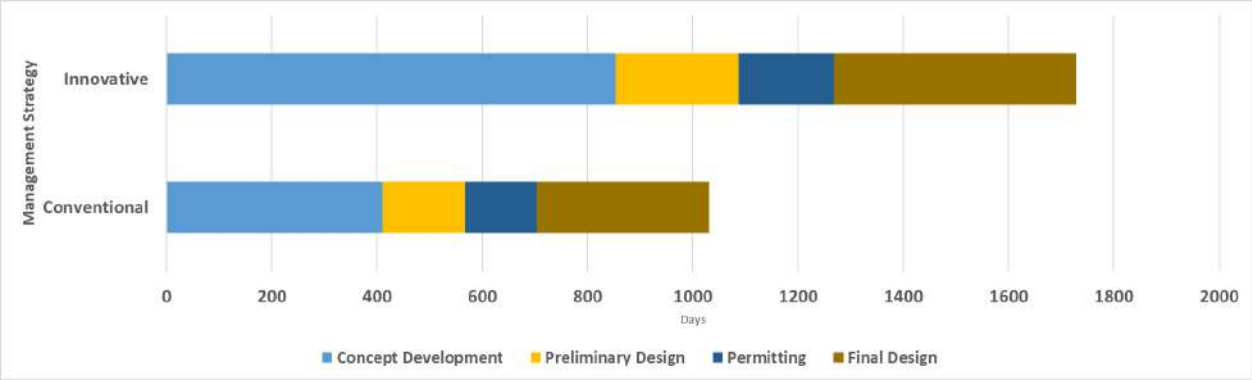

Figure 3. Average design timelines for innovative management strategies compared to traditional strategies, including conceptual design and data collection from NJDOT Back bay projects between 2014 and 2025.

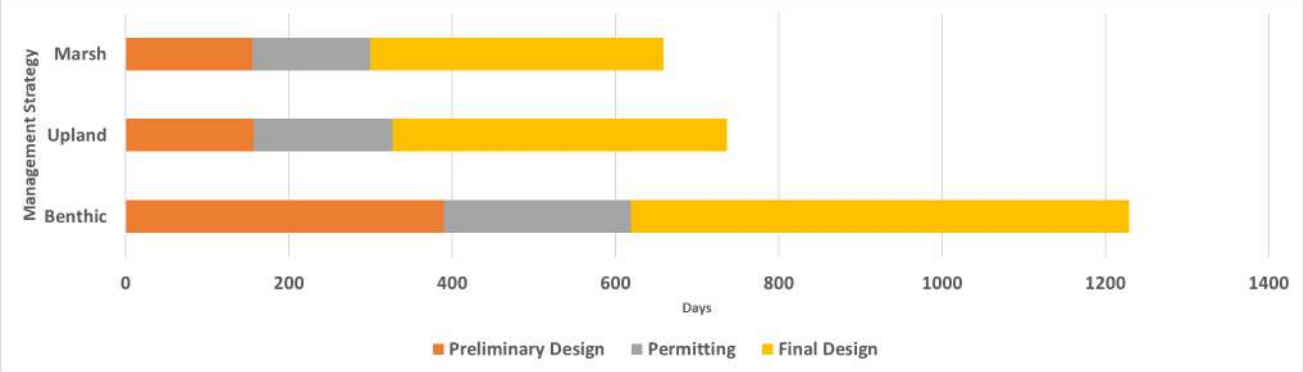

Figure 4. Average design timeline for innovative management strategies utilized by NJDOT Back bay projects between 2014 and 2025.

This is partially due to the type of equipment and placement technique used, but also because of the more extensive need and use of adaptive management and monitoring (Table 3). Innovative beneficial use projects may require years of post-construction monitoring (Douglas *et al*., 2024).

Table 3. Average timeline and dredging rates for dredged material management strategies utilized by NJDOT Back bay projects with small dredges between 2014 and 2025.

	n	Design (days)	Procurement (days)	Dredging Rate (CY (m^3)/dredging day)*	Post Construction Monitoring (years)
Beach Replenishment	8	757	178	3,067 (2,345)	none
Confined Upland Disposal	14	1306	124	1,213 (927)	none
Benthic Restoration	5	2546	121	1513 (1,157)	up to 3 years
Upland Beneficial Use	6	1829	130	918 (702)	none
Marsh Enhancement	2	811	86	740 (566)	up to 3 years

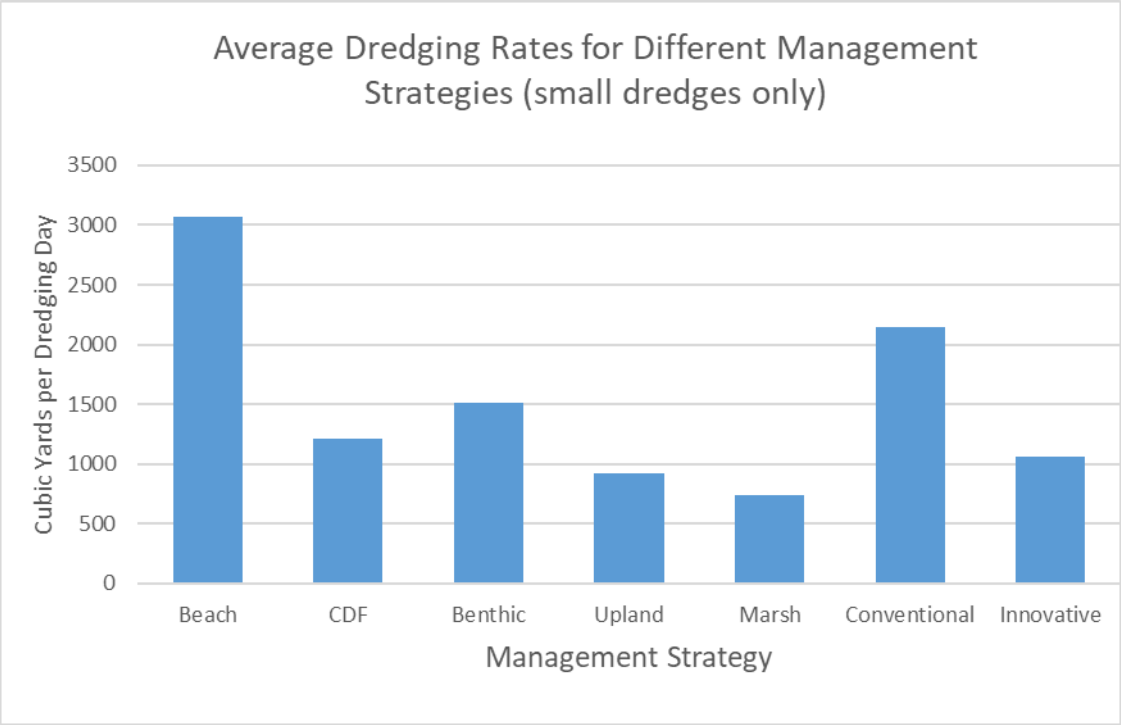

Figure 5. Average dredging rates for dredged material management strategies utilized by NJDOT Back bay projects with small dredges between 2014 and 2025.

The time for construction is influenced by the volume, dredging technique and management strategy (Figure 5). For small hydraulic dredges used in the Back-bay region of NJ from 2012 to 2024, the most efficient strategy was beach nourishment, and the least efficient strategy was marsh replenishment. In general, innovative beneficial use has been about twice as slow as conventional strategies. Placement at restoration sites, especially small sites with low grade tolerances, requires slow and careful placement. Larger restoration sites with more relaxed tolerances can achieve higher rates. Upland processing can also reduce efficiency, mostly due to capacity limitations and processing time.

Adaptive Management and Monitoring

Adaptive management is a technique for managing construction projects when using innovative strategies or working in sensitive ecosystems. When implementing a beneficial use project, monitoring is often separated into three phases: (1) Before Dredging, (2) During Construction, and (3) Post Construction.

- Before Dredging – Site selection and strategies may need to change as a function of site-specific information and pre-application regulatory review. While it is uncommon for this process to be the subject of a written plan, there needs to be a general understanding among stakeholders that it may be necessary to make significant changes in the project prior to construction.
- Construction - There needs to be a clearly articulated monitoring plan during construction. Sediment loss, elevation, compaction, consolidation, wildlife observations, and other required or desired parameters should be stated clearly upfront. Trigger points for action should be discussed and set as well as the actions that will be taken should those triggers be reached. Identify who will be responsible for taking action and how it will be funded.

- Post Construction – Determine the frequency and parameters that will be monitored. Determine the trigger points and actions to be taken. Identify the timelines, responsible party and funding for actions.

Benefits

The benefits of beneficial use have long been recognized by the dredging community; however little attention has been given to quantifying or monetizing these benefits. The fact that innovative beneficial use often takes longer and costs more than traditional methodologies makes this unlikely to be sustainable if other strategies are available. To change this, the dredging community, including both resource managers and municipalities, need to begin to realize the value of these projects.

Identifying the benefits is relatively easy but monetizing them requires consensus on the value of benefits, from a community resilience, transportation and wildlife habitat perspective, combined. This is controversial at best, but we took a first run at the problem which proved instructive (Table 4).

The transportation cost and benefits were straightforward. New Jersey's MTS supports a maritime activity that generates over $50 billion a year for the State. On the shore, the value of recreational and light commercial maritime use generates $8.5 billion a year in economic impact. With 200 miles (322 km) in the State Channel network, this gives us a value per mile of $42.5 million/yr. We cleared 33.7 miles (54.2 km) between 2014 and 2025 giving us a programmatic value of $1,432,250,000 *per year*.

A similar approach was used to quantify the benefits of innovative beneficial use. For the five major categories of benefits achieved in NJ; marsh habitat, non-bathing beaches, construction fill, shoreline stabilization and benthic habitat and looked for a defensible value to estimate the value of what was generated.

Marshes provide habitat for wildlife and protect coastal communities from storm damage. We used the annual duck hunting revenue as a start. Duck hunting generates $2.2 billion in activity every year in NJ. There are approximately 750,000 acres (30,3514 hectares) of public duck hunting land in NJ, which means that every acre is worth $2,933 ($7333/hectare).

Sea bottom supports the entire coastal ecosystem in a variety of ways. We used the average annual revenue from commercial shellfish, which is $1 billion per year. One could probably add recreational shellfish too, but these numbers cannot easily be separated. There are approximately 7.2 million acres (2.9 million hectares) of shallow water habitat in NJ coastal waters, which gives us a value of $139 per acre ($345/ hectare).

Bathing beaches are worth an estimated $40 billion a year to New Jersey's economy alone. There are 140 miles of oceanfront beach on the Jersey shore which means that every mile is worth about $286 million. Using an average of 30 acres of beach per mile, each acre of beach is worth $9.5 million *per year*.

Bathing beaches are obviously worth more than non-bathing beaches, however. Non-bathing beaches support wildlife and protect marshes. We estimated their worth at $3 billion per year based on recreational use such as bird watching. There is an estimated 75,800 acres (30,675 hectares) of wildlife beach (or potential wildlife beach) which works out to be a value of about $49,460 an acre ($97,863 a hectare).

Stable shorelines are critical to protecting coastal communities, so a direct value can be calculated per mile based on the average number of homes on the NJ shore and their value. We used Brigantine as a typical

shore community. For the 7.2 miles (11.6 km) of waterfront property there are 1300 units per mile (812 per km) valued at an average of $300,000 per unit. This means that every mile of shoreline is worth $3.9 million or $5,318 per linear foot ($27,600 per meter).

The value of land that has been enhanced by construction fill is difficult to parse, so we simply used the going rate that NJDOT pays for fill, not including delivery, which is $30 per ton ($33 per Metric ton).

Table 4. Annualized Benefits for Infrastructure Benefitting from Beneficial Use of Dredged Material in NJ Atlantic Coastal Zone.

Infrastructure	**Economic Impact (annualized $)**	**Units in NJ Atlantic Coastal Zone (approximate)**	**Value per Unit created**
Navigation Channels	$8,500,000,000	325 nm (523 km) (State and Federal)	$26.1 M/nm ($16.3 M /km)
Benthic Habitat	$1,000,000,000/yr (shellfish value only)	7,200,000 acres (2,900,000 hectares)	$139/acre ($345/hectare)
Marsh Habitat	$2,200,000,000/yr (duck hunting only)	750,000 acres (303,514 hectares)	$2,933/acre ($7,248/hectare)
Beach Habitat	$3,000,000,000/yr	75,750 acres (30,655 hectares)	$49,460/acre ($97,863/hectare)
Recreational Beach	$40,000,000,000/yr	54,000 acres (21853 hectares)	$740,741/acre $(1.8 M/hectare)
Shoreline (Brigantine)	$3.9 Million/mile ($2.4 Million /km)	7.2 miles ($11.6 km)	$5,318/ft ($27,600/m)
Construction Fill	NA	NA	$30/ton ($33/Metric ton) (average NJDOT cost)

Benefit to Cost Ratio

The benefit to cost ratio (CBR) is used to justify the cost of a project by comparing it to the value generated. Since 2014, the State Channel Dredging Program has generated about $319 million in benefits including beneficial use, at a cost to DOT of approximately $112 million. This returns a CBR of almost 3:1 (Table 5). That makes dredging and the associated costs a real value. It easily supports the additional 2% escalation that innovative beneficial use costs. However, dredging projects are not always able to compete with other financial demands and funding is usually limited. There is also not a large public voice for maritime transportation, so it has a hard time competing for limited funds. The high BCR for our program is also influenced by the relatively small cost compared to Federal dredging jobs. Other states that do not have a similar shore economy likely will not have the same results.

One can argue the details of our approach, and with additional effort get closer to an actual value, however we believe this is as an order of magnitude approximation. From it we can easily see that innovative beneficial use, while costly, does not impact the value of the transportation benefits achieved when there is

no other choice for dredged material management. Refinement of the value of the benefits is an ongoing project as are refining the engineering and permitting process for beneficial use.

Table 5. State Channel Dredging Program Benefits from Beneficial Use Strategies (2014-2025).

	Number of units constructed	**Value generated per unit created (from Table 5)**	**Value created by program**	**Total Programmatic Value**	**Cost to NJDOT**	**Cost Benefit Ratio**
Navigation Channels	76.7 nm (12.2 km)	$26.1 M/nm ($1.42 M/km)	$200 M	$318.6 Million	$111.7 Million	2.86
Benthic Habitat	255.3 acres (103.3 hectares)	$139/acre ($345/ hectare)	$35,487			
Marsh Habitat	100.8 acres (40.8 hectrares)	$2,933/acre ($7,333/(hectare)	$296,000			
Recreational Beach	84.4 acres (34.2 hectares)	$740,741/acre (1.85 M/hectare)	$62.5 Million			
Beach Habitat	6.6 acres (2.67 hectares)	$49,460 per acre ($97,863 per hectare)	$326,426			
Shoreline	2350 ft (716m)	$5,318/ft ($27,600/m)	$12.5 M			
Construction Fill	1,430,000 tons (1,297,000/M ton)	$30/ton ($33/M ton) (average DOT cost)	$42.9 M			

Case Studies

The following are examples of innovative beneficial use projects conducted in NJ between 2014-2025.

Manasquan

- Beneficial Use: Beach replenishment on non-bathing beach and landfill cover
- Location: Manasquan, NJ, (2021-2022)
- Designer: WSP/GBA and Dewberry Engineers
- Contractor: H&L Contracting
- Total Dredging Days: 41
- Total Volume Dredged: 81,742 CY (62,496 m^3)
- Total Tons Trucked: 33,600 (30,481 M tons)
- Total Trucking Time: 10 weeks

- Cost of construction and oversight: $7,303,309
- Cost of engineering and permitting: $299,586
- Cost of monitoring: $70,700
- Project Summary: Engineers determined that 88,250 CY (67,472 m^3) of material would need to be removed to restore 8 channels to navigability. A total of 81,742 CY (62,496 m^3) of material was dredged over the course of 465 dredging days utilizing a 16-inch (40.6 cm) hydraulic cutterhead pipeline dredge. Approximately half the material was placed at a non-bathing beach, and the remaining fine-grained material was dewatered in a nearby parking lot using geotextile bags and later beneficially used as daily cover at the Monmouth County Reclamation Center (MCRC). In total, 21 geotextile bags ranging in size from 150 (45.7 m) to 259 feet (79 m) long and 95 feet (46 m) wide were arranged in four layers to contain the material. After allowing a minimum of 32 days to dewater, the bags were opened and the dewatered sediment trucked to MCRC over ten weeks. A total of 3 acres (1.279 hectares) of beach were replenished and 33,600 tons (30,481 M tons) of landfill cover provided. (Figure 6)

Figure 6. Upland beneficial use and non bathing beach nourishment in Manasquan. Top row: geotextile bags, dewatered dredged material, storage of dredged material at landfill. Bottom row: Dog beach prior to nourishment, beach placement, final restored beach.

Fortescue

- Beneficial Use: Marsh Enhancement, Shoreline Stabilization, Beach replenishment on bathing and non-bathing beaches
- Location: Fortescue, NJ, (2015-2017)
- Designer: WSP/GBA and Dewberry Engineers
- Contractor: Wickberg Marine
- Total Dredging Days: 41
- Total Volume Dredged: 37,140 CY (28,396 m^3)
- Cost of Construction and Oversight: $4,214,090
- Cost of Engineering and Permitting: $486,655
- Cost of Monitoring: $600,000

- Project Summary: Engineers determined that 80,000 CY (61,164 m^3) of material needed to be removed from the Fortescue channel to restore navigability. Over the course of 41 dredging days spanning two dredging seasons, 37,140 CY (28,396 m3) of sediment was dredged from the Fortescue channel and placed on the marsh and beaches using a 12-in (30.5cm) hydraulic cutterhead pipeline dredge. Approximately 8,500 CY (6500 m3) of fine-grained sediment was pumped directly into the Fortescue marsh via a network of high density-polyethylene (HDPE) pipelines and valves. Sediment slurry was contained on the target areas using approximately 20,000 ft (6100 m) of compost-filled polyethylene tubes. Another 21,000 CY (16,100 m3) of course grained material was used to reconstruct a 1,100-ft long (335 m) 100-ft (30.5 m) wide protective dune on the leading edge of the marsh. The sand was placed into a surge pit constructed on the marsh and the sand removed using an excavator and bulldozed into place. The remaining 7,000 CY (5352 m^3) coarse-grained material was utilized to replenish two nearby beaches: one a remote non-bathing beach, the other a village bathing beach. A total of 6.6 acres (2.67 hectares) of marsh were enhanced, 1100 feet (335 m) of shoreline stabilized, and 1.6 acres (0.65 hectares) of beach replenished (Douglas *et al.,* 2021). (Figure 7)

Figure 7. Beneficial use at Fortescue Wildlife Refuge. Top row: original dune, dune during construction, final dune. Middle row: non bathing beach prior to nourishment, beach during construction, final day of grading. Bottom row: marsh prior to platform elevation, marsh during placement, final marsh after several years of growth.

Abbotts Meadow

- Beneficial Use: Marsh Enhancement
- Location: Lower Alloways Township, NJ (2023-2024)

- Designer: WSP/GBA Engineers
- Contractor: H&L Contracting
- Total Dredging Days: 33
- Total Volume Dredged: 677,500 CY (517986 m3)
- Cost of Construction and Oversight: $40,412,285
- Cost of Engineering and Permitting: $1,303,504
- Cost of Monitoring: $718,291
- Project Summary: Engineers determined that 600,000 CY (458,733 m3) of material needed to be removed from the NJ Windport berthing area under construction in Salem County, NJ. The Abbott's Meadow Marsh, a 400-acre (162 hectare) wetland site located within the 1600-acre (647-hectare) Abbott's Meadow Wildlife Management Area in Lower Alloways Creek Township, Salem County, was identified by NJDEP as a site requiring marsh platform restoration and stabilization to restore normal hydrology. Engineers determined that 830,316 CY (634,822 m3) of sediment would be needed in eight areas to raise the marsh platform to an elevation that would support native marsh vegetation. A total of 677,500 CY (517,986 m3) of fine sand and silt were dredged over 33 dredging days and pumped directly into the marsh utilizing a 24-inch (61 cm) hydraulic cutterhead pipeline dredge, a booster pump and 34,000 linear feet (10363 m) of pipeline. A total of 89 acres (36 hectares) of marsh were restored (Douglas et al., 2024). (Figure 8)

Figure 8. Beneficial use at Abbott's Meadow Wildlife Refuge. Marsh prior to placement, during placement and immediately after placement.

Cape May RR CDF

- Beneficial Use: Habitat Restoration
- Location: Cape May, NJ (2018)
- Designer: Dewberry Engineers
- Contractor: Wickberg Marine
- Total Tons Trucked: 64,425 CY (49256 m3)
- Total Trucking Time: 50 Days
- Cost of Construction and Oversight: $556,559
- Cost of Engineering and Permitting: $199,928
- **Project Summary**: The Railroad CDF in Cape May is located at the eastern end of the Cape May Canal. As per an agreement with the USACE Philadelphia District, NJDOT excavated and removed 64,425 CY (49256 m3) of dewatered coarse-grained sediment from the Railroad CDF in 2018 and placed it in a stockpile at the nearby Higbee Beach Wildlife Refuge. The material will be used in

NJDEP's restoration of the refuge. A total of 4,295 trucks moved a total of 64,425 CY (49256 m3) of material over the course of 50 days. (Figure 9)

Figure 9. Innovative beneficial use at Railroad CDF. Left to right: Excavation of CDF, CDF capacity generated, stockpile for future habitat restoration at Higbee Wildlife Refuge.

Brigantine

- Beneficial Use: Shoreline stabilization and benthic enhancement
- Location: Brigantine, NJ (2020-2021)
- Designer: Dewberry Engineers
- Contractor: Wickberg Marine
- Total Dredging Days: 42
- Total volume dredged: 21,823 CY (16685 m3)
- Cost of Construction and Oversight: $1,289,835
- Cost of Engineering and Permitting: $243,637
- Cost of Monitoring: $144,835
- Project Summary: Engineers estimated that 27,000 CY (20643 m3) of sediment needed to be removed to restore navigability to this state channel serving several marinas and private berths. Material was dredged hydraulically and placed adjacent to nearby islands to stabilize the shoreline and improve benthic habitat for shellfish and wading birds. A total of 21,823 CY (16685 m3) was removed with a 12-inch (30.5 cm) hydraulic cutterhead dredge over the course of 42 dredging days. In the process 23.6 acres (9.55 hectares) of habitat were created or enhanced. (Heeren et al., 2022). (Figure 10)

Figure 10. Innovative beneficial use at Sunflower and Boot Islands, Brigantine, NJ. Top row: impassable channel with boot island benthic enhancement area in background, hydraulic placement, overview of project area after construction. Bottom row: Sunflower Island prior to stabilization, during construction and after stabilization.

Wildwood

- Beneficial use: Landfill cap and construction fill
- Location: Wildwood, NJ (2023-2024)
- Designer: Dewberry Engineers Contractor: Mobile Dredging and Video Pipe
- Contractor: Mobile Dredging and Video Pipe
- Total Dredging Days (3 dredges): 241
- Total Volume Dredged: 110,659 CY (84,605 m3)
- Total Tons Trucked: 110,659 T (100,388 Metric Tons)
- Trucking Time: 188 days
- Cost of Construction and Oversight: $12,633,701
- Cost of Engineering and Permitting: $432,099
- Cost of Monitoring: $144,835
- Project Summary: Engineers estimated that 124,481 CY (95,173 m3) of sediment needed to be dredged to restore navigability to 7 State channels serving the City of Wildwood, North Wildwood and West Wildwood, NJ. Material was hydraulically dredged and dewatered using a combination of hydrocyclones and geotextile bags. The dewatering was performed at one of three shoreside sites in Wildwood (3.4 (1.38), 3.5 (1.43) and 1.6 (0.68) acres (hectares) in size). Once dewatered, the material was beneficially used to cap and close a sanitary landfill and contour the site as a passive recreation park.

  Dredging was initiated on 12/21/2023 utilizing up to three dredges (two 10-inceh (25.4 cm) and one 12- inch (30.5 cm) over the course of 214 calendar days and completed on 8/19/2024. A total of 110,660 CY of sediment was removed from the seven channels to a depth ranging from 5-12 feet (1.5 m – 3.7 m) MLW. Of that amount, 8,000 CY of sand was separated with the hydrocyclones and the remaining material was dewatered in 137 geotextile bags. Geotextile bags were stacked as

high as four layers. One site was used for two rounds of dewatering; material was excavated and placed at the landfill between rounds. Once emptied, geotextile bags were disposed of in a sanitary landfill. Sand was utilized for beach replenishment on a non-bathing beach at the waterside edge of the landfill. (Figure 11)

Figure 11. Manasquan upland beneficial use. Hydraulic dredging to mechanical dewatering. Top row: landfill prior to cap, geotextile bags, dewatered dredged material. Bottom row: landfill during capping, hydrocyclones, separated sand. Far right: aerial view of finished cap.

CONCLUSIONS

In summary,

- Innovative beneficial use projects are often more expensive than conventional projects.
- Innovative beneficial use projects are often more time-consuming to design, permit and construct than conventional projects.
- Innovative beneficial use projects, particularly those that have restoration goals, may require adaptive management during or after construction.
- Innovative beneficial use projects often require extensive post construction monitoring and evaluation and may result in additional costs for adaptive management.
- Innovative beneficial use projects often require coordination with outside stakeholders including other agencies, landowners, municipalities, community groups and non-governmental organizations (NGOs).
- While more costly than conventional approaches, the costs are easily justified by the magnitude of the navigational benefits generated, at least in the case of New Jersey.

Innovative beneficial use is a sound and sustainable strategy for managing dredged material when other traditional methods are not available or are impractical for the location. This is especially true if the regulatory agencies have policies that encourage beneficial use in general.

Cost and schedule are a challenging aspect of most innovative beneficial use projects, especially when they occur in sensitive coastal environments. It is essential that resource managers are on board with the strategy of innovative beneficial use as it is often helpful if they defend the need for the dredged material on their site during the permitting process. While the engineering will often need to be done by the owner, we find it useful to have the landowner apply for the beneficial use or restoration permit.

We have found that well-informed stakeholder groups are an effective way to manage innovative beneficial use programs. Taking this a step further, regional planning groups like the Regional Dredging Team or the Restoration Task Force established in New Jersey ensure that projects that are planned in advance are vetted before the permits are even filed.

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DATA AVAILABILITY

All of the data used during this study are available from the corresponding author on request.

BROADENING BENEFICIAL USE TO ACHIEVE GREATER COASTAL RESILIENCE IN THE GREAT LAKES

B.C. Suedel[1] and J.A. Miller[2]

EXTENDED ABSTRACT

Great Lakes communities are experiencing increased frequency in coastal flooding and erosion, causing property damage, putting lives at risk, and disrupting local economies. Recent historic high lake levels illustrate the widespread vulnerabilities along the coast. Natural and Nature Based Features (NNBF) are measures and techniques that can be incorporated into shoreline protection to reduce flood risk and improve resilience of coastal and inland water systems. The beneficial use of dredged material can play a key role as a resource for implementing NNBF. NNBF integrates seamlessly with the concept of Multiple Lines of Resilience (MLR), whereby multiple strategies are used to develop a system of comprehensive, resilient, and sustainable coastal risk solutions. However, current understanding of NNBF and MLR coastal resiliency measures is lacking, resulting in dearth of confidence on the applicability and cost-benefit of beneficial use of dredged material (BUDM) measures in the Great Lakes. A paradigm shift from conventional coastal infrastructure practices to NNBF is needed to confidently consider BUDM as a contributor for promoting broader application of these innovative, sustainable, and resilient measures.

Sustainable sediment management approaches are needed that work with nature to provide present and future value for the benefit of both people and nature. To address these challenges, there are considerable efforts underway to identify sustainable solutions to increase beneficial use of dredged material in the Great Lakes. There are several successfully completed dredging projects in the Great Lakes region that created or restored habitats as illustrative examples for using dredged sediment as an effective natural resource to reverse coastal degradation trends. Focusing on multiple dredge sediment placement sites in the region, this presentation will illustrate how dredged sediment can be used to build features to help restore wetlands, stabilize shorelines, and support biodiversity.

The US Army Corps of Engineers Great Lakes districts in Buffalo, Chicago, and Detroit have implemented dredging projects throughout the Great Lakes that adhere to Engineering With Nature® (EWN®) principles while providing multiple benefits. Among others, such projects include Braddock Bay on Lake Ontario, NY, Cat Island near the Port of Green Bay on Lake Michigan, WI (Bridges et al. 2018), Piping Plover habitat on Lake Superior in WI, Clinton River mouth on Lake Michigan, MI (Bridges et al. 2021), Interstate Island in Duluth-Superior Harbor, MN/WI, and North Sandy Pond on Lake Ontario, NY (Tritinger et al. 2024). Such projects that enhance coastal resilience while restoring habitats can serve as illustrative examples for using dredged sediment as an effective natural resource to reverse ecosystem and coastal degradation trends. Focusing on multiple dredge sediment placement sites in the region, how dredged

[1] Research Biologist, Engineer Research and Development Center - U.S. Army Corps of Engineers, 3909 Halls Ferry Rd, Vicksburg, Mississippi 39180, USA, T: 1-601-634-4578, Email: burton.suedel@usace.army.mil.
[2] Research Environmental Engineer, U.S. Army Corps of Engineers, Engineering Research and Development Center, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180, USA, T: 312-259-6826, Email: jennifer.miller@usace.army.mil.

sediment can be used to build features to help restore wetlands, stabilize shorelines, and support biodiversity were illustrated. Each dredging project applies principles of EWN to leverage natural processes for long-term sustainability, offering scalable models for enhancing ecosystem resilience along freshwater coasts.

The findings emphasize that the beneficial use of dredged sediment as a nature-based solution can provide long-term benefits, including substantial habitat restoration, recreational benefits, and dredging and navigation cost efficiencies. Results of the projects listed herein, as well as others, provide valuable insight into how sustainable dredged sediment management practices can be implemented regionally. Identifying and articulating the multiple economic, environmental, and social benefits of NNBF will strengthen capability and build capacity for applying EWN principles in USACE flood risk management, navigation, and ecosystem restoration projects, and will contribute to achieving the USACE 70 percent goal for sediment beneficial use. These findings emphasize that the beneficial use of dredged sediment as a nature-based solution can provide long-term benefits, including substantial habitat restoration, recreational benefits, and dredging and navigation cost efficiencies. Results of these projects provide valuable insight into how sustainable dredged sediment management practices can be implemented globally on freshwater coasts.

Keywords: Dredging, Engineering With Nature®, sustainability, dredged material, sustainable sediment management.

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THE COMPLETED TEXAS-SIZED PLANNING EFFORT FOR BENEFICIAL USE OF DREDGED MATERIAL

I. Fisher [1], D. Opdyke[2], A. Horine[3], K. Haviland[4], T. Merendino[5], and R. Newby[6]

EXTENDED ABSTRACT

Millions of cubic yards of sediment dredged from federal channels and privately dredged channels each year to maintain Texas's maritime commerce are "lost" from sediment-starved systems. Most of this dredged material goes to either confined or open bay placement areas, many of which are nearing capacity and provide little environmental benefit. This common method of disposal of dredged material is a lost opportunity for our coastal wetlands and other coastal assets, which are impacted by sea level rise and other coastal hazards.

Beneficial use (BU) of dredged material is a solution to this problem that helps to retain material within the geomorphological system and restore coastal wetlands. Benefits from BU include economic value in ecosystem services and commercial value in maritime, fishing, and wildlife revenue.

Ducks Unlimited (DU) has been leading a multi-year effort in Texas to identify, prioritize, plan, design, permit, and construct BU sites. The lynchpin of this effort is an ongoing RESTORE Act-funded Texas Beneficial Use of Dredged Material Master Plan (TEXBUMP) that coordinates efforts, identifies efficiencies, builds consensus, identifies and prioritizes sites, and produces plans and guidelines that will result in cost savings and streamline future BU projects. This project expands and builds on recently completed and ongoing regionally focused BU planning work that DU is conducting by synthesizing existing information and gathering additional information pertaining to the identification, preliminary prioritization, and concept design of potential BU project sites along the Texas Coast.

Texas Beneficial Use Groups (TEXBUGs) have been established for the four coastal regions. The planning effort relied on input from key stakeholders that represent state and federal agencies, non-governmental organizations, municipalities, and private landowners. Potential BU projects were solicited through the TEXBUMP website and project submission form, as well as previous DU efforts. Nearly 400 projects were on the master list of potential BU projects, which contain most sites suggested over the past 10-plus years through this and other BU initiatives. These potential projects were reduced to 164 projects constituting the

1 Senior Coastal Engineer, Anchor QEA, 1217 Hwy 35 South, Rockport, Texas 78381, USA, T: 361-450-6208, Email: ifisher@anchorqea.com.
2 Practice Area Lead, Anchor QEA, 901 S. MoPac Expressway, Suite 150, Austin, Texas 78746, USA, T: 512-707-2738, Email: dopdyke@anchorqea.com.
3 Principal Coastal Engineer, Anchor QEA, 500 N. Water Street, Suite 1010, Corpus Christi, Texas 78401, USA, T: 361-450-6945, Email: ahorine@anchorqea.com.
4 Staff 3 Scientist, Anchor QEA, 100 Light Street, Suite 1220, Baltimore, Maryland 21202, USA T:410-794-7784, Email: khaviland@anchorqea.com.
5 Director of Conservation Programs, Ducks Unlimited, 915 Front Street, Richmond, Texas 77469, USA, T: 832-595-0663, Email: tmerendino@ducks.org.
6 Maritime Division Waterways Coordinator, Texas Department of Transportation, 6230 E. Stassney Lane, Austin, Texas, 78744, USA, T: 512-917-9357, Email: Edward.Newby@txdot.gov.

Initial Priorities List. Concurrently, a publicly available GIS-based Decision Support System (DSS) was developed to help evaluate site suitability for the 164 projects that were on a weighted characteristic matrix to rank the likelihood of success. Through the DSS, professional judgement, and input from the TEXBUGs, 21 projects were selected for the Final Priorities List and advanced to concept-level designs.

While DSSs have existed for more than 3 decades, recent advances in GIS techniques, computational power, and spatial data availability have made them increasingly powerful tools for coastal planning and management (Barzehkar et al. 2021). This DSS brings together multiple layers of spatial data within the regions of interest along the Texas Coast, classifies these layers based on underlying data in terms of their suitability for the restoration type, and combines the suitability of the layers into one output raster covering the entire region of interest. The output rasters function as a heatmap, showing areas of high and low overall suitability for the restoration type.

In Texas, various DSSs have been developed to guide coastal planning, making use of the large amount of publicly available coastal data. DSSs aim to guide decision-making processes involving site selection and should be used in conjunction with professional judgement and site-level assessments before final decisions are made. The BU DSS for this project can guide, but not prescribe, siting decisions for habitat restoration projects using dredged sediment.

DSS models for two of the most common restoration types, bird islands and wetlands, were created for this project. Due to infrequent occurrence, other BU types will be evaluated on a case-by-case basis. DSS construction started by identifying characteristics that informed the suitability of a location for a BU project and had a publicly available coastwide dataset. Some characteristics spanned both BU types.

Each site characteristic was developed into a coastwide map on a 10-meter-by-10-meter raster grid resolution. This resolution provides a high degree of fidelity to small-scale spatial characteristics within acceptable computer processing times. The characteristics were also categorized as threshold, assigned a range between 0 and 1, or exclusionary, assigned a value of 0 or 1. Exclusionary criteria identified fatal flaws. A score of 0 automatically eliminated a location from further consideration. The relative importance of each threshold characteristic was determined to assign a weight, or value, to each. The weights were defined such that their sum for a given restoration type is 1. Local experts in each restoration type were engaged to provide feedback on each characteristic and its associated weighting.

For each grid cell, the value of each threshold characteristic is multiplied by its weight then summed across all threshold characteristics for that restoration type. The result is a preliminary suitability score between 0 and 1. This preliminary score became the final score, unless the grid cell had any exclusionary criteria score a 0, in which case the final suitability score became 0.

There are limitations to the DSS. Notably, the results are strongly dependent on the quality and comprehensiveness of the input data, highlighting that professional judgment and the input of stakeholders will always be necessary to inform the final decisions on restoration projects.

Through the DSS, professional judgement, and input from the TEXBUGs, 21 projects were selected for the Final Priorities List and advanced to concept-level designs. These projects, along with a detailed summary, are captured in the final Master Plan. Implementation Guides developed for each of the four coastal regions in Texas were also developed to help streamline the process for local stakeholders. Overall, the Final Priorities List, Master Plan, and Implementation Guides provide a road map for project champions to obtain funding and ultimately implement more BU projects for the benefit of the state and our ecosystems.

Although specific to Texas, the TEXBUMP provides a model that can be reproduced elsewhere. Gulf and Atlantic coastal states facing similar sediment and wetland loss issues can adapt the framework by building a scalable GIS-based DSS using regional datasets, establishing regional stakeholder groups, and embedding BU planning within existing dredging programs.

Keywords: Beneficial use, dredged material placement, marsh creation, marsh restoration, rookery island, bird island, maintenance dredging, beach nourishment, feeder berm, seagrass restoration, seagrass protection, tidal flat restoration

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PORT HOUSTON: NAVIGATING GLOBAL TRADE RESILIENCE

L.S. Brownell[1]

EXTENDED ABSTRACT

For more than a century, the Houston Ship Channel (HSC) has served as the backbone of the regional economy. Its official opening as a deep-draft navigation channel in 1914 established a protected inland port that supported the region's thriving oil and cotton industries and laid the foundation for sustained economic growth and development. Connected to the 15-mile Galveston Entrance Channel, the 52-mile HSC is the busiest waterway in the United States, accommodating more than 17,000 deep-draft vessel transits and 210,000 barge movements annually. The channel provides access to over 200 private industrial facilities as well as Port Houston's eight public terminals: Barbours Cut, Bayport, CARE, Jacintoport, Old Manchester, Bulk, Turning Basin (North and South), and Woodhouse. Together, these facilities have helped transform the Houston region into one of the nation's most important centers for trade, industry, and logistics.

Continued population growth in Houston and throughout Texas is driving increased domestic and international trade, including exports, imports, manufacturing activity, and energy-related commerce. Rising demand for e-commerce products, household goods, building materials, food, and beverages has fueled import growth and attracted new distribution and logistics investments to the region. In recent years, companies along the HSC have invested more than $50 billion in new facilities and expansions, supporting significant growth in polyethylene resin production for export markets around the world. Reflecting this momentum, international exports from industries located along the HSC grew 50 percent faster than total U.S. waterborne export tonnage between 2009 and 2019 (Martin Associates, 2020). Based on 2023 waterborne tonnage data, Port Houston is the nation's leading port by waterborne tonnage, handling more cargo than any other U.S. port by a substantial margin (USDOT, 2026).

This paper focuses on the navigation and regulatory considerations associated with five (5) long-term growth initiatives along and within the Houston Ship Channel: Project 11, Pelican Island, Bayport East End, Barbours Cut Northside Expansion, and Project 12. Listed in order of anticipated implementation, these strategic projects are intended to support continued industrial and port expansion, enhance operational efficiency, and sustain the Houston region's economic resilience and growth well into the next century.

Project 11. Project 11 — HSC Expansion Channel Improvement Project — the 11th major improvement project in the HSC history, includes widening the channel by 170 feet (from 530 to 700 feet) along its Galveston Bay reach, widening the Bayport and Barbours Cut Channels to 455 feet, deepening some upstream segments (up to -46.5 feet Mean Lower Low Water [MLLW]), making other safety and efficiency improvements (i.e., bend easings), and constructing new environmental features. Port Houston and the United States Army Corps of Engineers, Galveston District (USACE-SWG) have committed nearly 100% of the engineering-grade material dredged — equating to over 15 million cubic yards — from Project 11 to beneficially create approximately 10-acres of bird islands, 276-acres of instant intertidal marsh, and 324-

[1] Chief Channel Infrastructure Officer, Port of Houston Authority, 2960 Riverby Road, Houston, Texas 77020, USA, T: 713-670-2605, Email: lbrownell@porthouston.com

acres of oyster reefs. Additionally, over 600 acres or 12.4 million cubic yards of future HSC Operation & Maintenance capacity will be available because of project construction.

To expedite funding and construction, Port Houston and industry stakeholders informally agreed to cost-sharing the project. The Port funded and completed the design and construction of Segments 1-2 (HSC, Bolivar Roads to Morgans Point and Barbours Cut Ship Channel), completing 73% of the total project by volume in five (5) years. Port Houston is currently developing a user fee in alignment with 33 U.S.C. § 2236 to enable industry stakeholders' contributions to the cost of Project 11. As a result of the Segments 1-2 completion, larger vessels of up to 15,000-17,000 TEU (in alignment with the Panama Canal) can call Bayport, and daylight restrictions for most vessels are removed through Hunting Bayou, resulting in nearly 24/7 movements of Aframax, Suezmax, and Liquefied Petroleum Gas (LPG) tankers. The USACE continues to progress on the remaining 27% of the project, Segments 3-6 (Barbours Cut Channel and HSC Sims Bayou to Upper Turning Basin), with expected completion between 2028 and 2030.

Pelican Island. Port Houston is collaborating with the USACE-SWG, to replace an existing dredged material management site with a new site of equivalent capacity on Pelican Island, located north of Galveston Island across the Galveston Harbor Channel. The proposed project would establish a new dredged material placement area that maintains the Corps' long-term dredged material management capacity while utilizing portions of both existing USACE and Port Houston property. In exchange for providing approximately 19 million cubic yards of equivalent dredged material placement capacity, Port Houston intends to pursue the transfer of approximately 1,525 acres of upland property and adjacent submerged lands. This exchange would facilitate the development of approximately 10,000 linear feet of waterfront property for future maritime and industrial uses. The land exchange was authorized by Congress through the Water Resources Development Act (WRDA) of 2024 (USACE, 2025). Throughout the planning and implementation process, Port Houston will work closely with local and regional stakeholders, including city and county officials, Pelican Island landowners and tenants, Texas A&M University at Galveston, USACE-SWG, Seawolf Park representatives, the fishing community, and other interested parties. Completion of the conceptual planning effort and execution of the federal Consent of Easement are targeted for December 2026.

Bayport East End. The Bayport East End development consists of both upland and in-water improvements, including wharf construction, pipeline relocations or removals, and the construction of a breakwater to reduce the effects of wind and wave action. During the first two (2) project phases, approximately 300,000 cubic yards of dredged material will be removed to establish a berth with a 45-foot operational depth and provide navigational access to the new wharf, which is scheduled for construction in 2028. The third phase of development, targeted for completion in 2032, will require the dredging of approximately 3.2 million cubic yards of material to create a new 1,600-foot turning basin. The dredged material is expected to be beneficially reused to improve berms at an existing dredged material placement area. In February 2026, Port Houston submitted a permit application to convert a previously permitted cruise terminal from an operating layberth into container wharves. Subject to completion of the USACE-SWG Section 408 review, Port Houston anticipates receiving the necessary federal permits in 2027.

Barbours Cut Northside Expansion. Port Houston's planned container terminal expansion will initially include two (2) new Neo-Panamax vessel berths, associated landside terminal support facilities, channel improvements to accommodate safe vessel transit, and construction of a new turning basin. The first phase is expected to become operational by 2032, with a second phase adding two additional Neo-Panamax berths by 2038. Port Houston submitted its permit application in March 2026. The U.S. Army Corps of Engineers, Galveston District (USACE-SWG), subsequently determined that the project will require preparation of an

Environmental Impact Statement (EIS) and recommended application and inclusion on the Fixing America's Surface Transportation (FAST-41) federal permitting dashboard. The terminal expansion is designed to:

- Provide scalable infrastructure capable of accommodating anticipated growth in the global container vessel fleet.
- Reduce vessel dwell times, improve operational efficiency, and enhance berth safety.
- Enable phased development that aligns with projected regional population growth and trade demand.
- Support regional and national economic growth through increased import and export capacity.
- Improve navigational access through construction of an enhanced access channel, turning basin, and berth pockets capable of safely accommodating larger vessels.
- Meet expanding maritime capacity needs while maintaining compliance with environmental, navigational, and operational requirements.

Navigation and dredged material management are key components of the project. The expansion will require disposal of the existing federal dredged material easement at Spilman Island to facilitate terminal construction, as well as development of three (3) new dredged material management areas. Together, these facilities are expected to provide approximately 20 million cubic yards of placement capacity to support both project construction and the next 50 years of maintenance dredging for the federal HSC and Barbours Cut Channels.

Project 12. Project 12 — Galveston Bay Area, Texas Modifications Study — following WRDA 2024 project authorization, Port Houston, in partnership with the Port of Galveston and Texas City, are working with the USACE on a Federal Interest Determination (FID) for appropriate project that aligns with the Building Infrastructure, Not Paperwork (BINP) initiative. The FID, when approved, will move forward the feasibility study to deepen the ship channels (up to 60 feet MLLW) and barge lanes (up to 20 feet MLLW) in the full Galveston Bay area of Texas, plus appropriate overdepth for advanced maintenance, with associated dredged material placement, disposal, and environmental mitigation. These improvements would serve to support modern containership and large liquid and bulk vessel trades. This $5-7 billion dollar estimated construction effort is expected to extend the HSC an additional 20 to 30 nautical miles into the Gulf of America, to reach equivalent navigable depths. This project requires significant dredged material management capacity focus to achieve new work and maintenance capacity requirements.

Summary. Port Houston is in the process of executing five (5) major long-term growth projects spanning the next decade-plus to expand capacity along and within the HSC. Collectively, these projects represent a substantial and coordinated multi-decade investment in navigation infrastructure, environmental stewardship, and regional economic growth.

Keywords: Port, Navigation, Resilience, Strategic, Economy.

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CHALLENGES OF CHANNEL DEEPENING CONFINED BY AGING INFRASTRUCTURE

A. Hamrick[1]

EXTENDED ABSTRACT

Ship channel deepening is a common improvement to accommodate deeper draft vessels to ports. When such modifications are made to waterways surrounded by aging or legacy infrastructure, the design becomes a complex engineering problem. Ensuring that the adjacent facilities maintain an acceptable factor of safety is the first requirement of developing a solution. Optional upgrades beyond maintaining the minimum safety criteria should also be considered to expand the wharf operational throughput and revenue potential. The following sections examine these challenges and the resulting engineering solutions within the context of the Houston Ship Channel Expansion Capital Improvement Project, Project 11, through Port Houston's Turning Basin and Manchester Terminals.

Project 11, has been in progress since 2010 when it was authorized to be studied by Congress. This project will widen the channel through Galveston Bay from 530 feet (161.54 m) to 700 feet (213.36 m) and deepen some upstream bayou reaches of the channel to various depths. Segments 5 and 6 of this project are the most upstream reaches of the Houston Ship Channel and are planned to be deepened from 37.5 feet (11.43 m) to 41.5 feet (12.65 m). These reaches of the Houton Ship Channel are surrounded by existing facilities, including two of Port Houston's eight terminals.

The Manchester and Turning Basin Terminals are general cargo facilities that trade commodities such as steel, cement, grain, and other breakbulk goods. These terminals include some of the oldest docks Port Houston owns, some nearing 100 years in age and no two share the same structural configuration. Original construction and subsequent rehabilitations were performed by different engineers under varying operational demands, resulting in a non-uniform structural inventory that increases analytical complexity.

The global stability study of these terminals was performed primarily by two engineering firms, Jacobs Engineering Group and the Joint Venture of Turner Collie & Braden, Inc. and Gahagan & Bryant Associates, Inc. Their study had two objectives: (1) to identify wharves that would have a decreased factor of safety due to the deepening of the federal channel, and (2) identify which wharves are capable of withstanding deepening of their berthing pocket without needing additional structural improvements. Utilizing historical geotechnical and structural information these firms were able to calculate the factor of safety under three loading conditions: undrained, drained, and fully softened soil strength. The study concluded that two wharves, City Docks 9 and 16, would not maintain an acceptable factor of safety once the federal channel was deepened, while two wharves, City Dock 17 and Manchester 3, could undergo berth pocket deepening without any retrofitting to the structure.

Concurrently to the global stability study, Port Houston conducted an economic analysis to determine where optional improvements would yield the greatest operational and financial benefit. Cargo volumes,

[1] Houston Ship Channel Project Manager 2, Port Houston, 2960 Riverby Road, Houston, Texas 77020, USA, T: 713-670-2438, Email: AHamrick@PortHouston.com.

vessel calls, and revenue generation were evaluated to identify the docks with the highest return on investment directly from berth pocket deepening. Short-listed wharves were advanced to a 10% design level to estimate improvement costs, which ranged from $3.3 million to $12 million. Based on these findings, two wharves, City Docks 9 and 32, were identified to have a promising economic advantage with a deeper berth pocket; however, the improvements required for retrofitting proved to be very complicated and costly which eliminated any further efforts to upgrade these wharves. City Docks 3, 16/17, and 20/21 were selected for additional retrofits to accommodate Project 11 depths.

To address the stability deficiencies at City Docks 9 and 16, drilled piers will be installed to penetrate the slip-plane failure surface. Pier size and spacing vary between the two docks due to differing geotechnical and structural conditions. Due to the existing conditions of City Dock 16 and the decision to accommodate berth pocket deepening, repairs to the existing sheet-pile bulkhead and installation of a new bulkhead are required. City Dock 3 will have a toe wall installed, which is being self-performed by the tenant. City Docks 20/21 were already approaching a condition that risked operational unavailability; their retrofit includes a full replacement of the bulkhead and fender system designed to accommodate the new berth pocket depth.

Dredging of Segments 5 and 6 is anticipated to begin in April 2028, with full Project 11 completion expected in 2029. All wharf improvements remain on schedule for completion within the next year, well ahead of dredging activities. The deepening of Segments 5 and 6 required balancing complex geotechnical, structural, operational, and economic constraints to protect and enhance the Turning Basin and Manchester Terminals. The global stability study provided a clear framework for identifying structural vulnerabilities and opportunities for operational gains. The resulting retrofit program—ranging from targeted drilled-pier installations to full bulkhead replacements—demonstrates a tailored, data-driven approach that integrates safety, performance, and financial strategy within the broader Project 11 schedule.

Keywords: Dredging, global stability, breakbulk cargo, wharf design, economic analysis.

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BAYESIAN EXPLORATORY DATA ANALYSIS TOOL FOR A SYSTEMATIC MULTI-VARIABLE ANALYSIS FOR SEA TURTLE TAKES DURING DREDGING OPERATIONS

A.D. Godfrey[1], B. Emery[2], M. Asborno[3], E. Mendez[4], and L. Huston[5]

ABSTRACT

The US Army Corps of Engineers South Atlantic Division (SAD) dredges over 50 MCY of sediment from federal navigation channels annually. Coastal dredging within SAD is often performed using hopper dredges. While hopper dredges are often the most effective type of dredge for maintaining safe navigation in open-water entrance channels, it is also a known cause of mortality to sea turtles listed under the Endangered Species Act (ESA). These mortalities, referred to as "Takes," are authorized by the National Marine Fisheries Service (NMFS) under an Incidental Take Statement for USACE dredging projects. Since the risk to sea turtles from hopper dredging in the southeast was first identified in the 1980's, USACE has developed and implemented engineering and operational controls to minimize the risk to sea turtles and other affected species.

Though anecdotal information exists regarding when and where turtle interactions with dredges occur, no definitive driver has been identified. Seasonal restrictions, intended to limit dredging during periods of higher turtle presence, create scheduling constraints for both USACE and the dredging industry, limiting USACE's ability to deliver the navigation mission while providing an unknown and possibly only marginal reduction in turtle takes. Other environmental and operational parameters may influence turtle interactions. To better understand these interactions, the Engineer Research and Development Center (ERDC) and SAD aim to examine the key drivers using a multi-variable analysis of records derived from existing operational and environmental datasets.

This paper reviews historic take records in combination with environmental variables to identify correlations during dredging operations. A new interactive Bayesian Exploratory Data Analysis (EDA) tool has been developed to quantify risk and uncertainty of turtle takes based on these variables.

The EDA tool generates charts depicting the probability of turtle take during dredging for the variable displayed, along with the accompanying histogram showing total occurrences of dredging (daily record) compared to occurrence of take. The outputs shown in this paper are phase one proof-of-concept for this tool.

Keywords: Environmental Dredging Windows, Hopper Dredges, Sea Turtle Takes, Endangered Species, Dredging Operations

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[1] Research Civil Engineer, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, T: 912-805-9033, Email: anna.d.godfrey@usace.army.mil
[2] Research Civil Engineer, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, T: 601-842-4632, Email: benjamin.e.emery@usace.army.mil
[3] Research Civil Engineer, Applied Research Associates, 119 Monument Pl, Vicksburg, MS 39180, USA, t: 601-634-2010, Email: magdalena.asborno@usace.army.mil.
[4] Research Physical Scientist, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, Email: enrique.mendez@usace.army.mil
[5] Research Computer Scientist, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, Email: logan.huston@usace.army.mil

INTRODUCTION

The South Atlantic Division (SAD) hosted a series of meetings in February and March 2024 with species experts to discuss the state of the science related to Endangered Species Act (ESA)-listed sea turtles, sturgeon, North Atlantic right whales, and species protected by the National Marine Fisheries Service (NMFS) under the Magnuson Stevens Act. One outcome was a defined list of variables that sea turtle experts from the National Oceanic and Atmospheric Administration (NOAA), NMFS, Georgia Environmental Protection Department (GAEPD), and South Carolina Department of Natural Resources (SCDNR) believed could be correlated to the probability of lethal take of sea turtles from hopper dredging (environmental, behavioral, dredging-operational related, etc.). The Engineer Research and Development Center (ERDC) explored and combined datasets owned by the U.S. Army Corps of Engineers (USACE) with datasets owned by state and federal agencies that contained these and additional potentially relevant variables to determine correlations. This initial effort is limited to a statistical analysis of the available data. It is not intended to include sea turtle behavior or to understand why any statistically significant correlations may exist. Those efforts may be addressed in the future and potentially in partnership with other agencies to leverage expertise.

The USACE navigation mission provides safe, reliable, efficient, and environmentally sustainable waterway transportation systems for movement of commerce, national security needs, and recreation. To achieve this mission, SAD routinely dredges over 50 MCY (USACE Continuing Analysis) of sediment from these waterways annually. The majority of the coastal dredging within SAD is performed using hopper dredges. These vessels excavate material hydraulically and transport it to a placement site in a hopper built into the hull of the vessel (Emery 2024). The sediment is obtained by dragging an intake "draghead" through the bottom sediment and pumping a mixture of sediment and water ("slurry") through the "drag arm" into the hopper portion of the vessel. While other types of dredges are available, hopper dredges are well suited for deep-draft open-water and high-traffic channels, due to their ability to operate continuously, under a wide range of environmental conditions, and their flexibility to move while dredging.

All hopper dredging in SAD along the Atlantic coast is performed under the NMFS South Atlantic Biological Opinion (SARBO), issued to USACE SAD and the Bureau of Ocean and Energy Management in March 2020. The SARBO analyzed the effects of dredging and dredging related activities to ESA-listed species under NMFS jurisdiction from the North Carolina/Virginia border south through the Florida Keys and in the US Virgin Islands and Puerto Rico. An Incidental Take Statement (ITS) is included, providing a limit of the number of lethal and non-lethal "take" covered under SARBO. The analysis in the 2020 SARBO considered the authorized lethal take from hopper dredging in combination of any other potential take of sea turtles from other activities that may occur in the area and determined sea turtle populations would still be able to survive and retain the ability to recover despite the authorized take. NMFS has completed similar consultations for dredging for other projects and in other areas. If a project exceeds the ITS defined in an ESA consultation, then work must cease and reinitiation of consultation is required to consider the effects of additional take.

Through the years, USACE has proven its ability to manage projects to avoid exceeding take and continues to strive to reduce take based on lessons learned and best available information. However, measures implemented to reduce take have also resulted in increased costs, delays, and for some projects, the inability to be dredged to completion. Without dredging, navigable waterways may become restricted to limited vessel drafts, causing cascading delays and increased costs in supply chain transportation, commerce, and military deployments. In addition, sea turtle take persists despite risk minimization measures. This paper considers numerous variables that may be associated with historic take. The outcome may inform if existing risk minimization measures, such as seasonal restrictions, are effective at reducing the potential for take or if other variables should be considered to reduce the risk of take.

Since the risk to sea turtles from dredging was first identified in the 1980's, a suite of risk minimization measures has been developed, tested, and implemented by USACE. Some of the measures include the implementation of seasonal restrictions, variations of a draghead deflector (Figure 1) intended to prevent entrainment, relocation trawling prior to dredging to decrease the density of turtles in the area during active dredging, and more. Monitoring efforts to quantify take were also implemented including screening on hopper dredges to account for observed take, NMFS-approved Protected Species Observers to monitor take, and equipment for USACE to monitor the operation of dredges for compliance. The effectiveness of these take risk minimization measures is solely determined by whether or not the dredges continue to take turtles. Many of these methods were applied at the same time and have been subject to continuous refinement and development by USACE, SAD, and ERDC over the last 45 years. Yet, the understanding of the specific variables that increase the probability of sea turtle take is still not fully understood, hence the need for and importance of this work.

For example, draghead deflectors have been used and tested by USACE. "NMFS has included the rigid deflector draghead design as part of the reasonable and prudent dredging alternative in the Biological Opinions for dredging projects throughout the southeastern United States since 1993" (Dickerson 2004). These draghead deflectors are designed to create a sediment wave directly in front of the draghead and push the turtles away from the draghead during dredging operations. USACE also requires contractors to maintain the draghead in contact with the bottom at all times during active pumping and turn pumps off when the draghead is in the water column to minimize the risk of entrainment to sea turtles and other marine species. However, the draghead deflectors slow production resulting in longer dredging time thus increasing exposure to species and operational costs.

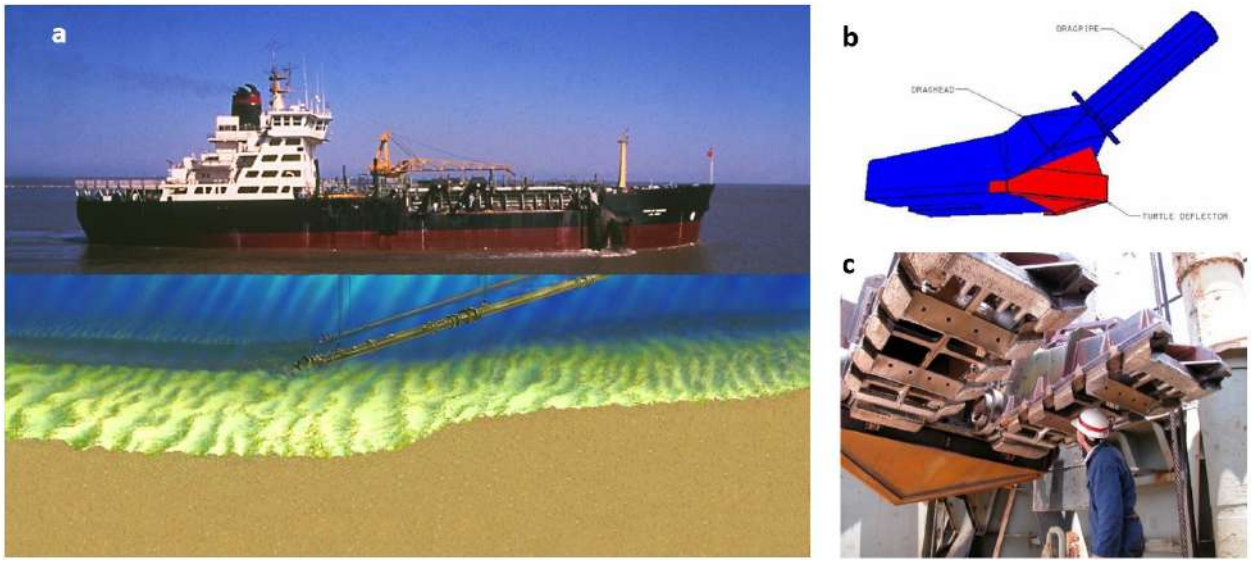

Figure 1. a) Hopper dredge with drag arm; b) Turtle Excluder Device (TED) schema; c) TED on draghead.

Seasonal restrictions were enacted to limit dredging to colder seasons when fewer sea turtles seem to be present. While a logical approach at the time, it did not account for sea turtle behavior and mobility during colder temperatures. This also limits the time when hopper dredging can be performed resulting in projects competing for available hopper dredges, driving up cost, and resulting in some projects not being started or completed when needed.

Despite these measures, interactions with turtles persist. Figure 2, below, shows the number of turtle takes during dredging operations versus active hopper pumping hours across the USACE enterprise. USACE

has and will continue to strive for improvements of species protection and meeting mission requirements. However, it should also be noted that USACE hopper dredging through the entire country still results in less than 1% of all sea turtle mortalities reported to the NMFS stranding network. According to the NMFS Stranding Network, approximately 3,900 sea turtles are reported dead each year when considering a combination of all sea turtle species (NOAA Fisheries n.d.). For comparison, ODESS records indicate USACE dredging results in an annual average of 33 lethal takes of sea turtles nationally including all species reported combined (green, Kemp's ridley, leatherback, loggerhead). For loggerhead sea turtles, USACE hopper dredging results in only 14 lethal takes per year nationally.

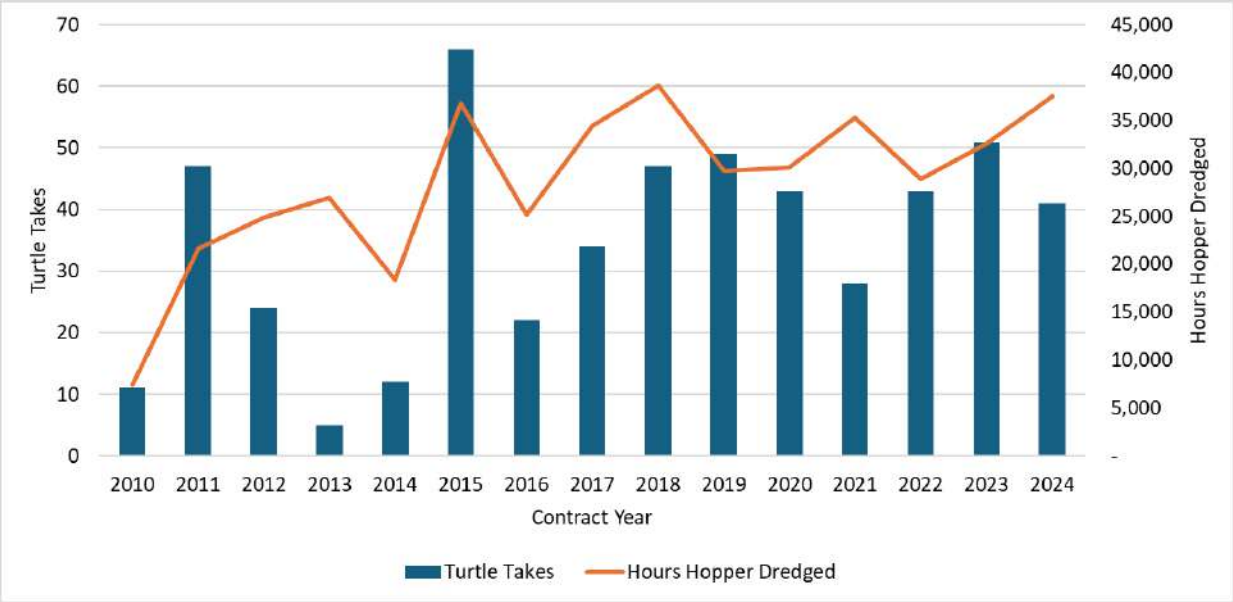

Figure 2. Turtle takes during dredging operations and active hopper pumping hours per year across the USACE portfolio.

Though anecdotal information exists on when and where turtle interactions with dredges occur, there has not been a definitive driver identified. Seasonal restrictions create scheduling pinch points for USACE and the Dredge Industry, limiting USACE's ability to achieve the navigation mission. Although seasonal restrictions are intended to reduce turtle take by restricting dredging during periods of higher sea turtle presence, they have not been proven to actually reduce numbers of turtle takes. Apart from seasonality, other environmental and operational parameters may be linked to turtle takes. In this context, ERDC and SAD aim to examine the main drivers of these interactions through a multi-variable analysis containing a litany of variables derived from existing operational and environmental datasets.

The outputs shown in this paper are the first phase proof-of-concept for this tool. USACE ERDC is continuing to input additional data points and refining the outputs. The second phase will also include analysis from turtle experts. An in-depth technical report explaining the methodology and EDA tool development with a more complete set of variable outputs is set to be published later in 2026.

STUDY APPROACH

USACE hosted a state of the science meeting in Charleston, South Carolina on July 31, 2024. The "sea turtle breakout group", comprised by experts from USACE and State/Federal regulatory agencies, at this meeting developed a list of variables that they recommended be considered when evaluating the risk of take of sea turtles from hopper dredging. The group acknowledged that data formatting challenges are inherent in this effort and understood that some details collected by USACE are proprietary and cannot be shared

publicly. ERDC has incorporated the recommended variables in this effort to the degree that they were available in the given datasets.

Recommendations were also made to use the variables to calculate and report the items listed below. This effort focused solely on collecting and reporting data. Future efforts may focus on these and other analysis.

Analysis and Reporting Requests:

- Zone (Spatial)
- Catch per unit effort (CPUE) that includes effort (e.g., pump hours, number of drag heads, drag head type/configuration) with no catch/take
- Turtle population and density

Available data covering the period between 10/09/2014 and 12/09/2024 was sought and obtained to identify correlations between sea turtle takes interactions during USACE dredging operations. This included both USACE owned data from Dredging Quality Management (DQM) (USACE n.d. -a), Resident Management System (RMS) (USACE n.d. -d), and Operations and Dredging Endangered Species System (ODESS) (USACE n.d. -b), which provide insight to historic dredging operations and turtle takes along with State and Federal Agency maintained datasets to collect environmental variables. These sets were linked through time and location markers. Stakeholder input from State and Federal Resource agencies was sought on the model and datasets being used.

RMS records are recorded on a daily basis and are not broken out by time of day; thus all take data is assessed on a per-day basis rather than at finer temporal intervals. Further, while each take has location specific information (latitude/longitude), it is tied to a specific dredging load rather than a precise point in time. The location reported for a turtle take is the centroid of the entire area where dredging occurred in that load.

Merging Datasets

geoRMS

The RMS and DQM datasets were integrated into a unified dataset to overcome the lack of geospatial reference that indicates where dredging occurred in each of the daily RMS records. The merge was based on the date of the report and standardized dredge plant name. The location where the dredge was operating was linked to the National Channel Framework (NCF) reach (USACE n.d. -c). The resulting RMS-DQM merge is referred to as “geoRMS”.

Merging NOAA and geoRMS

To integrate environmental data from NOAA with the geo-enriched dredging operational data, spatial relationships between NOAA monitoring stations and NCF reach centroids were established using geographic coordinates. For each geoRMS record, the closest NOAA gauge station is identified by computing the haversine distance between latitude-longitude coordinates. In cases where multiple NCF reaches are associated with a single RMS record, it is assumed that all reaches for a given reporting data are spatially proximate; therefore, the closest gauge is determined based on representative coordinates. A single location is then assigned to each geoRMS record using the first NCF reach in the associated list.

NOAA observations, which may be recorded at sub-hourly intervals (e.g., minute-level frequency), were temporally aggregated to align with the daily resolution of the geoRMS dataset. This aggregation was performed by computing the daily mean and standard deviation for each parameter, producing “daily averaged” quantities suitable for downstream analysis.

Preliminary analysis identified Daily Averaged Water Level as a key predictor of turtle takes. Because water level measurements are referenced to location specific Mean Lower Low Water (MLLW), daily averaging removes intra-day tidal variability while retaining both the mean water level and the influence of local tidal amplitude. To better capture tidal dynamics and non-tidal variability, additional features were derived, including tidal amplitude and the daily average rate of change in the water level ($\Delta H/\Delta T$). These features collectively represent both periodic tidal fluctuations and longer term environmental changes not constrained to a 24-hour cycle. The resulting daily aggregated NOAA variables were subsequently merged with the geoRMS dataset, producing a combined geoRMS-NOAA dataset for analysis.

Exploratory Data Analysis Tool

With these datasets, ERDC has developed an interactive Bayesian Exploratory Data Analysis (EDA) tool that quantifies sea turtle take risk from the dredging records and numerous variables available including those related to environmental site conditions, project details, and more (Emery 2026). The results show the probability of turtle takes during dredging events in relation to a multitude of independent variables. The tool performs simple preprocessing and utilizes a Graphical User Interface (GUI) for data exploration and analysis of importance of multiple variables derived via mutual information, seen in Figure 3 below. The tool is faster and easier to understand than searching through pre-generated images.

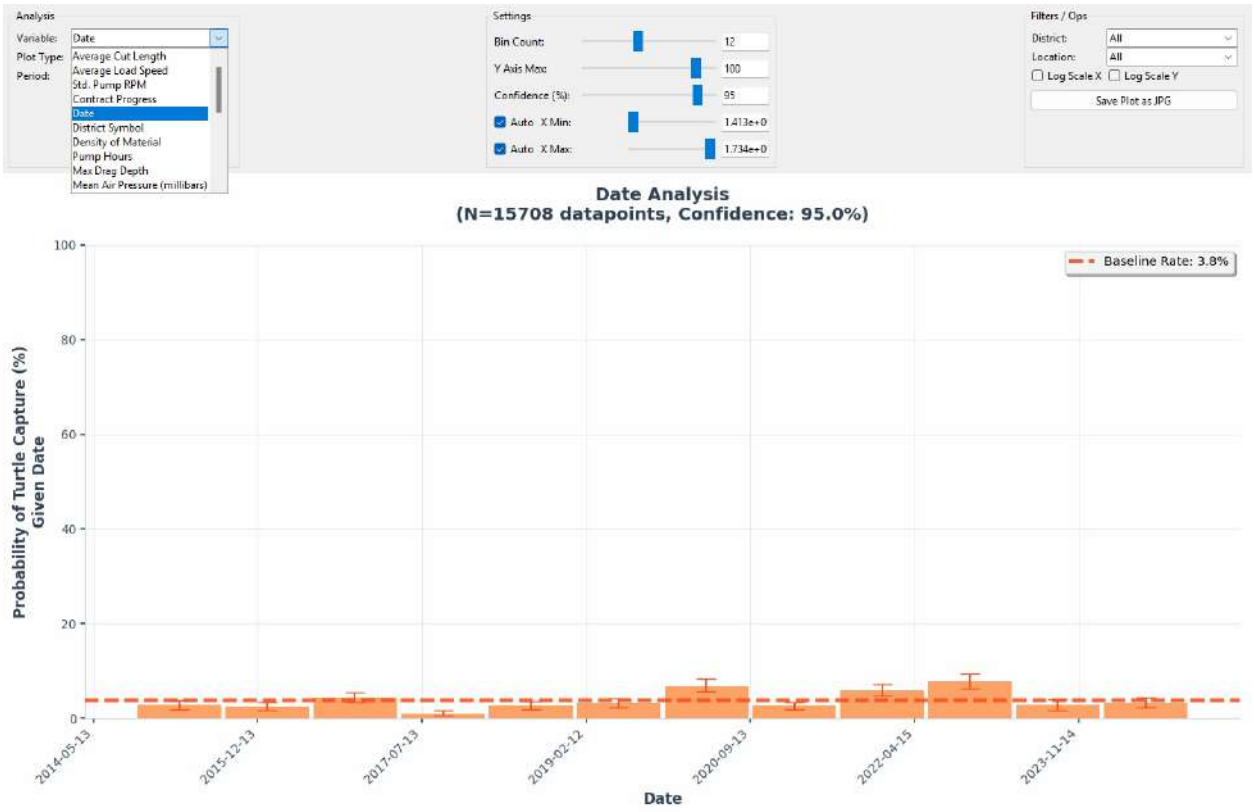

Figure 3. Graphical User Interface of EDA tool.

The EDA tool enables the user to bin, post select, and calculate uncertainty for the data in real time. It provides three types of plots: (i) the probability of a take and uncertainty in the probability given the data; (ii) the probability distribution for hours per take and uncertainty in that estimate given the data; and (iii) the histogram of the data. These do not include uncertainty estimates, since they represent realized frequencies rather than inferred underlying rates. The tool accommodates multiple variables, displayed along the horizontal axis, and provides flexible binning strategies. Data may be binned either linearly across

the variable range or by quantiles, i.e., percentages of the data. Quantile-based binning automatically adjust each bin to have the same amount of data to yield more precision in the y estimate at the cost of uncertainty in the x estimate. This reflects the inherent tradeoff in binning between resolution in predictor space and statistical confidence in response estimates.

Uncertainty is quantified in credible intervals, parameterized by a user-defined confidence level representing the posterior probability that the true parameter lies within the specified interval. Both the confidence level and plotting bounds are user adjustable. Additionally, logarithmic scaling options are available to enhance visualization of variability across orders of magnitude.

The tool supports both categorical and continuous variables and allows filtering by spatial attributes such as district and location. For temporal analyses, a time-wrapping feature is implemented to facilitate examination of periodic patterns across multiple timescales (e.g., annual, lunar, or weekly cycles). This functionality enables rapid assessment of potential temporal dependencies. Preliminary analyses indicate that observed patterns are not artifacts of binning, filtering, or temporal transformations.

FINDINGS

Mutual Information

The normalized mutual information chart below (Figure 4) shows the percentage of data that can be explained by an individual variable. For example, approximately 36% of the data (take or no take) can be predicted if *only* Tide Amplitude is known ahead of time. Likewise, knowing 'District Symbol' only can be used to predict approximately 5% of the data. The chart's error bars indicate the range of correlation values for each interval, based on a 95% confidence level. The mutual information rank is to be considered together with the error bars.

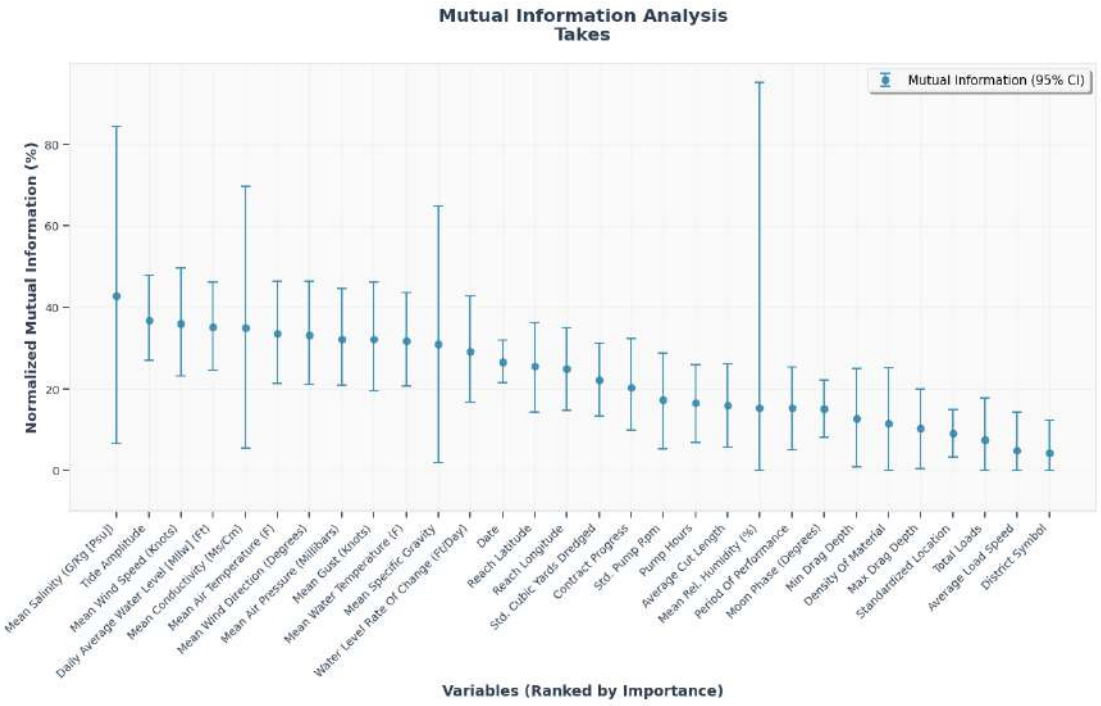

Figure 4. Normalized mutual information as a measure of importance.

Confidence intervals are represented by the error bars. Due to the use of estimators to approximate mutual information, imperfections may arise. The confidence intervals represent the range within which the true

value is expected to lie 95% of the time, assuming all dredging events from 2014 to the present were replicated.

Tool-Derived Take Probability and Histogram Charts by Variable

The charts presented below were derived using the EDA tool and depict the probability (with 95% confidence/credibility) of taking a turtle during dredging operations regarding the individual variable shown, along with an accompanying histogram showing total occurrences of dredging (in days) as compared to occurrence of take.

Each probability chart shows a baseline rate representing the average probability of take given the reported value for the variable evaluated. This explains the variability observed between plots. Therefore, the baseline rate effectively represents the null hypothesis, indicating the probability of an outcome assuming a constant or no relationship to the parameter. Included in the probability charts are error bars for each data bin, representing the range of values that would fall within the defined confidence level, set at 95% for this report.

An important distinction, credible intervals represent the range within which the true value has a specified probability (e.g., 95%) given the observed data. The term "credible interval" is less commonly used; therefore the authors chose to use "confidence" for clarity. True confidence intervals, for instance, refer to intervals that when the data is resampled 1,000 times, would contain the true parameter in approximately 950 of the resamplings.

Figures 5-9 show a few examples of many that may be created using the tool. As the user adjusts the confidence level, the error bars associated with each probability will also be adjusted. Similarly, if the user changes the total number of "bins", effectively changing how the data is sliced, the visual output and probabilities will be updated.

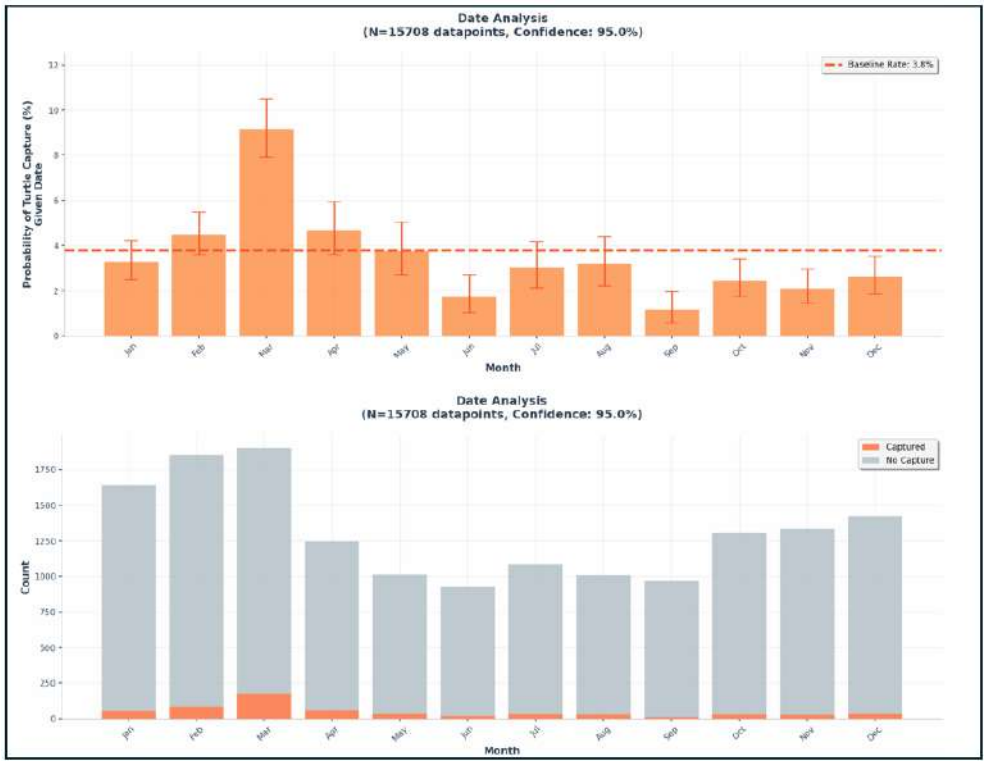

Figure 5. Example output for month v. take.

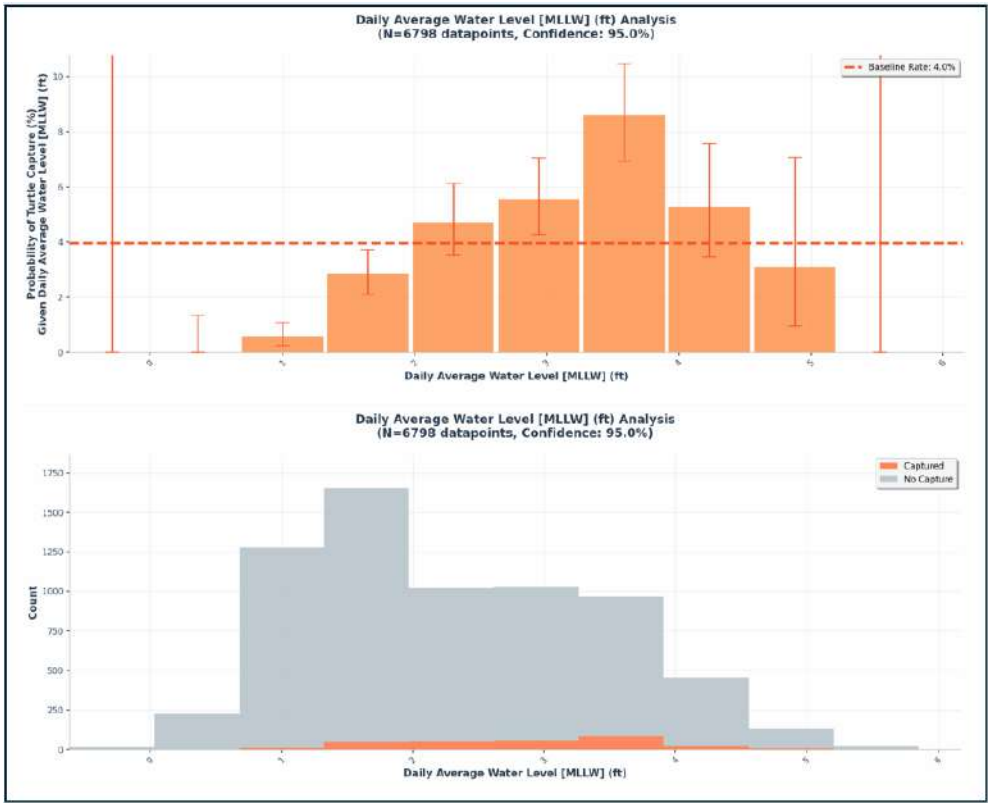

Figure 6. Example output for Daily Averaged Water Level (ft) v. take.

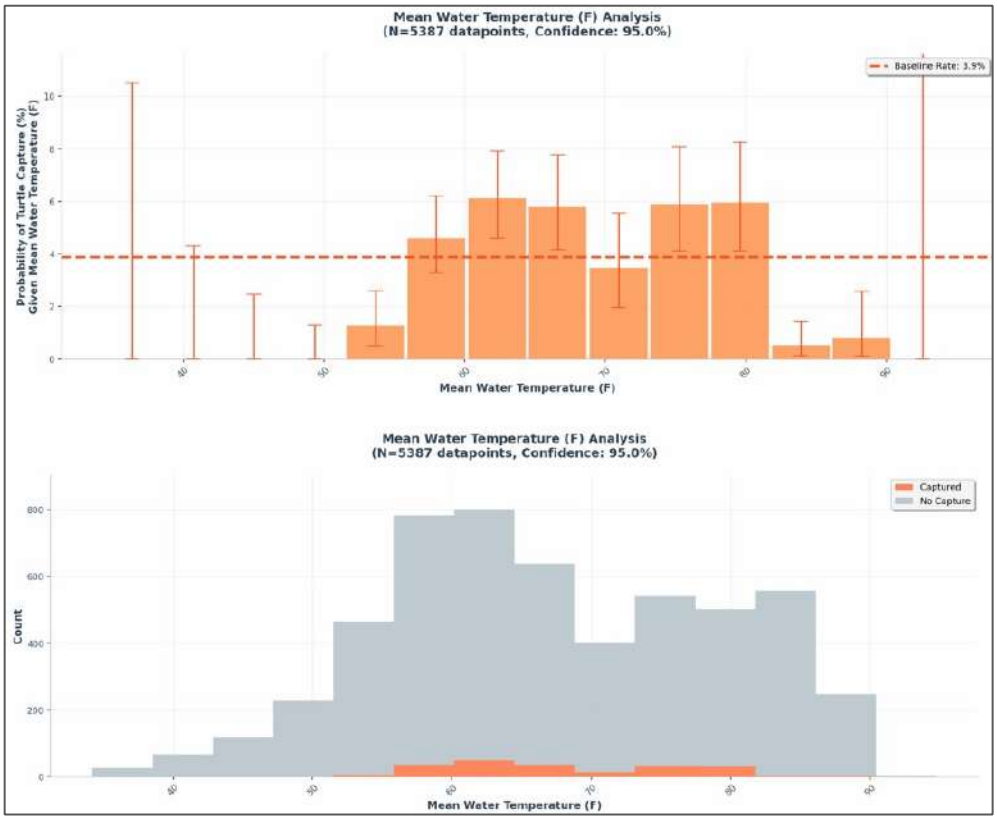

Figure 7. Example output for mean water temperature v. take.

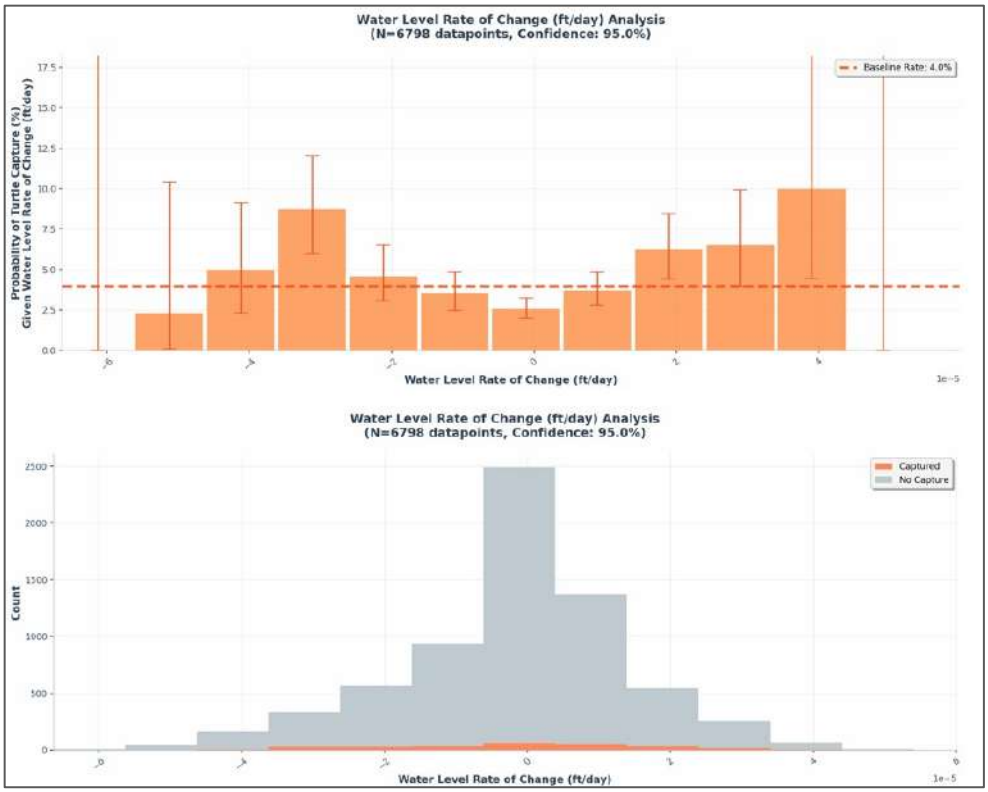

Figure 8. Example output for water level rate of change v. take.

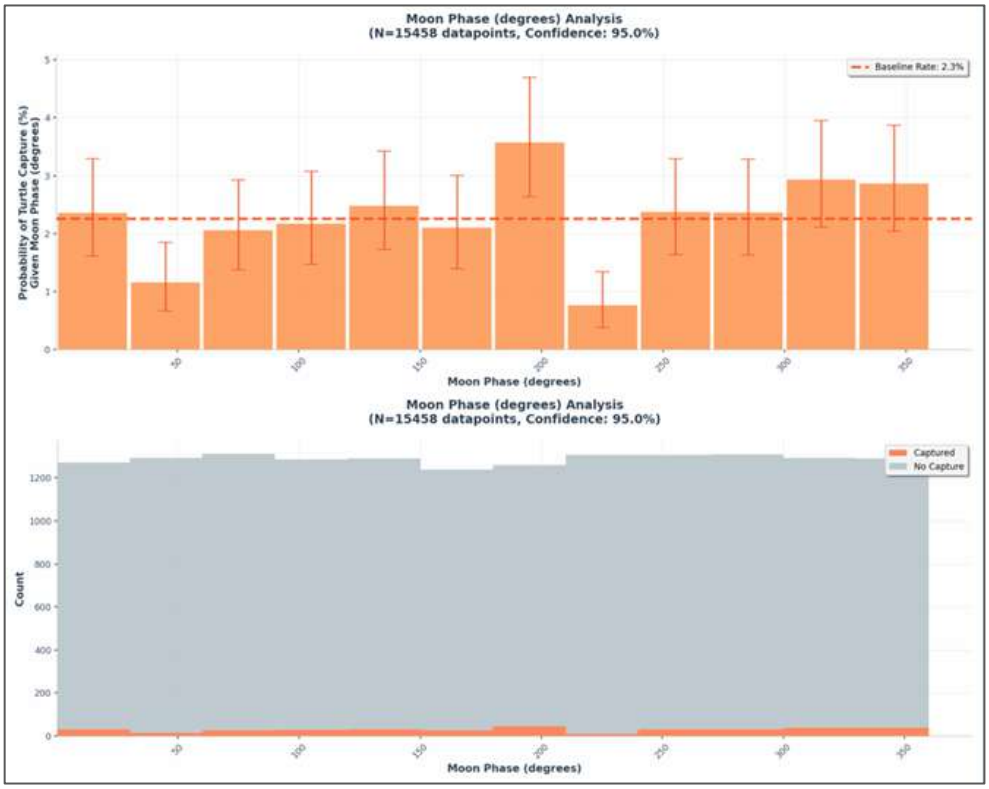

Figure 9. Example output for moon phase v. take (New Moon = 0°/360°; Full Moon = 180°). Moon phase has a relatively low mutual information percentage.

CONCLUSIONS

The resulting outputs from the developed EDA Tool presented in this paper show distinct variable trends associated with turtle takes within the South Atlantic Division. This tool can be used to find and show correlations that can be used by sea turtle experts to help understand when and where the probability of take may increase or decrease. USACE SAD aims to coordinate with sea turtle experts to analyze this data in the next phase of this research to better understand the potential causation of why sea turtles respond differently to the variables analyzed. While these results are not intended to be used to predict turtle takes in any given project, they do provide strong evidence indicating that variables other than just seasonality should be considered to minimize the risk of take. Historically, "winter" months from December to the end of March were considered the best time for hopper dredges because colder water temperatures result in a lower density of turtles present. Yet this analysis indicates that the probability of sea turtle take during hopper dredging in March is approximately twice that in the previously restricted summer months. While dredging has not occurred in many locations to confirm this correlation between month dredged and sea turtle take, the correlation does exist where dredging has occurred during the summer months.

Development of this tool to analyze variable was the first step in this effort to understand causation of turtle takes during hopper dredging operations. This tool can be applied to larger datasets and altered to provide results at varying confidence levels, apart from the 95% confidence level output shown in the paper. Due to proprietary information within the tool, dissemination will be restricted and at the discretion of SAD.

These types of models are only as strong as the data that is supplied for analysis. Additional dredging data points throughout SAD within summer months would bolster this assessment.

RECOMMENDATIONS AND FUTURE DIRECTIONS

This initial effort is limited to a statistical analysis of the available data. It is not intended to include sea turtle behavior or to understand why any statistically significant correlations may exist. Those efforts will be addressed in the next phase of research, in partnership with other agencies to leverage expertise. ERDC will continue to refine the outputs of this tool by expanding the years, variables, and regions being analyzed. The ability to work outside of historical time constraints will provide valuable data to be added to further refine the analysis.

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CITATION

Godfrey, A.D., Emery, B.E., Asborno, M., Mendez, E., and Huston, L. "Bayesian Exploratory Data Analysis Tool for A Systematic Multi-Variable Analysis for Sea Turtle Takes During Dredging Operations," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

DATA AVAILABILITY

Data, models, and code generated and used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

ACKNOWLEDGEMENTS

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EVALUATION OF NAVIGATION CHANNEL SHOALING FOR THE GREEN HARBOR NAVIGATION IMPROVEMENT PROJECT

Michael B. Kabiling[1]

ABSTRACT

The Green Harbor River in Marshfield, Massachusetts, experiences chronic shoaling within its Federal Navigation Channel (Federal Channel) as sediment enters the system from multiple sources, including long-period wave-driven bypassing around the jetties, aeolian transport from the southwest beach, and storm-driven overtopping of the East Jetty. Because the river has a limited tidal prism and weak ebb currents, it cannot effectively flush sediment seaward. As a result, the channel requires maintenance dredging approximately every 1.5 years, with an average annual dredged volume of about 20,451 cubic yards (15,635 m³). To reduce long-term dredging frequency and associated costs, the U.S. Army Corps of Engineers (USACE) New England District (NAE) is evaluating a sediment-reduction alternatives study that includes constructing a sediment settling basin, raising the East Jetty crest elevation, and extending the East Jetty seaward. The study also evaluates a No Action scenario to establish a baseline against which the effectiveness of the proposed shoaling-reduction alternatives can be compared. To support this evaluation, Taylor Engineering developed and validated an integrated two-dimensional numerical modeling framework using the MIKE21 Flexible Mesh (FM) Version 2025 system. The framework couples hydrodynamic, spectral wave, and sediment transport and morphology models to simulate physical processes. The model applies user-defined, time-varying hydraulic gate operations at Dyke Road, while Massachusetts Bay tidal forcing and free outflow at the Cape Cod Canal define the downstream boundaries. The spectral wave model incorporates hindcast wave conditions from the USACE Wave Information Study and applies standard wave-breaking and bottom-roughness parameters appropriate for the regional coastal environment. The hydrodynamic model reproduced field-measured water levels near the Anchorage in the Green Harbor River with excellent agreement during both the hydrodynamic model calibration and verification, confirming its ability to simulate tidal dynamics accurately. The sediment transport model, driven by the hydrodynamic and wave model outputs, reproduced observed 2023 shoaling patterns and captured approximately 77% of the measured sediment deposition during calibration. Average-year hydrodynamic and wave forcing model verification results closely matched historical maintenance dredging records, accurately predicting 91% to 93% of the average annual dredged volumes. Model results indicate that the middle and lower reaches of the Green Harbor River experience the greatest shoaling and collectively account for approximately 57% of total sediment deposition within the Federal Channel. Based on its strong calibration and verification performance, the paper considers the modeling framework reliable for evaluating sediment management alternatives and for assessing modified dredging strategies, including partial dredging approaches.

Keywords: tidal inlet morphodynamics, navigation channel shoaling, shoaling reduction, integrated sediment transport modeling, wave–current–sediment coupling, maintenance dredging, jetty-sediment interactions.

[1] Senior Coastal and Water Resources Engineer, Taylor Engineering, Inc., 10199 Southside Blvd., Suite 310, Jacksonville, FL 32256, USA, T: 904-256-1340, Email: mkabiling@taylorengineering.com.

INTRODUCTION

Navigation channels located at tidal inlets rank among the most morphodynamically active environments in coastal engineering practice. Tidal forcing, wave-driven currents, wind setup within the harbor from persistent directional wind, and longshore sediment transport act together and continuously interact with engineered features such as jetties, revetments, and dredged channels. The Green Harbor River Federal Navigation Channel (Federal Channel) in Marshfield, Massachusetts (see Figure 1), exemplifies these challenges. Since its initial construction in 1968, the channel has experienced persistent shoaling, requiring frequent maintenance dredging and repeated rehabilitation of the inlet jetties. Despite decades of engineering intervention, sediment deposition continues to impair navigation and has prompted renewed evaluation of sediment management strategies.

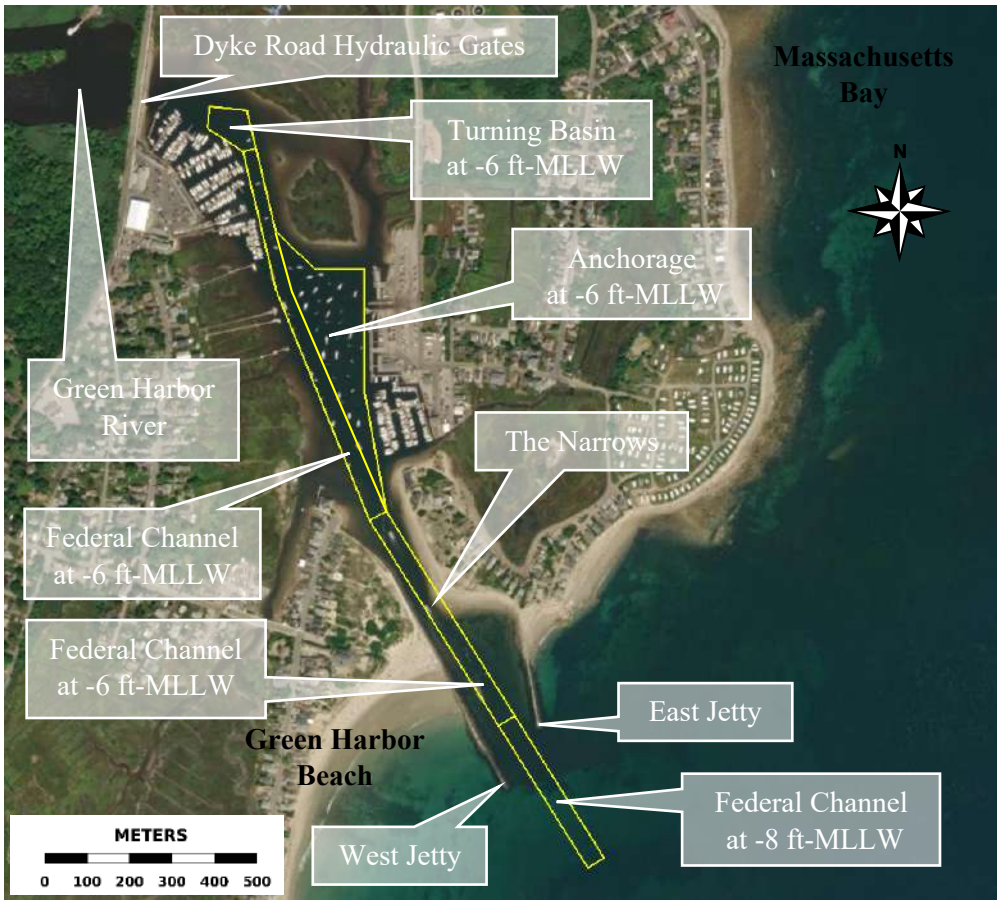

Figure 1. Location of the study's area of interest, the Federal Channel, and maintenance dredging template.

The Green Harbor River discharges into Massachusetts Bay along a wave-exposed stretch of coastline approximately 30 miles (48.3 km) southeast of Boston, and roughly midway between Boston Harbor and the Cape Cod Canal. East and West stone jetties stabilize the inlet and define a narrow entrance channel that leads into an interior harbor system. The region experiences semi-diurnal astronomical tides with mean tidal ranges of approximately 9 ft (2.7 m). However, the limited size of the harbor basin results in a relatively small tidal prism within the Green Harbor River. Consequently, tidal currents alone cannot effectively flush sediment back offshore once it enters the inlet. Instead, sediment transported into the system settles in

low-velocity areas within the entrance channel, turning basin, and anchorage, where it accumulates and contributes to ongoing shoaling.

Multiple sediment sources supply material to the inlet, including wave-driven longshore transport along the adjacent shoreline, sediment bypassing around the seaward ends of the jetties, wave overtopping of the East Jetty during storm events, aeolian transport from the southwest beach, and wave reflection from the interior face of the West Jetty. Once sediment enters the inlet, flow expansion and energy dissipation reduce transport capacity and promote deposition, which leads to shoal formation within the Federal Channel and adjacent harbor areas. These processes have persisted despite structural modifications and repeated maintenance dredging, indicating that the inlet functions as a net sediment sink.

The State of Massachusetts initially constructed the Green Harbor Jetties around 1898. The Federal Government later adopted and authorized the Green Harbor as a Federal Navigation Project on December 15, 1965. During construction, dredging of the 8-ft (2.4-m) entrance channel, 6-ft (1.8-m) interior channel, turning basin, and anchorage removed approximately 140,200 cubic yards (107,190 m^3) of material (see Figure 1). At the same time, engineers raised and extended the West Jetty to a crest elevation of +12 ft (+3.7 m) mean low water (MLW) and connected it to the shoreline with a gravel dike, while they rebuilt and raised the East Jetty to +14 ft (+4.3 m) MLW between 1968 and 1969. These improvements sought to stabilize the inlet and reduce shoaling; however, sedimentation resumed shortly after construction and required continued maintenance.

Between 1969 and 2024, the U.S. Army Corps of Engineers (USACE) New England District (NAE) conducted 37 documented maintenance dredging events within the Federal Channel. Approximately 46% of these events addressed only the 8-ft (2.4-m) entrance channel, another 46% included both the entrance and interior channel reaches, and the remaining 8% included dredging in other harbor areas. Over this period, the average dredging interval equaled approximately 1.5 years, with an average dredged volume of 30,881 cubic yards (23,610 m^3) per event. These values correspond to an average long-term sedimentation rate of approximately 20,451 cubic yards (15,635 m^3) per year.

The dredging events have historically placed dredged material at nearshore disposal areas along Green Harbor Beach or at offshore disposal sites in Cape Cod Bay. Although nearshore placement provides some beach nourishment benefits, it has not measurably reduced sediment accumulation within the navigation channel. Offshore placement removes sediment from the littoral system but does not change the mechanisms that transport sediment into the inlet. As a result, dredging has primarily served as a reactive maintenance measure rather than a long-term solution to sedimentation.

In addition to dredging, the NAE has repeatedly maintained and rehabilitated both inlet jetties. Between 1968 and 2018, six major jetty improvement projects reset displaced armor stone, placed new armor units, constructed revetments to tie the jetties to the shoreline, installed a sheet-pile sand barrier within the East Jetty, and repaired storm damage from major winter storms and nor’easters. Despite these efforts, wave overtopping and sediment bypassing continue to occur, particularly during energetic storm conditions.

Given the persistent nature of shoaling and the increasing cost and frequency of dredging, the NAE initiated a numerical modeling study to evaluate alternatives designed to reduce sediment deposition within the Federal Channel. The present phase of the study evaluated a No Action alternative, which assumed no new settling basin and no further jetty improvements, to establish baseline conditions against which the performance of sediment-reduction measures could be assessed.

Applied numerical modeling was used to characterize shoaling patterns and sediment volume distribution within the Federal Channel. This paper describes the data collection, model development, and model validation processes used to support this effort. Field measurements and compiled datasets provided the input data for model development, calibration, validation, and model boundary conditions used to evaluate channel shoaling.

DATA COLLECTION AND ANALYSIS

The numerical modeling effort relied on comprehensive datasets that describe tides, winds, waves, topography, bathymetry, land cover, and sediment characteristics. The study area extended across Massachusetts Bay, Cape Cod Bay, Plymouth Bay, Duxbury Bay, Kingston Bay, the Green Harbor River, and portions of the Cape Cod Canal, reflecting the regional scale of processes that influence sediment transport at the inlet.

Tide Data

The data collection compiled tidal data from multiple National Oceanic and Atmospheric Administration (NOAA) tide stations located near the study area, including Brant Rock, Duxbury, Plymouth, Scituate, Sagamore, Sandwich, Provincetown, and Boston (see Figure 2). These data show that the region experiences semi-diurnal astronomical tides, with mean tidal ranges varying from approximately 7.9 ft (2.4 m) to 9.9 ft (3.0 m). At Brant Rock, near the mouth of the Green Harbor River, the mean tidal range equals approximately 9.1 ft (2.8 m). The data processing referenced tidal datums to the North American Vertical Datum of 1988 (NAVD88) using NOAA VDatum software (https://www.vdatum.noaa.gov/vdatumweb/) where necessary.

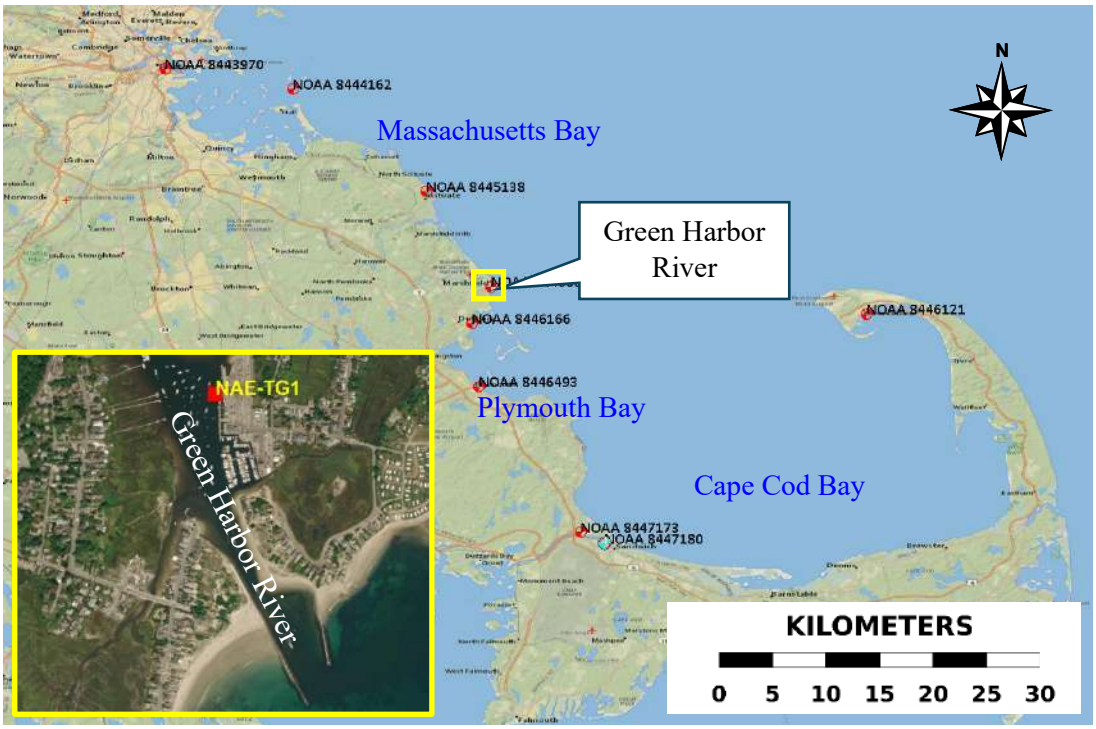

Figure 2. Locations of NOAA tide stations and NAE water level measurement station (NAE-TG1).

NAE Field Measurement of Inshore Tide Level

To support hydrodynamic model calibration and verification, the NAE deployed a temporary water level gauge (NAE-TG1 in Figure 2 inset) within the Green Harbor River from June 20 to July 25, 2024. The gauge recorded water levels at five-minute intervals and provided high-resolution data for evaluating model performance. Comparisons between measured water levels and predicted astronomical tides from the Brant Rock NOAA 8446009 station showed close agreement, with minor deviations caused by wind setup and other meteorological effects. The model development explicitly accounted for these non-tidal components during model calibration.

Wind Data

The data collection obtained wind data from Marshfield Municipal Airport, located approximately 2 miles (3.2 km) northwest of the river mouth. Analysis of the wind record during the water-level measurement period showed that winds predominantly originated from the southwest, south-southwest, and west-southwest, consistent with regional climatology. Approximately 21% of the recorded winds fell below 1.25 miles per hour (2.0 km/hr), indicating periods of minimal wind forcing. Although wind speeds were generally moderate, wind forcing contributed to short-term water-level variability and influenced wave generation in nearshore areas.

Wave Data

The data collection and review characterized wave conditions using hindcast data from the USACE Wave Information Study (WIS) Station 63059, located approximately 16.2 miles (26.1 km) northeast of the Green Harbor River in water depths of about 226 ft (68.9 m). This station provides hourly records of significant wave height, peak wave period, and mean wave direction from 1980 through 2023. Analysis of these data indicates that dominant wave energy approaches from the east, east-southeast, and east-northeast, while the largest waves typically originate from the northeast during major storm events (see Figure 3). Extreme value analysis performed by the U.S. Army Engineer Research and Development Center (ERDC) indicates that offshore significant wave heights of approximately 16 ft (4.9 m) occur annually, while 27.5-foot (8.4-m) waves have a 1-percent annual exceedance probability (https://wisportal.erdc.dren.mil/).

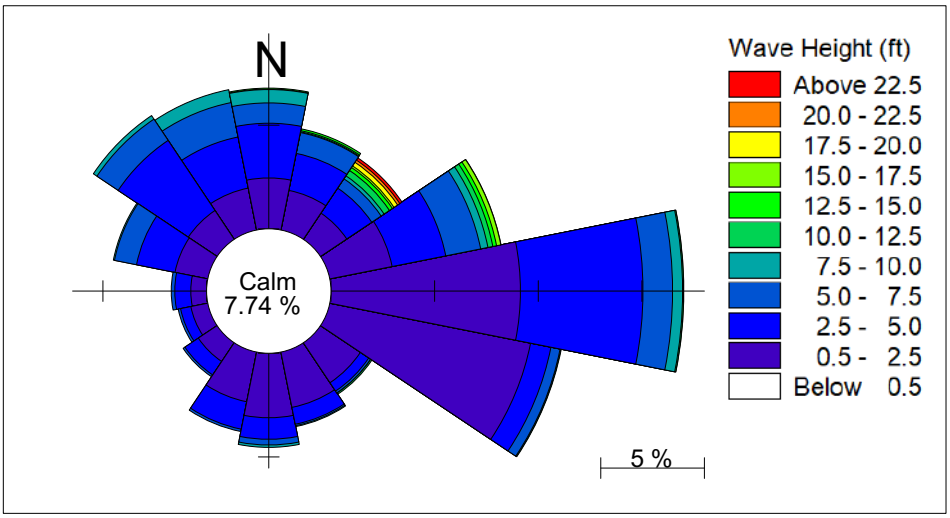

Figure 3. Hindcasted wave rose at WIS Station 63059.

Topography, Bathymetry, and Landcover Data

The data collection compiled topographic and bathymetric data from multiple sources to develop a detailed representation of the seabed and shoreline. The USACE North Atlantic Coast Comprehensive Coastal Study (NACCS) ADCIRC model (USACE 2015) mesh provided the base regional bathymetry (see Figure 4). The NAE datasets collected in 2018, provided by the USACE, supplied higher-resolution topographic and bathymetric data for nearshore and inshore areas. The data processing supplemented these datasets with NAE-supplied Green Harbor River bathymetric surveys conducted in March 2023, October 2023, February 2024, April 2024, and June 2024 (see Figure 5). The data processing converted all datasets to a common horizontal datum (North American Datum of 1983 [NAD83] State Plane Massachusetts) and vertical datum (NAVD88) and merged them into a consistent digital elevation model for numerical modeling.

The data processing used land cover classifications from the 2021 National Land Cover Database (https://www.usgs.gov/data/national-land-cover-database-nlcd-2021-products) to assign spatially varying Manning's n values in the hydrodynamic model. The data processing adjusted these values within the Green Harbor River and nearshore areas to reflect local hydraulic conditions.

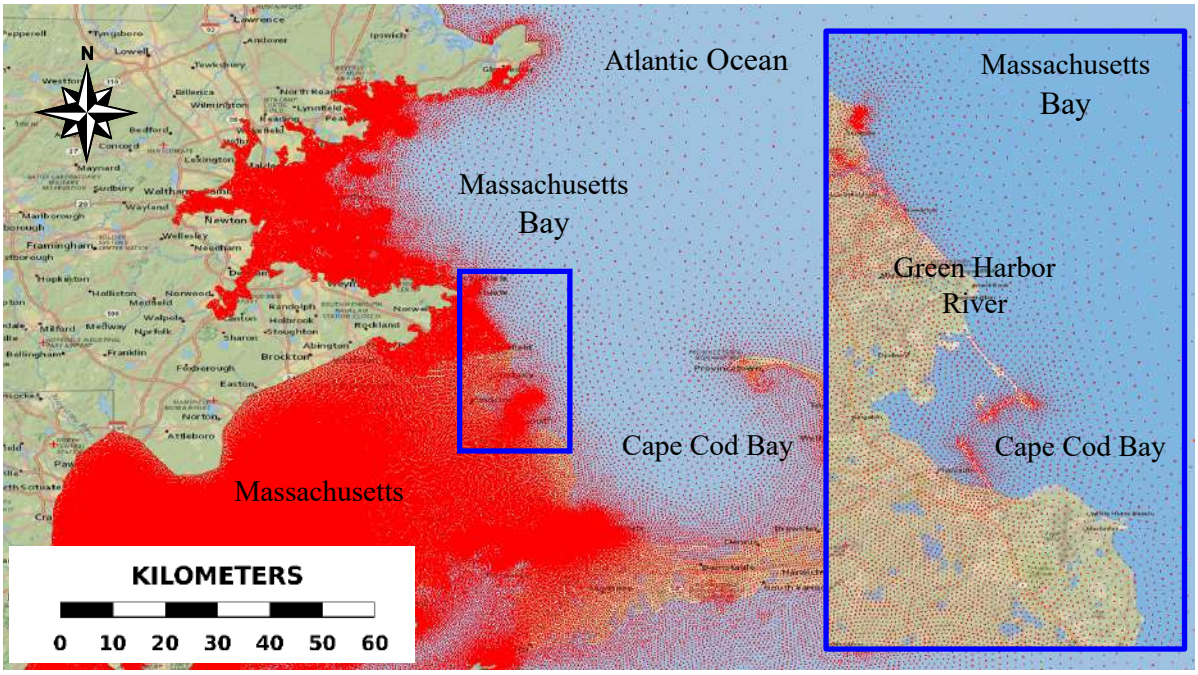

Figure 4. USACE NACCS ADCIRC model bed elevation points.

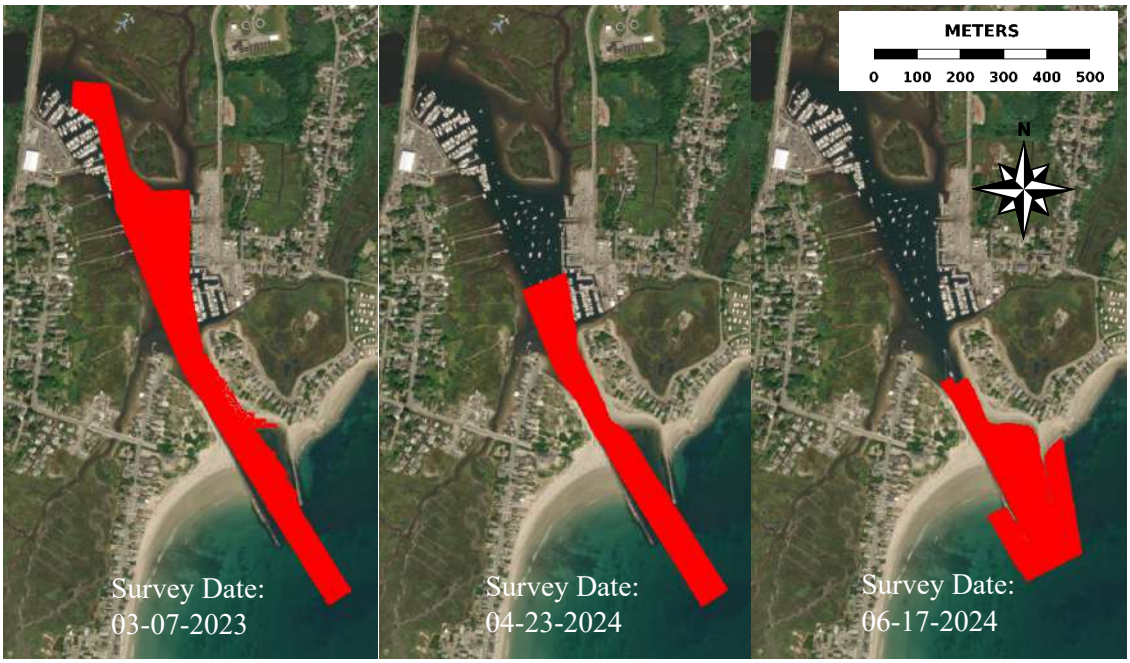

Figure 5. Coverage areas and survey dates of select NAE-provided Green Harbor River bathymetry survey data.

Sediment and Other Geotechnical Data

The NAE collected surface grab samples and core samples at select locations within the harbor to characterize sediment properties. Laboratory analyses showed that surface sediments near the proposed settling basin footprint consist primarily of well-sorted fine sand with an average median grain size (D_{50}) of approximately 0.25 millimeters (mm) and a geometric gradation (or classification of sediment particles into different size fractions) of about 1.8. Core samples indicated higher fines content and poorer sorting below approximately 0.7 ft (0.2 m) below bed, with an average median grain size of approximately 0.09 mm. The data processing used these sediment characteristics to parameterize the sediment transport model.

MODEL DEVELOPMENT AND MODEL VALIDATION

This section describes the numerical modeling framework developed to evaluate hydrodynamics, waves, sediment transport, morphology, and littoral processes within the Green Harbor River Federal Channel and surrounding coastal waters. The modeling system simulates water surface elevations, depth-averaged currents, wave transformation, sediment transport, erosion, deposition, and resulting bed-level changes across the study area. The numerical domain represents portions of the Atlantic Ocean, Massachusetts Bay, Cape Cod Bay, Plymouth Bay, Duxbury Bay, Kingston Bay, the Green Harbor River, the Cape Cod Canal, and adjacent inshore waterways as interconnected two-dimensional systems.

The model development applied the MIKE21 Flexible Mesh (FM) Version 2025 modeling suite (DHI 2025), which integrates hydrodynamic (HD), spectral wave (SW), and sediment transport (ST) and morphology models within a fully coupled framework. In this system, the spectral wave model calculates wave radiation stresses and passes them to the HD model, where waves influence current magnitude and direction. The HD model computes tide- and wave-generated flow velocities that drive sediment transport. The ST and morphology model then calculates erosion and deposition, updates bed elevations, and returns these morphological changes to the SW and HD models. This dynamic feedback allows the modeling system to simulate complex nearshore, inlet, and estuarine processes with high physical fidelity. Coastal

engineers widely apply the MIKE21 FM system for nearshore, inlet, and navigation channel studies because it resolves wave–current–sediment interactions that govern shoaling behavior.

The following subsections describe the model formulation, mesh development, boundary condition specification, calibration, verification, sensitivity analysis, representative hydraulic period selection, and ST and morphology model validation. The modeling used this framework to estimate sediment deposition rates within the Federal Channel dredging template under existing conditions and to provide support to the evaluation of sediment-reduction alternatives.

Hydrodynamic Model

The MIKE21 FM HD model solves the time-dependent depth-averaged equations of mass and momentum conservation to compute transient water surface elevations and flow velocities (DHI 2025). The model applies finite-volume numerical methods on an unstructured mesh to represent complex coastal and estuarine geometry. The governing equations account for conservation of mass, momentum in the horizontal directions, and turbulence closure. The model includes representations of wetting and drying, Coriolis acceleration, wind stress, spatially varying bed friction, and turbulent exchange through eddy viscosity or Smagorinsky formulations (DHI 2025). The model also allows flexible specification of boundary conditions, including time-varying water levels, flows, velocities, and internal flow sources or sinks.

Hydrodynamic Model Setup and Mesh Development

The model mesh development constructed a finite-volume mesh to map bathymetry and topography into the MIKE21 FM framework. The mesh consists of triangular and quadrilateral elements whose size varies spatially to balance computational efficiency with resolution needs. In offshore and regional areas distant from the inlet, element side lengths reach approximately 10,000 ft (3,048 m). Near the Green Harbor River, the jetties, and The Narrows, element sizes decrease to approximately 5 to 30 ft (1.5 to 9.1 m) to resolve steep bathymetric gradients, narrow channels, and strong velocity gradients (see Figures 6 and 7).

Mesh development leveraged the existing USACE NACCS ADCIRC Version 01 (USACE 2015) mesh as a foundation. The MIKE21 domain represents a subset of the ADCIRC domain. Using Massachusetts shoreline shapefiles and high-resolution aerial imagery, the study regenerated the mesh in nearshore regions, within the Green Harbor River, and between the river and adjacent inland waterways. Outside these areas, the study retained or modestly modified the original ADCIRC mesh. The final model domain (see Figure 6) extends from the mouth of the Green Harbor River approximately 16.5 miles (26.6 kms) offshore to the northeast, 36.3 miles (58.4 kms) to the northwest, and 31.3 miles (50.4 kms) to the southeast. Inland, the domain includes more than 3 miles (4.8 kms) of the Green Harbor River, extending upstream to near Marshfield Municipal Airport. These extents ensure that the model captures the dominant tidal and wave processes that influence sediment transport within the Federal Channel.

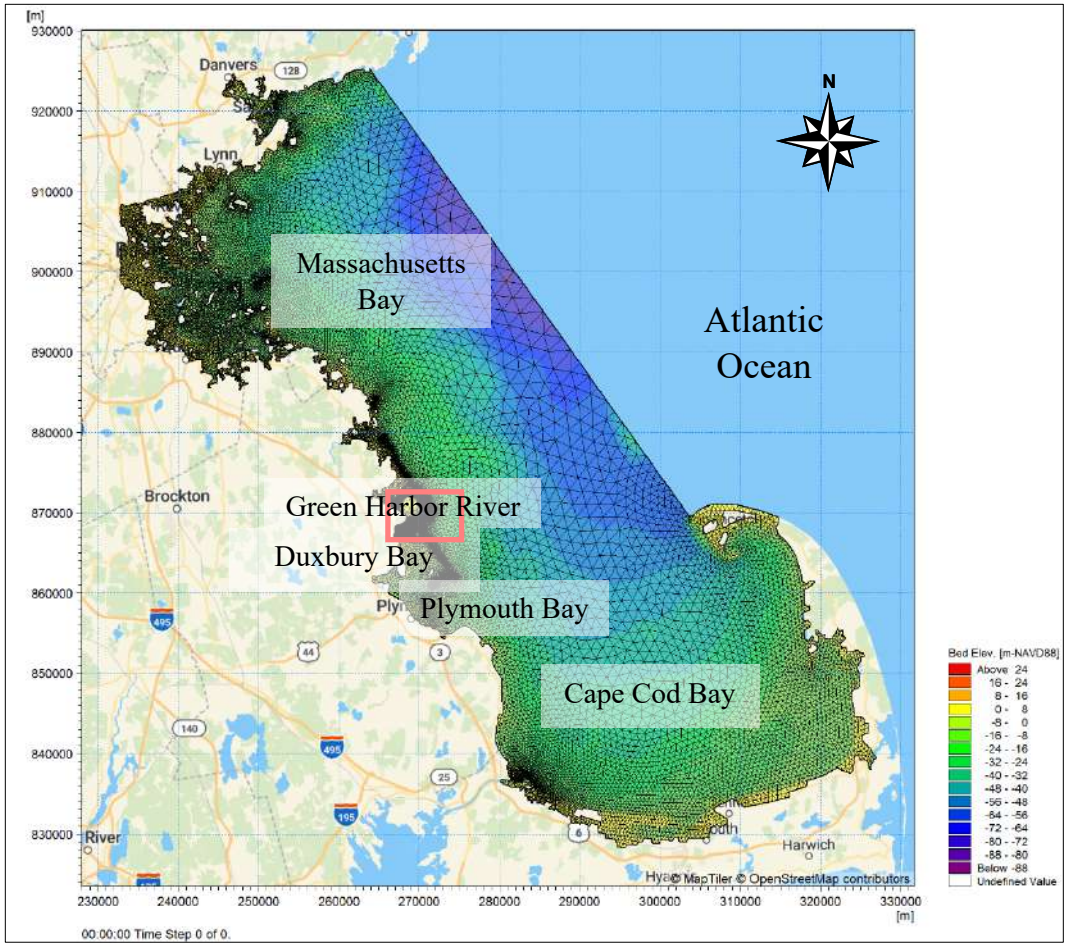

Figure 6. Model domain, bed elevations, and model mesh (inset, shown in Figure 7 for the area of interest).

Multiple datasets provided bathymetric and topographic input to the mesh. The NACCS ADCIRC mesh supplied the base regional bathymetry. The NAE-provided 2018 USACE dataset replaced the model topography and bathymetry data in and around Marshfield with higher-resolution data. The Green Harbor River surveys collected on March 7, 2023; October 5, 2023; February 6, 2024; April 23, 2024; and June 17, 2024 updated the model in-river bathymetry. Thus, the study replaced older survey data with newer data wherever coverage overlapped. All datasets were converted to a common horizontal reference (NAD83 State Plane Massachusetts Federal Information Processing Standards [FIPS] 2001) and vertical reference (NAVD88).

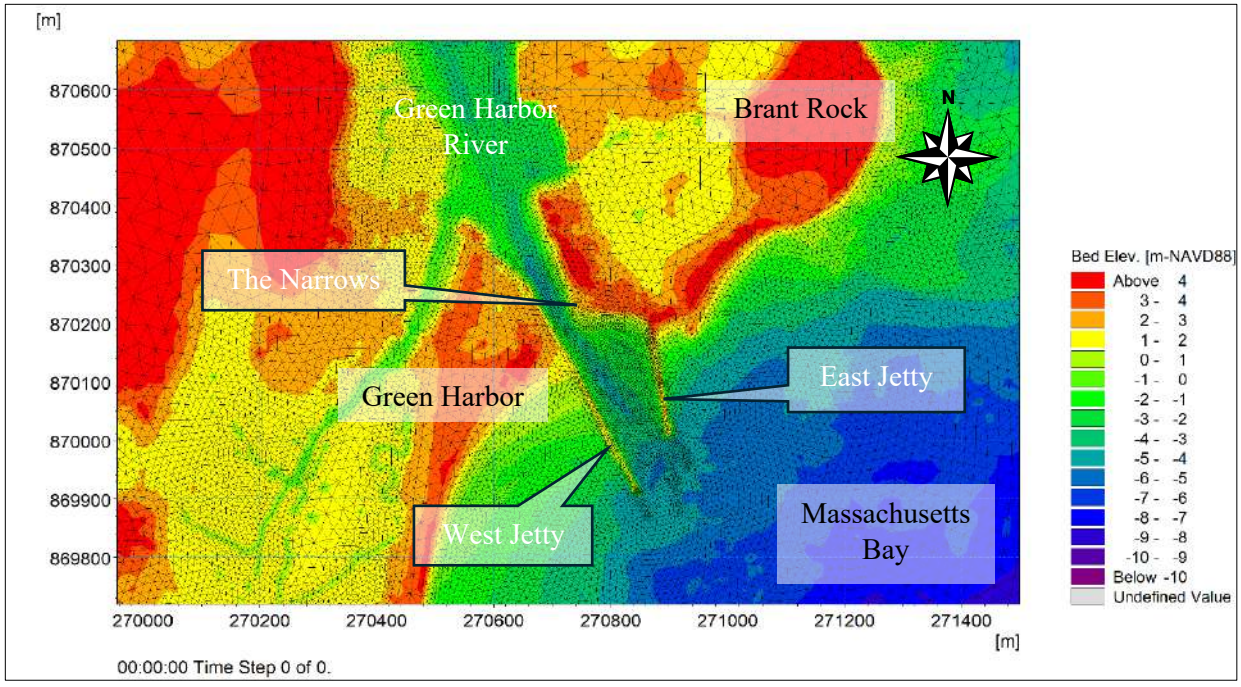

Figure 7. Model bed elevations and mesh in the area of interest.

For HD model calibration and verification, the mesh development used the June 17, 2024 bathymetry to reflect conditions during the June–July 2024 water-level measurements. For ST model calibration, the study used the March 7, 2023 post-dredge bathymetry to match the shoaling observation period.

The mesh development prepared and edited the mesh using SMS Version 13.3.14 (https://aquaveo.com/downloads-sms) and MIKEZero Version 2025 (DHI 2025). These tools allowed direct interpolation of digitized bathymetric datasets onto the mesh and facilitated refinement in areas of interest.

Bed Roughness and Boundary Conditions

The model development assigned spatially varying Manning's n values based on land cover classifications from the 2021 National Land Cover Database (https://www.usgs.gov/data/national-land-cover-database-nlcd-2021-products) and guidance provided in the HEC-RAS 2D User's Manual (USACE 2023). The model applied lower roughness values in offshore and deeper bay areas and higher values within the Green Harbor River and marsh-influenced regions.

The hydrodynamic model applied time-varying water-level boundary conditions along the offshore boundary and specified free outflow at the Cape Cod Canal boundary. For internal hydraulic control, the model incorporated user-defined, time-varying opening and closing of the Dyke Road hydraulic gates, which regulate flow exchange between the lower and upper portions of the Green Harbor River. Where the mesh boundary lacked a specified condition, the model assumed a slip boundary, preventing flow normal to the boundary.

For HD model calibration and verification simulations, the model boundary development adjusted predicted offshore tides to account for meteorological influences. The model boundary development calculated an offset between measured water levels at Station NAE-TG1 and predicted astronomical tides at the Brant Rock NOAA 8446009 station and applied this offset along the offshore boundary. This approach

incorporated wind setup and other non-tidal effects into the boundary forcing. For baseline simulations, the model applied spatially and temporally varying predicted tides generated using the MIKE21 global tide model.

Hydrodynamic Model Calibration and Verification

The HD model calibration used measured water-level data that the NAE collected at Station NAE-TG1 between June 21 and July 7, 2024. Before calibration, the model calibration applied a 0.5-hour moving average to the measured data to remove short-period oscillations caused by vessel traffic and local wind effects. The model calibration iteratively adjusted Manning's n values until modeled water levels matched measured data. The calibration process identified a Manning's n value of 0.035 $s/m^{1/3}$ for the Green Harbor River as providing the best agreement. The calibrated model applied Manning's n values of approximately 0.025 $s/m^{1/3}$ in the Atlantic Ocean and Cape Cod Bay, 0.035 $s/m^{1/3}$ in Duxbury and Plymouth Bays, and 0.030 to 0.035 $s/m^{1/3}$ in nearshore areas. Table 1 shows statistical comparisons of modeled and measured water levels for the model calibration and verification. The statistical comparisons yielded a mean error (ME) of 0.044 ft (0.013 m), a root mean square error (RMSE) of 0.241 ft (0.073 m), and a correlation coefficient (CORREL or r) of 0.998 during calibration. The model calibration mean error represents less than 0.5% of the local mean tidal range. The statistics all indicate excellent model performance.

Table 1. Mean errors, root mean square errors, and correlation coefficients for Station NAE-TG1 water levels during HD model calibration and verification.

Model Validation	Station	Mean Error (ME) (ft) / (m)	Root Mean Square Error (RMSE) (ft) / (m)	Correlation Coefficient (CORREL or r)
Calibration	NAE-TG1	0.044 ft (0.013 m)	0.241 ft (0.073 m)	0.998
Verification	NAE-TG1	0.027 ft (0.008 m)	0.296 ft (0.090 m)	0.995

Figure 8 shows a comparison of the calibration model-calculated (blue line) and measured (red line) water level time series (hydrographs) at Station NAE-TG1 over the calibration period. In general, except for slight overestimations/underestimations at high tides and slight underestimations at low tides (likely due to unknown changes in bathymetry and deviations due to local wind setups), Figure 8 shows very good agreement between data and model-calculated water elevations. Based on favorable comparison statistics and very good visual comparisons of the modeled and measured water level in the river, this paper considered the HD model's water level calculation well-calibrated in the area of interest.

The model development verified the model using an independent dataset from July 8 through July 25, 2024 without further parameter adjustment. Table 1 verification statistics included a ME of 0.027 ft (0.008 m), an RMSE of 0.296 ft (0.090 m), and a CORREL (or r) of 0.995. Time-series comparisons confirmed close agreement between modeled and measured water levels. Therefore, the model development deemed the HD model well-calibrated and well-verified.

Sensitivity analyses showed that water levels at Station NAE-TG1 varied minimally across Manning's n values ranging from 0.025 to 0.040 $s/m^{1/3}$. Among these values, 0.035 $s/m^{1/3}$ provided the best overall agreement and served as the final calibrated roughness value.

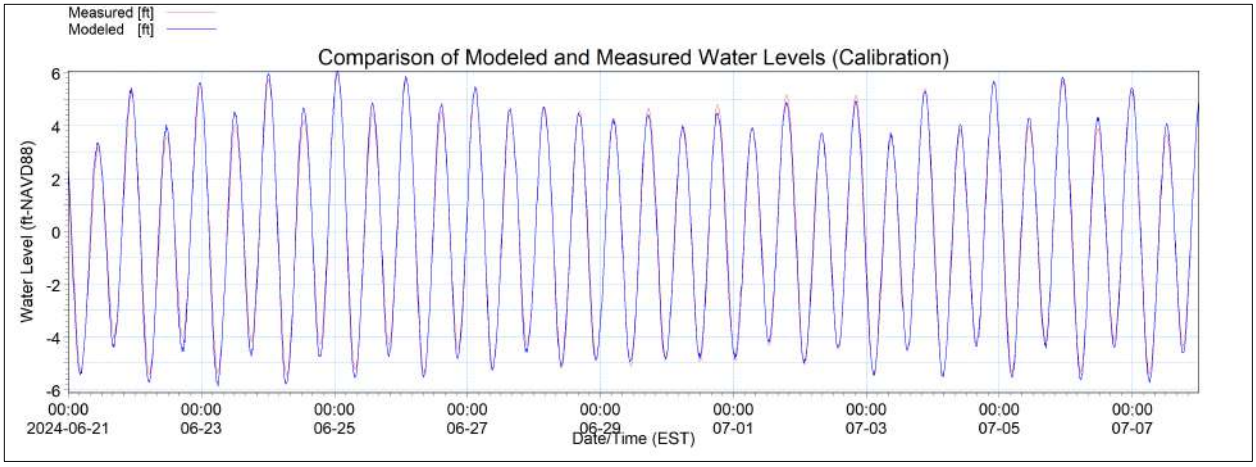

Figure 8. Comparison of modeled and measured water level at Station NAE-TG1 for Green Harbor River using Manning's n = 0.035 (HD model calibration period).

Wave Model

The MIKE21 FM spectral wave (SW) model simulates the generation, propagation, and transformation of wind-generated waves and swell. The model solves the spectral wave action balance equation using finite-volume methods to produce two-dimensional wave spectra. The model accounts for depth-induced refraction, wave–current interaction, diffraction, nonlinear wave–wave interaction, and dissipation from breaking, bottom friction, and whitecapping.

The SW model used the same mesh and domain as the HD model. Offshore boundary conditions consisted of hindcast wave data from USACE WIS Station 63059, including significant wave height, peak period, and mean wave direction. The model boundary development applied zero-wave conditions along inshore boundaries, as wind-generated waves from these boundaries do not significantly affect inlet hydraulics. The model applied a wave breaking gamma value of 0.8 and Nikuradse roughness (DHI 2025) values of 0.131 ft (0.040 m) offshore and 0.033 ft (0.010 m) in nearshore and inshore areas.

Sediment Transport and Morphology Model

The MIKE21 FM ST model simulates non-cohesive sediment movement as both bedload and suspended load using flow velocities from the HD model and wave radiation stresses from the SW model. The model calculates sediment transport rates using pre-generated lookup tables that account for combined wave-current forcing. The morphology module updates bed elevations based on computed erosion and deposition.

Sediment Transport Model Setup and Boundary Conditions

The ST model used the same mesh and domain as the HD and SW models. The model boundary development applied zero sediment-flux gradients at outflow boundaries and zero bed-change gradients at inflow boundaries. Given the large distance between the boundaries and the area of interest, these assumptions do not affect results within the Green Harbor River. Because sediment sampling locations did not cover the entire dredging template, the ST model development treated the D_{50} values (in the *Sediment and Other Geotechnical Data* section) as initial estimates and refined the D_{50} through the sediment transport model calibration.

Sediment Transport and Morphology Model Calibration

Measured shoaling volumes at selected areas of the Green Harbor River between the post-dredge bathymetry survey on March 7, 2023, and the pre-dredge bathymetry survey on October 5, 2023, provided the ST model calibration data. Figure 9 shows the measured shoaling volumes at Areas 1 – 10 in the river based on subtracting the March 7, 2023 survey data from the October 5, 2023 survey data. The contour scale indicates the amount of deposition volume (yellow to orange contours) and erosion volume (blue to purple contours) in each area.

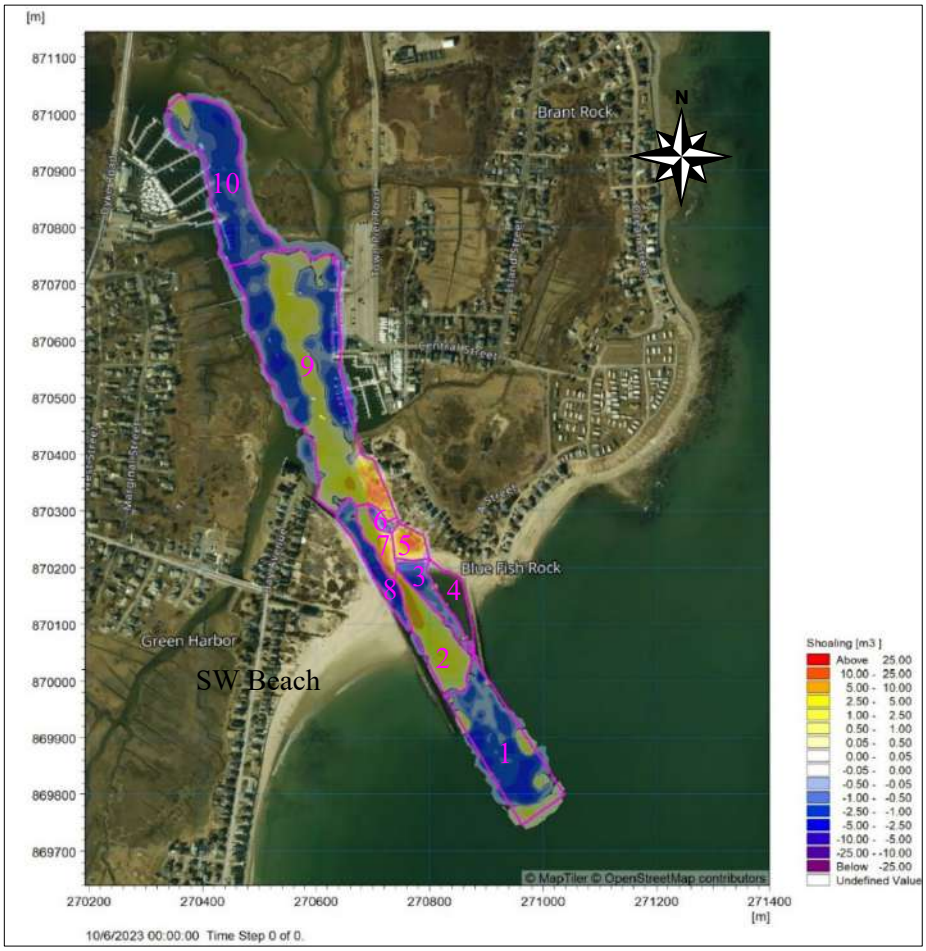

Figure 9. Measured Green Harbor River shoaling volume (in m^3) based on March 7, 2023 post-dredged survey and October 5, 2023 pre-dredged survey data.

Figure 9 shows mostly net erosion just offshore of the East and West Jetties (Area 1), as inshore- and offshore-directed currents carry sediments and result in net transport of sediments into the river. These sediments are deposited in Area 2, Area 7, and the middle portion of Area 9 as the flow velocities weaken because the river widens in these areas. The NAE estimated that aeolian transport likely deposits on average 1,000 cy/yr (765 m^3/yr) from the southwest beach to Areas 5, 6, 7, and 9 (just north of Area 6). Net erosions at Areas 3 and 8 likely contributed to the net depositions in Area 7 and Area 9, respectively. The east and west portions of Area 9 likely experience net erosion (blue contour) induced by the piers located along the banks of the river. Similarly, the several piers in Area 10 likely induced the net erosion reflected in the survey data. There is no data in Area 4 from the March 7, 2023, and October 5, 2023 surveys; thus, there is no measured shoaling volume shown in the figure for Area 4.

The model development calibrated the ST model using observed shoaling between March 7 and October 5, 2023. The ST model calibration compared modeled shoaling volumes with measured shoaling volumes across the defined river areas and iteratively adjusted the D_{50} from 0.25 mm to 0.45 mm. Consistent with NAE confirmations that aeolian transport can deposit sediments along the east shore of the river, this study distributed a total of 1,300 cy (994 m^3) of aeolian transport to Areas 5, 6, and 7 in addition to the model-computed shoaling. The ST model calibration selected a D_{50} of 0.40 mm because it best reproduced observed shoaling patterns in the dredging template, particularly near the jetties and the proposed settling basin footprint. Figure 10 shows the modeled areas' percent shoaling and the percent total net shoaling (77%) relative to the measured shoaling in Green Harbor River with D_{50} = 0.40 mm.

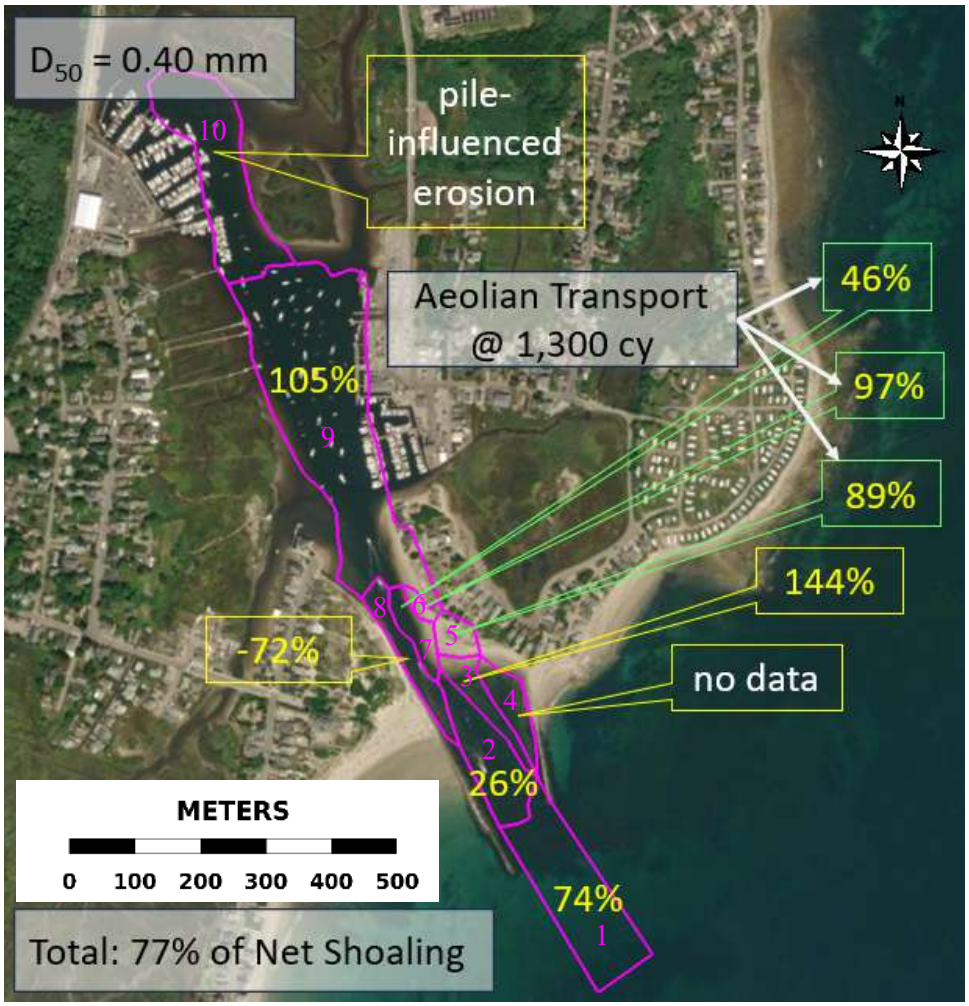

Figure 10. Modeled percent shoaling in Green Harbor River with D_{50} = 0.40 mm relative to the measured shoaling between March 7 and October 5, 2023.

Sediment Transport and Morphology Model Verification

The ST model verification selected 2011 as a representative hydraulic year by analyzing the 1980 – 2023 WIS Station 53059 hindcasted wave data and identifying the year that best matched the long-term average gross and net littoral transport. ST model verification involves a one-year model simulation using the representative year 2011 and comparison of the modeled total shoaling volume in the dredging template at the end of the representative year with the average dredging volume of 20,451 cy/yr (15,635 m^3/yr). The

NAE provided the dredging template, divided into the three reaches shown in Figure 11. This paper further subdivided the dredging template area into 12 zones (Zones A – L) as shown in Figure 11.

- Upstream Reach – 6 ft below mean lower low water (6 ft-MLLW or 1.8 m-MLLW) deep channel from near E Street to near the Green Harbor Yacht Club marina (includes Turning Basin, Anchorage, and the adjacent Federal Channel reach in Figure 11)
- Middle Reach – 6 ft-MLLW (1.8 m-MLLW) deep channel from mid-length of the jetties to near E Street in Blue Fish Rock (i.e., Federal Channel at -6 ft-MLLW [-1.8 m-MLLW] in Figure 11), and
- Downstream Reach – an 8 ft-MLLW (2.4 m-MLLW) deep channel from the entrance to mid-length of the jetties (i.e., Federal Channel at -8 ft-MLLW or -2.4 m-MLLW in Figure 11).

The ST model verification process performed two ST model verification simulations—the first model simulation used the riverbed elevation based on the March 7, 2023 post-dredge bathymetry, and the second simulation used the authorized depths in locations where the March 7, 2023 post-dredge bathymetry was above the authorized depths shown in Figure 1 (for the Downstream Reach, Middle Reach, and Upstream Reach in Figure 11). The use of two starting riverbed elevations, one each for the two ST model verification runs, covers cases when the dredging occurred only in some parts of the dredging template (e.g., after the March 7, 2023 post-dredge survey) and when dredging occurred at all riverbed elevations above the authorized depths. The two ST model verification runs applied (a) the model parameters from the calibrated model; (b) a model simulation period of one year (i.e., 2011); and (c) the 2011 predicted tides and WIS Station 63059 hindcasted waves along the offshore boundary to estimate the hydraulics, sediment transport, and erosion/deposition in the river. The first model verification simulation results show the sediment deposition in the whole dredge template totals to approximately 18,704 cy (14,300 m^3) or 91% of the average annual dredging volume of 20,451 cy/yr (15,635 m^3/yr). The second model verification simulation results show the sediment deposition in the whole dredge template totals to approximately 19,057 cy (14,570 m^3) or 93% of the average annual dredging volume. The results from these two model simulations verified the ST model calibration and validated the performance of the ST model to accurately evaluate sediment deposition in the dredging template. Thus, this paper deemed the ST model well-calibrated and verified to estimate the effect of alternatives to reduce sediment deposition in the Federal Channel dredge template.

FINDINGS AND RECOMMENDATIONS

Baseline conditions (no basin, no East Jetty crest raising, and/or no East Jetty extension) model results for a year with an average amount of sediment supply from the nearshore area provide the following findings.

1. The largest sediment depositions occur in Zones D – K (see Figure 11).
2. However, Zones F – K (see Figure 11) have the largest sediment depositions per unit area and account for approximately 57% of the modeled sediment deposition in the dredge template. Model results show 7%, 10%, 11%, 9%, 7%, and 13% of the deposited sediments in the dredge template lie in Zones F, G, H, I, J, and K, respectively.
3. The modeled sediment depositions in Zones F – K (see Figure 11) are approximately 1.5 to 3.0 times greater than the average deposition in the dredging template.
4. The modeled high flow velocities at The Narrows (See Figure 1) can induce bed armoring through the preferential retention of larger sediments, accounting for the observed accumulation of cobble material that effectively constricts the channel at the Narrows.

Therefore, this paper recommended that the next phase of the NAE study should evaluate an alternative's performance to reduce sediment deposition in the Federal Channel, mainly based on the alternative's capability to reduce sediment deposition in Zones F – K. The next phase will evaluate the Federal Channel shoaling reduction performance of (1) the construction of a sediment settling basin within the harbor, (2) raising a portion of the East Jetty crest elevation, and (3) extending the East Jetty seaward. Future refinements to the model could incorporate sediment surface grab sampling across a wider area, together with laboratory analyses, to enhance the spatial characterization of sediment distributions.

Figure 11. Locations of sediment deposition evaluation Zones A – L in the Green Harbor River Federal Channel dredging template.

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CITATION

Kabiling, M.B. “Evaluation of Navigation Channel Shoaling for the Green Harbor Navigation Improvement Project”, *Proceedings of the Western Dredging Association Dredging Summit & Exposition ‘26, Montreal, Quebec, Canada,* July 20-23, 2026.

DATA AVAILABILITY

Some or all data, models, or code generated or used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

ACKNOWLEDGEMENT

The USACE-NAE funded this study to develop a model to analyze shoaling patterns and distributions in the Green Harbor Federal Channel.

THE ECONOMICS OF SEDIMENT MANAGEMENT

T. Bridges[1] and R. Ramsdell[2]

EXTENDED ABSTRACT

This hybrid session will combine short presentations with panel discussion and audience engagement to highlight opportunities to advance the use of economic analysis to guide sediment management practice, including the management of dredging operations. Sediment management poses billions of dollars of cost to U.S. taxpayers, the private sector, and the economy. Economic costs are associated with shoreline erosion; channel shoaling; reservoir sedimentation; dredging and subsequent disposal, placement, and management; and other sources. Sediment management can also create benefits and economic value in the form of restored shorelines and habitats, reduced risks from the development of nature-based solutions, or through the restoration of sediment processes that reduce the need for future dredging. Economics, engineering, and data science (including artificial intelligence) provide a powerful combination of approaches and methods to analyze costs and benefits that reveal opportunities to reduce costs, create benefits, and inform strategies for sediment management. This session will bring together panelists from government, academia, and the private sector to identify and discuss new approaches for exploring the economics of sediment management to guide future practice.

Panel members:

- Dr. Craig Landry, Professor, Agricultural and Applied Economics, University of Georgia; clandry@uga.edu
- Sam Kingsley, CEO, 3D Continuum, Inc.; sam@3dcontinuum.com
- Dev Raveendran, Capital Projects Manager, Hamilton-Oshawa Port Authority, Canada; draveendran@hopaports.ca
- Marcel Hermans, Engineering Project Manager, Port of Portland, Oregon, USA; Marcel.Hermans@portofportland.com
- Isaac Hametz, Baltimore Program Director, The Nature Conservancy; isaac.hametz@TNC.ORG

Keywords: Benefit-Cost Analysis, Operations Research, Cost Estimation, Sustainability, Resilience

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[1] Professor of Practice, College of Engineering at the University of Georgia, 1708C Boyd Research Center, Athens, GA 30602, USA, T: 706-202-7645, Email: todd.bridges@uga.edu. (corresponding author)
[2] Principal, Dredging Resources, 630-805-1776, Email: Robert.Ramsdell@dredgingresources.net.

AN OVERVIEW OF ENVIRONMENTAL DREDGING INITIATIVES IN THE CANADIAN GREAT LAKES/ST LAWRENCE RIVER AND THE FEDERAL GOVERNMENT PROGRAMS INVOLVED

R. Joyner[1] and R. Santiago[2]

EXTENDED ABSTRACT

On the Canadian side of the Great Lakes and St Lawrence River major environmental dredging projects associated with the Canadian federal government are promoted through three programs which address the assessment and management of contaminated sediment: Great Lakes Areas of Concern (AOC), The St Lawrence Action Plan (SLAP) and the Federal Contaminated Sites Action Plan (FCSAP). The AOC and SLAP programs are administered by the Canada Water Agency (CWA) who works with provincial and local partners (including the site owners) to advance specific projects in relation to funding, approval of scope, and public engagement. FCSAP is administered through Environment and Climate Change Canada and empowers various government department to address contamination on their property.

In Ontario the AOCs and their associated goals are driven by the Canada US Great Lakes Water Quality Agreement (Canada & United States, 2012) and the Canada Ontario Agreement (Environment and Climate Change Canada & Ontario Ministry of the Environment, Conservation and Parks. 2021). Under the AOC program sediment management is associated with the removal of beneficial use impairments (BUI) in the various AOCs. The most common BUIs associated with contaminated sediment are Degradation of benthos, Restrictions on dredging activities, Fish tumors or other deformities, Degradation of fish and wildlife populations and Restrictions on fish and wildlife consumption.

The AOC program has been a driving force behind some of the largest sediment remediation and environmental dredging projects on the Canadian side of the Great Lakes. Since 1994 approximately 1.3 million m3 of contaminated sediment has been managed under the AOC program with approximated 623,000 m3 of that managed via environmental dredging. Sediment contamination issues within the AOCs focus on “legacy” contaminants with PAHs, PCBs, metals, and mercury being the biggest drivers for environmental dredging. The AOC program’s long history with environmental dredging includes historic projects completed in the Collingwood, Niagara River (Welland River at Atlas Steel), Thunder Bay (Northern Wood Preservers Site) and Detroit River (Turkey Creek) AOCs. However, some of the largest AOC environmental dredging projects have just recently been completed in the Hamilton Harbour AOC at Randle Reef and at the Port Hope AOC. In addition, future AOC environmental dredging projects are anticipated to include sites at Hamilton Harbour (Dofasco Boat Slip), Niagara River (Lyons Creek East), Thunder Bay (North Harbour), and the St Marys River (Algoma Boat Slip).

SLAP is another federal initiative in the Quebec portion of the St Lawrence that addresses environmental issues associated with contaminated sediment. Under SLAP the assessment sediment contamination in

[1] Senior Sediment Remediation Specialist, Canada Water Agency, 867 Lakeshore Road, Burlington, Ontario, L7S 1A1, Canada, T: 905-220-4285, Email: Rupert.Joyner@cwa-aec.gc.ca.
[2] Sediment Remediation Unit Head, Canada Water Agency, 4905 Dufferin St. Toronto, Ontario, M3H 5T4, Canada, T: 416 460-8945, email: Roger.Santiago@cwa-aec.gc.ca. (corresponding author).

the St Lawrence seeks to define locations where the exposure of aquatic organisms and humans to contaminated sediments are a concern. The risk from contaminated sediment is evaluated according to the Criteria for the Assessment of Sediment Quality in Quebec and Application Frameworks: Prevention, Dredging and Remediation (Environment Canada and Ministère du Développement durable, de l'Environnement et des Parcs du Québec. 2007). By assessing exposure and effects on ecological and human receptors, it will also be possible to target sites that pose specific issues for future management including potential environmental dredging.

Within the Great Lakes/St Lawrence corridor the other parallel government program associated with the largest and most significant sediment remediation and environmental dredging projects is associated with the clean-up of federally owned water lots. These sites are therefore managed via the FCSAP program. The FCSAP program enables federal departments to manage environmental liabilities associated with contamination on their properties and is administered by Environment and Climate Change Canada (ECCC). FCSAP runs on a five year funding cycle and the program is currently in Phase V which runs from 2025-2030. Significant FCSAP environmental dredging projects are under way or planned in the Great Lakes/St Lawrence River including Portneuf Wharf, Whitby Harbour, and Kingston Inner Harbour.

These three government programs are not mutually exclusive and there is often overlap between the FCSAP sediment projects and the AOC, broader GL programs and SLAP. Together they combine to meet government objectives related to the management of federally owned contaminated sites and protecting/restoring the health of the Great Lakes/St Lawrence. The implementation of the Lyons Creek East remediation in Niagara and the Thunder Bay North Harbour design and implementation is anticipated to involve both FCSAP and the AOC program.

Keywords: Environmental dredging, contaminated sediment, Areas of Concern, Great Lakes, St. Lawrence River

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DEVELOPING ENVIRONMENTAL PROTECTION REVIEW GUIDANCE FOR A CANADIAN WORKING HARBOR

E. Crawford[1], J. Low[2], P. Bartha[3], L. Persowich[4], F. Wong[5], A. Corp[6], and M. Larsen[7]

EXTENDED ABSTRACT

Victoria Harbour is a large working harbor located on the southern tip of Vancouver Island, British Columbia, with a long history of impacts from shipbuilding, mills, coal storage and gasification, and manufacturing. It was identified as a Class 1 Contaminated Site (high priority for action) by the Government of Canada and is being remediated by Transport Canada (TC) through the Federal Contaminated Sites Action Plan program. The programmatic remedial strategy identified for the site includes a phased approach of early actions for hazardous waste-level contamination, secondary remediation of shorelines with lower levels of contamination, and monitored natural recovery of most of the harbor. This overall approach considered the status of the site as a working harbor, realistic cleanup goals, and the long-term sustainability of the remedy given harbor uses. Victoria Harbour is part of the traditional territory of the Esquimalt Nation and Songhees Nation, who have been engaged throughout the development of the remedial strategy and have indicated that reducing ongoing pollution is key to the management of this portion of their core territory.

The Victoria Harbour Floor is administered by TC on behalf of the Government of Canada, who manages the Public Port. As part of their responsibilities to sustain the working harbor and protect the environment, TC performs environmental reviews required by existing government regulations. The Environmental Protection Review (EPR) program is one of these environmental reviews that is performed under the Port Activity Review.

Under the Canada Marine Act and the Public Port and Public Port Facility Regulations, TC's designated Port Official is responsible for prohibiting activities that pollute soil, sediment, or water within the boundaries of the Public Port. TC developed the EPR as a science-based assessment conducted on proposed

[1] Senior Regional Environmental Supervisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada, T: 604-360-9440, Email: eric.crawford@tc.gc.ca
[2] Regional Environmental Advisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada, T: 236-330-2687, Email: jessica.low@tc.gc.ca
[3] Regional Environmental Advisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada, Email: philip.bartha@tc.gc.ca
[4] Environmental Specialist, Environmental Services and Contaminated Sites Management, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada, T: 778-955-7358, Email: laurel.persowich@pwgsc-tpsgc.gc.ca
[5] Senior Environmental Specialist, Environmental Services and Contaminated Sites Management Pacific Region, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada, T: 236-330-4105, Email: fiona.wong@pwgsc-tpsgc.gc.ca
[6] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.
[7] Principle Scientist, Anchor QEA, 949 Market Street, #700, Tacoma, Washington 98402, USA, T: 206-903-3359, Email: mlarson@anchorqea.com

projects to determine potential impacts that could pollute soil, sediment, or water within the boundaries of the Public Port. TC's Port Manager, with support from TC environmental staff, has been conducting EPRs for more than a decade in compliance with regulatory requirements. The goal of the EPR process is to identify appropriate mitigation measures so that the activities may be performed safely without resulting in pollution of Victoria Harbour.

The EPR process begins with an initial review of proposed work by TC to identify and screen "Controlled Activities" that have a high risk of environmental contamination. If TC determines that proposed work includes one or more Controlled Activities, they will require a detailed activity review which may include review of environmental data and engineering analyses.

Activities that require mitigation measures include the following:

- Dredging
- Expanded commercial navigation
- Placement or removal of utilities (e.g., water, power, telecommunications, transportation, or other similar services) or outfall conveyances (e.g., stormwater pipes and tunnels)
- Shoreline modification
- Stormwater and other discharges
- Structure construction or removal

Mitigation measures are best management practices that reduce the potential for environmental harm associated with the proposed activity. For each reviewed activity, TC Environmental Staff determine which mitigation measures will be required based on literature review, environmental data, and engineering design reports, as applicable. This ensures environmental risks are reduced while still facilitating the activity. Sometimes, additional information is needed for TC to adequately characterize the environmental risks and therefore TC cannot confidently assign Required Mitigation Measures. In this case, the proponent will be asked to conduct additional research or otherwise return to TC additional information to aid in the analysis.

Only after the Port Manager deems the project is in compliance with Required Mitigation Measures and sufficient supporting documentation is provided can the activity commence. During the implementation of the activity, it is the responsibility of the proponent to conduct the activity in full compliance with the mitigation measures listed in the Port Manager's decision.

As an example, a dredging project involving removal of contaminated sediments would trigger a detailed review of the project because of the potential to redistribute contamination, expose subsurface contamination, and counteract natural recovery processes. Required Mitigation Measures would likely involve utilization of silt curtains, managing dredge stockpiles, managing residuals, barge dewatering requirements, and use of a residuals management cover.

The EPR process sets forth a uniform, predictable, and transparent process for evaluating work in a Public Port in Canada and mitigation of environmental risks through a series of reviews and information exchanges. Continued implementation of EPRs is a key element of the remedial strategy for Victoria Harbour, enhances the protection of this vital resource, while allowing the harbour to continue to be a working waterfront.

Keywords: Mitigation, dredging, institutional controls, contamination, BMPs

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ASSESSING OFFSHORE SAND EXTRACTION AS A SUSTAINABLE STRATEGY FOR THE MAGDALEN ISLANDS (QUÉBEC, CANADA)

M. Audet Daigle [1] and A. Mercier-Rémillard [2]

ABSTRACT

The Magdalen Islands, located in the centre of the Gulf of St. Lawrence within Canada's Atlantic Maritime provinces, are on the forefront of climate change. Sea-level rise, driven by climate change, is locally exacerbated by land subsidence, a consequence of the last glaciation. As a result, more than 70% of the coastline is at risk of erosion and flooding. National Road 199, which connects the archipelago from end to end, is largely built on tombolos and coastal spits (>50 km), making it highly vulnerable to these coastal hazards. In recent years, numerous interventions have been carried out annually by Québec's Ministry of Transport and Sustainable Mobility (MTMD) to protect the roadway or repair existing structures. These interventions require significant logistical and coordination efforts to respond to emergencies, ensure that sufficient volumes of material are available at all times on the archipelago, and adequately safeguard this critical transportation link.

To conduct beach nourishment operations, MTMD primarily relies on uncontaminated sand obtained from dredging small harbors and navigation channels, as no sand pits are active on the archipelago. However, the volumes currently available no longer meet the growing needs. MTMD is therefore seeking local solutions to secure a sustainable, long-term sand supply for the protection of Road 199.

Extracting sediments from offshore borrow areas is a common practice in several countries to address shortages in granular materials. Given that the Magdalen Islands are largely surrounded by sandy seabed, this approach presents, in theory, promising potential to meet local sand needs. However, because offshore dredging is not currently regulated in Québec or Canada, a review of recommended international practices provides a valuable starting point to assess the applicability of this supply method. WSP is conducting this review on behalf of MTMD to better understand the operational, legislative, and environmental contexts surrounding such activities elsewhere in the world. The findings of this review help clarify the issues and opportunities associated with this method for potential future application in Québec and Canada.

Keywords: Offshore Dredging, Beach Nourishment, Canadian Regulatory Framework, Best Practices

INTRODUCTION

The Magdalen Islands (Îles-de-la-Madeleine) form a low-lying archipelago located in the central Gulf of St. Lawrence, at the eastern edge of Québec, Canada (Figure 1). Owing to their geomorphology, exposure to energetic wave climates and post-tropical storms, and limited elevation above mean sea level, the islands are particularly sensitive to coastal erosion and flooding. These vulnerabilities are intensifying as a result of climate change, through both global sea-level rise and an increase in the frequency and intensity of storms. Locally, the effects of relative sea-level rise are further amplified by ongoing post-glacial land

[1] Project Manager-Dredging and Sediment Management, WSP Canada inc., Maxim.AudetDaigle@wsp.com
[2] Project Manager, Geomorphologist and Oceanographer, WSP Canada inc., Audrey.Mercier-Remillard@wsp.com

subsidence, placing the Magdalen Islands among the most climate-exposed coastal regions in eastern Canada.

Figure 1. Location of the Magdalen Islands and Road 199

More than 70% of the archipelago's coastline is currently considered at risk of erosion or flooding. This vulnerability poses a critical challenge for the protection of National Road 199, the sole continuous transportation corridor linking the islands from end to end. Over 50 km of this roadway are built on narrow tombolo and spits, often bounded by the open ocean on one side and lagoons or wetlands on the other. The coastal squeeze phenomenon occurring in this location prevents landward retreat no realistic realignment or bypass options, making the roadway highly susceptible to storm damage, breaching, and long-term shoreline retreat. Maintaining the integrity of Road 199 is therefore essential not only for transportation and economic activity, but also for emergency response and the social cohesion of the archipelago.

In recent years, Québec's Ministry of Transport and Sustainable Mobility (MTMD) has undertaken numerous coastal protection and emergency response interventions to protect Road 199 and associated infrastructure. These works typically rely on beach nourishment and related soft-engineering solutions, which require substantial volumes of clean, well-graded sand. Due to the absence of active terrestrial sand pits on the Magdalen Islands, the MTMD currently depends almost exclusively on uncontaminated sand recovered from maintenance dredging of small harbours and navigation channels. While this approach has historically provided a locally sourced material, the volumes available through conventional dredging are increasingly insufficient to meet growing and recurrent needs driven by accelerating coastal hazards.

Securing a reliable, sustainable, and long-term source of suitable sediment has thus become a central challenge for coastal adaptation planning in the Magdalen Islands. In many coastal regions worldwide, this challenge has been addressed through the extraction of sand from offshore borrow areas, specifically designated for supplying beach nourishment and coastal protection projects. Large-scale offshore sand extraction is a well-established practice in countries such as the United States, the Netherlands, Belgium, and the United Kingdom, where it is supported by dedicated regulatory frameworks, environmental assessment procedures, and long-term strategic planning. In Québec and Canada, however, offshore dredging conducted solely for sediment supply purposes is not currently regulated, and no precedent exists for its application in support of coastal adaptation.

In this context, the MTMD has commissioned WSP to evaluate offshore sand extraction as a potential future sediment supply option for the Magdalen Islands. This paper presents the results of a review of international practices related to offshore sand extraction, with a focus on operational approaches, governance and regulatory structures, and environmental management measures. The objective is to identify key principles and lessons learned that could inform future discussions on the feasibility and applicability of this approach within the Québec and Canadian context, while highlighting the main technical, environmental, and institutional considerations that would need to be addressed prior to any implementation.

OFFSHORE SAND EXTRACTION: CONCEPT AND APPLICABLE TECHNOLOGIES

Offshore sand extraction refers to the removal of unconsolidated sediment from the seabed for the primary purpose of supplying granular material, most commonly for beach nourishment, coastal protection works, or, in some jurisdictions, construction uses. Unlike conventional dredging activities, which are carried out to maintain navigation depths in ports, harbours, and access channels, offshore sand extraction is conducted independently of navigational requirements and targets specifically identified sediment deposits, commonly referred to as borrow areas. In this context, offshore borrow areas function as marine equivalents of terrestrial sand pits.

From a technical perspective, offshore sand extraction typically involves the removal of sandy sediments from subtidal environments beyond the active surf zone, at water depths selected to minimize interference with nearshore coastal processes. The extracted material is then transported hydraulically or with a vessel to designated receiving sites, such as eroding beaches or dunes, or engineered coastal protection works. When used for beach nourishment, the objective is not only to replace sediment lost through erosion but also to enhance the resilience of the coastal system by restoring its morphodynamic processes (dissipation of wave energy through gentler slope, littoral drift, etc.).

The main advantage of offshore sand extraction for coastal protection projects is that it can be planned around sediment needs, allowing volumes, grain size characteristics, and extraction timing to be aligned with the project’s requirements. In opposition, depending on regular maintenance dredging activities are constrained by different factors that influence the availability and volumes of available sediments.

For the Magdalen Islands, offshore sand extraction represents a shift from the current sediment management strategy which mostly relies on importing materials or using dredging leftovers. In theory, the archipelago represents a strong candidate for offshore sand extraction since the surrounding seabed is predominantly sandy. Nevertheless, the applicability of this approach depends on multiple factors, including sediment characteristics, water depth, distance from shore, environmental sensitivity, vessel availability, and regulatory feasibility.

Dredging Technologies Applicable to Offshore Sand Extraction

Beyond the conceptual and geographical considerations discussed in the previous section, the feasibility of offshore sand extraction is inherently dependent on the availability and suitability of dredging methods. Dredge type, sediment handling capacity, and discharge methods govern not only the technical limits of extraction but also project costs, operational flexibility, and environmental performance.

Internationally, offshore sand extraction is generally undertaken using trailing hopper suction dredges (THSDs; see Figure 2), which are self-propelled vessels capable of extracting sediment through suction drag heads mounted on articulated pipes. These vessels temporarily store dredged material in onboard hoppers, allowing partial dewatering during transport before offloading at a placement site or intermediate transfer location. The operational flexibility of THSDs—particularly their ability to operate without fixed connections to shore—makes them well suited to offshore environments and large-scale sediment supply projects. Other dredge types exist but are typically limited to small volumes or site-specific applications and are rarely used for dedicated offshore borrow operations.

Figure 2. 1) Schematic view of a trailing hopper suction dredge (THSD): A) Suction pipe (drag arm). B) Dredge head. C) Hopper for sand dewatering, storage, and fluidization. D) Sand discharge point toward the placement site (WEDA, 2019). 2) Example of a THSD reproduced from Kettle et al. (2018). 3) Illustration of sand unloading using a floating pipeline system (www.floatinghosesllc.com). 4) Illustration of sand unloading using the rainbowing process (www.portsmouth.co.uk)

INTERNATIONAL REGULATORY AND OPERATIONAL FRAMEWORKS

While dredging techniques for sand extraction purposes define the technical feasibility of such activities, their deployment is ultimately governed by regulatory, institutional, and environmental frameworks. International experiences show that offshore sand extraction is not solely used for engineering purposes but can be a regulated coastal management practice that integrates resource stewardship, environmental

protection, and long-term planning. The following subsections summarize the regulatory and operational frameworks in countries where offshore sand extraction is well established.

United States

In the United States, offshore sand extraction for coastal protection purposes is primarily regulated at the federal level by the Department of Interior (DOI) under the Outer Continental Shelf Lands Act (OCSLA). Jurisdiction generally applies beyond state waters (above three nautical miles offshore), where non-biological seabed resources are managed by the federal government.

The Bureau of Ocean Energy Management (BOEM) is responsible for identifying offshore sand borrow areas, issuing permits or leases, and overseeing environmental assessments and monitoring requirements. All permits are issued between two fixed limits: above 3 nautical miles offshore and maximum 50 m depth. Borrow areas are identified through geological, and geophysical investigations, with an emphasis on sediment compatibility, volume availability, and minimal environmental impact. Additionally, the BOEM requires several studies and analysis to start the permitting process, such as a completed environmental impact assessment, all data regarding granulometry, drilling tests, bathymetry, benthos, etc.

Although sand extraction for beach nourishment is regulated similarly to other purposes or materials, leases for coastal protection projects are typically granted on a non-competitive basis and are free, due to their public-interest nature. Over the past several decades, offshore sand extraction has supplied over 125 million m^3 of sediment to beach nourishment projects, establishing it as a well-developed and institutionalized practice. For further information, Elko *et al*. (2021) exhaustively summarizes project management for beach nourishment projects in the United States.

Netherlands

The Netherlands represent one of the most advanced and strategically integrated examples of offshore sand extraction frameworks. Sand resources on the continental shelf are managed at the national level as part of a long-term coastal and sediment management strategy. Needs for sediments are expected to increase proportionally to sea level rise since the country relies on large scale beach nourishments for flood protection.

Designated extraction zones extend from the outer limit of the territorial sea (12 nautical miles offshore) to depths not exceeding 20 m. Annual extraction volumes are substantial: about 30 M m^3 are extracted every year and half of those are used for beach nourishment projects. The authorities recommend extractions deeper than 2 m, even for small-scale projects, as this approach significantly increases the efficient use of sand reserves and has lower impacts on benthic organisms.

Environmental considerations are embedded in the planning process and different criteria are mandatory for the extraction project to be authorized, for instance further from the coast possible to reduce the risk to birds, avoid areas that could impact the longshore sediment transport, extraction solely of sediment crests (and not trough), etc. Additionally, an environmental impact assessment and monitoring program must be prepared in order to obtain a permit. Dutch authorities favor lower-beach nourishments, i.e., at the foreshore level within the closure depth zone, rather than direct discharge on the upper beach to prevent disturbances for beach users, reduce the costs and GHG emissions, and feeds the longshore sediment transport for many years.

Belgium

Exploration and extraction of marine sand and gravel fall under the jurisdiction of the Federal Ministry of the Economy, which retains final decision-making authority but delegates day-to-day management to the Operational Directorate for Natural Environments (DO Nature) through its Scientific Service for the Management Unit of the Mathematical Model of the North Sea (SSUGMM). The SSUGMM is responsible for coordinating multiple uses of Belgian marine waters, including sand extraction, offshore energy production, and aquaculture.

Sand and gravel extraction is permitted only within clearly defined zones established in the 2014 Belgian Marine Spatial Plan (PAEM). These zones are primarily located on submerged sand dune systems composed largely of coarse sand. Sand thickness varies significantly, reaching 20–50 m along dune crests, while interdune areas contain finer, thinner sediment layers. Extraction activities are subject to strict depth limits (< 5 m), and operations exceeding authorized depths have led to temporary or permanent closures of certain zones. In some cases, previously exploited areas have been reclassified for alternative uses, such as seabed disposal, due to insufficient natural recovery following dredging.

The concession permitting process follows the Continental Shelf Act and associated royal decrees. Applicants must submit an environmental impact report, which undergoes technical review, public consultation, and inter-agency coordination through a consultative commission. Environmental assessments focus on seabed alteration, turbidity, contaminant release, impacts on benthic organisms, and potential effects on coastal protection functions. Final authorization is granted or denied by the Federal Minister of the Economy, based on binding advice from the minister responsible for the marine environment. Two types of concessions exist, i.e., ordinary (< 100 000 m^3/month) and extraordinary (> 100 000 m^3/month). Both subject to time constraints, royalties/m^3 extracted, and annual caps determined through governmental review. Since marine sand extraction began in 1976, the majority of extracted material has been used for terrestrial purposes, with coastal nourishment accounting for only a limited share of total volumes.

United Kingdom

In England, offshore aggregate extraction operates within a competitive and commercial framework and includes royalties of about 2,5 CAD \$/m^3 (*The Crown Estate*, 2022). Approximately 12 M m^3 of sand and gravel are dredged annually, accounting for about 20% of the United Kingdom's total sediment demand, with roughly 10% of extracted volumes used for coastal projects such as beach nourishment (UK Parliament, 2010). Marine aggregate extraction began in the 1960s and was initially regulated through a licensing system with limited environmental oversight. Since the late 1980s, however, regulatory requirements have progressively strengthened, and Environmental Impact Assessments are now mandatory for dredging activities likely to produce significant environmental effects.

Since 2007, offshore sand extraction has been subject to an integrated regulatory framework governing marine works, navigation safety, environmental protection, and monitoring obligations. In parallel, the characterization and long-term management of offshore sand resources have evolved significantly. Beginning in 2013, the federal government launched the Key Resource Area initiative to anticipate future sediment needs while minimizing environmental impacts. This program consolidated existing geological information and performed extensive offshore geophysical surveys across four priority regions, providing a more robust scientific basis for identifying and safeguarding high-potential sediment resources.

All offshore aggregate extraction activities in English waters now require a marine license, awarded through a competitive bidding process managed by The Crown Estate within a comprehensive marine spatial

planning framework. Since 2021, the entire English marine area is covered by marine plans designed to balance competing uses and protect sediment resource areas from incompatible developments.

Offshore sand extraction for beach nourishment projects follows the same commercial and regulatory processes as extraction for terrestrial use, with no volumes reserved specifically for coastal protection. Operations are subject to long-term licences, strict environmental monitoring requirements, and are predominantly carried out using (THSDs equipped with continuous vessel positioning systems. Licenses are typically located between 5 and 35 km from the coast at depths between 10 and 40 m.

Canada

In contrast to the jurisdictions described above, no dedicated legislative framework and permitting pathway currently exist in Canada for offshore sand extraction conducted specifically for sediment supply purposes. Federal legislation establishes Canadian ownership of non-biological seabed resources within 200 nautical miles of the coast, while provincial jurisdictions may extend offshore under certain conditions, which introduces uncertainty regarding the regulatory status of marine sand.

The only documented large-scale dredging activity undertaken outside of navigational requirements occurred in Lac Saint-Jean between the 1960s and 1970s, where a total of approximately 1.5 M m^3 of sediment were dredged and used to nourish approximately 60 km of shoreline over 20 years. This project highlighted both technical limitations and geomorphic constraints, particularly related to nearshore extraction and equipment suitability. More recent investigations into subaqueous borrow areas in Lac Saint-Jean were abandoned due to unsuitable sediment characteristics and contamination concerns. Overall, the Canadian experience underscores the absence of an established regulatory and operational framework for offshore sand extraction, reinforcing the relevance of international case studies as a foundation for future discussions in Québec and Canada.

INSIGHTS FROM INTERNATIONAL OFFSHORE SAND EXTRACTION FRAMEWORKS

The review of international experiences in offshore sand extraction highlights a series of recurring principles that transcend national contexts, despite differences in governance structures, coastal settings, and market drivers. Across all jurisdictions examined, offshore sand extraction is treated not merely as a dredging activity but as a managed use of marine resources, requiring long-term planning, regulatory oversight, and coordination with other maritime activities. This perspective supports the development of stable operational frameworks that balance material supply needs with environmental protection and competing uses of marine space.

A first common principle is the central role of public authorities in defining extraction conditions and safeguarding marine resources. In all cases, offshore sand extraction is regulated at the national or federal level, with governments retaining control over access to the resource through permits, licenses, or leases. Extraction zones are spatially delimitated beforehand, often within broader marine spatial planning frameworks, and are subject to explicit limits on depth, extraction thickness, duration, and allowable volumes. These constraints are informed by geological knowledge and are designed to prevent overexploitation and minimize geomorphologic and ecological impacts on the seabed and adjacent coastlines.

Environmental assessment and monitoring constitute a second key pillar shared across jurisdictions. All reviewed frameworks require environmental impact assessments prior to authorization, focusing on seabed alteration, turbidity, benthic habitats, contaminant release, and potential effects on coastal processes.

Importantly, environmental oversight does not end with permitting: long-term monitoring programs are systematically implemented to track seabed recovery, sediment dynamics, and ecological responses during and after extraction. This adaptive management approach allows authorities to refine extraction practices over time and, when necessary, restrict or suspend activities in sensitive areas.

A third common lesson concerns the operational standardization of offshore sand extraction. Despite the availability of different dredging methods, large-scale offshore extraction is overwhelmingly carried out using trailing hopper suction dredges. This convergence reflects the vessels' operational flexibility, efficiency, and suitability for offshore environments, as well as their compatibility with regulatory requirements for volume control, positional accuracy, and environmental monitoring. Similarly, approaches to sediment discharge, whether through pipelines or direct release, are selected based on project objectives and environmental constraints, reinforcing the importance of integrating engineering choices into regulatory and environmental decision-making.

Finally, international experience demonstrates that offshore sand extraction is most effective when embedded within a long-term resource management strategy rather than treated as a short-term supply solution. The frameworks developed by the countries discussed in the previous section have all invested heavily in resource characterization, data consolidation, and forward-looking planning to ensure the continued availability of compatible sediments. These efforts underscore the importance of predictability, scientific knowledge, and institutional coordination in supporting sustainable offshore sand extraction practices that contribute meaningfully to coastal adaptation and infrastructure resilience.

TOWARD A QUÉBEC AND CANADIAN FRAMEWORK FOR OFFSHORE SAND EXTRACTION

Based on the insights from international frameworks, WSP developed a methodology for a potential framework for offshore sand extraction for coastal protection projects, from concept development to implementation. This methodology aims to consider not only the existing regulations and the MTMD project requirements, but also site-specific uncertainties. The methodology consists of five phases:

Phase 1: Opportunity Study (Concept)

Aims to identify potential offshore sediment sources, define applicable regulatory and permitting pathways, and international best practices, and develop a preliminary sand extraction strategy, including preliminary cost estimates.

Phase 2: Preliminary Design (Pre-feasibility)

Aims to confirm suitable sediment sources through field investigations, initiate discussions with authorities, refine the sand extraction strategy, and improve cost estimates based on confirmed conditions.

Phase 3: Detailed Preliminary Design (Feasibility)

Aims to start the environmental permitting and regulatory processes, complete an environmental impact assessment (including all studies demanded by the authorities), update sand extraction and beach nourishment concepts, and develop preliminary designs and cost estimates for authorization.

Phase 4: Detailed design (Plans and Specifications)

Aims to finalize engineering designs (both dredging and beach nourishment), complete additional environmental authorization requirements, and prepare final plans, specifications, and cost estimates.

Phase 5: Construction

Execution of the offshore sand extraction and beach nourishment works, including technical and environmental monitoring during the works and post-construction long-term monitoring program.

Figure 3 presents the different phases described above.

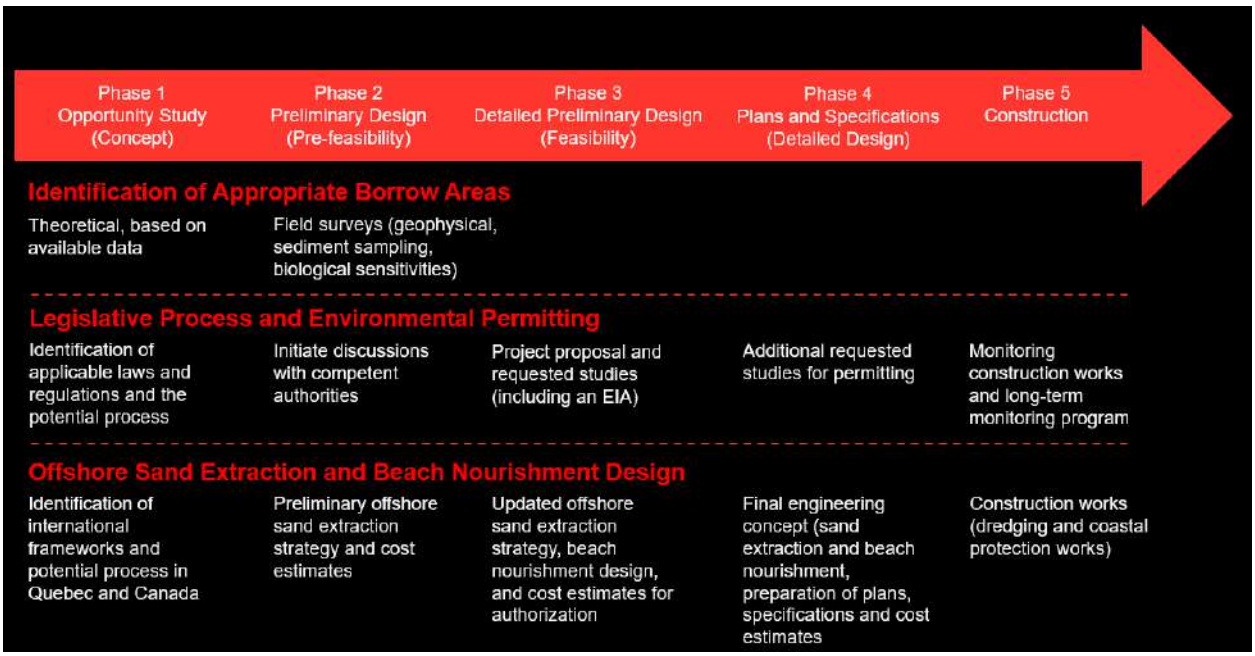

Figure 3. Summary of the different phases for an offshore sand extraction project for beach nourishment

Earlier phases focus on identifying potential offshore borrow areas using available data and criteria related to water depth, distance from shore, expected sediment characteristics, and compatibility with coastal protection needs. In parallel, consultation with provincial and federal authorities is required to clarify applicable legislative thresholds, define authorization pathways. At this stage, the objective is not to secure approvals but rather to align expectations and establish a shared understanding of regulatory and permitting requirements.

As the project advances toward pre-feasibility and feasibility, the emphasis shifts towards reducing borrow areas uncertainty through technical and environmental studies. These include geophysical surveys, sediment sampling, and assessments of environmental sensitivity, which will allow for the development of a preliminary dredging strategy. Given the absence of a predefined regulatory pathway, it is highly likely that offshore sand extraction projects would be subject to both provincial and federal environmental impact assessment processes. Presenting offshore sand extraction and beach nourishment activities within a multi-year framework could improve regulatory efficiency by reducing the need to repeat full

environmental impact assessments for each individual intervention, similar to the approach already applied to long-term maintenance dredging programs authorized in Québec.

APPLICABILITY TO THE MAGDALEN ISLANDS: KNOWLEDGE GAPS

While international experience demonstrates that offshore sand extraction can be implemented as a structured and regulated sediment supply strategy, its applicability in the Magdalen Islands is yet to be confirmed. The archipelago presents a distinct physical, ecological, and socio-economic context that requires a site-specific assessment. Based on the review of international practices, three main categories of knowledge gaps must be addressed to evaluate the feasibility of offshore sand extraction as a future option for coastal protection in the archipelago.

Sedimentological and Technical Feasibility

The feasibility of offshore sand extraction around the Magdalen Islands depends primarily on the presence of suitable sediment deposits that can be extracted efficiently and sustainably. Although the seabed surrounding the archipelago is generally sandy, critical information remains limited regarding sediment grain size distributions, thickness and spatial continuity of deposits, and potential volumes available for extraction. Compatibility between borrow material and beach sediments is also essential to ensure the effectiveness and durability of nourishment projects.

In addition to sediment characteristics, operational constraints must be evaluated, including water depths suitable for THSD, distance between potential borrow areas and project sites, and exposure to waves and currents. Understanding regional coastal dynamics (closure depth, sediment transport pathways, and storm-driven sediment transport) is also key to avoid extraction that could negatively affect nearshore morphodynamics or existing sediment budgets. Detailed geological, geophysical, and hydrodynamic studies are therefore required to determine technical feasibility.

Environmental and Social Considerations

Environmental considerations represent fundamental components in assessing offshore sand extraction for the Magdalen Islands. The surrounding marine environment supports diverse and productive ecosystems, and several areas may be environmentally sensitive or legally protected. Current key uncertainties concern the distribution and sensitivity of benthic habitats, including benthic high density and diversity hotspots, and habitats supporting commercially important species, highly frequented areas for fishing activities, and marine protected areas. Further uncertainties concern the existing or future marine structures, for instance submarine cables, shipwrecks, and unexploded ordnances (UXO), and navigation routes.

Economic considerations

In addition to technical and environmental considerations, the economic viability of such a project remains to be determined for the Magdalen Islands context. The multiple cost estimates undertaken during the four first phases serve as guidelines to determine if this solution could be a cost-effective one. The costs associated with mobilization, operation, environmental impacts, and monitoring must therefore be weighed against the benefits of securing a predictable local sediment supply for future coastal protection needs, especially in the context of climate change.

CONCLUSIONS

This paper examined offshore sand extraction as a potential long-term sediment supply strategy for coastal protection projects in the Magdalen Islands, in a context of accelerating erosion, increasing intervention

needs, and limited local material availability. Existing frameworks in other countries show that offshore sand extraction is a well-developed practice when supported by clear regulatory and permitting processes, targeted extraction zones, and thorough environmental assessment and monitoring programs. In countries where it has been successfully implemented, offshore dredging is embedded within long-term sediment management and coastal adaptation strategies rather than treated as isolated dredging activities.

The applicability of this approach to the Magdalen Islands remains contingent on addressing several critical knowledge gaps. These include the geological and sedimentological suitability of offshore deposits, potential environmental and biological constraints, and the operational realities of dredging in an exposed insular environment. Moreover, the absence of a dedicated regulatory framework for offshore sand extraction in Québec and Canada represents a fundamental issue that would need to be resolved through early regulatory coordination and consultation with all parties involved.

From a longer-term perspective, decisions regarding offshore sand extraction will ultimately need to be informed by comparative economic considerations. Assessing this option compared to current practices, largely characterized by emergency-driven interventions, opportunistic use of locally dredged sediments, and reliance on imported materials, will be essential. While offshore sand extraction may offer greater predictability in sediment supply, its relevance for coastal adaptation in the Magdalen Islands will depend on nourishment demand, operational scale, and the regulatory conditions under which such activities could be authorized. Viewed in this context, offshore sand extraction should not be considered an immediate solution, but rather a potential component of an integrated, long-term strategy aimed at enhancing the resilience of critical coastal infrastructure such as Road 199 in the face of ongoing climate change.

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STAKEHOLDER AND INDIGENOUS ENGAGEMENT FOR A CANADIAN SHORELINE REMEDIATION

E. Crawford[1], J. Low[2], L. Persowich[3], F. Wong[4], Amy Corp[5], and M. Larsen[6]

EXTENDED ABSTRACT

Victoria Harbour is a large working harbour located on the southern tip of Vancouver Island, British Columbia, with a long history of impacts from shipbuilding, mills, coal storage and gasification, and manufacturing. Transport Canada (TC) operates the Public Port of Victoria and manages a variety of uses, including a water airport, industry, a cruise ship terminal, recreational vessels (whale watching tours), float homes, and public recreational use. It was identified as a Class 1 Contaminated Site (high priority for action) by the Government of Canada and is being remediated by TC through the Federal Contaminated Sites Action Plan program. The programmatic remedial strategy identified for the site includes a phased approach of early actions for hazardous waste-level contamination, secondary remediation of shorelines with lower levels of contamination, and monitored natural recovery of most of the harbour. Victoria Harbour is part of the traditional territory of Esquimalt Nation and Songhees Nation, who have been engaged throughout the development of the remedial strategy.

One shoreline targeted for remediation as part of this phased approach is the Cecelia Cove shoreline. Cecelia Cove and the adjacent uplands were historically used for lumber mill operations from the mid-1800s to the late 1980s. Contaminants include dioxins/furans, polycyclic aromatic hydrocarbons (PAHs), and pentachlorophenol.

In 2019, TC worked with Esquimalt Nation and Songhees Nation on a Traditional Knowledge Traditional Use study. During that study, Esquimalt Nation and Songhees Nation members observed heavy pollution at this shoreline, including oil sheen, odour, wood waste, poor beach quality, and unhealthy marine resources. Workshops are being held with the First Nations' marine teams to understand future shoreline uses, desired target species for habitat restoration, and areas of cultural significance for incorporation into the conceptual design. The remediation strategy at this shoreline will continue to be discussed with

[1] Senior Regional Environmental Supervisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada, Email: eric.crawford@tc.gc.ca T: 604-360-9440
[2] Regional Environmental Advisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada, Email: jessica.low@tc.gc.ca T: 236-330-2687
[3] Environmental Specialist, Environmental Services and Contaminated Sites Management, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada, T: 778-955-7358, Email: laurel.persowich@pwgsc-tpsgc.gc.ca
[4] Senior Environmental Specialist, Environmental Services and Contaminated Sites Management Pacific Region, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada, T: 236-330-4105, Email: fiona.wong@pwgsc-tpsgc.gc.ca
[5] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.
[6] Principle Scientist, Anchor QEA, 949 Market Street, #700, Tacoma, Washington 98402, USA, T: 206-903-3359, Email: mlarson@anchorqea.com

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Esquimalt Nation and Songhees Nation as the design continues, and their input will continue to be incorporated into the planning and design.

In addition to engagement with Indigenous communities, stakeholder coordination will be discussed. Stakeholders at this site include the upland developer, the municipality, regional departments, and provincial departments who own the beach park, overwater walkway, and heavily utilized biking trail; the three rowing clubs and schools with floats within the remediation area; engaged environmental groups; and the public. The strategy for stakeholder engagement will be discussed, including example products to help convey TC's vision while managing expectations given the constraints of the federally funded program.

Keywords: Contamination, sediment, First Nations, stakeholders, working harbour.

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MANAGEMENT OF A CANADIAN WORKING HARBOUR: VICTORIA HARBOUR PROJECT OVERVIEW

E. Crawford[1], J. Low[2], L. Persowich[3], F. Wong[4], A. Corp[5], and M. Larsen[6]

ABSTRACT

Victoria Harbour is a large working harbour located on the southern tip of Vancouver Island, British Columbia. The harbour has a long history of impacts from shipbuilding, mills, coal storage and gasification, and manufacturing. Transport Canada operates the Public Port of Victoria and manages a variety of uses, including a water airport, industry, a cruise ship terminal, recreational vessels (whale watching tours), float homes, and public recreational use. It was identified as a Class 1 Contaminated Site (high priority for action) by the Government of Canada and is being remediated by Transport Canada through the Federal Contaminated Sites Action Plan program. The remedial strategy identified for the site includes a phased approach of early actions for hazardous waste-level contamination, secondary remediation of shorelines with lower levels of contamination, and monitored natural recovery of most of the harbour. This overall approach considered the status of the site as a working harbour, realistic cleanup goals, and the long-term sustainability of the remedy given harbour uses. Victoria Harbour is part of the traditional territory of the Esquimalt Nation and Songhees Nation, who have both been engaged throughout the development of the remedial strategy.

Early action remediations were implemented at two sites between 2004 and 2018. At Rock Bay, historical coal tar releases prompted remediation using a coffer dam, which resulted in the removal or treatment of over 90,000 tons of material and restoration of over 5,800 square metres of intertidal and shallow subtidal substrate. In Middle Harbour, legacy polychlorinated biphenyl (PCB) contamination was identified in two localized areas and addressed through dredging. Following remediation and confirmatory sampling, results indicated that sediment contamination in both areas was reduced and that these areas no longer pose a risk to humans or the environment.

[1] Senior Regional Environmental Supervisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada
[2] Regional Environmental Advisor, Programs Transport Canada, Western and Yukon Region, Government of Canada, 800 Burrard St, Vancouver, BC V6Z 0B9, Canada
[3] Environmental Specialist, Environmental Services and Contaminated Sites Management, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada
[4] Senior Environmental Specialist, Environmental Services and Contaminated Sites Management
Pacific Region, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada
[5] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.
[6] Principle Scientist, Anchor QEA, 949 Market Street, #700, Tacoma, Washington 98402, USA, T: 206-903-3359, Email: mlarson@anchorqea.com

The project is currently focusing on the refinement of a harbour-wide Source Control and Sediment Management Plan, which outlines remedial strategy options identified for the remaining areas of the harbour. The preferred option is a compilation of harbour-wide actions and discrete shoreline remediations. Harbour-wide remedial actions include priority stormwater source control, sanitary waste controls, implementation of the Environmental Protection Review program, and monitoring of natural recovery within the harbour. Targeted shoreline remediations are being evaluated, including dredging and capping at several shorelines, one of which is currently anticipated to be implemented in the next few years.

Keywords: Dredging, remediation, contamination, risk, restoration

INTRODUCTION

Located on the southern end of Vancouver Island in British Columbia, Canada, Victoria Harbour is an active working harbour administered by Transport Canada (TC) and one of Canada's designated Public Ports (Figure 1). The harbour is currently undergoing source control efforts and targeted remediation planning is underway as part of the Victoria Harbour Floor Project (the Project) to address historical and ongoing sources of contamination.

The harbour is part of the traditional territories of Esquimalt Nation and Songhees Nation, whose members trace their ancestry to the Coast Salish lək'wəŋən people, who have occupied southern Vancouver Island for thousands of years (Kennedy 2006). The lək'wəŋən people harvested fish (particularly salmon and herring), shellfish, marine plants, waterfowl, marine mammals, deer, camas, berries, and other resources from the harbour and surrounding areas in their traditional territory (Esquimalt Nation 2014; Victoria Harbour History Project 2017). Marine resources are central to Esquimalt Nation and Songhees Nation's ways of life and remain important for food, social, cultural, and ceremonial reasons (Hemmera 2019, 2021). First Nations members no longer officially harvest within Victoria Harbour, primarily due to concerns with contamination from urban and industrial pollution, as well as fishery closures and declining abundance of marine resources (Hemmera 2019). Esquimalt Nation and Songhees Nation have been engaged throughout the development of the remedial strategy.

Victoria Harbour has been a busy commercial and industrial harbour since the mid-1800s. Historical commercial and industrial uses included ship building, sawmills, tanneries, machine shops, coal storage, coal gasification, railroad and navigation terminal operations, warehouses, lumber yards, paint manufacturing, and various other types of manufacturing. Victoria Harbour is currently a working harbour with a mix of residential, commercial, industrial, and recreational land uses. Industrial land uses continue to occur along the harbour shoreline in several areas, including active sand and gravel operations, shipyard and ship repair activities, and metals recycling. Hotels, restaurants, public walkways, residential areas, marinas, and marine terminals are located along much of the Inner and Outer Harbour shorelines.

Current navigation uses of the harbour include operation of recreational vessels (from kayaks and small boats to large yachts and tour boats), ferries, commercial vessels (e.g., tugs and barges, fishing trawlers, and vessels visiting the Point Hope Shipyard), large cruise ships berthing in the Outer Harbour, and government vessels (e.g., Coast Guard vessels). In addition to the diverse mix of navigation uses, the Victoria Inner Harbour Aerodrome is used by seaplanes. It is the most active seaplane aerodrome in Canada.

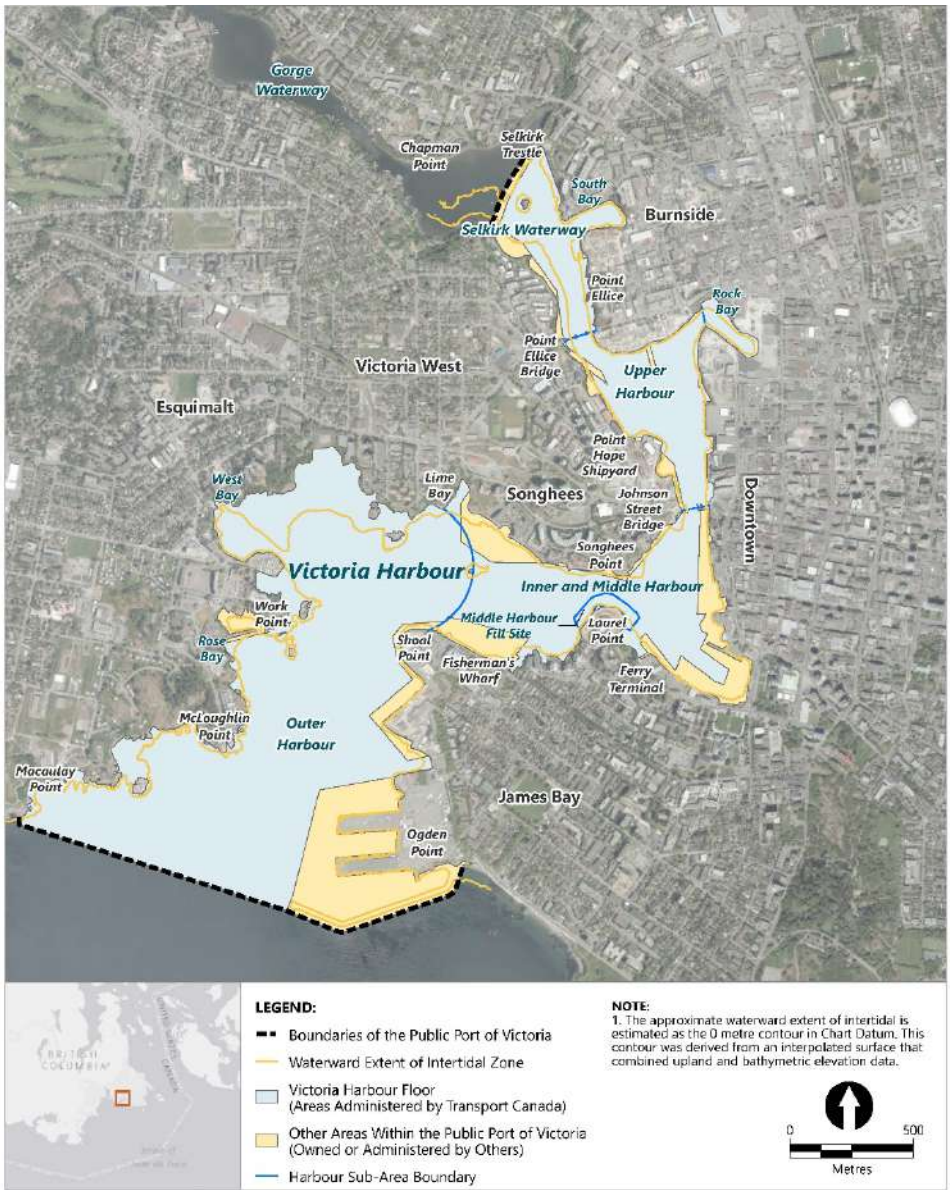

Figure 1. Victoria Harbour

Victoria Harbour was identified as a Class 1 Contaminated Site (high priority for action) by the Government of Canada and is being remediated by TC through the Federal Contaminated Sites Action Plan (FCSAP) program. The main goal of FCSAP is to reduce environmental and human health risks from known federal contaminated sites and associated financial liabilities. The Project is a TC-led contaminated sites initiative with the goal of achieving environmental protection while sustaining the working harbour. Over the past 30 years, TC has been working to improve and protect environmental conditions of the Victoria Harbour seafloor. The Project includes development and implementation of a remedial strategy that will reduce and control levels of pollutants in sediments and associated sea life.

Project work completed to date has included decades of environmental testing, completion of an Ecological Risk Assessment (ERA) and Human Health Risk Assessment (HHRA), technical studies, initiation of source control coordination, targeted remediation of the Rock Bay and Middle Harbour Fill Site (MHFS)

areas (Figure 2), and environmental monitoring. Overall, this work has shown that harbour floor sediment is recovering, but additional actions may be needed to reduce environmental risks for all users. Recent work in the harbour has focused on furthering the understanding of potential risks in the harbour and ways to address the remaining risk.

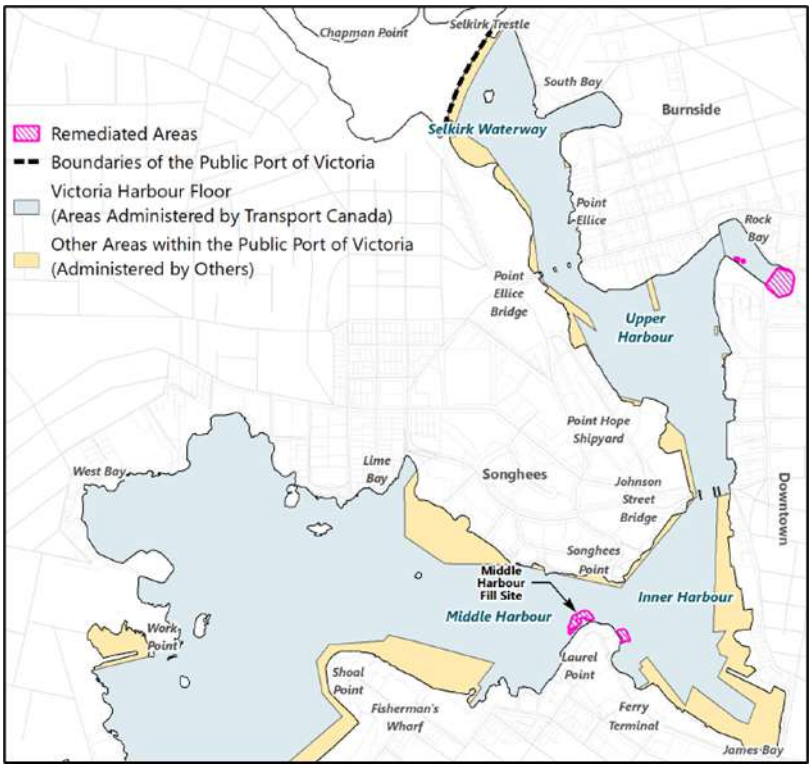

Figure 2. Previously remediated areas of Victoria Harbour.

PREVIOUS REMEDIATIONS IN VICTORIA HARBOUR

Following identification of sediment contamination hotspots through harbour floor studies and risk assessment activities in the late 1990s and early 2000s, TC conducted two targeted remediation (early action) projects at Rock Bay and MHFS. The locations of these previously remediated areas of Victoria Harbour are shown on Figure 2.

Rock Bay Remediation Project

The Rock Bay Remediation Area was previously identified by TC for remediation to address legacy contamination in soils, groundwater, and marine sediments associated with the operation of a historical coal gasification facility and other historical industry activities. The work was initiated to address areas of hazardous waste and areas exceeding project objectives as defined in the Revised Recommended Remedial Strategy for the Rock Bay Site (Golder 2003). Over 90,000 tons of material was treated or disposed of during this effort and over 5,800 square meters (m^2) of intertidal and shallow subtidal substrate was restored (Figure 3). Final sediment remediation activities were completed in 2016. Much of the Rock Bay work involved the aggressive removal of subsurface sediment and soil contamination through the use of a coffer dam. Remediation activities greatly reduced the amount of contaminants of concern (COCs) present locally and reduced the risk of the movement of COCs throughout the harbour.

During development of the Rock Bay Remediation Project, TC undertook source control coordination efforts with the City of Victoria to address pollution from City outfalls 626 and 627. These two large outfalls discharge at the head of Rock Bay and were identified as contributing substantial pollutant loads to the harbour. In relation to these outfalls, the City of Victoria continues to monitor stormwater and sediments, and undertake source tracing and source control work as necessary to respond to identified pollution.

Figure 3. Remediation at Rock Bay

Middle Harbour Fill Site Remediation Project

Between 2017 and 2018, TC conducted remediation in the nearshore area of the MHFS, which was impacted by legacy pollution associated with operations of a historical paint factory. Elevated pollutant levels had been identified in the sediments, fish, and other aquatic organisms at the site, and elevated ecological risks had been identified for birds.

The selected remedial action for the site included sediment removal of hazardous wastes and other sediment contaminated by polychlorinated biphenyls (PCBs), dioxins and furans (D/F), heavy metals, and carcinogenic polycyclic aromatic hydrocarbon (cPAH) compounds. The removed materials were transported off site for treatment/disposal followed by backfill with clean sediment and placement of an enhanced natural recovery layer to control dredging residuals.

The site work also included an upland component that consisted of excavation of contaminated soils and backfill with clean soils (Figure 4). The work resulted in significant reductions in surface sediment concentrations of PCBs, D/F, lead, and cPAH compounds. A post-remediation risk assessment (Anchor QEA 2020) documented that the remediation was consistent with the objectives established in the Options Analysis and Remedial Action Plan/Risk Management Plan (Anchor QEA 2016).

DEVELOPMENT OF A REMEDIAL STRATEGY

The remedial strategy for the harbour was developed based on data evaluations conducted as part of a decades-long investigation into harbour sediment, water, and sea life tissue chemical concentrations. These

data were used to inform human health and ecological risk modeling, which in turn allowed for the development of remedial objectives and a long-term management plan for the harbour. A conceptual site model for Victoria Harbour is presented in Figure 5.

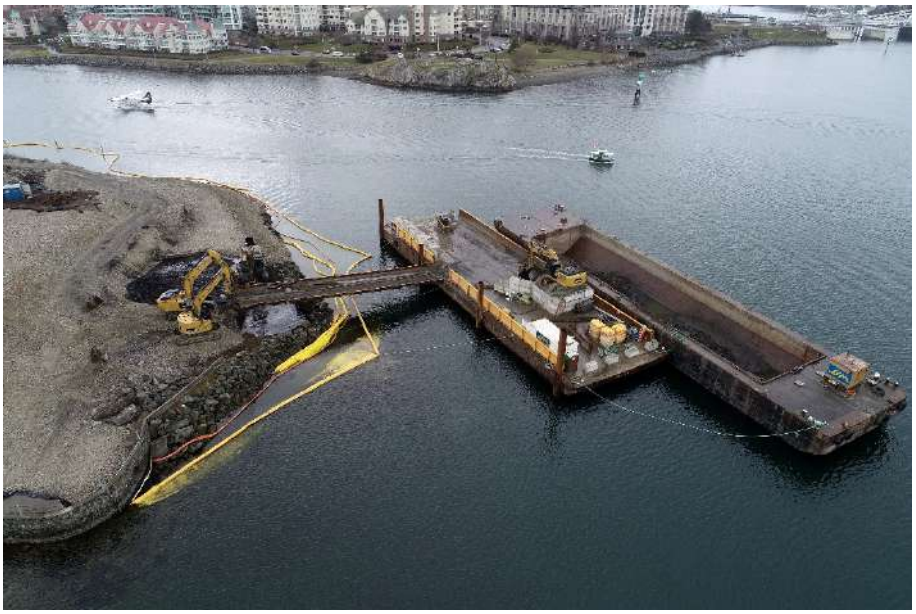

Figure 4. Active remediation at Middle Harbour Fill Site

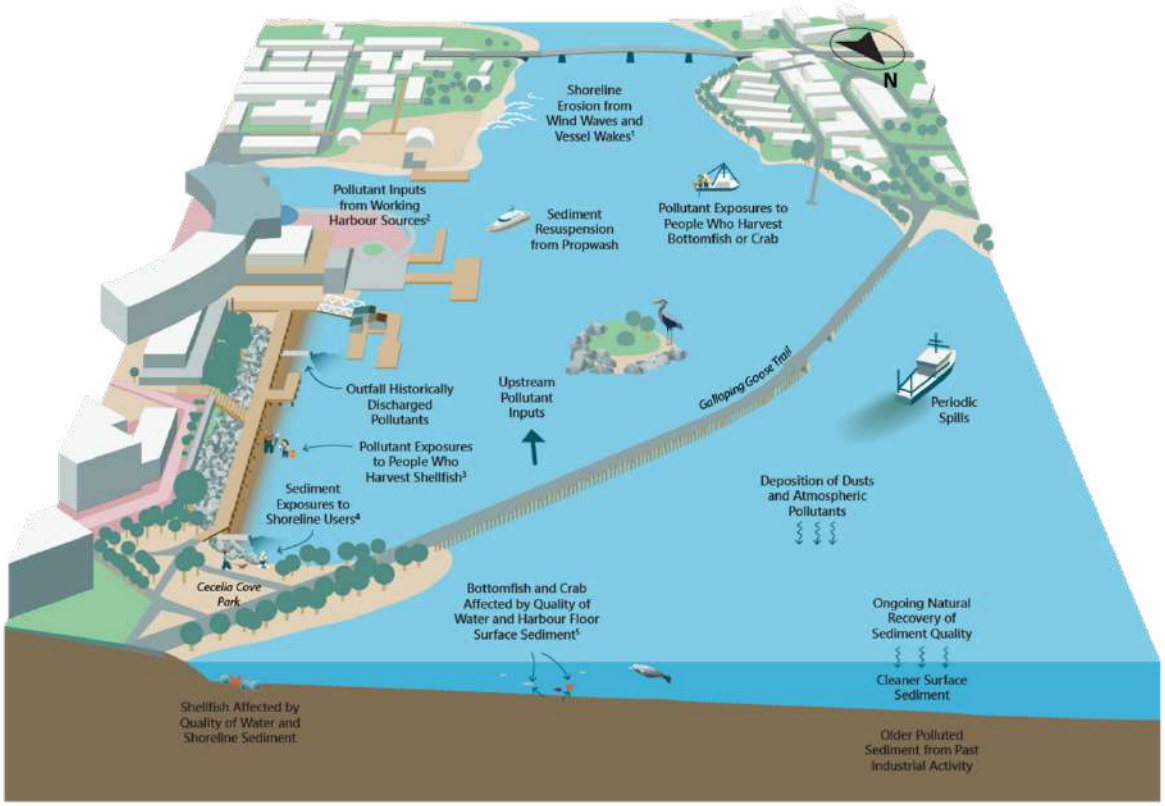

Figure 5. Conceptual site model of Victoria Harbour

Human Health Risk Assessment

A HHRA was conducted to evaluate the pathways by which humans may come into contact with potentially harmful chemicals in the environment (Anchor QEA 2022). The HHRA focused on different uses of the harbour, such as visiting the beaches or eating sea life from the harbour, and the potential health risks associated with exposure to pollutants. Primary exposure routes identified in the HHRA include swimming (exposure to pollutants in the water by accidentally drinking the water or absorption through the skin), beach use (exposure to pollutants in the sediment [sand] through touching or accidentally ingesting polluted sediment), and sea life consumption (exposure to pollutants by eating sea life that have accumulated pollutants in their tissues). A graphic representation of exposure routes is presented in Figure 6.

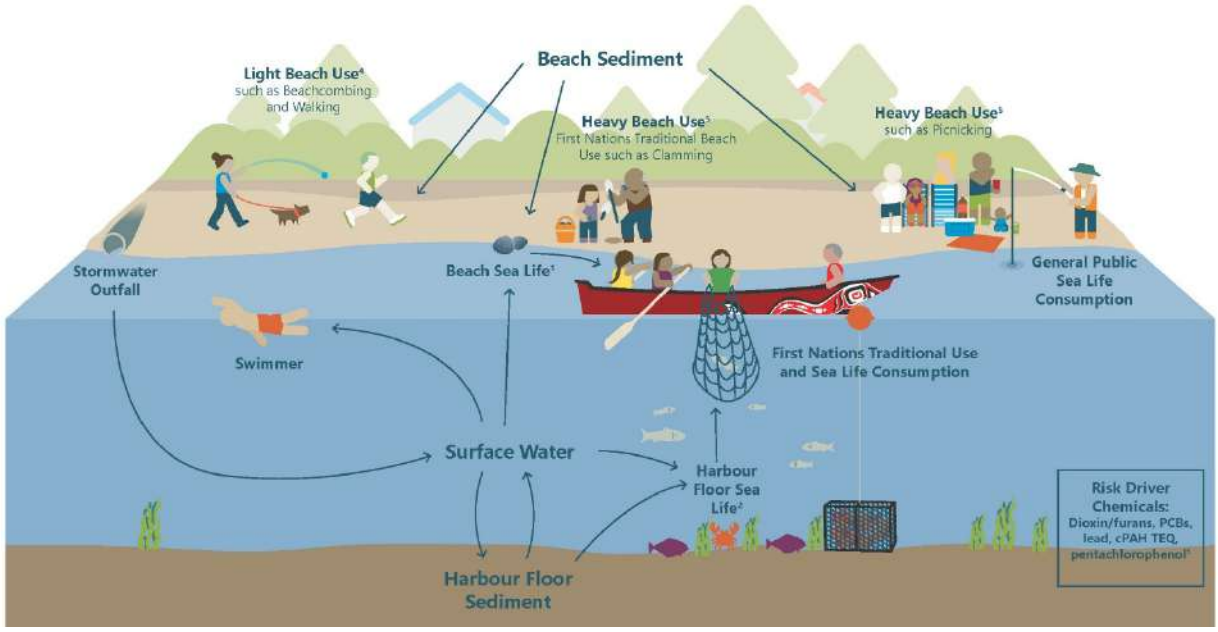

Figure 6. Human health exposure pathways and receptors as identified in the HHRA.[7]

Although swimming is prohibited in the harbour, the HHRA evaluated potential risks associated with inadvertent contact with harbour surface water. The assessment found that chemical concentrations in surface water were below Canadian drinking water screening levels and do not pose a risk to beach users

7. Figure Notes:
1. Beach sea life includes clams, mussels, oysters, chiton, and seaweed.
2. Harbour floor sea life includes crabs, octopus, urchin, seaweed, shrimp, and bottomfish.
3. Extensive chemical testing has been completed for the Victoria Harbour floor. Risk driver chemicals were identified for sediment as those site-related chemicals resulting in cancel risks or non-cancer hazards above acceptable levels and for sea life as those site-related chemicals resulting in cancer risks or non-cancer hazards above acceptable levels in multiple scenarios and/or that exceed acceptable risk levels in any one sea life exposure scenario by a factor of two or greater.
4. Light use includes low-contact activities (such as beachcombing and walking) in which only hands may contact sediment.
5. Heavy use includes high-contact activities in which hands, arms, and legs may contact sediment.

and swimmers. Because chemical pollutants were below screening levels in surface water, the risk assessment does not evaluate swimming further.

The HHRA evaluated risks associated with beach use, including dermal contact with contaminated sediments. The assessment found generally acceptable risks for beach users throughout the harbour on a limited basis. However, site-associated health risks were unacceptable for individuals participating in frequent activities (i.e., 5 days per week) at certain beaches located in the Inner Harbour, Upper Harbour, and Selkirk areas of the harbour floor.

The HHRA evaluated potential risk associated with consuming a mixed diet of sea life, as well as risks associated with consuming a single type of sea life, such as clams or crabs, throughout the year. Three consumption scenarios were evaluated: one recreational scenario, and two First Nations scenarios. First Nations' harvesting and consumption were evaluated using two separate scenarios, both considering harvests from all locations in the harbour. Across all scenarios, the HHRA identified risk from consumption of portions of the mixed diet and from consumption of some individual sea life types.

In addition to chemical contamination, some areas of the harbour have also been identified to have elevated levels of fecal indicator bacteria (FIB), which pose a health risk to humans through direct contact and consumption of contaminated shellfish (a sanitary bivalve closure has been maintained in Victoria Harbour for decades in response to elevated bacterial concentration[8]). Sources of sanitary contamination have been traced to stormwater outfalls affected by improper sewage connections. Other sources include illicit discharges from vessels and animal feces entering the harbour.

Ecological Risk Assessment

After more than a decade of study and two rounds of FCSAP Expert Support Review, the 2014 Final Ecological Risk Assessment (ERA) for the harbour floor was completed (Azimuth and SLE 2014). The ERA provides a baseline assessment of ecological risks present at that time prior to implementation of subsequent remediation activities. The receptors evaluated in the ERA and ERA Addendum (Anchor QEA 2021) included benthic communities (invertebrate communities living in the harbour floor sediments), fish, mammals, reptiles, and birds.

The 2014 ERA documented that most of the harbour's ecological receptors have negligible to low risk, with the exception of benthic communities in South Bay, fish throughout the harbour, and birds throughout the harbour. Uncertainty associated with low-to-moderate risks identified for fish and birds were generally high. Additional studies were conducted to refine the understanding of risks to fish and birds (Anchor QEA 2021). Risks to fish were refined with additional fish tissue testing. Results of fish testing confirmed that risks to fish from chemical contaminants were in fact negligible. Risks to birds were further evaluated using a refined food chain model, incorporating data from recent fish and shore crab testing. Risks to great blue heron were confirmed to be negligible throughout most of the harbour but were higher in certain portions of the harbour (i.e. MHFS) that were subsequently targeted for remediation.

[8] Fisheries and Oceans Canada maintains a closure to bivalve harvests within Area 19.1 due to sanitary contamination concerns.

Remedial Objectives

Project goals for the harbour include reducing human health and ecological risks and associated liabilities while sustaining working harbour uses, aligning source control efforts, preventing recontamination, and respecting TC's ongoing relationship with local First Nations and the broader community. Having developed a thorough and comprehensive conceptual site model, remedial objectives that serve these goals were defined based on findings of previous investigations, the HHRA, and the ERA.

Remedial Options Analysis

A Remedial Options Analysis (ROA) was conducted (Anchor QEA 2023) to evaluate the strategies available to achieve the remedial objectives and select a preferred remedy. The first step in the ROA was development of candidate remedial actions. Actions are made up of two parts, the "what" of the action and the "where." Candidate actions were developed by identifying a proven technology capable of application in Victoria Harbour. Then, different areas for application of candidate remedial technologies were screened. These included harbour-wide areas, shoreline beach areas, and subtidal harbour areas. Targeted remedial areas (shorelines and subtidal) were evaluated for their ability to contribute to human health risk reduction if remediated. Together, screening of applicable technologies and of target areas resulted in a suite of potential remedies which then underwent a scoring process based on 1) progress toward reducing risk for sea life consumption or beach use, 2) benefits score of each action, including how well each action aligns with TC's project goals and vision for the harbour, and 3) cost-effectiveness of the action. A selected remedy was then carried forward into more detailed harbour-wide planning documentation.

LONG-TERM PLANNING

Development of the SCSMP

The overall harbour-wide plan, known as the Source Control and Sediment Management Plan (SCSMP) will direct future remediation activities within Victoria Harbour. Alongside proposed shoreline cleanups, the SCSMP describes other major remedial components including source tracing and source control measures to identify and eliminate ongoing sources of contamination to the harbour as well as long-term monitoring to track harbour recovery (Figure 7). This overall approach considers the status of the site as a working harbour, realistic cleanup goals, and the long-term sustainability of the remedy given harbour uses.

Figure 7. Sources of contamination to Victoria Harbour and solutions for controlling inputs.

Following selection of the preferred remedy, the SCSMP was developed to guide long-term remediation throughout the harbour. The SCSMP builds on the high-level remedy identified in the ROA and satisfies the risk management/remedial strategy requirement of Step 7 of the FCSAP guidance. The plan incorporates information and feedback from Esquimalt Nation and Songhees Nation throughout the process to date and TC will continue to solicit feedback from both Nations moving forward.

The SCSMP will identify potential locations to receive additional targeted remediation, building on previous successful remediations at Rock Bay and MHFS. Active remediation involves removal of contaminated sediments via mechanical dredging, and placement of clean backfill (capping) at some areas. The use of an activated carbon amendment within cap material is also proposed in certain areas to further isolate contamination. One of the areas identified for early action under the SCSMP is the Cecelia Cove Shoreline.

Cecelia Cove Shoreline

Historically, the Cecelia Cove shoreline was used for log booming and barge tie-ups (SLE 2010). Currently, this shoreline is adjacent to a park with a boardwalk and rowing/paddling floats. The Cecelia Cove shoreline was selected for early action remediation ahead of harbour-wide actions due to the presence of elevated concentrations of chemical contaminants (dioxin/furans and PAHs) in sediment and clam tissue. The planned remediation will remove this contamination and prevent potential unacceptable human health exposures (Figure 8). Additionally, Esquimalt Nation and Songhees Nation identified the site as one of the most contaminated shorelines in Victoria Harbour during the 2019 TKTU study, and both have recommended that the cleanup of the shoreline be prioritized.

Currently, design is under way with an anticipated construction timeframe of 2028-2029. The proposed remediation follows the previous successful shoreline cleanups conducted by TC at Rock Bay and the MHFS. The project proposes removing polluted sediment through dredging and placing clean beach materials to restore the beach. The clean material would improve habitat quality, and portions of the beach will be capped to stabilize the shoreline and prevent recontamination. Monitoring will be conducted after construction to document that remediation goals are achieved. The project is expected to improve environmental quality of the harbour floor.

Figure 8. Current (left) and predicted future (right) conditions at Cecelia Cove Shoreline.

Harbour-wide Actions

Together with targeted remediation, harbour-wide actions are anticipated to reduce the amount of contamination present in the harbour. Harbour-wide actions include priority stormwater source control, sanitary waste controls, Environmental Protection Review implementation, and harbour floor monitoring.

Harbour-wide actions complement targeted remediations to form a comprehensive plan for improving environmental quality in the harbour.

Priority Stormwater and Sanitary Waste Source Control

There are 95 stormwater outfalls that drain directly into Victoria Harbour from either the City of Victoria or Township of Esquimalt. These outfalls have the potential to contribute chemical and sanitary contamination to harbour surface water and sediments. TC has reviewed stormwater monitoring data and ranked outfalls based on the hazards they pose to the health of the harbour. TC is coordinating with upland infrastructure owners to limit inputs to the harbour through regular monitoring of problematic outfalls, source tracing, and source control.

Environmental Protection Review Implementation

Under the Canada Marine Act and the Public Port and Public Port Facility Regulations, TC's designated Port Official is responsible for prohibiting activities that pollute soil, sediment, or water within the boundaries of the Public Port. To support this responsibility, TC developed Environmental Protection Reviews (EPRs), which are a science-based assessment of proposed projects used to evaluate the potential for soil, sediment, or water pollution within the Public Port.

Project activities that require mitigation measures include the following:

- Dredging
- Expanded commercial navigation
- Placement or removal of utilities (e.g., water, power, telecommunications, transportation, or other similar services) or outfall conveyances (e.g., stormwater pipes and tunnels)
- Shoreline modifications
- Stormwater and other discharges
- Structure construction or removal

TC conducts EPRs to review proposed working harbour activities undertaken by other parties (e.g., dredging and modifications to shorelines) and identify appropriate mitigation measures to prevent pollution of Victoria Harbour. TC's Port Manager, with support from TC environmental staff, has been conducting EPRs for more than a decade in compliance with regulatory requirements.

Harbour Floor Monitoring

In Victoria Harbour, natural processes are improving the environmental quality of the subtidal portions of the harbour floor. These processes principally include burial and mixing by cleaner sediments, contaminant immobilization through weathering and geochemical processes, and destruction of contaminants through natural biodegradation processes. Harbour floor monitoring refers to the monitoring of beneficial effects of natural recovery processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants (USEPA 2005). The ability of the harbour floor to recover naturally has been evaluated through multiple lines of evidence including geochronology, modeling, and temporal trends over decades of data collection (Figure 9).

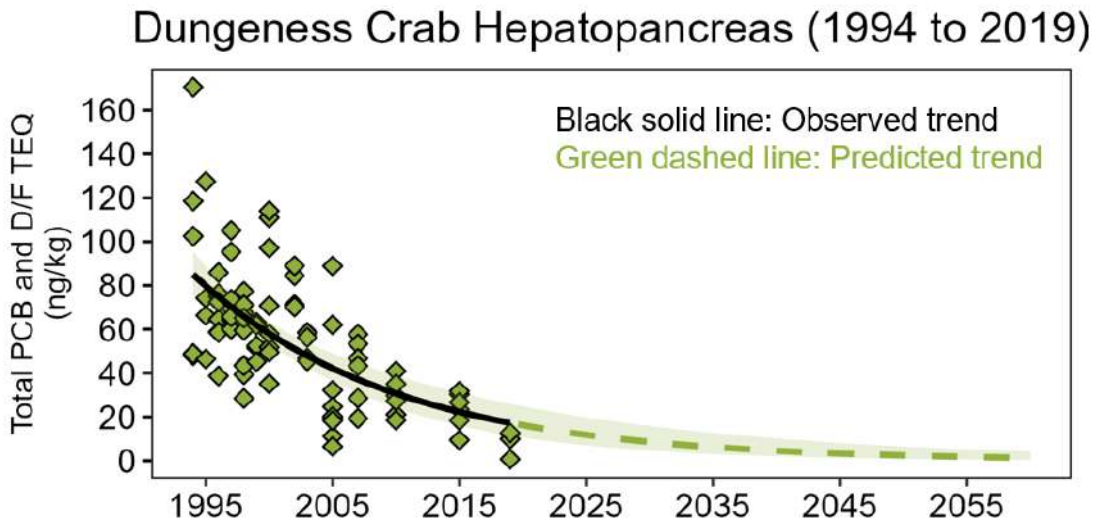

Figure 9. Dungeness crab tissue PCB and D/F toxic equivalence (TEQ) concentration trends

The harbour floor monitoring program began in 2024 and is anticipated to continue over the coming decades (Figure 10). The program involves taking periodic sediment samples to track the concentration of COCs over time in various media and updating the HHRA following each cycle.

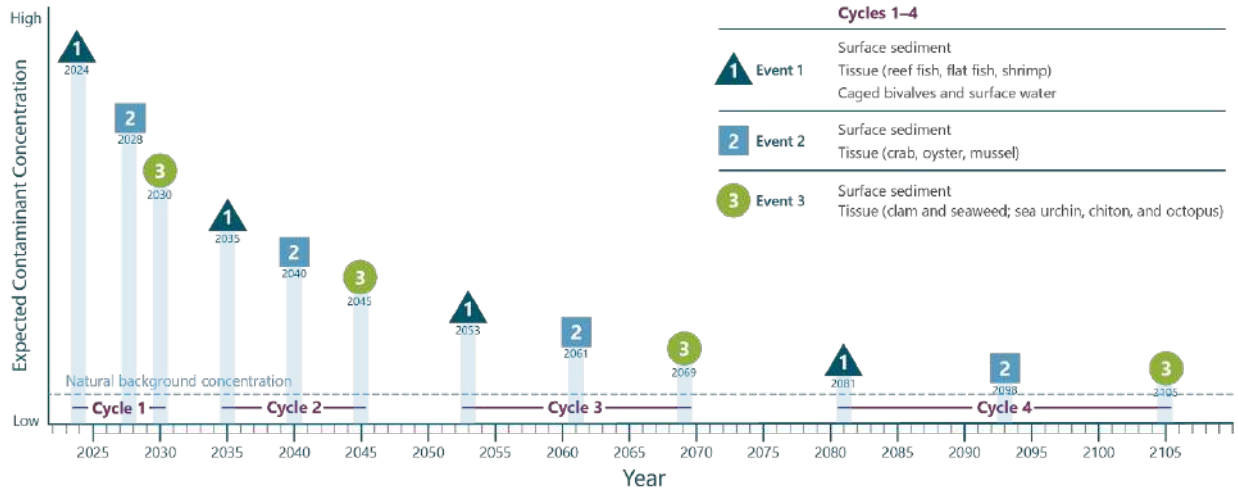

Figure 10. Harbor floor monitoring event proposed schedule

CONCLUSIONS

The long industrial history of Victoria Harbour has resulted in legacy contamination that TC is continuing to evaluate and address. Although remediation of highly contaminated sediment at Rock Bay and MHFS has successfully reduced contamination and improved environmental quality, more work is required.

The SCSMP is being developed to define strategies for implementing both targeted remediation and harbour-wide actions to achieve remedial action objectives. While development of the SCSMP continues, design is underway for the Cecelia Cove shoreline remediation project. The completion of remediation at all proposed shorelines in addition to ongoing harbour-wide activities are intended to address legacy

contamination in a way that allows for continued use of the working harbour by its various users and support future uses.

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DATA AVAILABILITY

All data, generated during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

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CFD-DEM DIGITAL TWINS FOR DREDGING OPERATIONS: FROM CRITICAL SLURRY TRANSPORT TO UNDERWATER ROCK PLACEMENT

D. Ilami[1] and J. Figlus[2]

ABSTRACT

Digital twin frameworks based on coupled computational fluid dynamics and the discrete element method are becoming increasingly relevant to dredging and offshore construction because many operational problems are governed by fluid-particle interaction, near-wall transport, and deposit formation. This study presents two representative computational fluid dynamics – discrete element method (CFD-DEM) applications that address different but connected dredging challenges: reliable hydraulic transport of settling solids in pipelines and controlled underwater placement of coarse protective rocks. In the first application, a particle-resolved horizontal slurry pipeline model was used to examine how settling, turbulence, and particle interactions influence the lower operating limit associated with deposition onset, with an emphasis on extracting practical transport indicators for critical velocity assessment rather than relying solely on bulk empirical interpretation. In the second application, a submerged fall-pipe rock placement model was used to quantify how the discharge configuration influences particle trajectories, seabed contact behavior, and final deposit geometry relevant to pipeline and cable protection. Across the slurry cases, the simulations demonstrated that the deposition risk was controlled by a localized near-wall balance that could be interpreted through CFD-DEM-derived transport metrics and translated into engineering guidance for operational control. Across the rock-placement cases, the results show that pipe inclination is the dominant geometric control on the berm shape, producing longer and flatter deposits as the inclination increases, whereas the discharge velocity has a comparatively limited influence on the final footprint within the tested range. Together, the two studies illustrate how CFD-DEM digital twins can support dredging decision-making at two distinct scales: the prevention of unwanted solid deposition during transport and the prediction of intentional granular deposition during subsea construction. The combined framework is proposed not as a replacement for the design practice but as a physics-informed supplement that can improve the interpretation, screening, and planning of complex dredging operations, where particle-scale mechanisms strongly affect system-level performance.

Keywords: Multiphase flow, particle-resolved simulation, pipeline deposition, fall-pipe installation, subsea protection, operational screening.

INTRODUCTION

Dredging and marine construction operations frequently involve the transport and controlled placement of particulate materials in environments where fluid motion, gravity, and particle interactions act simultaneously. Two examples are particularly important in practice. The first is the hydraulic transport of settling solids through pipelines, where operating below a safe transport velocity can lead to deposition, blockage risk, production loss, and excessive maintenance. The second is the underwater placement of coarse rocks for the protection of subsea pipelines and cables, where the deposit shape, local loading, and

[1] Ph.D. Student, Texas A&M University, Department of Ocean Engineering, 200 Seawolf Parkway, Galveston, Texas 77554, USA, T: 409-740-4807, Email: dariush1995@tamu.edu.
[2] Associate Professor, Texas A&M University, Department of Ocean Engineering, 200 Seawolf Parkway, Galveston, Texas 77554, USA, T: 409-741-4317, Email: figlusj@tamu.edu (corresponding author).

placement accuracy directly affect the installation quality and long-term performance. Although these applications differ in scale and objectives, both are governed by the same underlying difficulty: bulk operating quantities are determined by local fluid particle mechanics that are not easily resolved by conventional design formulas alone (Doron and Barnea 1993, Oroskar and Turian 1980, Rice et al. 2020, Xie and Lin 2025).

In slurry pipeline transport, the lower operating limit is commonly interpreted through the critical deposition velocity, which remains a central design quantity in dredging, mining, and other solid-transport systems. Classical correlations and layered models have provided useful engineering guidance for decades, but they also compress a complex near-wall process into a small set of bulk variables. Deposition onset is influenced by settling, turbulence, stratification, interphase momentum exchange, and particle collisions near the pipe invert line. Experimental and numerical studies have shown that the transition from suspended transport to bed formation is sensitive to particle properties, concentration, and local flow structure, which explains why universal prediction remains difficult across operating ranges (Doron and Barnea 1995, Gillies et al. 1991, Oroskar and Turian 1980, Ravelet et al. 2013, Rice et al. 2017, Rice et al. 2020).

A related challenge is the placement of underwater rocks (Ilami and Figlus 2026). Fall-pipe operations are widely used when protective rock must be placed with higher accuracy than conventional dumping methods, particularly around subsea pipelines, cables, and other offshore assets. The engineering objective is not merely to deliver material to the seabed but to place it in a geometry that satisfies protection, stability, and clearance requirements. Prior studies have shown that impact conditions, outlet configuration, and local hydrodynamics all influence the final berm or pile, while the broader offshore protection literature makes clear that deposit geometry and particle arrangement matter for structural safety and post-installation performance (Cai et al. 2022, Hinwood and Lipski 2002, Li et al. 2022, O'Loughlin et al. 2020, Xie and Lin 2025). However, the discharge process itself is still less understood than the response of the final rock berm.

These two operational problems are increasingly good candidates for digital twin thinking. A useful digital twin in dredging is not just a visualization model or a high-fidelity simulation run in isolation. It is a physics-based computational framework that can connect particle-scale behavior to engineering decisions, such as safe transport limits, discharge configuration, and expected deposit outcomes. CFD-DEM is well suited for this role because it resolves the carrier flow on an Eulerian grid while tracking the motion and interaction of individual particles in a Lagrangian sense. This capability has already been proven valuable in slurry transport and granular discharge studies, where continuum-only methods often miss the collision-driven and near-wall mechanisms that control the operational behavior (Capecelatro and Desjardins 2013, Di Felice 1994, Kloss et al. 2012, Tsuji et al. 1992).

This study uses this common framework to examine two dredging-relevant applications. The first application addresses slurry transport in a horizontal pipe and focuses on how CFD-DEM can be used to interpret deposition tendency and critical velocity behavior through physically meaningful transport indicators rather than through empirical threshold fitting alone. The second application addresses underwater rock placement from a fall pipe and evaluates how the discharge configuration influences rock trajectories, seabed contact behavior, and resulting deposit geometry. The purpose of this study is to demonstrate how CFD-DEM digital twins can support both the prevention of unwanted deposition during transport and the prediction of intentional deposition during subsea construction.

By placing these two case studies side by side, this study highlights a broader point relevant to dredging practice: transport control and placement control are not separate numerical problems but different expressions of the same fluid-particle mechanics. In one case, the engineering goal is to avoid accumulation, whereas in the other, it is to create a controlled accumulation. The results show how particle-resolved simulations can provide operational insights in both settings while remaining targeted to practical questions

that matter in design and construction. This makes CFD-DEM a promising tool for next-generation dredging workflows, in which simulations are used not only for explanation after the fact but also for screening, interpretation, and planning before and during operations.

METHODOLOGY

Common CFD-DEM Framework

Both case studies were simulated using a two-way coupled computational fluid dynamics (CFD) and discrete element method (DEM) framework in Star-CCM+ (Siemens, 2025). In this approach, the carrier fluid was solved in an Eulerian framework, whereas the solid phase was tracked as individual particles in a Lagrangian framework. This method was selected because both applications are governed by local fluid-particle interactions, particle collisions, and near-boundary transport processes that are not captured adequately by bulk continuum descriptions alone.

The fluid phase was treated as incompressible and Newtonian in nature. The governing continuity and momentum equations are as follows:

$$\nabla \cdot \left(\varepsilon_f \mathrm{u}_f\right) = 0 \tag{1}$$

$$\frac{\partial(\varepsilon_f \rho_f \mathrm{u}_f)}{\partial t} + \nabla \cdot \left(\varepsilon_f \rho_f \mathrm{u}_f \mathrm{u}_f\right) = -\varepsilon_f \nabla p + \nabla \cdot \tau_f + \varepsilon_f \rho_f \mathrm{g} - \mathrm{M}_{fp} \tag{2}$$

where ε_f = fluid volume fraction, u_f = fluid velocity, p = pressure, τ_f = stress tensor, ρ_f = fluid density, and M_{fp} = momentum exchange term between the fluid and particle phases. Turbulence was represented using the standard $k - \varepsilon$ model.

Particle motion was governed by Newton's second law,

$$m_p \frac{\mathrm{d}\mathrm{u}_p}{dt} = m_p \mathrm{g} + \mathrm{F}_{drag} + \mathrm{F}_{lift} + \mathrm{F}_{coll} \tag{3}$$

where m_p and u_p are the particle mass and velocity, respectively, and the force terms represent the gravity, hydrodynamic drag, lift, and contact forces. The particle–particle and particle-wall interactions were resolved using the Hertz-Mindlin contact model. The same CFD-DEM framework was applied to both applications to maintain consistency in the treatment of fluid-particle interactions and granular transport.

Slurry Transport Simulations

The slurry transport simulations were conducted in a straight horizontal pipe with length $L = 5.0$ m and inner diameter $D = 0.05$ m, yielding $L/D = 100$. The carrier phase was water with a density $\rho_f = 1000$ kg m^{-3} and dynamic viscosity $\mu = 1.0 \times 10^{-3}$ N s m^{-2}. The solid phase consisted of quartz-like spherical particles with a density $\rho_p = 2{,}650$ kg m^{-3}. The simulated cases covered particle diameters from 1.5 to 3.0 mm and solid volume fractions from 0.93% to 3.00%. A representative inlet velocity of 1.5 m s^{-1} was used for the main transport cases, corresponding to the turbulent bulk flow regime. Figure 1 shows the initial particle distribution for a specific simulation case.

The pipe domain was discretized using polyhedral meshes. Mesh independence was verified using multiple base sizes, and a base size of 0.004 m was adopted for the production simulations. The resulting mesh contained approximately 3.5×10^5 cells. A fluid time step of 1.0×10^{-3} s was used, and the particle phase was integrated with DEM sub-cycling using a time step of 2.0×10^{-4} s. The simulations were run for a

time of 3.0 s, corresponding to approximately 90% of the particle transit time through the domain. The particle positions and velocities were exported during the simulation for post-processing.

Figure 1. Initial particle distribution at the inlet of the horizontal slurry-pipe simulation for particles of diameter 2.5 mm and solids volume fraction of 0.93%.

The fluid-particle interaction model included drag and lift forces appropriate for particle-laden flow in a liquid carrier. The CFD-DEM setup was verified by comparing the single-phase pressure drop with the Blasius friction relation and verifying the dilute-particle settling behavior with standard drag-based terminal-settling estimates. After validating the computational setup, the particle trajectories were analyzed to evaluate the local transport behavior near the pipe invert. Post-processing focused on physically meaningful transport indicators derived from particle motion, including settling tendency, upward hydrodynamic support, vertical spreading, and collision-related upward activity. These quantities were used to compare the relative deposition tendencies among the simulated slurry cases.

Underwater Rock Placement Simulations

The underwater rock-placement simulations considered submerged discharges from an inclined fall pipe onto a horizontal seabed. The computational domain was 6 m long, 1 m wide, and 4 m high. The fall pipe had a length of 2 m and an inner diameter of 0.20 m. The pipe outlet was maintained 1.20 m above the seabed for all cases, whereas the pipe inclination angle with the horizontal was varied between $\theta = 30°$ and $75°$ to evaluate its influence on rock trajectories and deposit geometry. Figure 2 provides a visualization of the setup. The carrier phase was water with a density $\rho_f = 997.56\ \mathrm{kg\ m^{-3}}$ and dynamic viscosity $\mu_f = 1.0 \times 10^{-3}\ \mathrm{N\ s\ m^{-2}}$. The solid phase consisted of spherical rock particles with a diameter $d_p = 0.10\ \mathrm{m}$ and density $\rho_p \approx 2{,}650\ \mathrm{kg\ m^{-3}}$. Each simulation discharged 307 particles, corresponding to a total analytical submerged weight of approximately 2,605 N.

The fluid domain was discretized using an unstructured polyhedral mesh with a base size of approximately 0.025 m and local refinement near the pipe interior, outlet region, and seabed. The fluid time step was 1.0×10^{-3} s, whereas the DEM time step was selected as a smaller fraction of the fluid time step to resolve particle contacts. At each global time step, the particle motion was advanced, the interphase momentum exchange terms were assembled, the fluid equations were solved, and the updated flow field was interpolated back to the particle locations.

The boundary conditions were defined to represent the submerged discharge into a quiescent water body. A prescribed velocity condition was imposed at the pipe inlets. Pressure outlet conditions were applied at the top and downstream boundaries of the model. The seabed was modeled as a rigid, no-slip wall. The

initial condition consisted of still water in the domain, with no particles present. Rocks were then introduced through the fall pipe according to the specified discharge conditions for each case.

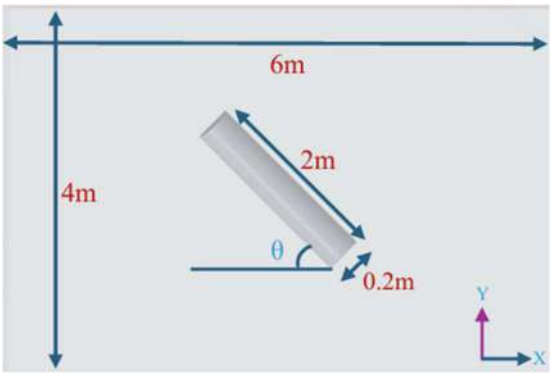

Figure 2. Schematic of the computational domain used for the submerged fall-pipe rock-placement simulations, showing the pipe geometry, inclination angle, and outlet elevation above the seabed.

A single-particle settling simulation was first performed to verify that the coupled CFD-DEM model reproduced the expected terminal-settling response in water. After this validation step, the full discharge simulations were analyzed in terms of particle trajectories, near-bed approach velocities, seabed reaction forces, and final deposit geometries. The main geometric outputs used in the analysis were the deposit length, deposit width, and maximum deposit height.

Comparative Analysis

The two case studies were examined within the same CFD-DEM framework to compare two different operational expressions of fluid-particle transport in dredging-related applications. In slurry pipe simulations, the main concern is unwanted deposition during transport. In the fall-pipe simulations, the objective is to control the deposition on the seabed. Therefore, the comparison was based on engineering outputs that are directly relevant to practice. For slurry transport, the analysis emphasized the transport indicators associated with the deposition tendency near the pipe invert. For underwater rock placement, the analysis emphasized deposit geometry and local interaction with the seabed. This common framework allowed the numerical results from both applications to be interpreted consistently in terms of fluid-particle mechanics and operational performance.

RESULTS

Slurry Transport Behavior

The slurry simulations showed that the deposition tendency in horizontal pipe flow was controlled by a localized near-wall transport balance rather than by the bulk velocity alone. Across the simulated cases, particle trajectories consistently indicated that the lower part of the pipe governed the transition toward deposition, where settling, turbulent redistribution, and collision-driven upward motion competed over a relatively thin region near the invert. A representative CFD-DEM snapshot is shown in Figure 3. The image illustrates a dispersed saltation-type regime near the pipe outlet rather than a fully developed stationary bed, confirming that the baseline operating condition remained within a transportable range while retaining clear near-wall particle concentration and interaction effects.

A comparison of the slurry cases revealed two practical trends. First, increasing the solid concentration at a fixed particle size increased the deposition tendency and raised the transport threshold. Second, the

influence of particle size over the tested range was non-monotonic, indicating that the relevant operating limit cannot be interpreted from the diameter alone without considering the associated changes in settling, collision frequency, and vertical redistribution. In the CFD-DEM-informed assessment, the predicted critical transport range across the tested families of parameters was approximately 1.18 to 1.53 m s^{-1}, and the agreement with the classical Oroskar-Turian benchmark remained within an engineering range suitable for operational screening.

From an operational perspective, the slurry results indicate that CFD-DEM can distinguish between cases that are close to the deposition onset and those with a stronger local redistribution capacity. This is useful in dredging applications, where a single conservative velocity criterion may not adequately represent changing solid properties or operating windows. Figure 3 shows a representative view of the transport regime associated with the near-wall behavior observed in the slurry simulations.

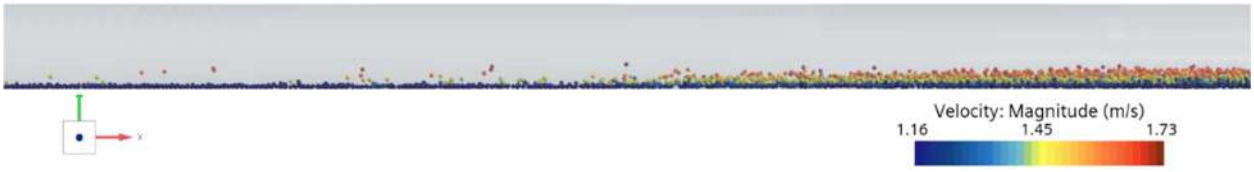

Figure 3. CFD-DEM snapshot near the pipe outlet for the representative slurry transport case, showing dispersed particle motion characteristic of a saltation-type transport regime.

Underwater Rock Placement Behavior

The submerged fall-pipe simulations showed that pipe inclination had a much stronger influence on deposit geometry than discharge velocity within the tested range of values. As the pipe angle increased from $\theta = 30°$ to 75°, the particle trajectories became steeper and more forward-directed, redistributing the discharged rock over a longer horizontal distance on the seabed. This trend is evident in Figure 4, which shows the final side-view deposit geometries for the four inclination cases tested. At lower angles, the rocks formed shorter and thicker piles. At higher angles, the deposits became flatter and more elongated.

The geometric changes were significant and systematic in nature. As summarized in Table 1, the deposit length increased from 4.798 m at 30° to 5.894 m at 75°, corresponding to an increase of approximately 23%. Over the same range, the maximum deposit height decreased from 0.271 to 0.158 m, indicating a much flatter final berm shape at steeper inclinations. The deposit width remained nearly constant at approximately 0.40 m for all cases, indicating that the pipe angle primarily redistributed the rock in the longitudinal direction rather than laterally. Another important point is that the deposit length approached a practical saturation beyond approximately 60°, because the 60° and 75° cases produced nearly identical footprint lengths, whereas the deposit height continued to decrease slightly.

These results have clear implications for engineering. In fall-pipe operations for subsea protection, steeper inclinations can be used to produce longer and lower deposits when wider longitudinal coverage is required, whereas shallower inclinations favor a more compact accumulation. The simulations also showed that near-bed particle motion remained relatively gentle, with low-impact deposition behavior that was consistent with controlled placement rather than highly energetic impact loading. This is important for protection work near pipelines and cables, where the final geometry matters, but the local placement process must also avoid excessive contact severity.

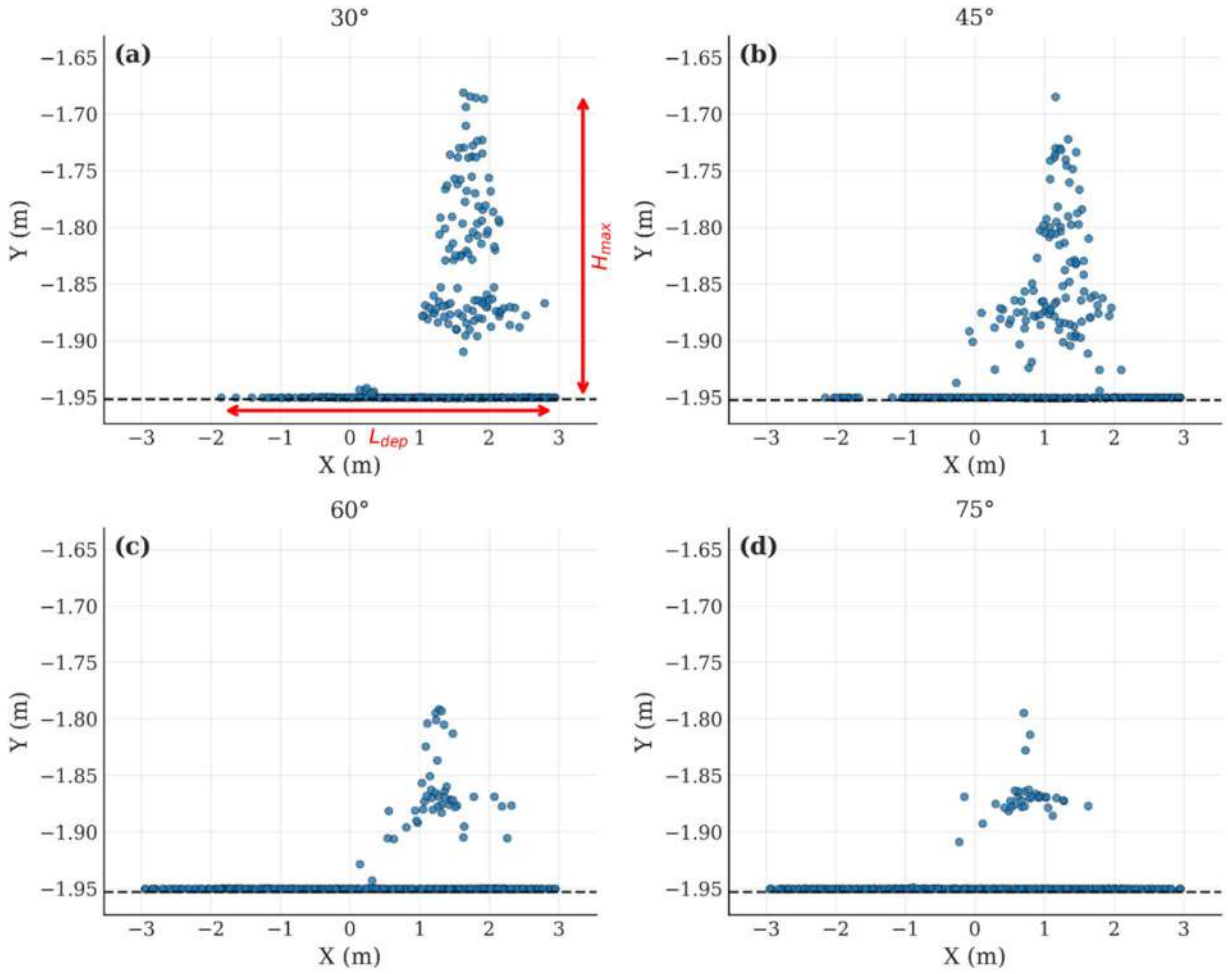

Figure 4. Final side-view deposit geometry for submerged fall-pipe rock placement at inclinations of 30°, 45°, 60°, and 75°, showing the transition from compact to elongated deposits as pipe angle increases.

Table 1. Summary of final deposit dimensions for the simulated fall-pipe inclination cases.

Angle (°)	L_{dep} (m)	L_{dep}/L_{pipe}	W_{dep} (m)	H_{max} (m)
30	4.798	2.399	0.401	0.271
45	5.102	2.551	0.401	0.268
60	5.893	2.946	0.401	0.162
75	5.894	2.947	0.400	0.158

Cross-Application Observation

Although the two case studies address different operations, their numerical results reveal the same physical principle. In a slurry pipeline, the engineering objective is to prevent particles from accumulating near the

lower boundary. In the fall-pipe case, the objective was to create a predictable accumulation on the lower boundary. In both cases, the outcome depends on how the fluid forces, gravity, and particle interactions redistribute solids close to the confining surface. The CFD-DEM framework captured this shared mechanism at the particle scale and translated it into engineering outputs that are directly relevant to dredging practices. For slurry transport, these outputs are related to the deposition tendency and threshold behavior. Rock placement is related to deposit footprint and thickness. This common interpretation supports the use of CFD-DEM digital twins as a practical screening and planning tool for dredging operations, in which fluid-particle mechanics play a controlling role.

DISCUSSION

The two case studies showed that transport and placement controls can be interpreted within a common fluid-particle mechanics framework. In the slurry pipeline problem, the design objective is to avoid sustained accumulation at the lower boundary of the pipe. In the fall-pipe problem, the objective is to create a predictable and controlled accumulation on the seabed. In both cases, the final behavior is determined by the competition among gravity, hydrodynamic forcing, and particle-particle interactions close to the confining boundary. This common structure explains why the same CFD-DEM framework was effective for both applications.

For the slurry cases, the results confirmed that the deposition tendency could not be interpreted from the bulk velocity alone. The representative CFD-DEM snapshot in Figure 3 shows that even when the flow remains in a transportable regime, the relevant behavior is concentrated near the pipe invert, where settling, turbulent redistribution, and collision-driven upward motion interact over a relatively thin layer of sediment. This observation is consistent with the classical view that critical deposition is a near-wall transport problem rather than a purely bulk flow threshold. In practical dredging operations, this means that two slurry systems operating at similar mean velocities may still exhibit different deposition risks if the particle size, concentration, or local redistribution capacity differ.

The simulated slurry trends also have direct operational significance. The increase in deposition tendency with increasing solid concentration is expected, but the non-monotonic particle size effect is equally important because it shows that the transport risk cannot be judged from the grain size in isolation. In practice, operators often rely on conservative velocity rules intended to avoid blockages under changing material conditions. The present results indicate that CFD-DEM-based digital twins can add value by identifying whether a given operating point is conservative or genuinely close to unfavorable near-wall accumulation. This makes the approach useful as a screening and interpretation tool, particularly when the material properties vary across dredging campaigns or along the pipeline route.

For the underwater rock-placement problem, the strongest result is that pipe inclination controlled deposit geometry much more strongly than the discharge velocity within the tested range. Figure 4 and Table 1 show a clear and systematic shift from short, thicker deposits at shallow angles to longer and flatter deposits at steeper angles. From an engineering standpoint, this implies that pipe angles can be treated as a direct geometric control parameter for the final berm footprint. The near-constant deposit width indicates that this control acts mainly in the longitudinal direction, which is especially relevant for fall-pipe operations near pipelines and cables, where longitudinal coverage and local clearance are often more important than lateral spread.

Another important result is the relatively gentle near-bed deposition behavior predicted in the rock-placement simulation. This supports the use of inclined fall-pipe placement when the goal is to build a stable protective cover while limiting the excessive severity of local impact. For subsea protection work,

the placement quality depends not only on the final deposit shape but also on how that shape is created. A numerically predicted deposit that is geometrically acceptable but formed through overly energetic local contact is undesirable near sensitive infrastructure. The results show that CFD-DEM can be used to evaluate both geometry and placement mechanics within the same framework.

Taken together, these two case studies demonstrate the broader value of CFD-DEM digital twins in dredging practice. This method does not replace the established empirical criteria or field experience. Its strength lies in providing a particle-scale interpretation layer between the bulk design rules and full-scale operations. In the slurry case, this interpretation is expressed through transport indicators associated with deposition risk. In the rock-placement case, it is expressed through the deposit geometry and near-bed interaction behavior. In both applications, the digital twin provides information that is difficult to obtain using conventional formulas alone.

The scope of this study was intentionally focused on representative cases that highlight the practical use of CFD-DEM for dredging-related applications. Within that scope, the results show that CFD-DEM digital twins can support dredging planning, operational screening, and engineering interpretation in situations where fluid-particle mechanics directly control performance.

CONCLUSIONS

This study presented two CFD-DEM applications relevant to dredging and subsea construction: horizontal slurry transport and submerged fall-pipe rock placement. Although the two applications address different operational objectives, the results show that both are controlled by the same particle-scale interaction between gravity, hydrodynamic forcing, and granular contact near the lower boundary.

For slurry transport, the simulations showed that the deposition tendency was governed by a localized near-wall balance rather than by bulk velocity alone. Increasing the solids concentration increased the deposition tendency, whereas the particle-size effect over the tested range was non-monotonic. These findings show that CFD-DEM can distinguish cases that are close to deposition onset from those with a stronger local redistribution capacity, which is useful for operational screening in dredging pipelines.

For underwater rock placement, the simulations showed that pipe inclination was the dominant factor controlling the final deposit geometry. As the inclination increased from 30° to 75°, the deposit length increased by approximately 23%, whereas the maximum deposit height decreased substantially. The deposit width remained almost constant. These results indicate that pipe inclination angle can be used as a practical control parameter to produce either compact or elongated protective deposits, depending on project requirements.

The combined results support the following three main conclusions. First, CFD-DEM digital twins can provide engineering insights into both transport- and placement-control problems using a common numerical framework. Second, the method is especially valuable when conventional bulk criteria are insufficient to explain how local fluid-particle mechanics affect operational behavior. Third, for dredging-related applications, CFD-DEM is best viewed as a physics-based supplement to existing design and construction practices.

Additional validation and broader parametric exploration will further strengthen this approach for direct project implementation. Even within the representative cases considered here, the results show that CFD-DEM digital twins have clear potential as practical tools for screening, planning, and interpretation in dredging operations, where particle-scale processes govern system-scale performance.

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DATA AVAILABILITY

Some or all data, models, or code generated or used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

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NOMENCLATURE

Symbol	Definition
C_v $[-]$	Solids volume fraction
D (m)	Inner diameter of the slurry pipe
d_p (m)	Particle diameter
$\mathrm{F_{coll}}$ (N)	Particle contact force
$\mathrm{F_{drag}}$ (N)	Hydrodynamic drag force
$\mathrm{F_{lift}}$ (N)	Hydrodynamic lift force
g (m $\mathrm{s^{-2}}$)	Gravitational acceleration vector
$H_{\max}$ (m)	Maximum deposit height
L (m)	Length of the slurry pipe
L_{dep} (m)	Final deposit length
L_{pipe} (m)	Length of the fall pipe

Symbol	Definition
M_{fp} (N m^{-3})	Fluid-particle momentum exchange term
m_p (kg)	Particle mass
p (N m^{-2})	Pressure
t (s)	Time
u_f (m s^{-1})	Fluid velocity vector
u_p (m s^{-1})	Particle velocity vector
W_{dep} (m)	Final deposit width
x (m)	Horizontal coordinate
y (m)	Vertical coordinate
ε_f [−]	Fluid volume fraction
μ (N s m^{-2})	Dynamic viscosity of the carrier fluid
μ_f (N s m^{-2})	Dynamic viscosity of water in the fall-pipe simulations
ρ_f (kg m^{-3})	Fluid density
ρ_p (kg m^{-3})	Particle density
τ_f (N m^{-2})	Fluid stress tensor

MULTIPHASE DREDGE FLOW CFD SIMULATIONS WITH ANSYS FLUENT

M.A.F. Taseen[1], M. Mohammadzadeh[1], V. Panchang[2] and J. Figlus[3]

ABSTRACT

Slurry transport in dredging pipelines is governed by the coupled effects of axial sediment deposition and cross-sectional stratification, which influence energy efficiency, pipeline wear, blockage risk, and maintenance. In practical dredging operations, distribution of non-uniform solids can accelerate inverted erosion, reduce effective flow area, and increase pumping requirements. Although numerous numerical studies have investigated cross-sectional concentration profiles or axial deposition behavior independently, efforts connecting these perspectives within a unified modeling framework that supports practical design decisions are lacking. Bridging this gap is particularly important when evaluating how localized geometric modifications, such as drop-tube insertion, influence deposition in horizontal pipelines. This study employs a three-dimensional Eulerian multiphase computational fluid dynamics (CFD) framework to investigate slurry flow in a horizontal pipeline using ANSYS Fluent, which provides established interphase drag and turbulence–multiphase coupling models. The study consisted of benchmark model validation followed by application to a modified drop-tube separator geometry. First, a straight horizontal pipe with a single solid phase is simulated under prescribed operating conditions to establish a baseline reference case. This configuration serves as a validation benchmark for cross-sectional solids distribution and stratification behavior. The model is then extended to a straight-pipe configuration incorporating a centrally located drop-tube while maintaining identical flow conditions and solids properties. The baseline three-dimensional simulations reproduce characteristic concentration peaks and stratification trends reported in prior studies. For the drop-tube case, the simulation was advanced for 12 s, corresponding to more than 3.4 main-pipe residence times. Under the fine-particle A1 condition (d_p = 90 μm, U = 3.0 m/s), the computed branch capture efficiency was 1.98%, while downstream C_v profiles showed localized near-invert concentration reduction followed by gradual re-development of the stratified profile. Collectively, the study highlights the importance of jointly considering axial and cross-sectional dynamics when evaluating slurry pipeline configurations and provides a framework for assessing drop-tube design modifications in dredging applications.

Keywords: slurry transport, sediment stratification, Eulerian–Eulerian model, drop-tube separator, beneficial use of dredged material

INTRODUCTION

Hydraulic transport of sediment–water mixtures through pipelines is fundamental to dredging operations, mining slurry transport, tailings relocation, and other bulk solids handling processes. In

[1] Graduate Researcher, Department of Ocean Engineering, Texas A&M University, Galveston, Texas, USA (corresponding author: taseen@tamu.edu).
[2] Regents Professor and W.H. Bauer Professor, Department of Ocean Engineering, Texas A&M University, Galveston, Texas, USA.
[3] Associate Professor, Department of Ocean Engineering, Texas A&M University, Galveston, Texas, USA.

dredging systems, efficient slurry conveyance directly affects production rate, pump energy consumption, pipeline wear, and overall project cost. Maintaining solids in suspension while minimizing excess pressure losses is therefore a key engineering objective in the design and operation of slurry transport pipelines.

The internal behavior of slurry pipelines is inherently complex because it involves coupled interactions among turbulence, particle settling, interphase momentum exchange, particle collisions, and wall effects. Depending on particle size, solids concentration, line velocity, and pipe geometry, solids may remain fully suspended, become vertically stratified, or transition toward moving-bed or deposited-bed regimes. Even under nominally suspended conditions, concentration gradients commonly develop, with higher solids fractions near the invert and lower concentrations near the crown. These non-uniform distributions can increase local wear, alter hydraulic resistance, raise pumping demand, and increase the risk of blockage or unstable operation. Thus, accurate prediction of solids concentration profiles is essential for both hydraulic design and process optimization. In dredging applications, redistribution of internal solids also affects downstream classification processes, in-line separation devices, and the beneficial reuse of dredged material.

With advances in computing power, Computational Fluid Dynamics (CFD) has become an increasingly important tool for slurry transport research. Eulerian–Eulerian multiphase formulations treat the liquid and solid phases as interpenetrating continua and solve separate conservation equations coupled through interphase exchange terms. This approach enables detailed prediction of velocity fields, turbulence structure, pressure gradients, and concentration stratification that are difficult to obtain experimentally. Previous ANSYS-based CFD studies have reported good agreement with measured slurry concentration and hydraulic gradient data over a range of pipe diameters, particle sizes, and concentrations. Examples include the work of Ekambara et al. using ANSYS-CFX, Kaushal et al. using Eulerian models for concentrated fine-particle slurries, and later analyses of particle-size effects and horizontal pipeline transport (Ekambara et al. 2009, Kaushal et al. 2012, Gopaliya and Kaushal 2015, 2016).

Among recent benchmark studies, Xiong et al. (2019) performed a comparative analysis between CFD and the DHLLDV model for fully suspended slurry flow in horizontal pipelines. Their work showed that an Eulerian CFD framework implemented in ANSYS Fluent could reproduce measured hydraulic gradients and vertical concentration distributions with reasonable accuracy across several experimental datasets. The study also highlighted the sensitivity of near-wall concentration prediction and the reduced accuracy that can arise for larger particles or transitional flow regimes (Xiong et al. 2019).

Experimental studies by Gillies et al. (2004) have likewise provided widely used benchmark measurements of vertical solids concentration distributions in horizontal slurry pipelines under controlled operating conditions. These datasets remain especially valuable for validation of CFD models because they capture concentration stratification over a range of delivered concentrations and particle sizes (Gillies et al. 2004).

While straight-pipe slurry transport has been studied extensively, less attention has been directed toward how localized geometric modifications can be used to intentionally redistribute or selectively extract solids during transport. This question is particularly relevant in dredging, where coarse sand fractions may be desirable for nourishment or construction, while finer silts and clays may require separate management. Conventional separation methods typically rely on screens, settling basins, or hydro cyclones, which require additional equipment footprint, pumping energy, and handling cost.

This separation challenge is directly connected to the growing emphasis on Beneficial Use of Dredged Material (BUDM). Current dredging practice increasingly treats dredged sediment as a resource for beach nourishment, marsh creation, wetland restoration, habitat development, and construction fill rather than as waste requiring disposal. In this context, early separation of coarse sand fractions during hydraulic transport could improve material routing, reduce downstream handling, and support more efficient beneficial-use placement strategies (U.S. Army Corps of Engineers 2024). One potential concept is in-line hydraulic separation, where local geometry promotes preferential settling and extraction of coarser particles while finer material continues downstream. One practical implementation is a vertical drop-tube branch connected to the invert of the main pipeline. Similar separator concepts have been proposed for coastal sediment harvesting and beneficial-use applications (Tucker et al. 2019). Such a device may act as a passive gravity separator by drawing the high-concentration near-bed layer into the branch under heterogeneous flow conditions, where coarser particles preferentially occupy lower elevations in the pipe cross-section (Wilson et al. 2006, Perkey et al. 2024). However, branch capture performance depends strongly on local hydrodynamics, turbulence structure, residence time, and redeposition behavior within the separator leg, all of which are known to influence slurry transport efficiency (Lahiri and Ghanta 2010).

The present study adopts the validated Eulerian CFD methodology of Xiong et al. (2019) as a numerical foundation and extends it to investigate in-line sediment extraction. First, the numerical framework is validated against selected benchmark slurry transport cases using measured concentration-profile data from Gillies et al. (2004). Second, the validated model is applied to a new separator geometry incorporating an extended vertical drop tube intended to enhance selective settling and capture of solids from the main pipeline.

The objectives of this study are to

1. Validate an Eulerian multiphase CFD framework against benchmark slurry concentration-profile experiments;
2. Assess turbulence-model sensitivity for more strongly stratified benchmark transport cases;
3. Apply the validated model to a novel long drop-tube separator geometry and
4. Evaluate whether the extended drop tube improves selective sediment capture relative to conventional short-branch concepts.

GOVERNING EQUATIONS

The present study employed the transient Eulerian–Eulerian multiphase framework implemented in ANSYS Fluent to simulate sediment-laden slurry transport. In this formulation, the liquid and solid phases are treated as interpenetrating continua, with separate continuity and momentum equations solved for each phase. This approach is widely used for slurry pipeline simulations and follows the methodology adopted by Xiong et al. (2019) for fully suspended slurry transport in horizontal pipelines (Xiong et al. 2019).

For each phase q, the continuity equation is expressed as:

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla.\left(\alpha_q \rho_q u_q\right) = 0 \quad (1)$$

where α_q is the phase volume fraction, ρ_q is the phase density, and $\mathbf{u}_q$ is the phase velocity vector. The momentum equation for phase q is written as:

$$\frac{\partial}{\partial t}(\alpha_q \rho_q u_q) + \nabla(\alpha_q \rho_q u_q u_q) = -\alpha_q \nabla p + \nabla . \tau_g + \alpha_q \rho_q g + M_{pq} \quad (2)$$

where p is the shared pressure field, τ_q is the stress tensor, **g** is gravitational acceleration, and $\mathbf{M}_{pq}$ represents the net interphase momentum exchange term arising primarily from drag and related interaction forces (ANSYS Inc. 2024).

Interphase drag was modeled using the Huilin–Gidaspow drag formulation, which is commonly applied in dense gas–solid and liquid–solid multiphase systems. Additional interphase forces included lift force, virtual mass force, and turbulent dispersion. Granular stresses of the sediment phase were represented using the kinetic theory of granular flow (KTGF), where particle collisions and fluctuating particle motion are incorporated through the granular temperature equation (Gidaspow 1994, ANSYS Inc. 2024).

Turbulence was modeled using the mixture k–ε model, which has previously shown satisfactory agreement for slurry transport in pipelines while maintaining reasonable computational cost (Xiong et al. 2019, Lahiri and Ghanta 2010).

METHODOLOGY

The investigation consisted of two sequential stages: (i) benchmark model validation and (ii) extension of the validated model to a drop-tube separator geometry.

Benchmark Validation

The first stage focused on reproducing benchmark slurry concentration-distribution cases reported by Xiong et al. (2019), based on the experimental measurements of Gillies et al. (2004). These cases involve fully suspended solid–liquid slurry transport of silica particles in water within a horizontal pipeline. Specifically, the A1–A4 and D1–D4 datasets were considered, with the latter referred to as the B-series in the present study for convenience (see Table 1). These cases differ primarily in terms of particle size (d_p) and delivered solids concentration (C_v), while maintaining consistent pipe geometry.

The objective of this stage was to verify that the present Eulerian–Eulerian ANSYS Fluent framework could accurately reproduce the measured vertical solids concentration profiles (C_v versus y/D). Boundary conditions, particle properties, and numerical settings were selected to closely follow those reported by Xiong et al. (2019), thereby enabling direct comparison with both the published CFD predictions and the underlying experimental data.

All validation cases correspond to a pipe diameter of $D = 103$ mm with silica particles of density $\rho_s = 2{,}650$ kg/m^3. The A-series employed fine particles of diameter $d_p = 90$ μm at a mean mixture velocity of $V_m = 3.0$ m/s, while the B-series used coarser particles of diameter $d_p = 270$ μm at a higher mean velocity of $V_m = 5.4$ m/s. Delivered solids concentration (C_v) was varied to generate four cases within each group.

At the inlet, a velocity-inlet boundary condition was prescribed with specified mixture velocity and phase volume fractions for both liquid and solid phases. A pressure-outlet condition at atmospheric pressure was applied at the outlet. The liquid phase was treated with a no-slip boundary condition at the pipe wall, while the solid phase employed a partial-slip condition following the Johnson and Jackson formulation. A wall roughness height of approximately 0.2 mm and a particle-wall

specularity coefficient of 0.05 were adopted in accordance with (Xiong et al. 2019).

Table 1. Benchmark validation cases adopted from Gillies et al. (2004) and Xiong et al. (2019).

ID	d_p (μm)	D (mm)	ρ_s (kg/m^3)	V_m (m/s)	C_v (%)
A1	90	103	2,650	3.0	19
A2	90	103	2,650	3.0	24
A3	90	103	2,650	3.0	29
A4	90	103	2,650	3.0	33
B1	270	103	2,650	5.4	10
B2	270	103	2,650	5.4	20
B3	270	103	2,650	5.4	30
B4	270	103	2,650	5.4	40

Validation was performed by comparing predicted vertical solids concentration distributions (C_v versus y/D) against the experimental measurements of Gillies et al. (2004) and the published CFD results of (Xiong et al. 2019). These concentration profiles provide a stringent test of model fidelity, as they directly reflect the competing effects of gravitational settling, turbulent suspension, interphase momentum exchange, and near-wall migration.

Drop-Tube Separator Application

Following validation, the numerical framework was extended to a modified pipeline geometry incorporating a vertical drop-tube branch intended to promote solids segregation through gravitational settling. The initial drop-tube simulation was limited to the A1 benchmark condition because A1 represents the fine-particle, fully suspended baseline case for which the validation agreement was strongest and the computational setup was most directly transferable. Using A1 as the first separator case allowed the drop-tube geometry to be evaluated under a conservative suspended-flow condition before extending the study to coarser particles, higher solids concentrations, or lower transport velocities. Therefore, the A1 case was treated as a proof-of-concept application rather than a complete parametric assessment of separator performance.

The main pipeline retained the A1 benchmark diameter (D = 103 mm) and was extended to a total length of $L = 101D$, preserving the fully developed flow requirement recommended by Xiong et al. (2019), for which approximately $50D$ of upstream length is required prior to profile extraction.

A vertical drop tube of diameter $1D$ was installed at $50.5D$ downstream of the inlet and extended downward from the invert of the main pipeline. An additional $50D$ downstream section was retained after the branch location to minimize outlet-induced disturbances.

Transient simulations were conducted for a total physical time of 12 s. Based on the mean mixture

velocity of $U = 3.0$ m/s and the total pipe length, the corresponding hydraulic residence time in the main pipeline was approximately 3.47 s. The selected simulation duration therefore represents more than 3.4 residence times, which was considered sufficient for the flow field and solids distribution to approach statistically steady behavior.

The drop-tube idea was introduced as a proof-of-concept separator, in which denser particles concentrated near the pipe invert may preferentially enter the branch under combined local pressure gradients and gravity.

To quantify separator performance, a capture (segregation) efficiency coefficient was defined as

$$\eta = \frac{m_{DT}}{m_{in} - m_{up}} \times 100 \quad (3)$$

where η is the segregation efficiency (%), m_{DT} is the sediment mass collected within the drop tube, m_{in} is the cumulative sediment mass introduced at the inlet, and m_{up} is the sediment mass still present in the upstream main-pipe section prior to the branch. This correction avoids penalizing particles that had entered the system but had not yet reached the separator.

In addition to branch-capture performance, the modified geometry was also used to examine how drop-tube insertion alters the downstream axial distribution of solids within the main pipeline. Localized extraction of sediment near the pipe invert can modify subsequent concentration stratification and redeposition behavior downstream. This aspect is practically relevant in dredging systems, where non-uniform solids distribution may accelerate pipe wear, reduce effective flow area, and increase pumping demand (Wilson et al. 2006).

RESULTS AND DISCUSSION

A-Series Validation

The A-series cases were reproduced with strong agreement using the baseline numerical settings recommended by Xiong et al. (2019). Figure 1 shows that the present simulations capture the progressive increase in solids concentration as delivered concentration increases from A1 to A4, as well as the expected enrichment of solids in the lower half of the pipe.

To quantify the level of agreement, Pearson correlation coefficients were calculated between the predicted and measured vertical concentration profiles. For the representative A1 case, the published Xiong et al. profile had a correlation coefficient of 0.8931 relative to the Gillies et al. experimental data, whereas the present simulation produced a higher correlation coefficient of 0.9213. This indicates that the present model reproduced the measured A1 concentration trend slightly better than the prior numerical result for this case.

The improvement is most apparent in the upper and lower portions of the pipe cross-section. In the upper region, the present profile follows the low-concentration suspended-particle trend more closely, while near the lower third of the pipe it better captures the increase in solids concentration associated with gravitational stratification. These regions are especially sensitive to the balance among turbulent suspension, particle settling, interphase drag, and wall treatment. The improved agreement therefore suggests that the selected interphase force models, wall boundary treatment, and turbulence settings

are suitable for reproducing the fine-particle suspended-flow behavior represented by the A-series cases.

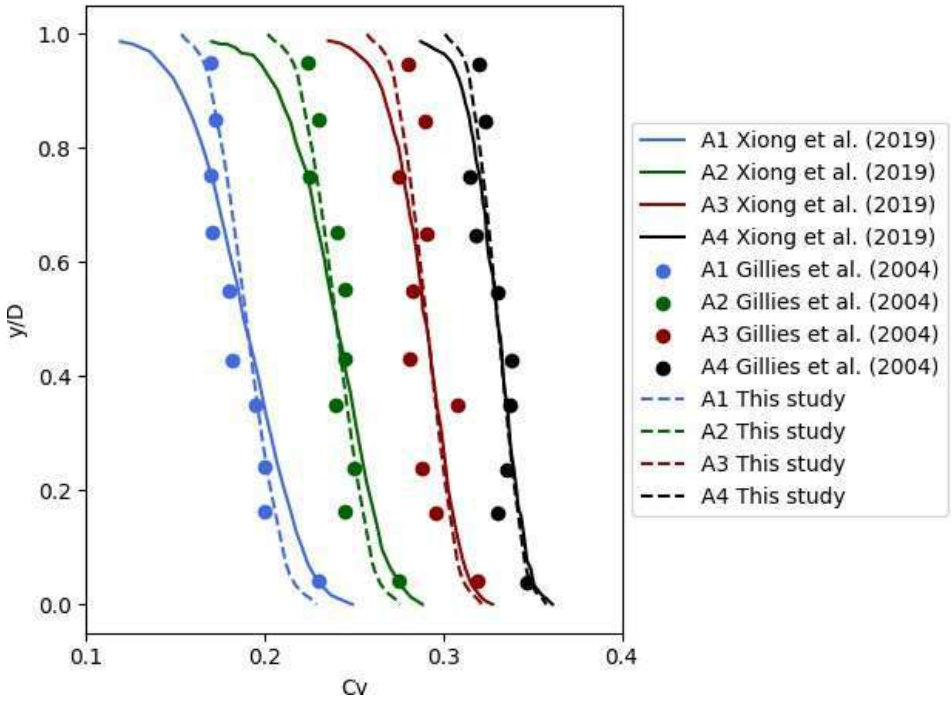

Figure 1. Validation of A-series concentration profiles (A1–A4).

B-Series Validation and Turbulent Dispersion Sensitivity

Initial simulations of the B-series cases using a turbulent dispersion coefficient of unity produced noticeable deviations from the benchmark data, particularly for the higher concentration conditions. The B-series particles are larger than those in the A-series (d_p = 270 μm compared with 90 μm), and therefore have greater inertia and settling tendency. As a result, their vertical distribution is more strongly controlled by the balance between gravitational settling, turbulent diffusion, and near-wall interactions. Small changes in the turbulent-dispersion coefficient can therefore produce larger changes in the predicted concentration profile than in the fine-particle A-series cases.

To enhance model performance, a parametric sensitivity study was conducted on the turbulent dispersion coefficient. It was observed that reducing the coefficient progressively improved prediction accuracy as solids concentration increased. In practical terms, lower turbulent dispersion reduced excessive upward remixing of solids and better preserved the experimentally observed near-bed concentration gradients.

Figure 2 presents the final calibrated B-series results, showing substantially improved agreement with benchmark trends across all four cases.

Representative sensitivity results for the low-concentration (B1) and high-concentration (B4) limits are shown in Figures 3 and 4, respectively. These comparisons show that the predicted concentration profile is sensitive to the selected turbulent-dispersion coefficient, particularly near the lower portion of the pipe where settling, turbulent remixing, and wall effects interact most strongly. For the B1 case,

the Pearson correlation between the predicted and measured concentration profiles was 0.9567 for the was 0.9567 for the published Xiong et al. result and 0.9232 for the present simulation.

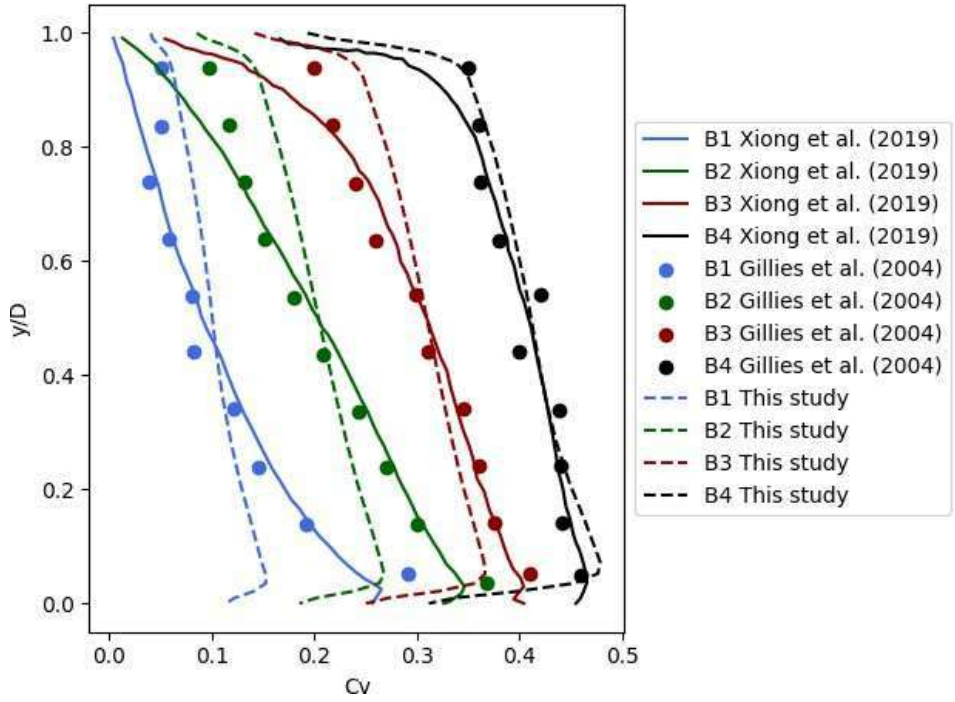

Figure 2. Validation of B-series concentration profiles (B1–B4).

Although the present B1 result remains slightly less correlated with the measured data than the published benchmark prediction, the high correlation value indicates that the overall vertical concentration trend is still reproduced reasonably well. The sensitivity becomes more important for the higher-concentration B4 case, where stronger near-bed stratification develops and changes in turbulent dispersion produce larger changes in the lower-pipe concentration peak. Thus, the turbulent-dispersion coefficient has a measurable influence on the predicted concentration structure, especially as particle size and solids loading increase.

Validation Summary

Overall, the validation study demonstrates that the present CFD framework is capable of reproducing benchmark slurry stratification behavior over a range of particle sizes, line velocities, and delivered concentrations. Strong baseline agreement was obtained for the A-series cases using the reference turbulent-dispersion setting. For the B-series cases, improved agreement required adjustment of the turbulent-dispersion coefficient, reflecting the greater sensitivity of the larger-particle cases to the balance between gravitational settling and turbulence-driven remixing. A more general treatment of turbulent-dispersion variation as a function of slurry transport characteristics is being developed. With these validations established, the model was considered sufficiently reliable for subsequent application to the gravity-assisted drop-tube separator geometry.

Initial Drop-Tube Performance Under A1 Conditions

Following successful validation, the benchmark A1 case was extended to include the proposed drop-tube separator geometry in order to assess whether measurable solids segregation could be achieved under the original fine-particle operating conditions (d_p = 90 μm, U = 3.0 m/s).

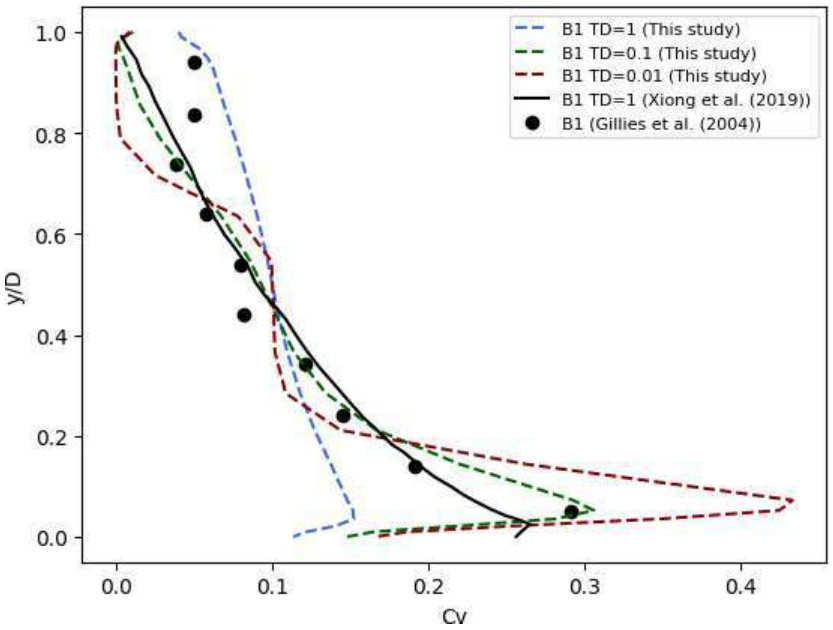

Figure 3. Turbulent-dispersion sensitivity for B1.

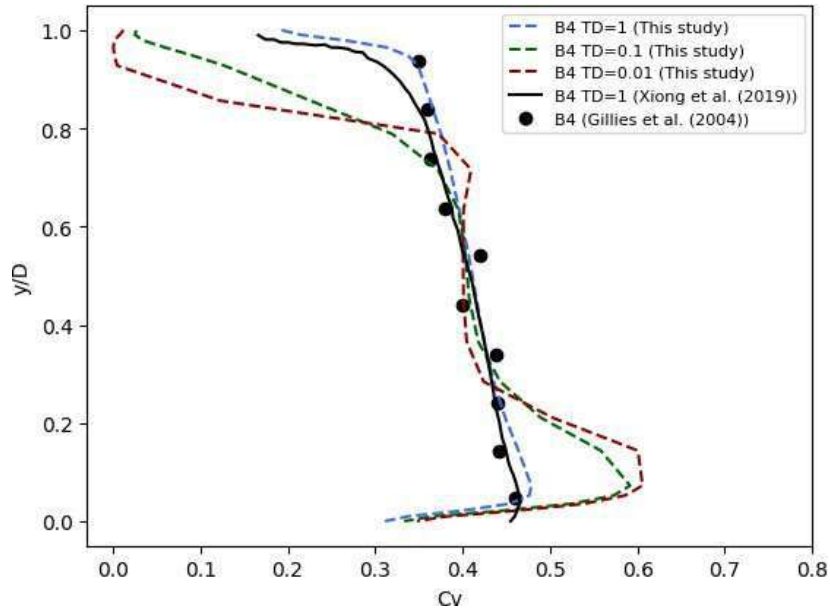

Figure 4. Turbulent-dispersion sensitivity for B4.

Figure 5 presents the sediment volume-fraction contour for the A1 drop-tube simulation. The main panel shows a magnified view of the drop-tube junction and branch entrance, while the inset shows the full computational domain. Solids remained predominantly suspended within the main pipeline, while only a localized portion of the near-invert sediment layer entered the drop tube.

Strong concentration gradients developed near the branch entrance, where the solids-rich near-bed layer interacted with the localized downward extraction region. However, most suspended particles continued downstream in the horizontal carrier stream. This indicates that the current geometry alone

was insufficient to produce substantial passive separation for the fine A1 sediment class under the imposed high-velocity operating condition. Within the 12 s simulation period, sediment concentration decreased rapidly with depth inside the branch because the settling velocity of the fine A1 particles was small relative to the main slurry transport velocity, and captured particles had limited time to migrate farther downward. Therefore, the observed branch distribution represents an early-time capture response rather than a fully accumulated sediment deposit.

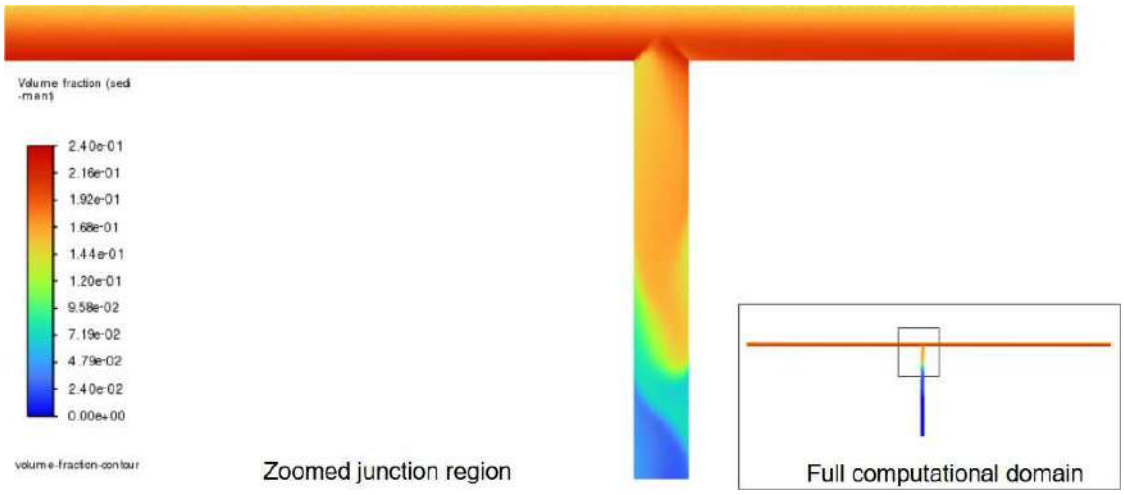

Figure 5. A1 drop-tube sediment volume-fraction contour.

The capture efficiency for the A1 drop-tube case was evaluated using Eq. (3):

$$\eta = \frac{m_{DT}}{m_{in} - m_{up}} \times 100 = \frac{2.52}{148.62 - 21.41} \times 100 = 1.98\% \quad (4)$$

where the sediment mass collected in the drop tube was m_{DT} = 2.52 kg, the total injected sediment mass over the 12 s simulation period was m_{in} = 148.62 kg, and the sediment mass remaining in the upstream main-pipe section was m_{up} = 21.41 kg. Here, the upstream main-pipe section refers to the portion of the pipe extending from the inlet to the drop-tube junction. This correction was applied to avoid penalizing sediment that had entered the computational domain but had not yet reached the separator location. The resulting capture efficiency of 1.98% indicates that only a small fraction of the fine A1 sediment was captured by the drop tube during the simulated period.

This low efficiency is consistent with the A1 operating condition, which combines fine sediment particles (d_p = 90 μm) with a relatively high main-pipe velocity (U = 3.0 m/s). Under these conditions, turbulent suspension and streamwise advection dominate over gravitational settling near the branch. Consequently, most of the sediment remained entrained in the horizontal carrier flow and bypassed the drop-tube opening.

To further examine the hydraulic effect of the separator, vertical centerline concentration profiles were extracted upstream of the branch, immediately downstream of the branch, and at 10D, 30D, and 50D downstream of the branch. Figure 6 shows that the upstream profile remains within the expected A1 concentration range before reaching the drop-tube junction. This indicates that the modified drop-tube geometry did not significantly disturb the incoming benchmark slurry structure prior to extraction.

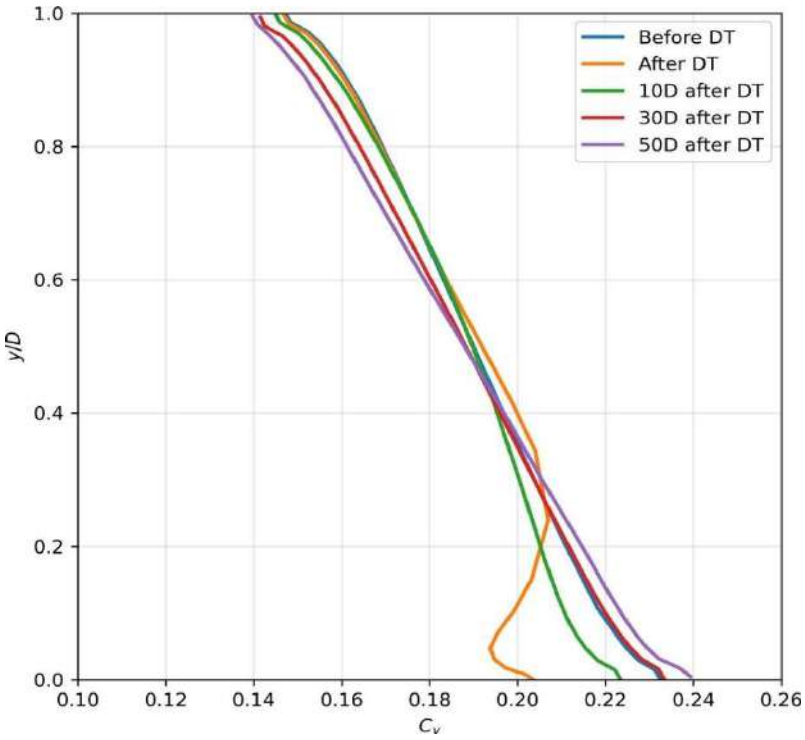

Figure 6. A1 concentration profiles before and after the drop tube.

Immediately after the branch, the lower portion of the profile exhibits a measurable reduction in solids concentration, consistent with localized removal of the near-invert sediment layer into the drop tube. Farther downstream, the profiles shown in Figure 6 gradually recover toward the original stratified suspended-flow shape, indicating continued redistribution through turbulent remixing and gravitational settling with increasing downstream distance.

Overall, the simulations demonstrate that the proposed separator geometry influences slurry transport behavior under fine-particle suspended conditions, but does not achieve strong gravitational segregation when particle settling velocity remains low relative to the dominant streamwise transport velocity. Under the A1 operating condition, turbulent suspension and axial advection were sufficient to keep most particles entrained within the carrier flow, thereby limiting passive branch capture.

These results indicate that separator effectiveness is governed not only by geometry, but also by the balance between particle settling velocity and hydraulic transport intensity. For gravity-assisted separation systems, settling velocity is a first-order parameter because it determines whether particles can migrate downward into the branch before being convected downstream by the carrier flow. For small particles, the terminal settling velocity may be approximated by Stokes' law,

$$w_s = \frac{\rho_s - \rho_l) g d_p^2}{18\mu} \tag{5}$$

showing that settling velocity scales with the square of particle diameter. Consequently, the fine A1 sediment class (d_p = 90 μm) possesses a very small settling tendency, making sustained suspension likely under the imposed line velocity. In practical terms, the available residence time near the branch was too short for most particles to descend appreciably before being swept past the junction.

This behavior may also be interpreted through competing timescales: a vertical settling timescale $t_s = H/w_s$ and a horizontal convective timescale $t_c = L/U$. Effective passive capture requires $t_s \leq t_c$, whereas the present A1 case remained in the opposite regime, with transport dominating over settling.

Substantially improved branch capture may therefore be possible under conditions that increase the relative importance of settling compared with streamwise transport, such as lower mixture velocity, larger particle diameter, increased density contrast, or modified separator geometry that increases local residence time. These conditions were not simulated in the present stage of the study; therefore, they should be interpreted as expected trends based on the settling and transport timescale arguments rather than as confirmed results. Additional simulations are currently being evaluated to quantify the influence of particle size, velocity, and separator-geometry variations, and these results will be presented in future work. For the fine A1 sediment transported at the relatively high baseline velocity considered here, the present results indicate that only limited passive separation should be expected from the current geometric modification alone.

CONCLUSIONS

An Eulerian–Eulerian slurry CFD framework implemented in ANSYS Fluent and following the methodology of Xiong et al. (2019) was successfully reproduced, validated, and extended to evaluate a gravity-assisted drop-tube separation concept for dredging pipeline applications.

Major findings are:

1. Benchmark A1–A4 concentration-profile cases were predicted with strong agreement relative to the experimental measurements of Gillies et al. (2004) and the published CFD results of Xiong et al. (2019), confirming the suitability of the selected multiphase framework for fine-particle suspended slurry transport.
2. The more strongly stratified B1–B4 cases exhibited greater sensitivity to turbulence-driven particle diffusion. Improved agreement was obtained through calibration of the turbulent-dispersion coefficient, demonstrating the importance of turbulence closures when modeling coarser particles and higher delivered concentrations.
3. The validated CFD framework was successfully transferred to a novel drop-tube branch geometry representing an in-line passive solids extraction concept applicable to dredging pipelines.
4. Under the baseline A1 operating condition ($d_p = 90$ μm, $U = 3.0$ m/s), branch capture efficiency was limited to approximately 1.98%. Most solids remained suspended and bypassed the separator, indicating that geometric modification alone was insufficient to produce strong segregation for fine particles at high transport velocity.
5. Despite modest direct capture, the drop tube measurably altered downstream concentration structure. Reduced near-invert solids concentration was observed immediately downstream of the branch, followed by gradual redevelopment of the stratified profile with axial distance.
6. The drop-tube separator results indicate that capture effectiveness is strongly governed by the balance between particle settling velocity and hydraulic transport intensity. For the fine-particle A1 case, turbulent suspension and streamwise advection dominated over gravitational migration, thereby limiting passive branch capture.

Overall, the present results suggest that passive in-line hydraulic separation may be feasible in dredging pipelines, but successful implementation requires operating conditions favorable to settling.

Improved performance is expected for coarser sediments, lower mixture velocities, increased branch residence time, or optimized separator geometry.

Future work should quantify capture efficiency as a function of particle size distribution, line velocity, and solids loading; evaluate pressure-loss penalties associated with branch extraction; and optimize branch diameter, branch length, insertion spacing, and multi-stage separator arrangements for field-scale beneficial-use dredging systems.

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DATA AVAILABILITY

All data, simulation files, processed results, and plotting scripts generated or used during this study are available from the corresponding author upon reasonable request.

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NOMENCLATURE

C_v	Local solids volume concentration (-)
D	Pipe diameter (m)
d_p	Particle diameter (m)
g	Gravitational acceleration (m/s^2)
H	Characteristic settling distance (m)
L	Characteristic horizontal transport length (m)
m_{DT}	Sediment mass captured in drop tube (kg)
m_{in}	Cumulative sediment mass injected at the inlet (kg)
m_{up}	Sediment mass remaining in the upstream main-pipe section before the drop-tube junction (kg)
p	Pressure (Pa)
t_c	Convective transport timescale (s)
t_s	Settling timescale (s)
U	Mean mixture velocity (m/s)
u	Velocity vector (m/s)
w_s	Particle settling velocity (m/s)
α_q	Volume fraction of phase q (-)
η	Separator capture efficiency (%)
μ	Dynamic viscosity (Pa s)

ρ Density (kg/m^3)
τ Stress tensor (Pa)

LAYERED MEDIA DETECTION: EFFICIENT MAPPING OF FLUID MUD

M. Holland[1], P. Pocwiardowski[2]

EXTENDED ABSTRACT

Accurate seabed mapping in environments with fluid mud is essential for safe navigation, particularly in dredged ports and estuarine zones. Traditional single-beam echosounders and in-situ measurement techniques, such as density profiling or shear strength testing, have been widely used to determine the 'navigable bottom.' However, these methods face limitations in spatial coverage and fail to meet the comprehensive data requirements of modern hydrographic standards, particularly the International Hydrographic Organization (IHO) Category Zone of Confidence A1 (CATZOC A1) for electronic navigational charts.

This study presents a novel approach that employs multibeam echosounders operating across an ultra-wide frequency range (80–400 kHz) to address the limitations of single-beam systems. The primary objective is to evaluate whether multibeam systems can meet CATZOC A1 criteria in layered media environments where fluid mud is present, thereby replacing conventional single-point or low-frequency sonar methods.

The approach leverages the swath coverage capability of high frequency multibeam sonars to achieve full bottom mapping, which is critical for CATZOC A1 certification. The wide frequency range allows for the acoustic characterization of layered sediments, distinguishing between suspended mud and consolidated substrates. This enables the determination of the shallowest safe navigable depth without relying on physical sampling or intrusive methods.

The proposed method successfully identified the navigable bottom in the presence of fluid mud, providing high-resolution bathymetric outputs that fulfill CATZOC A1 requirements. The multibeam system demonstrated comparable accuracy to low-frequency single-beam echosounders while offering superior spatial coverage. This performance supports the use of multibeam as a reliable, efficient alternative for mapping in complex sedimentary environments.

This research highlights the potential for a paradigm shift in hydrographic surveying in layered media. By eliminating the need for time-consuming in-situ sampling and enhancing data quality, this multibeam-based method can streamline workflows, reduce operational costs, and significantly improve navigational safety. The approach is particularly applicable in dynamic port environments and waterways where fluid mud frequently alters the bathymetric profile.

Keywords: Fluid mud, navigable bottom, mapping, multibeam, CATZOC

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[1] VP Sales Canada and Great Lakes, NORBIT Subsea, 102 – 4430 Chatterton Way, Victoria, BC, V8X 5J2, Canada, +1 506 451 5250, matt.holland@norbit.com
[2] Product Director Subsea, NORBIT Subsea, 292 King Daniel Ln, Goleta, CA, 93117, USA , +1 805 452 4910, pawel@norbit.com

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MANAGEMENT OF SUSPECTED UNEXPLODED EXPLOSIVE ORDNANCE IN SEDIMENT REMEDIATION

M. Bodman[1], R. Thomas[2], D. Ormerod[3], and A. Corp[4]

EXTENDED ABSTRACT

Esquimalt Harbour is a large working harbour located on southern Vancouver Island, British Columbia, with a long history of impacts from shipbuilding, mills, canneries, and naval activities. Due to historical naval activities, there are various active and former military sites that may contain munitions and explosives of concern (MEC) and unexploded explosive ordnance (UXO) that have been discarded into waterbodies and become entrained in the sediments. These MEC and suspected UXO are typically not sources of contamination; however, they may be co-located with contamination related to historical harbour activities. The presence of MEC or UXO poses a challenge in the remediation of contaminated sediments, both due to the need to remove them prior to transportation of the sediment for disposal, as well as the concern for safety of workers completing the remediation efforts.

Common investigation survey methods used to identify the nature and extent of MEC and UXO include side-scan sonar, magnetometer, and diver-based or remotely operated vehicle (ROV) surveys, however, each of these methods has their respective limitations. Geophysical survey methods can produce false positives or inconclusive results and do not allow for confirmed documentation of the presence and extents of MEC and UXO within subsurface sediments. Due to these limitations, site managers also typically consider historical information to determine the expected presence of MEC and UXO and then employ risk management strategies to guide the inclusion of management techniques during implementation of remedial actions.

Various MEC and UXO management techniques have been used during sediment remediation projects in Esquimalt Harbour and have been developed and refined through lessons learned from the completion of eight separate sediment remediation projects within the Harbour. Prior planning to determine appropriate requirements and coordination for sediment disposal was a critical first step in determining requirements that the contractor must complete to segregate MEC and UXO. Segregation has been incorporated into design documents through a requirement to screen all dredged sediment through a minimum material screen size. Clear communication pathways and stop work procedures are established in the design specifications to guide both finds at the processing facility as part of screening and for chance finds during the course of

[1] MARPAC Environment Officer CFB Esquimalt, Department of National Defence, PO Box 17000 Station Forces, Victoria, British Columbia, V9A 7N2, Canada, 250-363-4824 D199, Michael.bodman@forces.gc.ca.
[2] Senior Environmental Specialist, Environmental Services, Contaminated Sites, Vancouver Island Group, Public Services and Procurement Canada, 401-1230 Government Street, Victoria, British Columbia V8W 3X4, Canada, 250-418-5731, Robert.thomas2@pwgsc-tpsgc.gc.ca.
[3] Principal Engineer. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2721, Email: dormerod@anchorqea.com.
[4] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.

dredging. Additional scope and schedule management planning is required to account for stop work occurrences when unsafe MEC or UXO are encountered, the slower dredge pace limited by processing rates, and the increased chances of discovering archaeologically significant materials.

During construction, material separation requirements are driven by available guidance that informs the method(s) for identifying and removing MEC and UXO (GICHD 2016). The MEC/UXOs must stay within a certain distance of the relevant military institution responsible for disposal but must also be stored a safe distance away from inhabited buildings. Based on the previously implemented remediation projects, the best location that meets the distance requirements for both collection and safe storage has been determined to be a barge or barges in the middle of the Harbour. The typical processing setup includes a material scow with recently dredged material which transits to the processing barge. There, sediment is transferred to over spill plates to conveyor belts which feed material into continuing reduced screen sizes until the minimum screen size requirement is met. Pickers observe the conveyor belts and screens for suspected MEC or UXO. This process requires trained personnel observing the segregation process under the guidance of a trained UXO professional, emergency procedures in place if MEC/UXO is discovered, and a secure magazine for temporary storage of safe-to-handle finds (BNQ 2015). An alternate segregation method originally considered was to require the contractor can spread the material out in a thin lift and employ visual methods and metal detectors. This was not instituted due to the significant space required to complete this method. These procedures typically add a significant complication to remedial efforts increasing both costs and durations of the remedial efforts and should be considered in development of design documents to ensure safety and compliance with landfill requirements for ultimate disposal of contaminated sediments. A byproduct of the segregation process often includes the discovery of archaeologically significant materials such as pre- and post-contact artifacts, and human or faunal remains that requires diligent archaeological oversight to appropriately characterize, document, and manage.

Once the materials have been separated and sorted, the military institution that has ownership of the materials is responsible for disposal. Live munitions are safely detonated and scrap or dead munitions are recycled if possible. The contractor is responsible for shipment of inert materials for disposal to the appropriate military institution which occurs separately from the disposal of contaminated sediment.

In summary, sites with the suspected presence of MEC and UXOs often have significant unknowns which require advanced planning, clear communication and design requirements, and ultimately adaptive management. There are limited options for segregating MEC and UXO available within the industry, so understanding the limitations and risks of proceeding can often be driving factors into planning sediment remediation projects. Overall, the segregation and management of suspected UXOs can be expected to lead to a 25% to 50% increase in project costs and increase duration by 10 to 25%.

Keywords: Dredging, munitions, unexploded ordinances, dredged material processing, project management

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AN EFFICIENT QA SYSTEM FOR DREDGING RELATED SAFETY QUESTIONS

A. Idle[1] and J. Hannon Jr[2]

ABSTRACT

This paper describes the development of a computationally efficient question answering (QA) system whose primary function is to answer dredging-related safety questions in the field using the U.S. Army Corps of Engineers EM 385-1-1 Safety and Health Requirements Manual as its knowledge source. The system employs a modular architecture that integrates an efficient information retrieval model with pre-trained transformer-based language models for answer generation. The system is designed to retrieve and interpret applicable safety requirements for dredging operations, even when presented with documents or query formulations it has not previously been trained on. The EM 385-1-1 was selected as the document knowledge base for this system, as the safety requirements outlined in the manual govern safety practices commonly applied to dredging activities, including dredge plant operations, heavy equipment hazards, confined spaces, and water-related risks. The results demonstrate the system's ability to accurately answer questions based on the safety manual, making it an effective tool to enhance decision making in the field.

Keywords: Question answering, information retrieval, dredge safety, EM 385-1-1, transformer models

INTRODUCTION

Dredging operations present a unique set of safety challenges due to the combination of heavy equipment and unpredictable site conditions. Crews working on dredging projects must comply with extensive safety requirements addressing hazards such as equipment operation, confined spaces, lifting operations, and exposure to water-related risks. These requirements are typically documented in technical safety manuals, which are often lengthy, complex, and difficult to navigate in time-critical field settings. As a result, dredging personnel may struggle to quickly identify specific safety requirements relevant to the task at hand.

Question answering (QA) systems offer a potential solution by enabling users to pose natural-language questions and receive accurate answers based on the requirements outlined in a safety manual or related document. These systems could improve access to safety guidance during planning and execution of field operations. However, many existing QA approaches rely on large language models that require significant computational resources, limiting their practicality for deployment in operational environments where computing capabilities may be constrained.

This paper presents a modular and computationally efficient QA system developed specifically to answer dredging-related safety questions using technical safety documentation. The system is evaluated using the U.S. Army Corps of Engineers EM 385-1-1 Safety and Health Requirements Manual, a 930-page regulatory document that governs safety practices commonly applied to dredging activities. By combining efficient information retrieval techniques with pre-trained transformer-based language models, the system

[1] Project Engineer, Manson Construction Co., 5985 Richard St Suite #1, Jacksonville, Florida 32216, USA, T: 904-821-0211, Email: Aidle@mansonconstruction.com.
[2] Project Engineer, Manson Construction Co., 5985 Richard St Suite #1, Jacksonville, Florida 32216, USA, T: 904-821-0211, Email: Jhannon@mansonconstruction.com.

demonstrates the ability to provide accurate, document-based answers without the use of large, resource-intensive models or domain-specific fine-tuning. The results highlight the system's potential to support safety-related decision-making during dredging field operations.

PRIOR LITERATURE

Analyzing Dense Passage Retrieval for Multihop Question Answering (Sidiropoulos et al. 2021)

The paper analyzes the performance of passage retrieval models in the context of complex (multi-hop) questions, aiming to understand how these models behave when multiple hops of reasoning are required. Dense passage retrieval has become a standard approach for retrieving relevant passages in open-domain question answering (QA), achieving state-of-the-art results in multi-hop QA as well. However, the paper notes that dense retrieval models have not been properly evaluated concerning the multi-hop nature of the problem, often focusing only on the end result of the retrieval pipeline. To address this gap, the authors provide an in-depth evaluation of dense retrieval models, unveiling both their successes and limitations. They introduce a hybrid retrieval approach that combines lexical and dense retrieval methods, which is highly competitive with state-of-the-art dense retrieval models while requiring substantially less computational resources. This hybrid approach leverages the strengths of both methods, aiming to improve the efficiency and effectiveness of multi-hop QA systems. The paper also performs a qualitative analysis to better understand the challenges behind passage retrieval for multi-hop QA. The authors highlight that multi-hop QA requires retrieval and reasoning over multiple pieces of information, which is fundamentally different from session search and conversational search. They emphasize the importance of decomposing complex information needs into independent facets, subtopics, or sub-tasks to support multi-hop QA effectively.

ColBERT Retrieval and Ensemble Response Scoring for Language Model Question Answering (Gichamba et al. 2024)

This paper explores the creation of a system that can answer technical multiple-choice questions about telecommunication standards. To help the system perform well on this domain-specific task, they utilized information retrieval models to retrieve passages from the 3rd Generation Partnership Project (3GPP) dataset, which consists of technical telecommunications documentation/standards. They experimented with three different retrieval methods, ColBERT, BM25, and a hybrid approach combining the results from both, and found that ColBERT was the best performer in this scenario. The retrieved passages are passed to a transformer-based model for answer generation; they tested two different transformer models (Phi-2 and Falcon-7B) independently and evaluated the system's performance. Phi-2 is the smaller of the two models with 2.7 billion parameters; it is designed for common-sense reasoning and language understanding and is resource-efficient.

Falcon-7B has 7 billion parameters and is known for performing well in text generation and understanding. When utilizing Phi-2, they fine-tuned the model on the TeleQnA dataset which consists of technical telecommunication questions and answers. When using the Falcon-7B model, the prompts do not include the multiple-choice options, thus the response will not align perfectly with the options. To handle this, they make use of an ensemble response scoring mechanism to score each response and select the highest scoring response. After Falcon-7B generates a response, they use cosine similarity between the response and each option. The authors fine-tuned the embedding model to determine the similar and contradictory texts and the option with the highest similarity to the response is chosen. This paper was successful at using smaller language models to handle technical queries. Phi-2 was the best performer and achieved an accuracy of 81.9%.

ColBERTv2: Effective and Efficient Retrieval via Lightweight Late Interaction (Santhanam et al. 2022)

This paper takes a stab at improving the effectiveness and efficiency of late interaction models. Late interaction models create multi-vector representations at the token level which are effective at capturing granular detail but can become very large in terms of required storage space. This paper addresses this by using ColBERTv2 which was developed by researchers at Stanford University and introduced in 2022. ColBERTv2 builds off the original ColBERT architecture, however, it creates multi-vector representations which allows for more detailed matching between queries and documents and also introduces a residual compression mechanism which can greatly reduce the size of the vectors without compromising the retrieval quality. Compression is achieved by using cluster centroids to capture context-aware semantics, allowing for compact storage through residual representations. ColBERTv2 also introduces a denoised supervision strategy which refines the signals during training through noise reduction which leads to improved retrieval quality. This paper discusses testing ColBERTv2 on multiple benchmarks to determine how well it stands up against other models. They found that ColBERTv2 reduces the space footprint of late interaction models by 6-10 times and outperforms existing retriever models based on extensive testing on 28 datasets.

Context-Aware Term Weighting for First Stage Passage Retrieval (Dai and Callan 2020)

This paper introduces the Deep Contextualized Term Weighting (DeepCT) framework, which aims to improve the accuracy of first-stage passage retrieval by using deep language models such as BERT to capture a term's contextual features. Key contributions are context-aware term weighting and the DeepCT framework. Traditional term frequency methods often ignore the context in which terms appear many times, leading to suboptimal term importance estimation. DeepCT addresses this issue by mapping contextualized term representations from BERT into context-aware term weights. DeepCT leverages the transformer encoder of BERT to capture semantic and syntactic features from a term's linguistic context. DeepCT also runs at offline index time, making it feasible to use it in first-stage retrieval. These weights are stored in an ordinary inverted index for efficient retrieval. The DeepCT framework shows improvements in retrieval accuracy over traditional methods, highlighting the importance of context-aware term weighting.

Dense Passage Retrieval for Open-Domain Question Answering (Karpukhin et al. 2020)

This paper presents an approach to open-domain question answering by utilizing a dense passage retriever (DPR) for the retrieval component in open-domain QA. Traditional methods like TF-IDF and BM25 which match keywords efficiently with an inverted index can be seen as representing the question and context in high dimensional, sparse vectors. Instead, this paper proposes using dense representations, where embeddings are learned from a small number of questions and passages through a dual-encoder framework. These are two independent BERT networks (base, uncased) and take the representation at the [CLS] token. The DPR is trained on dot-product similarities. The dense retriever significantly outperforms traditional sparse methods, achieving 9 to 19 percent higher top 20 passage retrieval accuracy. A table is provided to showcase the improvement is consistent across multiple open-domain QA datasets. By leveraging dense representations, the DPR reduces the reliance on large, computationally expensive models, making it more feasible and practical for standard machines. The paper states that on a comparable CPU with 512 GB of memory, the DPR can process 995 questions per second.

Retrieval-Augmented Generation Approach: Document Question Answering using Large Language Model (Muludi et al. 2024)

This research explores a method of improving traditional document-based question answering systems which are typically difficult to implement, require substantial resources, and can produce incorrect fabricated answers. The paper tackles this issue using retrieval-augmented generation (RAG). RAG integrates information retrieval with the text generation process, essentially linking a pre-trained language model to an external knowledge base. They aim to create a system which can automatically process external documents provided by the user, retrieve relevant information from the documents based on the question, and generate accurate answers using that knowledge. By providing the language model with document-based knowledge, they aim to reduce inaccurate answers. Their system utilizes a vector store retrieval model which feeds the relevant passages to GPT-3.5 Turbo, a transformer model, to generate answers using its pre-trained knowledge along with the knowledge from the passages. They evaluate their system on a proposed dataset (created by the authors) and on Stanford's SQuAD dataset. Based on their metrics, which include ROUGE, BERTScore, BLUE, and Jaccard Similarity, their system outperforms others and proves to be effective at accurately answering document-based questions.

Unsupervised Document Expansion for Information Retrieval with Stochastic Text Generation (Jeong et al. 2021)

The paper addresses the challenge of vocabulary mismatch in information retrieval (IR), where terms between queries and documents are lexically different but semantically similar. Traditional methods often require a large volume of query-document pairs to train expansion models. To overcome this, the authors propose an Unsupervised Document Expansion with Generation (UDEG) framework that uses a pre-trained language model to generate diverse supplementary sentences for the original document without relying on labeled query-document pairs. The UDEG framework introduces stochastic perturbations to the embeddings of generated sentences, enhancing the diversity of the supplementary content. This approach aims to enrich document representations, thereby improving retrieval performance. The authors validate their framework on two standard IR benchmark datasets, demonstrating that UDEG significantly outperforms existing expansion baselines. A key advantage of the UDEG framework is its ability to generate relevant terms for documents during indexing time, which avoids delays in responding to user queries. This contrasts with query expansion methods that augment queries with additional terms, which can be less efficient. The paper highlights that document expansion can provide more context-related terms due to the generally longer length of documents compared to queries.

DATA

The U.S. Army Corps of Engineers EM 385-1-1 Safety and Health Requirements Manual will serve as the information retrieval knowledge base for this system. The EM 385-1-1 is a 930-page document outlining occupational safety protocols and regulations. Processing the document for retrieval first entails converting the PDF to a raw text file and performing some manual cleaning. This includes removing the table of contents which comes before each section and removing long lists of words which resulted from tables and figures in the PDF. Leaving this text would confuse the model. From there, the cleaned text file is split into passages and indexed using the retrieval model's framework. Though the transformer model being utilized can handle 512 tokens, it was found through experimentation that 100 tokens lead to better answer extraction than longer passages. A sliding window approach was also tested, in which each passage would contain overlapping text from the previous passage to capture more context, however, this led to longer passages which the model did not perform well on. The poor performance on longer passages is likely due to the nature of the document used for retrieval. A short section in the manual can cover many different

areas on a specific topic and likely confuses the model when trying to extract an answer. Figure 1 below illustrates the document handling process.

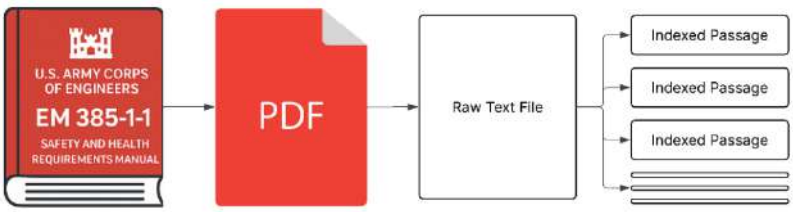

Figure 1. Indexed Passage Creation for Retrieval Model

The dataset used for evaluation consists of 100 safety-related questions and gold-label answers developed by the project team. The questions were formulated by reading through the EM 385-1-1 manual and determining questions that should be answerable through text extraction. The system is not trained on any questions from this dataset or any other dataset related to the EM 385-1-1 manual prior to evaluation. All answer predictions will rely on information retrieval from the document and the language model's pre-training.

The team explored the possibility of fine-tuning the language model on a QA dataset related to workplace safety or other related safety fields, however, no suitable datasets were located. While creating a custom dataset for fine-tuning is an option, the timeframe for this experiment precludes this.

METRICS

To assess the performance of the custom question answering (QA) system developed for job safety related queries, the F1 score was employed as a primary evaluation metric. The F1 score, widely used in extractive QA tasks, measures the harmonic mean of precision and recall based on token overlap between predicted answers and ground truth references. The evaluation was conducted using the Hugging Face evaluate library, specifically its implementation of the SQuAD metric. This tool normalizes both predictions and references—removing punctuation, lowercase, and stripping articles—to provide a fair comparison that emphasizes semantic accuracy over exact phrasing. The system's predictions and corresponding human-annotated answers were formatted to include unique question identifiers and textual spans, allowing for seamless integration with the metric. By leveraging this method, the evaluation captured the system's ability to retrieve and synthesize accurate information from previously unseen technical documents, demonstrating its generalization capabilities in a zero-shot setting.

MODELS

This QA system is built on a modular architecture including three core components: an information retriever (IR) model, a transformer-based language model for text extraction, and a classifier model to handle yes/no questions. The IR model being utilized is ColBERTv2, the latest version of ColBERT, which is a late interaction model. ColBERTv2 employs cross encoder distillation, hard negative mining, and a compression mechanism leading to superior performance and a reduced space footprint all while maintaining the retrieval quality. ColBERTv2 also introduces a denoised supervision strategy which refines the signals during training through noise reduction which leads to improved retrieval quality (Khattab et al. 2021). ColBERT will be paired with a multi-hop retrieval method in effort to maximize retrieval coverage and context. During the first hop, passages are retrieved based on the original question. A reformed question with additional context is then created by concatenating the top scoring answer from the first hop with the

original question. The second hop retrieves passages based on this new reformed question. During answer extraction and scoring, the original question is used to preserve relevance. This multi-hop retrieval process is illustrated below in Figure 2.

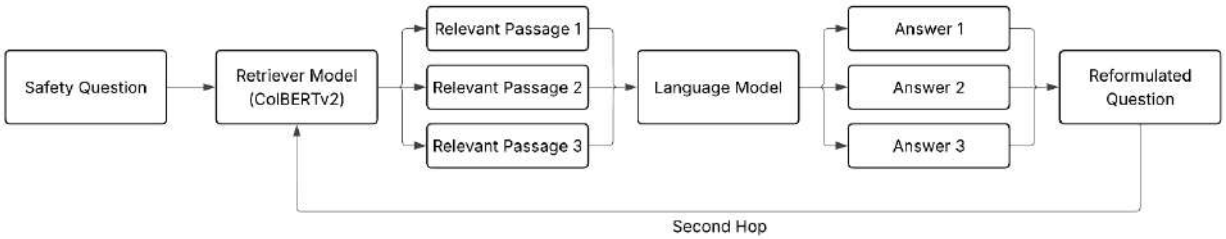

Figure 2. Multi-Hop Passage Retrieval with Question Reformulation

The multi-hop retrieval approach not only maximizes the retrieval coverage but also enhances the contextual understanding by utilizing the answers retrieved in the first hop as part of the query reformulation. This enables the system to retrieve more relevant documents and answer queries with a broader and more accurate context. Throughout the answer extraction and scoring process, the original question is preserved to maintain relevance, ensuring that the final answer is closely aligned with the user's intent. This process reflects a multi-step reasoning mechanism where the system iteratively refines its understanding and response by incorporating both the original and newly gathered context.

Recent studies have demonstrated the effectiveness of multi-hop retrieval in complex domains like question answering, where the ability to dynamically incorporate context can lead to significantly better performance on tasks requiring deep understanding or multi-step reasoning (Khattab et al. 2021). By employing this strategy, ColBERTv2 with multi-hop retrieval can outperform traditional single-hop systems, especially in cases where the answer to a question cannot be fully extracted from a single document but requires synthesis from multiple sources.

The development team initially planned to fine-tune BERT base on the SQuAD dataset for question answering and utilize the fine-tuned model for extractive question answering for the system. After fine-tuning and some experimentation, the team concluded that better results could be achieved by using a version of BERT already fine-tuned by Google. Specifically, the google-bert/bert-large-cased-whole-word-masking-finetuned-squad from HuggingFace was tested. Google first pre-trained this model using whole-word masking and then fine-tuned it for question answering on the SQuAD dataset. This model performed well for the task at hand, however, the team tested one more candidate before making a final decision. It was found that RoBERTa, specifically deepset/roberta-base-squad2 from HuggingFace, was the best contender. This model is already fine-tuned on the SQuAD 2.0 dataset and was found to offer faster and more accurate answer extraction than BERT.

To expand the system's question answering abilities, a zero-shot classification model was incorporated to handle yes/no safety questions that cannot be addressed by the extractive question answering component. The facebook/bart-large-mnli model from HuggingFace was selected for this purpose. Originally developed for natural language inference, this model is based on the BART architecture and fine-tuned on the Multi-Genre Natural Language Inference (MNLI) dataset. The classifier evaluates candidate hypotheses constructed from predefined labels, enabling it to determine whether a given passage supports or refutes a yes/no safety query. Figure 3 illustrates how the system handles binary questions. For a full system diagram, see Figure 4.

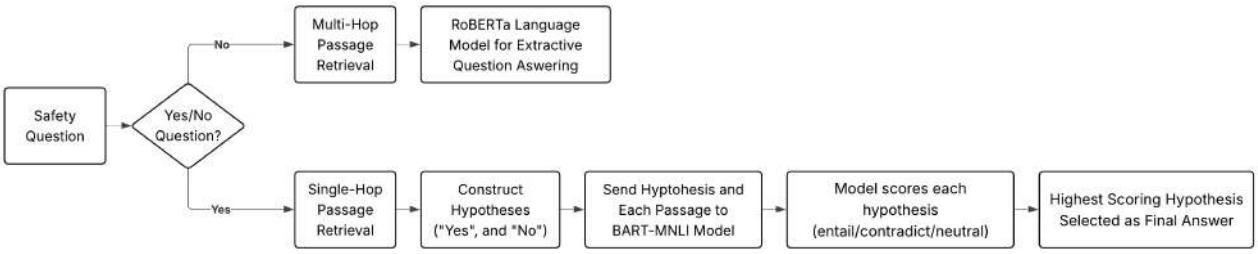

Figure 3. Handling of Yes/No Questions using BART-MNLI Classifier Model

METHODS

The initial step completed was processing the EM 385-1-1 document and creating a corpus for ColBERT. As discussed in the data section previously, processing the document entailed converting the PDF to a text document, cleaning up some unneeded information such as the table of contents, splitting the document into passages, and using ColBERT's framework to index the passages. The last two steps were repeated several times afterward when testing the system's performance with varying passage sizes. With this document, the system was found to perform best with one hundred token passages.

After creating the corpus, the team successfully set up ColBERTv2 for retrieval. Access to ColBERTv2 was gained by cloning ColBERT's GitHub repository. Some initial queries were tested, and it was established that retrieval was working properly, and relevant passages were being retrieved from the corpus. The team was also able to successfully incorporate a multi-hop method where two retrieval hops are performed for each query. The first hop is performed based on the original question, and the second hop is performed using a reformed version of the question based on the top scoring answer from the first hop. An example of this would be if the query asks, "What is PPE?" and the top-scoring answer from the first hop is "personal protective equipment." The reformulated question would then be: "What is PPE, considering the phrase 'personal protective equipment'?" During answer extraction and scoring, the original question is used. During final answer scoring, the answers from both hops are considered. This method leads to additional passages being evaluated based on a question with more context.

The team initially pursued fine-tuning BERT base for question answering on the SQuAD dataset. This was performed successfully; however, it was becoming an iterative process adjusting the training parameters and re-training to minimize training and evaluation loss. Even with only two epochs, it seemed that overfitting was occurring based on a decrease in training loss but an increase in evaluation loss. Due to time constraints, the team decided that much better performance would be achieved by using a model that has already been fine-tuned for question answering.

Two language models which are already fine-tuned for question answering were tested in the system and both performed well answering questions about the information in the EM 385-1-1 manual. The team first tested google-bert/bert-large-cased-whole-word-masking-finetuned-squad, which performed well and was able to produce accurate answers to most questions the team prompted it with during testing. Though this model seemed to satisfy the needs of the system, the team also tested deepset/roberta-base-squad2 which not only seemed to produce more accurate answers but also extracted answers faster.

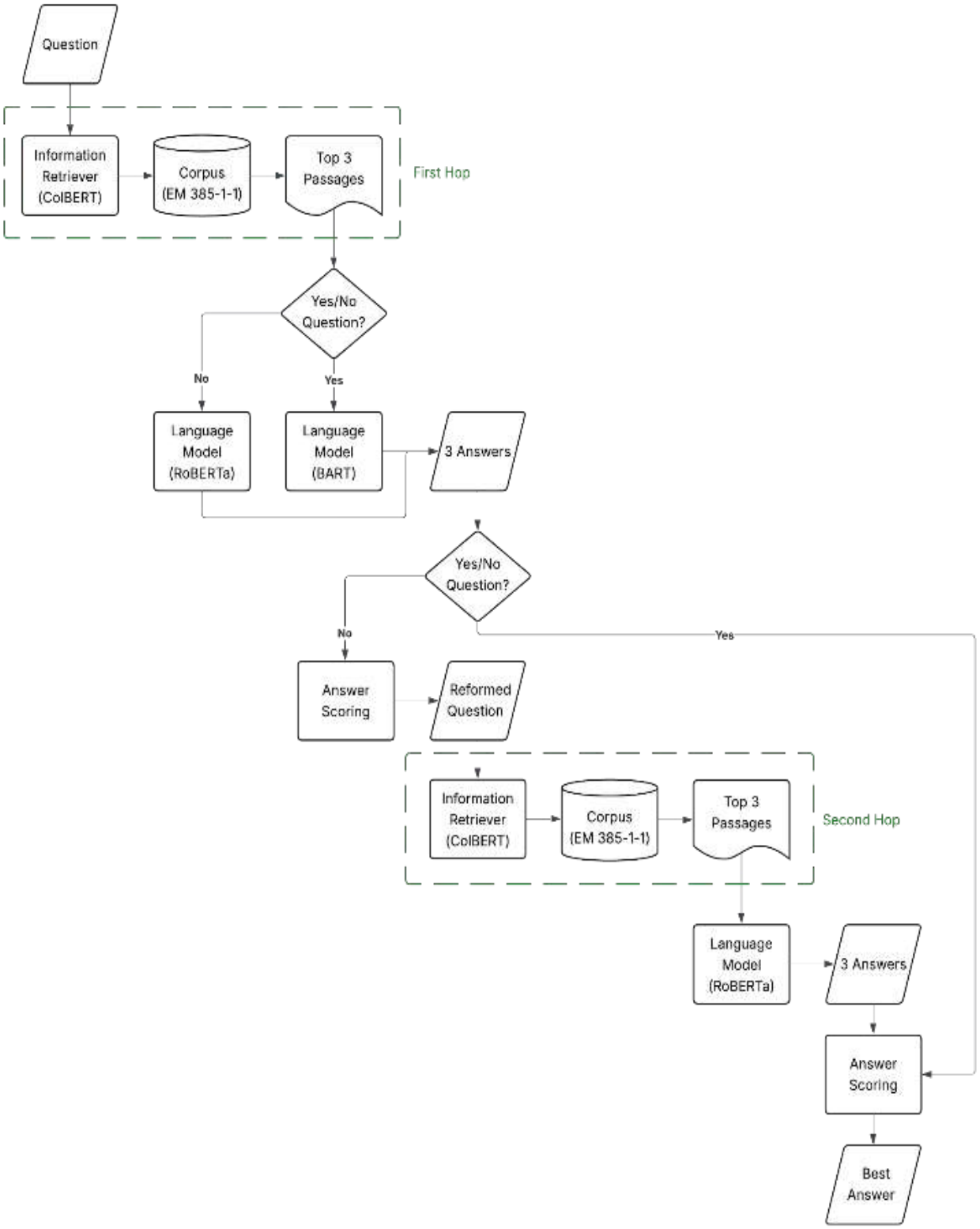

Figure 4. Full Dredge Safety QA System Diagram

At this stage, the development team was satisfied with the system's performance based on initial safety question testing. Due to using a language model which generates answers through direct text extraction, the system was unable to answer yes/no questions. To address this, the team successfully employed facebook/bart-large-mnli, a zero-shot classifier model. When the system is prompted with a query, the first word of the question is analyzed to determine if it's a yes/no question, if so, the zero-shot classifier is used rather than RoBERTa. When utilizing the zero-shot classifier, multi-hop is disabled because the reformed question would not make sense with the current reformation method.

The system was now at a point where the development team was satisfied with its performance based on the initial safety questions thrown at it during testing/experimentation. At this point, the team developed an evaluation dataset consisting of one hundred question–answer pairs. The system demonstrated strong performance across most questions on the evaluation dataset. Performance was measured using F1 score and Exact Match, computed with the Hugging Face evaluate library via its implementation of the SQuAD metric.

RESULTS

The system achieved an F1 score of 76.4% and an Exact Match score of 61.0%, indicating strong zero-shot performance on previously unseen, domain-specific safety documents. A snippet of the evaluation results can be found below in Figure 5. This result suggests that the combination of ColBERTv2's efficient late interaction retrieval mechanism and a transformer-based answer extraction model can generalize effectively without domain-specific fine-tuning. An F1 score at this level compares favorably with prior work on zero-shot question answering over technical documentation, where Gholami and Noori report an end-to-end F1 score of approximately 49% on AWS technical corpora without any domain-specific training (Gholami and Noori 2021). The high score reflects the system's ability to locate and extract semantically relevant spans of text that closely match the reference answers, even when those answers are embedded within complex or unfamiliar language typical of regulatory and technical documentation. Future work will involve exploring additional methods to improve information retrieval and answer selection and developing a safety QA dataset based on other safety documents for domain-specific fine-tuning. Improving retrieval and answer extraction could include adjusting the multi-hop methodology based on the reviewed literature, exploring ways to combine answers and information from different passages, and experimenting with the existing retrieval parameters. Though the system is already performing well, additional experimentation could lead to better results along with exposing the language model to safety-related language for additional training. Eventually, the corpus could even be expanded with additional safety documents leading to a wider knowledge base for question answering.

Question	Gold Label Answer	Predicted Answer	Exact Match	F1 Score
What is PPE?	Personal Protective Equipment	Personal Protective Equipment	☑	100
Is PPE a control measure?	Yes	yes	☑	100
What is a grounding conductor?	a conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes	a conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes	☑	100
What type of fire is an electrical fire?	Class C	Class C	☑	100
What is an RAC?	Risk Assessment Code	Risk Assessment Code	☑	100
What is an AHA	Activity Hazard Analysis	Activity Hazard Analysis	☑	100
When should an alternate SSHO be provided?	When the SSHO is off-site for a period longer than 24 hours	If the SSHO is off-site for a period longer than 24 hours	✗	92
When should torches be inspected?	Before each use	before each use	☑	100
What does a torch inspection include?	Leaking shutoff valves, hose couplings, tip connections and damaged torch tips	leaking shutoff valves, hose couplings, tip connections and damaged torch tips	☑	100
What type of containers should be used to collect flammable trash?	Self-closing containers		✗	0
What standards need to be followed when handling flammable liquids?	NFPA 30 and NFPA 30A	NFPA 30, NFPA 30A, or other applicable standards	✗	62
How far do heaters need to be from gas containers?	6 ft (1.8 m)	6 ft (1.8 m)	☑	100
What's required if combustible materials have been exposed to a fire hazard?	A fire watch shall be assigned to remain at the location for at least One (1) hour after the exposure has ended	a fire watch shall be assigned to remain at the location for at least one (1) hour after the exposure has ended	☑	100
Do you need a fire watch when welding near flammable materials?	Yes	yes	☑	100
Which section discusses requirements of confined spaces?	Section 34	Section 34	☑	100
Is smoking allowed in maintenance vaults?	No	no	☑	100
How often must crane operators get physical exams?	Every 2 years and any time a condition is observed that may impact safe operation	every 2 years	✗	33
When should pre-operation tests be performed on cranes?	When cranes are erected and after each climbing operation	when cranes are erected and after each climbing operation	☑	100

Figure 5. Snippet of Evaluation Dataset and Results

CONCLUSIONS

Overall, the system exceeded the development team's expectations and successfully met all initial design objectives for supporting dredging-related safety inquiries. It can accurately answer questions based on technical safety documentation relevant to dredging operations without relying on large, resource-intensive models or extensive domain-specific training. Future work could involve testing additional methods to improve information retrieval and answer selection and developing a dredging-focused safety QA dataset based on EM 385-1-1 and other dredging-specific safety documents for targeted fine-tuning. Improving retrieval and answer extraction could include adjusting the multi-hop methodology based on the reviewed literature, exploring methods for combining safety information from multiple passages, and experimenting with existing retrieval parameters to better reflect dredging use cases. Although the system is already performing well, additional experimentation could further enhance performance by exposing the language model to a broader range of dredging safety terminology and operational scenarios. Over time, the document corpus could be expanded to include additional dredging-related safety references, resulting in a more comprehensive knowledge base for answering safety questions encountered during dredging field operations.

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DATA AVAILABILITY

Some models and code generated during the study are proprietary or confidential. These may be provided upon request with restrictions on republication and use.

ENGINEERING STRATEGIES FOR RESERVOIR SEDIMENT REMOVAL USING AUTOMATED SEDIMENT TRANSFER SYSTEMS

L.Gehrmann[1] and T.Groß[2]

ABSTRACT

Reservoir sedimentation represents a critical challenge for sustainable dam operation and long-term water infrastructure management. Progressive sediment accumulation reduces storage capacity, affects hydropower generation and flood control functions, and disrupts downstream sediment continuity. Conventional dredging approaches in reservoirs typically rely on periodic large-scale sediment removal and disposal, which can involve high operational costs, significant environmental impacts, and interruptions to reservoir operation.

This paper presents an alternative sediment management strategy based on continuous sediment extraction and downstream transfer, illustrated by the ConSedTrans® technology developed by Hülskens Sediments. The system integrates suction-based sediment extraction with automated control and pipeline transport to transfer sediments downstream of the dam under controlled hydraulic conditions.

Unlike conventional dredging approaches that remove sediment from the river system, the continuous sediment transfer concept aims to maintain reservoir capacity while restoring sediment continuity downstream. Operational parameters such as sediment concentration, hydraulic transport capacity, and real-time monitoring allow sediment transfer rates to be adjusted to flow conditions and environmental constraints.

The presentation discusses when and why continuous dredging strategies may be preferable to episodic dredging, particularly in reservoirs with high sediment loads and limited disposal options. Engineering aspects including system configuration, operational requirements, sediment characteristics, and integration into existing dam infrastructure are analyzed.

Case study experiences from European reservoirs demonstrate the technical feasibility of continuous sediment transfer and highlight potential benefits such as reduced lifecycle costs, minimized environmental disturbance, and improved downstream morphodynamic stability. The results indicate that continuous sediment management can represent a viable long-term strategy for sediment-laden reservoirs.

Keywords: Autonoumous Dredging, beneficial uses, slurry transport, reservoir sedimentation

INTRODUCTION

Rivers are vital for human well-being and the functioning of ecosystems. They provide a range of benefits such as water supply, food production, energy generation, recreation, and climate regulation. However, rivers are also under increasing pressure from human activities that alter their natural flow regimes, water quality, and sediment transport. One of the most widespread and impactful human

[1] Project Manager, Hülskens Sediments GmbH, Hafenstr. 3, 46483 Wesel, Germany
[2] Directive Manager, Hülskens Sediments GmbH, Hafenstr. 3, 46483 Wesel, Germany

interventions on rivers is the construction of dams and reservoirs, which create barriers to the longitudinal connectivity of river systems. Dams and reservoirs can have significant negative effects on the sediment balance of rivers, leading to sediment accumulation in the upstream areas and sediment deficiency in the downstream areas. This can affect the morphology, ecology, and resilience of rivers, as well as the services they provide to society. The aim of evaluating alternative methods of sediment removal in river systems is to assess the environmental and climate impacts of different sediment management strategies in impounded waters, and to propose a sustainable approach that can improve the sediment continuity and the resilience of rivers.

This discussion opens with an explanation of how dams cause sediment deficits in water bodies and examines the resulting consequences for river systems and deltas. It then assesses how sediment continuity contributes to river resilience. The discussion further presents alternative methods for improving sediment continuity in impounded waters, including their respective advantages and disadvantages. A key component is the presentation of continuous sediment removal methods in impounded waters, which represent a novel technique for the controlled and constant transfer of sediment from a reservoir to the tailwater. This new approach to reservoir management also includes the potential for supplementary environmentally beneficial measures, such as methane gas collectors to capture and utilize methane produced by reservoirs.

Sediment Retention in Reservoirs: Environmental implications

The environmental impacts of sediment retention in reservoirs can be classified according to the location where they occur: in the reservoir, in the downstream river, or in the river delta.

Reservoir

The accumulation of sediments within a reservoir can lead to the transportation of organic materials, nutrients such as phosphorus, and contaminants like cadmium, zinc, or other heavy metals. An increase in the concentration of nutrients, organic matter, and pollutants in a reservoir, or dissolved into the interstitial water, can lead to eutrophication, which may trigger excessive growth of algae and other aquatic plants. Such eutrophication can reduce the oxygen available to fish and other organisms, resulting in fish kills, unpleasant odors and tastes, and an increased risk of toxic algal blooms (Sonarghare et al. 2020).

Anaerobic conditions within the sediment can generate methane gas. Methane in reservoirs and lakes is produced through a combination of processes, such as microbial decomposition of organic matter in sediments and the water column. Factors such as temperature, trophic status, and phytoplankton blooms play a crucial role in methane production and emissions in water bodies (Waldo et al. 2021).

Methane release from lake sediments is influenced by sediment shear strength, which affects methane storage and release. Factors such as sand content and water content play a role in determining sediment shear strength and, subsequently, methane storage and release. Water depth also influences methane storage and ebullition, with deeper water leading to increased hydrostatic pressure and larger bubble formation (Shiba 2015).

Furthermore, sedimentation can increase the load on dam structures and potentially affect turbine operation, outlet blockage, and dam safety. The operational consequences of accumulated sediment in a reservoir include reduced storage capacity, flood retention potential, hydropower capacity, and drinking water volume (Perera et al. 2023).

Downstream River

Sediment transport is a key factor that determines the river morphology, as it affects the erosion and deposition of sediment along the river course. Sediment retention in reservoirs can affect river morphology in several ways. Sediments play a pivotal role in defining river morphology on small and large scales, shaping river ecosystems by transporting nutrients and pollutants.

Changes in sediment fluxes in river systems can have significant impacts on their stability, geomorphology, ecology, and socioeconomic activities. Increased sediment fluxes can lead to deposition in river channels, altering habitats, increasing flood risk, and requiring dredging for maintenance. Decreased sediment fluxes in sediment-starved waters can intensify erosion, degrade ecosystems, affect aquatic productivity and food webs, and threaten food security. By reducing the downstream sediment supply, sediment retention in reservoirs can also alter both the cross-sectional and longitudinal profiles of river channels. The cross-sectional profile describes the shape and size of the river channel at a given location, whereas the longitudinal profile describes the elevation and slope of the channel along its length. Reduced sediment supply can promote erosion and incision of the river bed and banks, resulting in narrower and deeper channels with steeper slopes, higher flow velocities, and increased shear stress. Erosion in river channels can lead to bank collapse, affecting river engineering structures, the stability of adjacent land, and geomorphic features such as deltas and beaches (Habersack et al. 2013, Perera et al. 2023, Zarfl et al. 2022).

In contrast to a sediment-starved river, excess sediment concentration in the downstream river, such as during flushing operations, can harm aquatic wildlife. Sediment flushing operations can lead to a decrease in macroinvertebrate density and richness due to the sensitivity of different taxa to sediment stress. For example, trout populations experience negative impacts from sediment flushing, with juveniles being especially vulnerable to changes in sediment pressure (Espa et al. 2019).

River Delta

The retention of sediment in a reservoir or river reduces sediment transport into river deltas, resulting in delta erosion where sediment removal by waves, currents, and tides exceeds the incoming sediment supply. Delta erosion refers to the loss of land and sediment in delta areas and can lead to coastal erosion, land subsidence, saltwater intrusion, and habitat degradation. Because less sediment is transported downstream, delta areas receive less material from the river, which can create a net loss of sediment and land over time (Perera et al. 2022, Edmonds et al. 2023, Speerli et al. 2020).

A decrease in downstream sediment transport into delta areas can alter the overall sediment composition and distribution of the entire delta. This can affect the stability and morphology of delta areas, as fine sediments can create more cohesive and compacted deltas, while coarse sediments can create looser and more dispersed deltas (Liu et al. 2023).

Episodic Sediment Management Strategies and Limitations

Sediment management is the process of controlling the quantity and quality of sediment in water resources, such as rivers, lakes, reservoirs, and estuaries, to achieve various objectives, such as flood control, water supply, hydropower generation, navigation, ecosystem protection and restoration, and recreation. Sediment management is essential for the sustainable use and management of water resources, especially in the context of climate change, population growth, urbanization, and land-use changes, which can alter natural sediment dynamics and cause adverse impacts on the environment and society (Speerli et al. 2020, Liu et al. 2017).

According to Morris (2020), sediment management practices can be classified into four main categories: sediment avoidance, sediment routing, sediment removal, and adaptive management strategies. Each

category includes several measures that can be implemented at different stages of the water resource development cycle, from planning and design to operation and maintenance. The following Figure 1 summarizes the main characteristics, advantages, and disadvantages of each category and its measures.

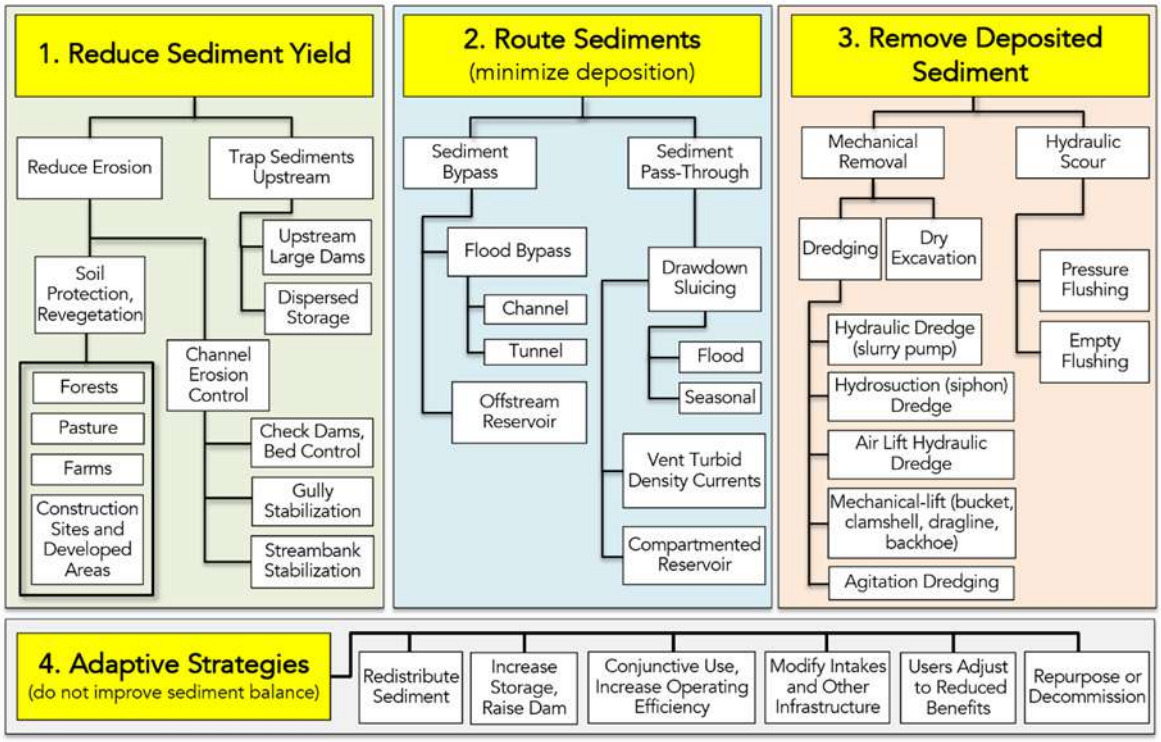

Figure 1: Sediment Management Strategies (Morris 2020)

Morris (2020) classifies active and passive sediment management methods under categories two and three. He distinguishes between sediment routing strategies, such as bypasses and passive sediment passing, and active removal strategies, such as mechanical removal by dredging or excavation, or by operating the reservoir outflow to cause flushing, which draws down sediment from a limited area close to the dam outlets and results in extremely high sediment concentrations in the river.

Route Sediments

River systems around the world generally exhibit high variability in sediment transport over time, or what is known as time compression. This occurs when sediment load increases with discharge, leading to a shorter time frame for sediment load compared to water discharge.

Routing strategies aim to keep the incoming sediment moving to minimize deposition. This can be achieved by routing sediment-laden floods either around the storage zone through a bypass or through the storage zone by pass-through. The overall strategy can be summarized as “store clear water—release muddy flows.” This approach is especially relevant where extreme sedimentation events can occur. Sediment bypass methods include diverting clear water into an offstream reservoir or building a flood bypass to route sediment-laden floods around the reservoir. Sediment pass-through options include venting turbid density currents, where clear and muddy flows are vertically separated; drawdown sluicing, where clear and muddy flows are separated in time; or compartmented reservoirs, which separate clear and muddy flows horizontally.

Remove Deposited Sediment

Sediment removal can be categorized into mechanical removal, including excavation and dredging, and flushing by hydraulic scour.

Dry excavation involves lowering the reservoir level to access deposits using earth-moving equipment. In areas with seasonal water-level changes, dry excavation in delta regions can occur during natural drawdown periods. Dry excavation is effective for removing coarse sediment that readily dries out, with some delta sediments even being sold commercially. However, it is usually impractical for poorly consolidated fine sediment unless it has been dewatered long enough to drain and consolidate. Transporting such sediment by truck along local roads or highways to distant disposal sites can lead to significant impacts, such as traffic, noise, road damage, and sediment dispersal.

Dredging, on the other hand, entails excavating material from underwater. The sediment can be reintroduced downstream or contained for dewatering. Hydraulic dredging is common for reservoirs due to its efficiency and low environmental impact. Specialized techniques like siphon dredging, which uses the reservoir's water level for energy, are also employed.

However, dredging is expensive, though costs can be reduced by discharging sediment downstream instead of transporting it inland. For hydropower projects, self-generated electricity can further cut costs. Land availability for sediment disposal poses economic and physical constraints, especially for large projects. The ultimate goal is to restore sediment transport in rivers, necessitating continuous dredging rather than sporadic large-scale campaigns.

Flushing, or empty flushing, involves draining a reservoir to let the river erode exposed deposits, then transporting the sediment through low-level outlets (LLOs) past the dam. It occurs in three stages: drawdown, emptying, and refilling. The process can take between one day and one month, depending on reservoir size. Flushing can have significant impacts on aquatic life and downstream infrastructure such as water supply intakes. The effects on aquatic species depend on factors like the magnitude and duration of high sediment concentration, oxygen content in the released water, sediment's oxygen demand, and the presence of contaminants. Managing the drawdown rate, diluting high concentration flows with clear water, scheduling flushing events to avoid sensitive periods like spawning, and releasing clear water after flushing are essential environmental mitigation measures.

LIMITATION OF EPISODIC AND SINGLE SEDIMENT REMOVAL STRATEGIES

Episodic sediment management strategies such as drawdown flushing, pressure flushing, and large-scale dredging campaigns are widely applied to mitigate reservoir sedimentation. However, their effectiveness is inherently limited by operational, hydraulic, environmental, and economic constraints. Annandale et al. (2016) emphasize that sediment management approaches rooted in a finite “design life” paradigm implicitly accept progressive storage loss and rely on intermittent interventions, often initiated only after substantial degradation of reservoir functionality has already occurred. Once large volumes of sediment have accumulated, their hydraulic remobilization becomes increasingly inefficient, and full restoration of storage capacity is rarely achievable in practice (Annandale et al. 2016).

Flushing operations are typically associated with short-duration sediment releases characterized by extremely high suspended sediment concentrations and limited dilution volumes. While the total amount of sediment released may be comparable to pre-dam sediment loads, the strong temporal compression of sediment discharge represents a fundamental deviation from natural transport regimes and can cause pronounced downstream impacts on aquatic ecosystems, water supply infrastructure, and channel morphology (Annandale et al. 2016). In wider reservoirs, flushing efficiency is further

constrained by the geometry of the flushing channel, which restricts sediment mobilization to a narrow active corridor while coarse material continues to accumulate outside the scoured zone.

Mechanical sediment removal methods such as hydraulic dredging and dry excavation face similar limitations when applied as episodic measures. They can locally restore storage volume, protect critical infrastructure such as intakes, or remove sediment from accessible areas, but they do not establish a long-term balance between sediment inflow and outflow. As long as sediment delivery from the catchment continues, the effect of isolated interventions remains temporary, and sediment accumulation resumes after the operation.

Single or infrequent dredging activities therefore represent a specific case within the broader limitation of episodic sediment removal strategies. From an engineering and economic perspective, such operations are constrained by high energy demand, abrasion of pumping equipment, and strong dependence on nearby disposal or placement sites. In reservoirs where sediment has accumulated over decades, deposited volumes can reach millions of cubic meters, making complete removal technically and economically prohibitive. Dredging is therefore typically limited to partial removal in accessible areas, leaving large portions of deposited sediment untouched.

Consequently, isolated dredging campaigns are suitable primarily as short-term mitigation or supporting measures within a broader, long-term sediment management framework. They may be necessary where immediate operational intervention is required, but as stand-alone measures they are poorly suited to sustaining reservoir capacity under continued sediment inflow.

CONTINUOUS SEDIMENT TRANSFER

The limitations of episodic and single sediment removal measures highlight a fundamental challenge in reservoir sediment management: approaches that intervene only intermittently are unable to establish a durable balance between sediment inflow and outflow. As long as sediment delivery from the catchment continues, strategies based on discrete events inevitably lead to recurring accumulation, increasing operational effort, and rising lifecycle costs. These constraints point toward the need for sediment management concepts that operate continuously or at short intervals, are hydraulically integrated into normal reservoir operation, and align sediment release more closely with natural transport processes. In this context, continuous sediment transfer represents an alternative engineering strategy aimed at maintaining reservoir capacity and downstream sediment continuity over the long term, rather than periodically correcting advanced stages of sedimentation.

The method of Continuous Sediment Transfer described in Detering et al. (2017) and Gehrmann (2024) in impounded waters is a special form of sediment release from the reservoir that aims to achieve a sediment flow in the tailwater that is as close to natural as possible.

As an addition to the variants listed by Morris (2020), the continuous sediment transfer method offers a combination of the management strategies of categories 3 and 4, as it transfers sediment to the tailwater continuously and not only during temporary events using fully automated suction dredgers.

This method requires the installation of special devices, known as SediMovers, that allow sediment to be transported out of the reservoir continuously or at short intervals without affecting water discharge or power generation. The sediment concentration introduced into the downstream water can be varied dynamically to match ecological constraints.

The advantages of this method are:

- Improving sediment continuity and the resilience of the river system by maintaining or restoring geomorphological and ecological processes and functions.
- The reduction of sediment accumulation in the reservoir and the associated problems, such as siltation or eutrophication.
- Increasing the lifespan and efficiency of the dam and reservoir by improving storage capacity, water quality and safety.

SediMover Overview

A SediMover uses a cutter and suction head to loosen and suspend sediment from the reservoir bed. If required, hydro jets may be added to the suction head to increase sediment mobilization and production. The loosened sediment is immediately captured by a high-performance pump, reducing uncontrolled resuspension and limiting turbulent currents near the reservoir bed. The resulting slurry is conveyed through a pipeline to a defined discharge zone, where the sediment is directly or indirectly reintroduced into the tailwater (Figure 2).

The SediMover is fully automated and can operate autonomously. It is therefore equipped with various sensors and measuring devices. Data is collected and analyzed in real time and used to optimize operation. The density and slurry discharge are measured in real time to adjust the sediment concentration introduced into the tailwater according to the transport capacity of the river. The vessel is GPS-tracked and moves around the reservoir using three to four winches. Using bathymetric survey data, the operational plan for addressing areas of sediment accumulation can be optimized for the greatest efficiency.

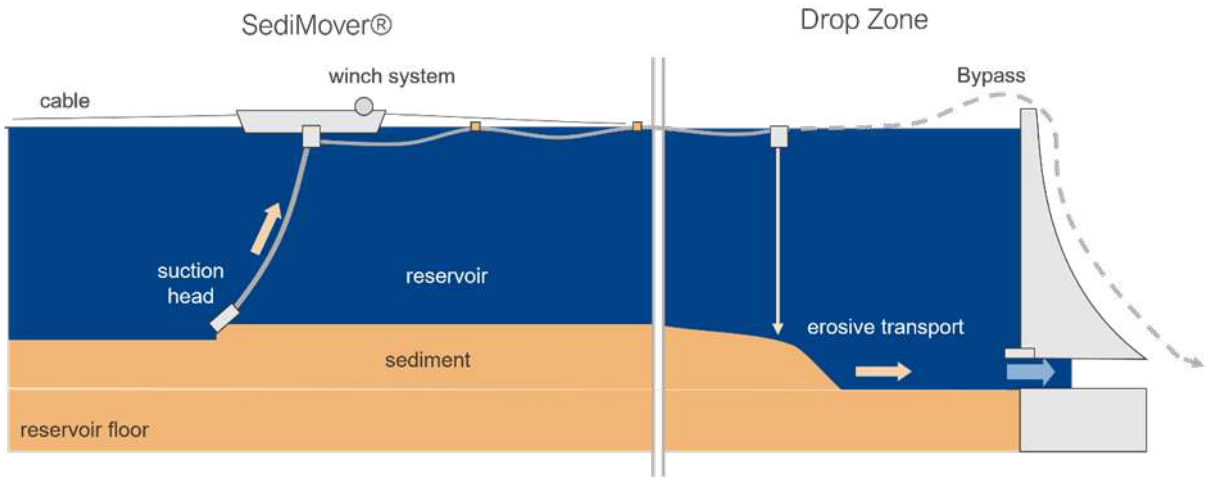

Figure 1: Functioning Continuous Sediment Transport (Gross et al. 2023)

Real-time Monitoring and Control System

The SediMover uses sensors and a high level of automation to record all necessary operational information in real time. Additionally, a monitoring program in the downstream river can be used to assess project performance and environmental impacts of sediment transport. Therefore, the following parameters are collected on the vessel and in the downstream river.

- Density measurement
- Flow volume
- Location tracking
- Height tracking

- Downstream flow tracking
- O_2 and TSS measurements downstream
- Weather data

The collected information is analyzed and stored in a cloud-based system, where it is used to regulate SediMover operation and thereby control sediment transport to the downstream river. Operational limit parameters, such as maximum sediment concentration or discharge thresholds, can be implemented in the control system to adjust or interrupt sediment transfer when defined limits are reached.

To avoid risk during floods or strong weather events, the system also includes weather and forecast data where available. The SediMover can therefore maneuver into protection mode at a preset position and restart operation after the event.

Energy Supply

The vessels are driven by electricity, which can be taken directly from the grid or supported by project-specific renewable energy, such as solar power. The vessels have low energy consumption and can be designed in an energy-saving variant, especially for regions with limited energy supply.

PROJECT EXPERIENCES

The practical applicability of continuous sediment transfer concepts has been investigated through several pilot applications at European reservoirs with differing geomorphological and operational boundary conditions. These pilot projects were implemented to evaluate technical feasibility under real reservoir conditions, including automated operation, sediment concentration control, and integration into existing dam infrastructure. Initial observations indicate that continuous sediment transfer systems can be adapted to a wide range of reservoir geometries and sediment characteristics, while allowing sediment releases to be regulated in accordance with downstream transport capacity and environmental constraints. Although site-specific design and operational parameters remain decisive, the European pilot projects provide valuable empirical evidence that continuous sediment transfer can function as a robust and scalable component within integrated sediment management strategies, supporting long-term reservoir sustainability.

CONCLUSIONS

Reservoir sedimentation remains one of the most persistent challenges for the long-term sustainability of dam and hydropower infrastructure. As demonstrated in this paper, conventional sediment management approaches such as flushing, dredging, and other episodic removal strategies can play an important role in mitigating sediment-related impacts but are fundamentally limited in their ability to establish a durable sediment balance. Their reliance on discrete operational windows, high sediment concentrations, and site-specific boundary conditions often results in short-term relief rather than sustained preservation of reservoir functionality.

The analysis highlights that maintaining reservoir capacity and downstream sediment continuity over the long term requires a shift away from purely episodic interventions toward management concepts that operate continuously or at short intervals and are integrated into normal reservoir operation. Continuous sediment transfer strategies address key limitations of flushing and single dredging campaigns by reducing temporal concentration of sediment releases, decoupling sediment management from extreme hydrologic events, and enabling controlled adjustment of sediment fluxes in line with hydraulic and environmental constraints. By approximating natural sediment transport processes more closely, these approaches offer a viable pathway to treating reservoir storage not as an exhaustible resource but as a renewable component of water infrastructure systems.

Continuous sediment transfer is not intended to replace all established sediment management techniques. Rather, it represents a complementary strategy that can be combined with routing, flushing, or targeted removal measures depending on site-specific conditions, sediment characteristics, and operational objectives. When applied as part of an integrated sediment management framework, continuous approaches have the potential to reduce lifecycle costs, limit environmental disturbance, and extend the functional lifespan of reservoirs. Future applications and monitoring results will be essential to further define design criteria, operational envelopes, and performance benchmarks for continuous sediment transfer in different reservoir settings.

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BENEFICIAL USE OF DREDGED MATERIAL FOR MARSH RESTORATION AT STOUTS CREEK IMPOUNDMENT

M.J. Marano[1], G. Clifton[2], K. Axt[3], J. Fisahn[4], L. Tagger[5] and J. McTavish[6]

ABSTRACT

The Stouts Creek impoundment site is a 109-acre portion of the federally owned Edwin B. Forsythe National Wildlife Refuge (EBFNWR) in Lacey Township, Ocean County, New Jersey. The defunct and degraded impoundment was identified by US Fish and Wildlife Service (USFWS) land-managers as a prime candidate for the beneficial use of dredged material (DM). Restoration would comprise lifting the impoundment floor to a healthy low-marsh elevation. The NJDOT Office of Maritime Resources partnered with EBFNWR to characterize the site's ecological, hydrological, and soil conditions. The Design Team of WSP USA Inc. (WSP) and Gahagan and Bryant Associates (GBA) designed a project to fill, monitor, and restore the tidal wetland habitat to a more sustainable condition.

The marsh surrounding the impoundment provides a buffer between the neighborhoods of Lanoka Harbor and Sunrise Beach from the Barnegat Bay. Pre-construction, the impoundment was functioning as a shallow, 1 to 3 feet in depth, brackish open water area with an organic fine-grained substrate. The prospective restoration area was not heavily utilized by wildlife and was approximately 20% vegetated.

The project featured beneficial use (BU) of approximately 170,000 cubic yards (CY) of DM from 11 nearby NJ Navigation Channels. These channels had no available placement options, so DM was directed to the impoundment's open water and degraded areas. One impoundment cell was filled to the targeted elevations, thereby promoting natural tidal flushing, carbon sequestration, and repopulation of native vegetation and critically endangered shorebirds. Additionally, the elevated marsh platform will protect nearby neighborhoods by mitigating storm surges, reducing coastal flooding, and combating sea level rise. Future project phases intend to develop a mix of mudflat, low and high marsh, and scrub-shrub habitats.

Extensive outreach was undertaken between State, Federal, and project stakeholders to strengthen trust and establish permitting conditions necessary to support the desired project goals. With stakeholder input, an

[1] Vice President, WSP USA, Inc., 2000 Lenox Drive, Lawrenceville, NJ, 08648, USA, T: 609-512-3516, Email: michael.marano@wsp.com
[2] Director , NJ Dept. of Transportation, Office of Maritime Resources, PO Box 600, Trenton, NJ, 08625, USA, T: 609-963-2108, Email: Genevieve.clifton@dot.nj.gov
[3] Vice President, WSP USA, Inc., 2000 Lenox Drive, Lawrenceville, NJ, 08648, USA, T: 609-512-3500, Email: katie,axt@wsp.com
[4] Design Engineer, WSP USA, Inc., 2000 Lenox Drive, Lawrenceville, NJ, 08648, USA, T: 609-512-3500, Email: joseph.fisahn@wsp.com
[5] President, Northland Airboats, LLC., 104 Fresh Ponds Road, East Brunswick, NJ 08816, USA, T: 908-331-1199, Email: ltagger@northlandairboats.com
[6] Design Engineer, Gahagan and Bryant Associates, 9008 Yellow Brick Road, Suite P, Baltimore, MD, 21237-5608, USA, T: 410-682-5595, Email: jamctavish@gba-inc.com

adaptive management plan was developed to support project construction. This plan included a robust construction monitoring element comprising twice-daily surveys of the active placement areas, along with entire site surveys, to compare fill progress to design target elevations. Construction access, and various fill techniques are discussed in detail. Target elevations were achieved; future site phases and long-term results will be projected.

Keywords: beneficial use, habitat restoration, adaptive management and monitoring, coastal resilience.

PROJECT LOCATION

The project is located in the central coastal region of New Jersey, Lacey and Berkeley Townships, Ocean County, (Figure 1.)

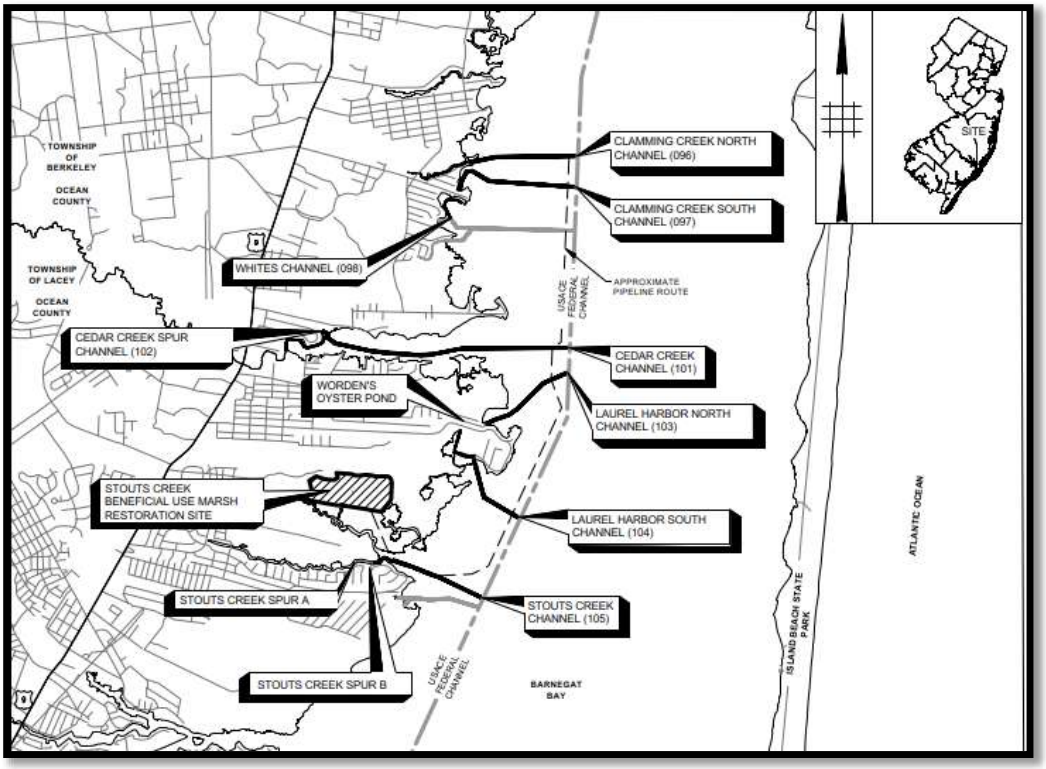

Figure 1. Project Location.

STOUTS CREEK IMPOUNDMENT SITE HISTORY

The Stouts Creek Impoundment project site is Federally owned and managed by the United States Fish and Wildlife Service (USFWS) as a National Wildlife Refuge (NWR). As a NWR site resources including fish and wildlife habitat are protected and enhanced, while providing a variety of compatible recreational and educational opportunities for the public. The Edwin B. Forsythe National Wildlife Refuge (EBFNWR) is a 48,000-acre refuge primarily consisting of wetlands, of which 78% is salt marsh interspersed with shallow coves and bays.

The project site was historically used as a salt hay farm and was widely ditched to support farming and mosquito control. In the mid-1950s a waterfowl hunting club created the initial western impoundment. A second impoundment was created to the east of the initial impoundment in the 1970s by State and local

agencies with the dual purpose of mosquito control and to create waterfowl habitat. The site was subsequently acquired by USFWS and incorporated into the EBFNWR. Water control structures were previously used to manipulate water surface elevations within the impoundments; however, these structures are no longer operational. In 2015, the perimeter berms were intentionally breached in several locations to promote tidal flushing of the impoundments.

The locations of these berms, impoundments, and the "cells" they create are shown below (Figure 2).

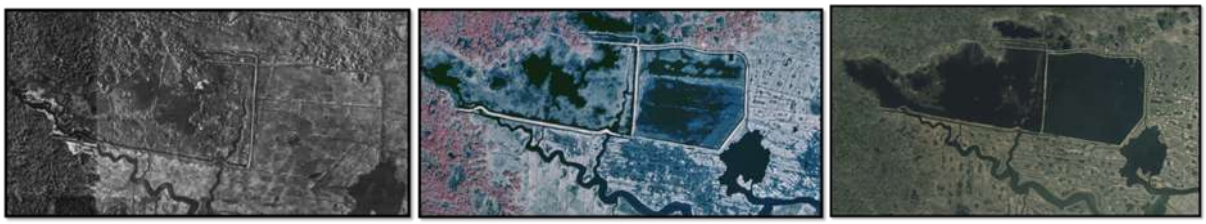

Figure 2. Stouts Creek Impoundment from left early-1970's, mid-1990's & 2015.

Approximately 80% of the area within the project site consists of open water with average depths of approximately 2 feet. Isolated islands of *Spartina alterniflora* are present in both impoundments, and the perimeter berms are dominated by *Phragmites australis*. Portions of the site located above elevation 1.5 ft. NAVD88 were characterized as uplands as they are located above the wrack line and do not meet the criteria for wetland hydrology. Existing habitat types and plant communities were mapped throughout the study area based on aerial imagery and verified in the field. The results of which are provided below in Table 1.

Table 1: Existing Conditions

EXISTING HABITAT CONDITIONS	ACRES
Low Marsh	15.61
Open Water	87.29
Phragmites emergent wetland	2.35
Upland Berms	4.03

DATA COLLECTION

Basemapping

An existing 3D model was developed by compiling several different datasets from various sources. Two separate public LiDAR datasets from 2014 (NOAA NGS, topobathymetric) and 2019 (USGS, topographic) were reviewed and subsequently field-verified by Gahagan and Bryant Associates (GBA). The 2019 USGS dataset predominantly covered the site, while the 2014 NOAA NGS dataset offered additional coverage in areas of deeper water that the 2019 dataset could not penetrate.

In December 2023, GBA verified the 2014 NOAA NGS dataset in the shallow to medium water depths, by collecting hydrographic survey data within the Barnegat Bay, along the shoreline, and within the shallow waterways connecting the impoundment to the bay. The bathymetric surveys were conducted with a shallow-draft vessel following the guidelines referenced in the US Corps of Engineers (USACE) Hydrographic Survey Manual EM 1110-2-1003 (2013), for navigation and dredging support surveys for soft bottom materials.

In January 2024, GBA performed several transects across the impoundment and along stretches of high and low marsh using a GNSS RTK rover from an airboat. The results of this survey determined a vertical adjustment factor to apply to the 2019 USGS dataset in areas of inundation and it verified the elevations in the high and low marsh ranges.

Figure 3 below shows the field data collected to adjust the larger, publicly available LiDAR data sets.

Figure 3. December 2023 and January 2024 GBA supplemental data collection areas

The combined, adjusted LiDAR datasets were then supplemented with the December 2023 hydrographic and January 2024 RTK data collected by GBA. These four datasets were processed, filtered, and combined using AutoCAD Civil3D software, and the composite surface created served as the basis of design.

Hydraulics and Hydrology

Two 2D HEC-RAS models were developed, a coarse model (250'x250' grid) of a portion of the Barnegat Bay and a fine model (30'x30' grid) of the project placement area. Boundary limits of the coarse model were selected by available USGS tidal stations with recorded water levels. The northern boundary condition utilized water levels at tidal gauge USGS 01408205, located at the Route 37 Bridge. The southern and eastern boundary conditions were taken from a USGS tide gauge station at Waretown, NJ in the Barnegat Bay (USGS 01409124) and the USGS tide station at Barnegat Light House (USGS 01409125), respectively. The extents of the fine model were defined by the first encountered major thoroughfares (Laurel Blvd.) in the community of Lanoka Harbor to the north and Nautilus/Capstan Drive in the community of Sunrise Beach to the south; both in Lacey Twp., NJ. The westerly boundary of the fine model was held at US Route 9. Tide elevations were extracted from the coarse model and were used as the eastern boundary condition for the fine model. To have a better understanding of the dynamics of the placement area, the fine model contained a 10'x 10' refinement region shown in red in Figure 4.

Figure 4. Fine Model

Water surface elevations were extracted from the fine model and compared against data collected by four loggers deployed by Rutgers University in the project area to verify the calibration of the model. Data at all four loggers was replicated by the fine model with the largest percent difference and largest median difference being 5% and 0.46 inches respectively (Figure 5) indicating that the model reflected the onsite conditions.

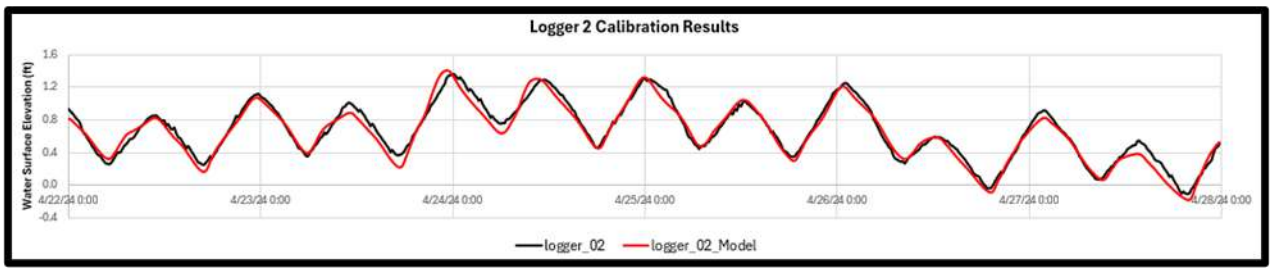

Figure 5. Fine Model Calibration Results Logger 2

Synthetic curves developed for the project site, including a neap cycle, a spring cycle, and a mixed tide were created from data collected at the USGS stations from 2018-2024 at the northerly, southerly and easterly coarse model boundaries. The tidal sequence for the fine model boundary was extracted from the coarse model to determine the project tidal range shown in Table 2 below.

Table 2: Tidal Elevations NAVD88

	MHHW	MHW	MLW	MLLW
Fine Model	1.18	0.82	0.07	-0.17

The model results are further corroborated with the existing habitat assessments based on biological benchmarks identified and surveyed on healthy marsh adjacent to the proposed placement area.

Biological Benchmarks and Habitat Assessments

Bio-benchmark data collection relates vegetation type or species to observed elevations to document the tolerance of different species to observed or measured hydrological and topographic site conditions. In December 2023, design team scientists conducted a bio-benchmark survey of the tidal marshes adjoining

the site. The environmental scientists flagged healthy low-marsh and high-marsh, plant species, as well as less-desirable invasive species to establish local target elevation ranges. Project surveyors then recorded the identified healthy habitat elevation ranges using GPS land survey methods.

While the hydrology of the study area has been altered through ditching, it provides the best analog of the microtidal regime of the future restoration site.

The results of the bio-benchmark survey are provided below in Table 3.

Table 3: Bio-Benchmark Survey Elevations (NAVD88)

HABITAT	AVERAGE ELEVATION	MINIMUM	MAXIMUM	NUMBER OF OBSERVATIONS
Phragmites australis	0.97	0.80	1.19	9
Spartina patens	1.10	0.81	1.25	10
Distichlis spicata	0.87	0.80	0.93	7
Spartina alterniflora	0.84	0.71	0.98	14
Scrub/Shrub	1.44	1.24	1.77	7
Upland Maritime Forest	2.58	2.49	2.72	3

Geotechnical – Subsurface Investigation and Analyses

A subsurface investigation program was performed within the east and west placement sites. A total of four boring locations were performed to identify the existing soils and determine design soil parameters.

Access to, and within, the placement areas was highly constrained due to the site being fully surrounded by soft, low-bearing-capacity marsh soils, interspersed with man-made ditches and tidal channels. These conditions prevented the use of conventional land-based equipment and limited the effectiveness of standard shallow-draft vessels. To address these constraints, subsurface investigations were performed using airboat-mounted drill rigs specifically configured for ultra-shallow and soft-substrate environments. Alternative methods, including tracked equipment or temporary access construction, would have required repeated traversal of vegetated marsh areas outside the project footprint, resulting in avoidable disturbance to the adjacent tidal wetlands.

Project partner Northland Airboats, based in Bayville, New Jersey, deployed custom-fabricated airboats capable of transporting personnel and drilling equipment across both inundated and exposed mudflat conditions without reliance on tidal access or ground-bearing support (Figure 6).

Figure 6. Subsurface investigations via Airboat

Borings encountered the following three distinct soil layers listed from mudline:

- Stratum C1 – Soft Cohesive Soil – 2-4 feet thick – silt and clay
- Stratum S – Loose/Medium Dense Sand – 4-6 feet thick
- Stratum C2 – Stiff Cohesive Soil – 15-17 feet thick to end of boring – dense sand and clay

AGENCY COORDINATION AND APPROVALS

The partnership between the NJDOT and the USFWS began shortly after Superstorm Sandy with a commitment to work toward opportunities to combine navigation safety with ecological restoration. This project exemplifies the multiple benefits generated when two different missions converge – marine transportation and environmental enhancement. The agencies worked closely to identify a site that would yield measurable improvements in ecosystem functionality, habitat quality and biodiversity, while at the same time providing the capacity to receive large volumes of DM and the flexibility to accommodate heavy construction equipment in a sensitive tidal marsh system. Agency staff worked together through each phase of project planning, development and construction.

USFWS actively engaged in the design process, articulating the overall vision and a set of restoration goals for the site. The vision for Stouts Creek was to create a low marsh wetland system that supported saltmarsh sparrow habitat, was connected to the larger wildlife refuge, and was largely self-sustaining and lower maintenance for USFWS field staff. USFWS had significant concerns related to marsh construction and equipment impacts. In turn, NJDOT Office of Maritime Resources (OMR) and the design team used the design process to educate USFWS about constructability and the need to have a technically feasible project when it came time to implement. A specific example of this collaboration was around construction schedule and balancing seasonal restrictions for Federal and State-listed species. The project required an 8-month optimized construction window. The project's State and Federal environmental permits had seasonal restrictions for winter flounder (Jan. 1 to May 31), anadromous fish (March 1 to June 30), diamondback terrapins (May to Oct.), Northern Long-eared Bats and Tricolored Bats (April 1 to Sept. 30), nesting migratory birds (April 1 to Aug. 31), and Bald Eagle (Jan. 15 to July 31). Taken collectively, the project's seasonal restrictions allowed only a 3-month window to construct the project.

The team worked together to develop an innovative construction sequencing approach that unlocked five additional months of available construction time, while minimizing impacts to sensitive species. For example, to lift the seasonal restrictions on work during bird and bat breeding and nursery periods, NJDOT hired a contractor to install soil erosion controls in the marsh and clear all woody vegetation along the placement site's berms before the April-September seasonal restriction went into effect. The contractor also closed the breaches in the impoundment's berm before the winter flounder window went into effect in January, allowing dredging and placement activities to continue through February. Though critical to the advancement of the Stout's Creek project, the cost-to-value determination on these activities remains a point of future consideration.

USFWS was the environmental permit applicant for DM placement and restoration activities. The project benefited by having the USFWS, as a federal agency and conservation steward, function as the permitting applicant. The State review process was streamlined by utilizing a federal consistency determination process, rather than requiring a full-scale State environmental permitting process. Regulators were amenable to negotiations around seasonal restrictions with a federal natural resource agency and land steward as the project advocate.

Agency coordination between NJDOT OMR and USFWS continued through procurement and construction phases and remains ongoing as the project transitions to post-construction monitoring and adaptive management. The agencies, along with additional natural resource organizations, are working together through a Beneficial Use Restoration Task Force to develop a pipeline of new BU placement sites, sharing best management practices and advancing opportunities to provide safe navigation and coastal resilience.

DESIGN AND PROCUREMENT

Dredging Design

NJDOT OMR identified a dredging need of approximately 170,000 CYs in the Berkeley Channel Complex including the following channels:

096 Clamming Creek North	102 Cedar Creek Spur
097 Clamming Creek South	103 Laurel Harbor North
098 Whites Channel	104 Laurel Harbor South
101 Cedar Creek	105 Stouts Creek
Wordens Oyster Pond (Municipal Channel)	Stouts Creek Spurs A & B (Municipal Channels)

In-situ channel material was sampled and characterized for geophysical and chemical properties following a New Jersey Department of Environmental Protection (NJDEP)-approved Sediment Sampling and Analysis Plan. Sampling results met NJDEP site placement criteria for ecological uses and indicated this material would be a prime candidate for BU placement.

A hydraulic cutter suction dredge was specified to pump the dredged slurry from the State's navigation channels to the placement site. The dredge pipeline would run overland within the proposed access corridor from Barnegat Bay into the impoundment areas. Within the site, DM would be evenly dispersed by shifting the discharge location, or by using multiple inflow points controlled by hydraulicly actuated wye-valves.

Habitat Restoration and Target Elevation Design

Preliminary earthwork calculations of the proposed placement site demonstrated the eastern impoundment cell had capacity to meet the Berkeley Channel Complex's dredging needs. Additionally, the corresponding and approximate post-consolidation designed fill elevations were selected to be comparable to the adjacent low- and high-marsh habitats. These calculations were used to identify the eastern impoundment cell as the primary DM placement and restoration area.

A target fill elevation of 0.8 ft NAVD88 was identified using the bio-benchmark field data in conjunction with the onsite tidal data and modeling. A marsh plain constructed at this elevation would greatly increase the probability of *Spartina alterniflora* to quickly establish throughout the restoration area.

In addition to the target fill elevation, a high marsh elevation of 1.1 ft NAVD88 was identified for use in creating the construction phase's upper fill tolerance. The high marsh elevation was identified using the same methodology as the target fill elevation enabling high-marsh *Spartina patens* to grow.

Settlement Analysis and Construction Elevation Design

An initial construction target elevation of 1.8 ft NAVD88 was selected to account for future consolidation of DM and settlement of the underlying soils (i.e. the construction target elevation was intentionally selected to be higher than the final ecological target elevation of 0.8' NAVD88). Primary consolidation of the DM was anticipated to decrease the placement grades to the target fill elevation. Following consolidation, any DM remaining above the high marsh elevation was to be brought down to the target elevation with a goal of creating an undulating low marsh plain with areas of high marsh.

Existing elevations, soil stratums, approximate placement thicknesses, and recommended soil design parameters identified and developed during the subsurface investigation were used to estimate the potential settlement of the DM using the software program Settle3. The total settlement was estimated to range anywhere from 7 (0.6 ft) to 16 inches (1.3 ft).

Based on the above analysis results, a construction target elevation of +1.8 ft NAVD88 with a vertical placement tolerance of ±6 inches (0.5 ft) was selected. The vertical placement tolerance was based on similar project experience and resulted in an acceptable placement elevation range between +2.3 ft and +1.3 ft NAVD88. Applying the calculated upper and lower settlement values to their corresponding construction tolerances gives approximate post-consolidation elevations between 0.7 ft and 1.0 ft NAVD88, in line with the proposed target elevation.

Containment, Breach Design and Filling Parameters

Proper containment of the DM sediment slurry is essential to achieve construction target elevations. The existing berms had a few existing breaches that were constructed by the landowner to promote tidal flushing that would need to be plugged prior to infill. Additionally, volume calculations performed during the dredging design were finalized using the selected target elevations but indicated the controlling low elevation of the existing perimeter berms would be insufficient to hold the slurry. The existing berms were designated to be cleared, breaches plugged and lifted to +3 ft NAVD88 to keep a minimum 8 inches of freeboard beyond the upper fill tolerance. Soft, silty borrow material would be taken from the interior of the existing impoundment's upper layer based on its availability and proximity to the berms. As a sediment control measure, a silt sock was proposed outwards of the berm lift to help contain the saturated borrow material.

The construction of this berm involved using a pontoon excavator to raise the existing dikes 0.5-1.5 ft throughout the +/- 4,500 LF impoundment perimeter as shown in Figure 7.

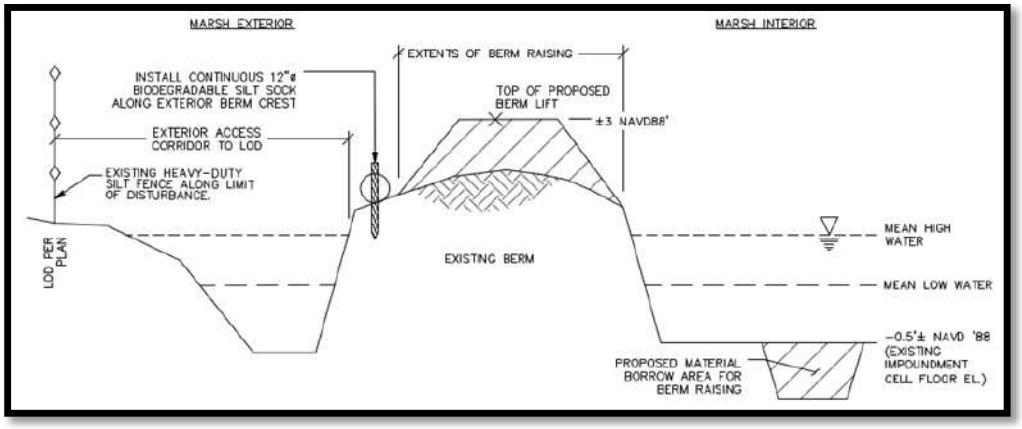

Figure 7. Berm Cross Section (Not to Scale).

To help achieve the selected target elevations, the impoundment site was gridded into reference cells. Contract specifications required the Contractor to complete fill placement in all the eastern column cells (e.g. A1, A2, A3) to the target elevations within tolerance, prior to moving west, and filling adjacent column cells. This segmental approach was intended to fill the impoundment area in a more even and deliberate manner, allowing cells to be filled to the construction tolerances and improving the likelihood of meeting the target fill elevations.

The segmental approach provided greater placement control and eliminated a filling scenario that treated the impoundment like a confined disposal facility (Figure 8). Placement cells could be further monitored by the use of grade stakes.

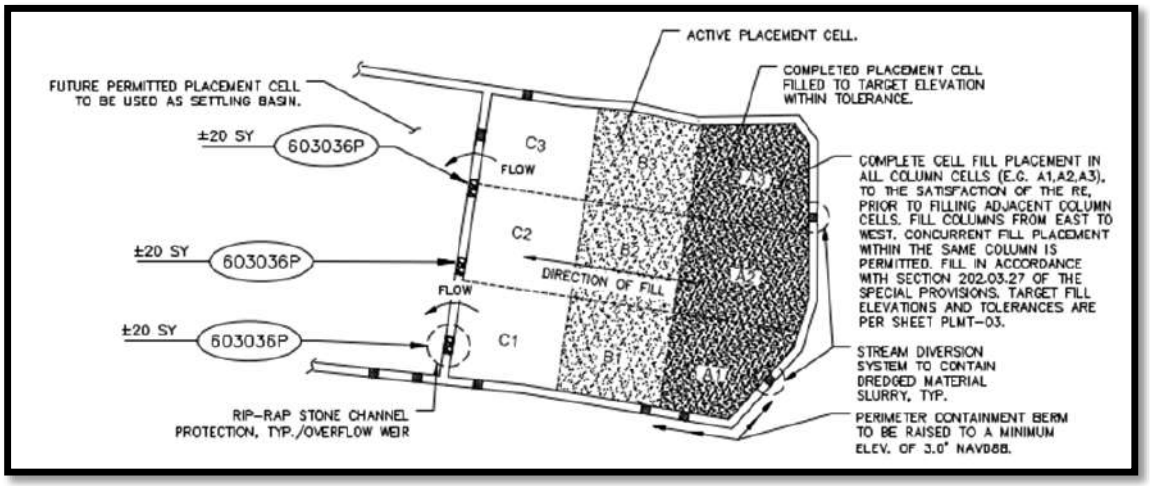

Figure 8. Dewatering Placement Cells (Not to Scale).

To dewater the impoundment sites, overflow weirs were designed to fit within the existing breaches in the impoundment site's western berm. Inflow from the eastern berm was selected to maximize the flow path, thereby minimizing the amount of suspended solids to reach the weirs. A hydraulic analysis of the proposed weirs was performed using typical inflow rates, desired freeboard, a 10-yr storm, and sediment retention to

size the weirs and minimize erosion of the existing berms. Lastly, the impoundment cell to the west of the site would effectively act as a settling basin for any sediments that may escape from the overflow weirs.

CONSTRUCTION

Mobilization

The Contractor began mobilization of the dredging plant and placement site equipment in late August 2025. The dredge and its associated equipment were staged in the Laurel Harbor South channel and connected to approximately 6,000 LF of 18" outer diameter HDPE pipeline. The pipeline booster and barge were staged alongside the north bank of Cedar Creek Channel at a location referred to as the Berkeley Island staging area. The Contractor's fleet of in-water equipment also included 3 tugboats, 2 excavator barges, 2 work skiffs, and a survey vessel.

Within the placement area, a 25-foot support airboat, and a CAT 326D Marsh Excavator were mobilized to perform placement site preparation work. Equipment and materials were mobilized through the designated access corridor to minimize adverse impacts to the marsh surrounding the placement site, as per the plans.

Materials required for site preparation, including filter sock and soil erosion and sediment control measures (e.g., silt fence), were delivered by barge to the marsh edge adjacent to the placement area at the mouth of Stouts Creek. Due to extremely shallow water depths and soft substrate conditions, further transport into the placement site was performed exclusively by airboat. This approach enabled movement of materials across both inundated and exposed marsh surfaces without reliance on tidal access, allowing consistent site access, improved field productivity and avoidance of wetland impacts.

Installation of perimeter erosion control measures was completed using a coordinated approach between the amphibious excavator and airboat-supported crews.

Materials were distributed and staged within the placement area by airboat, allowing the excavator to install filter sock and silt fence along the project limits in accordance with the design plans (Figure 9). This method eliminated the need for alternative access construction and allowed installation to proceed without deviation from the project schedule.

Figure 9. Airboat assisting filter-sock installation.

In addition to the pipeline connected to the dredge, another 19,000 LF of pipeline was brought to the site and staged in 1,000 LF segments at the Berkeley Island staging area for future use with longer pipeline

dredging reaches. An additional 1,000 LF of pipeline was staged in multiple segments within the placement site to allow for maneuverability of the discharge point.

A Contractor-suggested deviation from the pipeline alignment shown on the plans was evaluated in coordination with the permitting agencies and landowner and approved in early September 2025. The revised alignment utilized an existing narrow, linear, tidal creek to provide a direct connection between Barnegat Bay and the placement site, eliminating the need to construct the pipeline along the originally permitted marshland access corridor.

Implementation of this approach involved pulling approximately 3,000 LF of pipeline through the creek using a single airboat in less than 4 hours, in lieu of assembling and dragging pipeline segments across upland marsh with a marsh excavator that would have taken weeks to implement. (Figure 10) The original alignment would have also required an additional 5,000+/- LF of pipeline and repeated traversal and impacts to vegetated marsh areas due only to temporary access.

Figure 10. Implemented inflow pipeline corridor (Contractor design).

The adopted method reduced overall pipeline length, simplified installation and maintenance, and effectively eliminated permanent wetland disturbance. This approach represents a notable and innovative construction optimization methodology for marsh-based DM placement projects, demonstrating the feasibility of utilizing existing tidal features and shallow-draft methods to improve constructability while minimizing environmental impacts.

Inflow Operations

The Contractor began DM placement on September 17, 2025 as per the plans in the northeast corner of the placement site, denoted as cell A3. A splash pad was installed via flange at the discharge end of the pipe in order to reduce slurry flow velocities and encourage solids to settle more rapidly. As part of the Contractor's means and methods to control the distribution of DM, the coarse-grained material that accumulated near the discharge point was used to create temporary earthen training dikes between the A and B cells. These training dikes served to aim the slurry flow south, into cells A2 and A1, as opposed to west, in order to retain as much sediment as possible in the A cells (Figure 11).

Figure 11. Inflow and temporary training dike construction.

This Best Management Practice (BMP) of temporary training dikes was applied throughout the placement process as a means to direct DM placement to specific locations based on field observations and feedback from daily monitoring surveys. By building training dikes directly along the edges of cells, it also allowed for clear delineation of each individual cell for OMR's review and consideration of acceptance.

In addition to the constant evaluation and construction of temporary training dikes, the Contractor was also responsible for monitoring the water levels within the site to ensure no overtopping of the perimeter dikes. In some cases, the Contractor needed to re-establish the elevation 3.0 ft NAVD88 along the perimeter berms. Furthermore, the on-site inspection staff and Contractor were responsible for observing the discharge water volumes and appearance at the weir structures. The discharge water exiting the placement area proved to be non-problematic in the early stages of placement, as the discharge point had significant distance (1000+ LF) between it and the weir discharge locations.

Direct inflow operations were concentrated in the following sequence; Cell A3, A2, A1, B1, B2, B3, C2. Cells C3 and C1 were never directly inflowed to.

Daily Survey Activities

A key component of DM placement operations' quality control was the ability to perform real-time surveys and traverse the entirety of the site on demand. Given the site's limited accessibility, a dedicated airboat was provided to support the GBA and OMR survey and inspection team, enabling consistent and reliable access to all areas of the placement site under varying tidal and substrate conditions, including mudflat and ice. The daily presence of an engineer, surveyor, and airboat captain allowed for twice-daily RTK surveys at any location of interest. These surveys were typically conducted at approximately 9:00 AM and 3:00 PM, and the results were shared with the owner, engineering team, and Contractor within hours. The typical shared products included an XYZ file and a color-coded PDF of survey points indicating where elevations were below tolerance, within tolerance, and above-tolerance (Figure 12).

These OMR-provided capabilities proved worthwhile by removing dependence on the Contractor. Having this survey team on site enhanced communication, eliminated Contractor dependence and added real-time feedback to the Contractor on a daily basis.

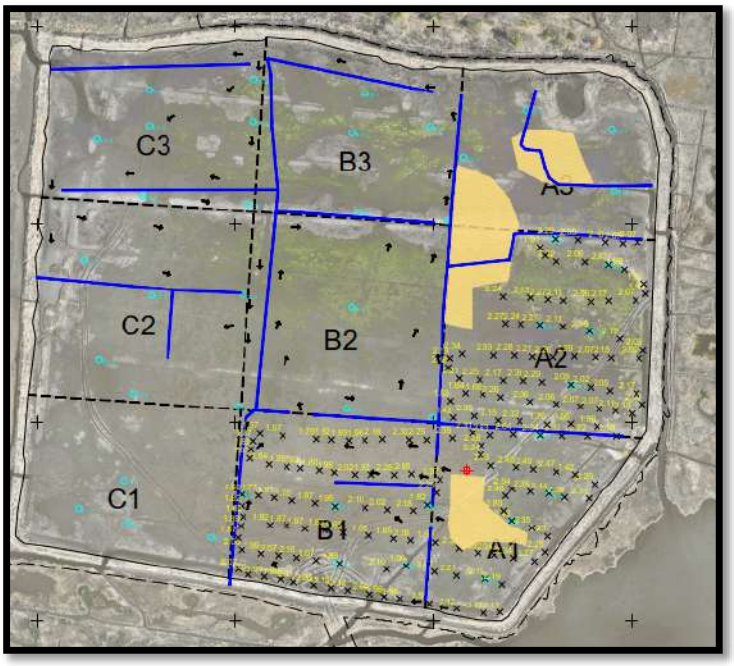

Figure 12. Portion of daily monitoring survey graphic from Nov. 15, 2025 PM.

Dredging Operations, Success, Pay and Excess Quantities

Dredging operations spanned from September 17, 2025 to February 25, 2026, with no activity occurring between December 5, 2025 to December 28, 2025 nor January 10, 2026 through February 15, 2026.

Dredging was performed on a 24-hr work schedule, utilizing the cutter suction dredge SCROD (18") for majority of the dredge areas and utilizing the cutter suction dredge GREAT GUN (12") in the exceptionally narrow waterways.

Without consideration for days where work was not scheduled/performed, dredging occurred over 88 working days, within 11 channels, totaling 143,530 CYPAY and 166,685 CYDIG. This equates to a project dig-to-pay ratio of 1.16.

The dredges worked a combined total of 1,217 hours of 1,923 hours scheduled, resulting in a time efficiency of 63%. With respect to dredge runtime, the Contractor was averaging a dig volume of 1,894 CY per day, or 137 CY per work hour of production.

MONITORING AND SHORT-TERM RESULTS

Pre-inflow survey

Between August 26-28, 2025 GBA performed a pre-construction placement site survey using a GNSS RTK rover from an airboat. This survey was pre-planned and transects were conducted in an organized fashion every 25 feet perpendicular to the length of the placement site. Topographic data points were collected approximately every 10 feet along the transects. This survey methodology was established during the pre-construction survey to create repeatability for all future monitoring surveys.

The pre-construction survey data was then modeled in Civil3D and compared to the existing basemap for a capacity analysis. The pre-construction surface ultimately yielded less air storage to the targeted fill elevation of 1.8 ft NAVD88 by approximately 40,000 CY, which equates to about 24%. It should be noted

that when considering the designated placement area spans 45.1 acres, the vertical accuracy of the survey equipment (expected 0.1 to 0.2 ft) creates an accuracy tolerance of nearly 15,000 CY. The delta between the composite basemap and the pre-construction survey suggests a vertical delta between surveys on the average of 0.6 ft, or 7 inches. This vertical delta could be due to a plethora of factors associated with the process of surveying marsh elevations, particularly with ponding, soft soils, and vegetation, but also could have been exacerbated by the adjustment made to the ponded areas within the 2019 LiDAR dataset.

For this project, given the conservative design parameters used for DM capacity calculations, the additional volume associated with the 6 inches of vertical tolerance above the target elevation, and the additionally permitted impoundment cell immediately west of the project placement area, the reduction in anticipated storage did not pose a threat to the construction of the project. This finding, however, does highlight the critical importance of survey accuracy, especially on marsh restoration projects of medium to large scale.

Monitoring Surveys

During the project, the GBA on-site surveyor conducted three separate full-site monitoring elevation surveys. These surveys were collected in addition to the twice-daily partial-site surveys with the purpose of providing interim snapshots of the placement site. Creating full site models of the placement site in its interim condition allowed the designers to review the placement elevation success achieved to-date, assess the remaining capacity of the site, and monitor the placed DM elevations for consolidation/settlement.

The first monitoring survey was performed on November 3-5, 2025, approximately halfway through the total dredging volume, at which time an estimated 84,000 CY had been removed of the available 167,150 CY. At the time of this survey, the inflow location had been concentrated in placement cells A3 and A2, though material had been observed accreting in cells B1, B2 and B3 during the daily surveys. The analysis from this monitoring survey yielded the following results:

- 45,000 CY of remaining air storage to target elevation 1.8 ft NAVD88
- 76,000 CY of remaining air storage to upper tolerance elevation 2.3 ft NAVD88
- 84,000 CY of DM approximately removed based on the reported dredge progress
- 97,000 CY of inflow DM between this monitoring survey and the pre-construction survey

Reviewing the results of this survey, the excess DM quantity delta of 13,000 CY between the inflow material observed and what was anticipated to be dug was initially flagged as a concern. At the time of this placement survey only one channel containing approximately 30,000 CY of material had been surveyed for After Dredge payment quantities, and the results did not indicate excess digging. Therefore, it was concluded that the placed DM was most likely bulking, somewhere on the order of 15% from its in-situ volume in the channel.

The second monitoring survey was performed on November 23-24, 2025, approximately 67% through the total dredging volume, at which time an estimated 113,000 CY had been removed of the available 167,150 CY. The analysis from this monitoring survey yielded the following results:

- 15,000 CY of remaining air storage to target elevation 1.8 ft NAVD88
- 36,000 CY of remaining air storage to upper tolerance elevation 2.3 ft NAVD88
- 113,000 CY of DM approximately removed based on the reported dredge progress
- 136,000 CY of inflow DM between this monitoring survey and the pre-construction survey

Consistent with the first monitoring survey, we continued to observe an apparent bulking factor on the placed DM, now estimated at 20% from its in-situ volume. After reviewing the remaining capacity in relation to the remaining quantities of material to be dredged, discussions began on potentially filling within the western permitted cell and the pre-inflow tasks that would be required to do so.

The third and final monitoring survey during active construction was performed on January 21-22, 2026, approximately 85% through the total dredging volume, at which time an estimated 142,000 CY had been removed of the available 167,150 CY. The survey results are:

- 11,000 CY of remaining air storage to target elevation 1.8 ft NAVD88
- 38,000 CY of remaining air storage to upper tolerance elevation 2.3 ft NAVD88
- 142,000 CY of DM approximately removed based on the reported dredge progress
- 135,000 CY of inflow DM between this monitoring survey and the pre-construction survey

It should be noted that extended period of dredging downtime between December 5 and December 28, as well as January 10 through the time of this survey affected the state of the site (dewatering consolidation settlement). Based on the results of this survey, and more specifically comparisons to the November 23-24 survey, it was apparent that the elevations of DM placed in the A and B cells were decreasing.

These conclusions were reinforced after conducting the post-construction monitoring survey on March 18-19, 2026. The survey results are:

- 4,300 CY of remaining air storage to target elevation 1.8 ft NAVD88
- 14,100 CY of remaining air storage to upper tolerance elevation 2.3 ft NAVD88
- 124,100 CY of inflow material observed between this monitoring survey and the pre-construction survey.

When comparing the total measured dredge quantity of 166,685 CY to the measured inflow quantity of 124,100 CY, this implies that the in-situ DM is only occupying 74% of that volume within the placement site (discounting losses). Pending any further geotechnical investigation is inconclusive as to how much of this reduction should be attributed to DM consolidation and/or underlying soil settlement. However, these findings do provide planning-level context for consideration of pairing future dredging projects with placement site capacities.

CONCLUSIONS/LESSONS LEARNED

- Formal partnerships between transportation and resource agencies facilitate the permitting process by making clear differentiations between partner roles, responsibilities and goals.
- Get agreement on restoration goals early and set realistic timelines for meeting those goals.
- Review soft goals with the contractor to ensure awareness and incorporate contractor-derived methodologies to reduce project impacts.
- Set realistic expectations for the land-owner and resource steward as to potential site-adjacent construction and access impacts.
- The contractor, the survey team, and the RE have to be in constant communication to make informed decisions on inflow locations.
- Temporary earthen training berms can be constructed throughout the placement process and do not need to be fully constructed before placement starts.
- Separate monitoring of engineering goals from biological controls

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CITATION

Marano, M. J., Clifton, G., Axt, K., Fisahn, J., Tagger, L. and McTavish, J. "Beneficial Use of Dredged Material For Marsh Restoration at Stouts Creek Impoundment," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

DATA AVAILABILITY

All data and models generated or used during the study are proprietary or confidential unless expressed as "publicly available". These data may be provided upon request with restrictions on republication and use.

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LABRANCHE MARSH CREATION PROJECT EXPERIENCE & LESSONS LEARNED

C. Markham[1], L.B. Valdez[2], N. Vazquez[3], C. Tennant[4], and M. Warwick[5]

ABSTRACT

The LaBranche Marsh Creation Project was undertaken to restore critical wetland habitat that had converted to open water due to long-term subsidence, storm impacts, and shoreline erosion. The primary objective of the project was to reconstruct a sustainable emergent marsh platform capable of supporting long-term ecological function. Approximately 6.15 million cubic yards (4.7 million cubic meters) of sediment were hydraulically dredged from Lake Pontchartrain and placed within three engineered marsh creation areas bounded by nearly 55,000 linear feet (16,770 linear meters) of earthen containment dikes. This paper presents the contractor's perspective on project execution, focusing on dredging operations, discharge management, dewatering calculations, and adaptive construction practices developed to overcome challenges and meet performance objectives.

Keywords: Dredging, marsh restoration, project planning, slurry transport, beneficial reuse.

INTRODUCTION

Pre-Project Conditions

The LaBranche Marsh project area is located along the southern shoreline of Lake Pontchartrain and historically consisted of extensive brackish marsh that provided important ecological and coastal protection functions. Over several decades, the area experienced progressive marsh loss resulting from regional subsidence, reduced sediment supply, storm impacts, and shoreline erosion. These processes led to widespread conversion of vegetated marsh to shallow open watger, fragmentation of remaining marsh platforms, and degradation of habitat quality.

Prior to construction, the site was characterized by large expanses of open water with limited emergent vegetation shown in Figure 1. Wind-driven wave energy from Lake Pontchartrain further exacerbated erosion, while reduced marsh continuity diminished the area's ability to attenuate storm surge. These conditions negatively affected fisheries' habitat, water quality, and the resilience of adjacent infrastructure, including Interstate 10, a critical hurricane evacuation route.

[1] Gulf & East Coast CSD Manager, Manson Construction Co., 5985 Richard Street, Suite 1, Jacksonville, FL 32216, USA, T: 904-821-0211, Email: cmarkham@mansonconstruction.com. (corresponding author).
[2] Senior Estimator, Manson Construction Co., 5985 Richard Street, Suite 1, Jacksonville, FL 32216, USA, T: 904-821-0211, Email: lvaldez@mansonconstruction.com.
[3] Production Engineer, Manson Construction Co., 5985 Richard Street, Suite 1, Jacksonville, FL 32216, USA, T: 904-821-0211, Email: nvazquez@mansonconstruction.com.
[4] Production Manager, Manson Construction Co., 5985 Richard Street, Suite 1, Jacksonville, FL 32216, USA, T: 904-821-0211, Email: ctennant@mansonconstruction.com.
[5] SVP Dredging, Manson Construction Co., 5985 Richard Street, Suite 1, Jacksonville, FL 32216, USA, T: 904-821-0211, Email: mwarwick@mansonconstruction.com.

Figure 1. LaBranche Fill Area following completion of dike and initial dredge placement

Project Objectives

The primary objective of the LaBranche Marsh Creation Project was to restore approximately 1,200 acres of sustainable emergent marsh capable of supporting long-term ecological function. Specific objectives included:

- Reestablishing marsh elevations suitable for vegetative colonization and persistence
- Improving habitat diversity through construction of tidal ponds and creek networks
- Enhancing hydrologic connectivity within the marsh platform and with Lake Pontchartrain
- Providing measurable storm surge attenuation benefits to adjacent transportation and flood protection infrastructure

From a construction perspective, an additional objective was to efficiently place large volumes of dredged material while maintaining tight elevation tolerances and mitigating negative environmental impacts during the construction phase.

APPROACH

Overall Construction Framework

The LaBranche Marsh Creation Project was executed using a phased hydraulic dredging and placement approach supported by purpose-built containment structures and adaptive water management. Approximately 6.15 million cubic yards (4.7 million cubic meters) of material were excavated from Lake Pontchartrain borrow area and hydraulically placed into three engineered Marsh Creation Areas (MCAs) bounded by earthen containment dikes. Construction sequencing was structured to optimize dredge production, manage settlement, and maintain containment integrity throughout placement operations.

Prior to marsh filling, approximately 54,600 linear feet (16,770 linear meters) of earthen containment dikes were constructed in multiple lifts to establish the MCAs. Additional work encompassed the installation of dewatering structures and staff gauges, targeted geogrid reinforcement, and the construction of tidal ponds and creek systems.

Earthen Containment Dikes (ECDs)

Earthen containment dikes (ECDs) were constructed to create separate and distinct marsh creation areas and provide temporary containment during hydraulic placement of dredged material. Construction was executed using amphibious excavators operating within designated access corridors and borrow limits as shown in Figure 2. Prior to excavation, dike footprints were cleared of organic and woody debris using

excavators equipped with hydraulic thumbs. Any organic debris encountered was placed within approved areas inside the containment footprint and inorganic debris was removed from the site.

Figure 2. Amphibious long reach excavators creating earthen containment dikes

Dike material was excavated from in-situ borrow areas located a minimum of 35 ft (10.6 m) from the dike toe, with equipment operating no closer than 15 ft (4.6 m) from the toe to maintain stability. Material was placed within the dike template above the minimum design elevation to account for anticipated settlement and shrinkage, then shaped and dressed to final grades and side slopes. ECD construction was accomplished over multiple lifts to reach the desired dike elevation. Where specified by the contract documents, woven geotextile reinforcement was installed at the dike base after achieving the required subgrade elevation, followed by placement of subsequent dike lifts.

Tidal Creeks

Prior to marsh fill placement, tidal creeks were excavated to plan dimensions and elevations using long-reach amphibious excavators. Excavation was performed from the marsh surface, with material side-cast within the marsh creation area. Spoil placement elevations were controlled to remain below +2.5 ft NAVD88 (+0.762 m) to preserve adjacent marsh platform elevations.

Tidal Ponds

A total of thirty-nine tidal ponds were constructed concurrently with tidal creeks using amphibious excavators. Pond excavation followed the plan-specified geometry, with excavated material initially side-cast adjacent to the pond footprint. A second excavator pass redistributed the spoil laterally to reduce localized mounding and ensure final elevations met the +2.5 ft NAVD88 (+0.76 m) maximum requirement. Design cross sections of the tidal ponds and creeks are shown below in Figure 3.

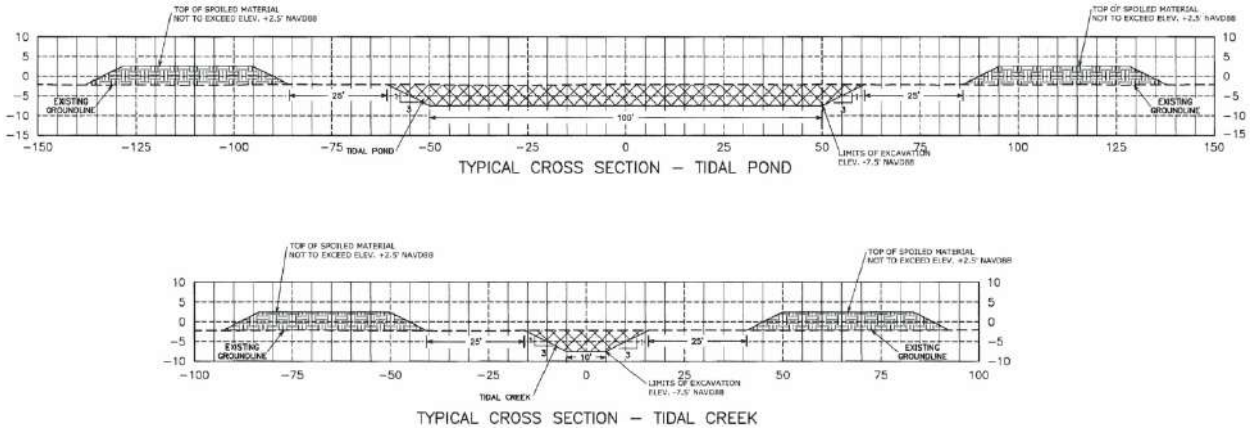

Figure 3. Tidal Pond and Tidal Creek Design Cross Section

Hydraulic Dredging Overview

Marsh creation was accomplished using the cutter suction dredge *Robert M. White*, which hydraulically excavated suitable material from Lake Pontchartrain and pumped it via pipeline to the fill area shown in Figure 4. Hydraulic dredging was selected due to its efficiency in transporting large volumes of material and its ability to uniformly place sediment over broad areas.

Figure 4. *Robert M. White* excavating & hydraulically transporting material from Lake Pontchartrain

Dredging operations were sequenced to balance production efficiency with containment stability and site access constraints. Pipeline alignments and discharge locations were adjusted throughout construction to support phased filling and minimize rehandling of material.

Slurry was conveyed through a combination of steel submerged pipe, float hose, sink hose, and shore-based HDPE pipeline. Pipeline configurations were modified as filling progressed, typically in 250 ft (76m) shore pipe increments, to maintain effective discharge control and support elevation management within each MCA.

Fill Management

Effective fill management was critical to achieving target marsh elevations and ensuring long-term project performance. Placement activities accounted for anticipated consolidation, dewatering, and settlement of dredged material. Fill heights were monitored continuously, and constant dike maintenance was performed to prevent breaching of containment features.

Placement Sequencing

Effective management of dredged material placement was critical in achieving target marsh elevations and long-term project performance. Placement activities were sequenced to promote consolidation, allow for adaptive elevation adjustments, and limit rehandling. Marsh creation cells were filled incrementally, with discharge locations rotated to distribute material evenly and prevent excessive mounding.

Temporary containment features and internal dikes were used as needed to direct slurry flow and retain material within individual placement cells. These features were adjusted throughout construction in response to observed settlement behavior and changing hydraulic conditions. Wye Valves were used to switch between MCAs with minimal downtime.

Dewatering and Water Management

Effective dewatering was essential to maintaining fill efficiency, supporting sediment consolidation, and preventing exceedance of marsh creation containment freeboard. Each MCA was outfitted with multiple aluminum flashboard riser dewatering structures connected to gravity effluent pipes discharging back to Lake Pontchartrain. A total of 10 structures were installed in MCA 1, with 15 structures distributed in both MCAs 2 and 3. These structures were designed to match dredge inflow capacity while maintaining minimum freeboard within containment dikes.

Boards were added incrementally as fill elevations increased, and structures were inspected multiple times per day. Where debris posed a clogging risk, inlet screening was installed to maintain discharge efficiency. Elevated external water levels were recognized as a limiting condition, requiring periodic operational adjustments to allow sediment settlement prior to drawdown

Design Basis and Assumptions

Dewatering structures were sized to accommodate the anticipated inflow generated by continuous cutter suction dredge operations. The design approach assumed a maximum dredge discharge velocity consistent with efficient slurry transport and continuous placement. While sediment settling within the marsh creation areas reduces the volumetric flow ultimately exiting each cell, dewatering capacity was conservatively based on the full dredge discharge flow to maintain hydraulic equilibrium during peak operations.

Water levels within each marsh creation cell were required to remain below the dike crest elevation to preserve freeboard and containment stability. The dewatering system was therefore designed to regulate water surface elevations under varying operational and external water level conditions, including lake stage fluctuations.

Weir Flow Analysis

The first stage of dewatering occurred as water passed over adjustable weir boards and into a collection box. Flow across the weir crest was evaluated using standard sharp-crested rectangular weir theory. This approach assumes:

- Uniform velocity distribution upstream of the weir
- Atmospheric pressure conditions within the nappe
- Subcritical flow conditions immediately upstream of the crest

The volumetric flow rate over the weir was calculated as a function of weir head and crest length using established rectangular weir equations. The experimentally derived weir coefficient accounted for approach conditions and head-to-crest geometry. Weir crest lengths were selected to pass the incoming hydraulic flow while limiting head buildup within the marsh creation cell, typically evaluated over a range of anticipated operating heads. Schematics for weir design are shown below in Figures 5 and 6.

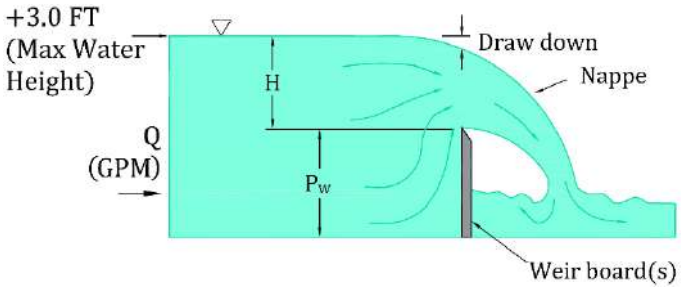

Figure 5. Sharp Crested Weir Side View

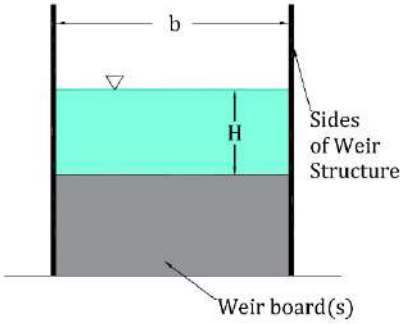

Figure 6. Sharp Crested Weir End View

$$C_{wr} = 0.611 + 0.075\left(\frac{H}{P_w}\right) \quad (1)$$

where C_{wr} = rectangular weir coefficient (unitless), H = height of water above the weir board (m), P_w = water depth measured down from weir board location (m).

$$Q = C_{wr}\frac{2}{3}\sqrt{2g}bH^{3/2} \quad (2)$$

where Q = volumetric flow rate over the weir (m^3/s), C_{wr} = rectangular weir coefficient (unitless), g = gravitational constant (m/s^2), b = weir length (m), H = height of water above the weir board (m).

Effluent Pipe Hydraulics

Following flow over the weir, water exited the collection box through effluent pipes penetrating the containment dikes and discharging back into Lake Pontchartrain. Flow within these pipes was analyzed as uniform open-channel flow under partially full conditions. Pipe diameters, slopes, and invert elevations were selected to maintain gravity flow while minimizing the potential for supercritical velocities.

Effluent pipe capacity was determined using Manning's equation, with roughness coefficients selected to represent smooth interior pipe conditions. Flow depth, hydraulic radius, and energy slope were evaluated to ensure the pipes could convey the design flow without pressurization. Schematic for effluent pipe design is shown below in Figure 7.

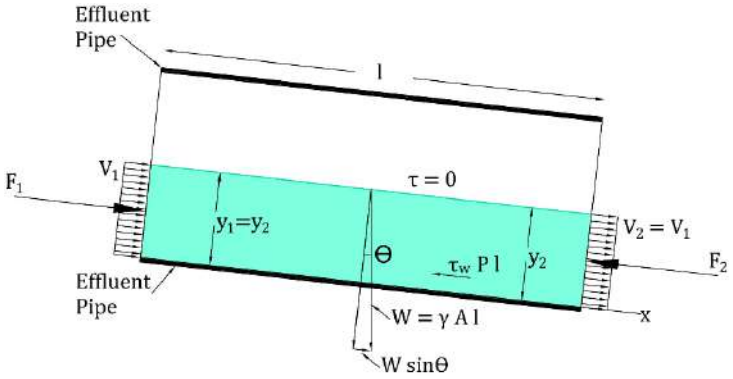

Figure 7. Effluent Pipe Side View

$$Q = \frac{k}{n} A R_h^{2/3} S_0^{1/2} \quad (3)$$

where Q = volumetric flow rate over the weir (m^3/s), k = is a constant value of 1 for SI units (unitless), n = Manning resistance coefficient ($s/m^{1/3}$), A = cross sectional area of water in the pipe (m^2), R_h = hydraulic radius (m), S_0 = is the bottom slope of the pipe (change in height divided by horizontal length) and assumes uniform water depth along pipe length (unitless).

Flow Regime Verification

Froude number checks were performed to verify tranquil flow conditions within the effluent pipes. Subcritical flow was maintained to reduce energy losses, limit erosion potential at outlets, and ensure predictable hydraulic performance. Where preliminary calculations indicated supercritical flow, pipe slopes or operating depths were adjusted accordingly.

Confirm pipe slope will provide uniform fluid depth along its length (subcritical flow) using the Froude number.

$$F_r = \frac{V}{\sqrt{gy}} \quad (4)$$

where F_r is the Froude number (unitless), V is the fluid velocity (m/s), g = gravitational constant (m/s^2), y is the pipe length (m).

Weir and effluent pipe flow designs were then related to the prescribed dike design and target fill elevations to very functionality of the complete system. The dewatering design utilized for the project is shown below in Figure 8.

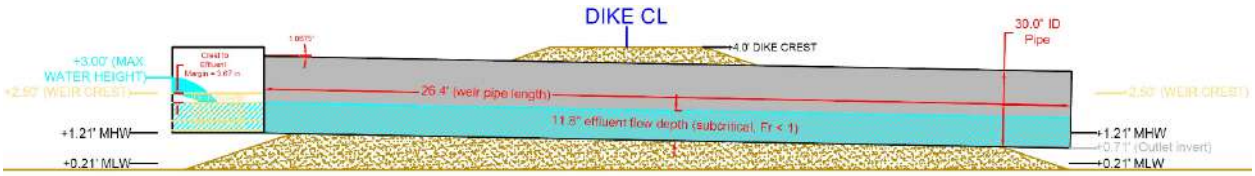

Figure 8. Dewatering System Schematic

Influence of External Water Levels

Historic lake water level data were reviewed to assess the frequency and duration of elevated tailwater conditions during the anticipated construction window. Periods of elevated lake stage were recognized as a limiting factor on dewatering efficiency, with reduced hydraulic gradient available across the effluent pipes. The overall dewatering approach accounted for these conditions by maintaining conservative freeboard allowances and allowing operational pauses when necessary to permit suspended sediments to settle prior to discharge.

Operational Integration

Dewatering performance was monitored throughout construction and integrated into adaptive fill management decisions. When observed water levels approached established thresholds, dredging operations were slowed or temporarily suspended to allow sediment settlement and controlled drawdown. This approach balanced production efficiency with containment integrity and environmental compliance.

Iron Cross Discharge Spreader

Project specifications required the dredge discharge pipe to split into at least three discharge points within the cell, with equal pipe diameters before and after the split. The owner's intent was reduced slurry velocities at the pipe outlets. A single assembly incorporating three discharge spreaders was designed to avoid unequal flow distribution caused by differing flow resistances in three separate lines and to reduce the operational burden of managing material placement at multiple locations. This configuration met project requirements while providing predictable and balanced hydraulic flow at each outlet.

Additional design criteria included preventing debris accumulation at pipe splits, using orthogonal coped angles to simplify fabrication, and maintaining a compact footprint for efficient fill placement and ease of moving the discharge spreader assembly. The small assembly required less equipment to move and reduced human exposure to hazards associated with moving large items in a marsh environment. The final solution featured a "T" shape with two side outlets positioned upstream of the discharge support pontoon and one inline outlet located downstream of the pontoon. Figure 9 below shows an isometric view of the three-point

spreader design. Figure 10 below shows the fill crew attaching the T-shape or “Iron Cross” discharge spreader to the plastic pipe in the fill. Figure 11 shows the discharge spreader in active dredging operation.

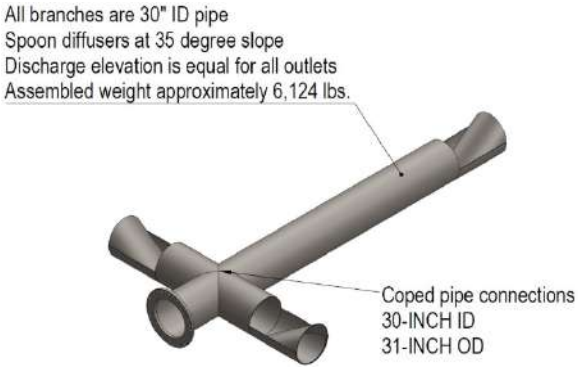

Figure 9. Isometric View of Three Point Discharge Design

Figure 10. Fill Crew Attaching Three Point Discharge

Figure 11. Three Point Discharge during active dredge disposal

CHALLENGES, SOLUTIONS & RECOMMENDATIONS

Challenge - Utility Hazards

Underground oil, gas, and electric utilities traversed the site. Every equipment crossing was planned in coordination with the respective utility owners, with timber mats laid for protection. Overhead powerlines added further complexity, especially where they ran parallel to underground utilities resulting in draft restrictions and air clearance restrictions in the same area. Figure 12 below shows the *Robert M. White* traversing under a 230kV powerline while mobilizing to the Marsh Creation Borrow Area.

Figure 12. CSD *Robert M. White* traversing under overhead powerlines

In the borrow area within Lake Pontchartrain, crews had to navigate around additional utilities, including high-voltage powerlines powering half of the city of New Orleans. These hazards posed life-threatening risks and required meticulous planning and constant vigilance.

Solution – Utility Hazard Surveys

Extensive Utility hazard surveys were performed prior to working across the entire footprint of the project. Survey methods included hydrographic and topographic with an RTK base station, magnetometer, hand probing and LIDAR survey mounted on both boats and drones. Using every reliable survey method available, the project team was able to confidently establish horizontal and vertical positioning for all underground utilities as well as overhead powerlines.

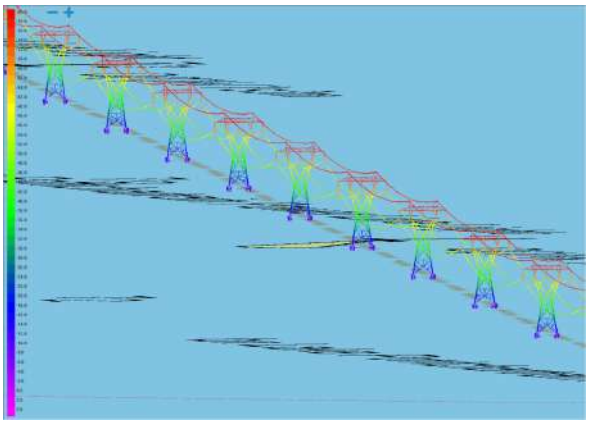

Figure 13. LiDAR Data of overhead powerlines

Recommendation – Utility Stakeholder Info Solicited Pre-Bid

Utility companies are often slow to respond and may provide incomplete information. If the Engineer/Owner were to establish early communication with utility owners and obtain available as-built records during the pre-bid phase, it would significantly assist the Contractor in managing the limited time and schedule constraints between award and construction start. Having more information available in advance allows for more effective planning and, reduces risk at bid time.

Challenge - In-situ Material in MCAs (Excessive Peat/Float-Ons)

The MCAs contained approximately 10 to 20 feet (3 to 6 m) of peat - organic material from partial decomposition of plant matter. This material is lightweight, buoyant, and well known for its poor suitability in earthen containment dike construction. When disturbed by mechanical excavation or placement of dredge fill, the peat tends to fracture into large masses and float, a phenomena commonly referred to as "float-ons". Float-ons can impede and redirect slurry and water flow, as well as obstruct dewatering structures as can be seen in Figure 13 below. This project experienced an excessive amount of float-ons, with some areas surfacing as big as basketball courts. The excavation of tidal creeks and tidal ponds likely exacerbated the situation by increasing disturbance of the underlying peat layer prior to marsh fill placement. Once the denser dredged slurry was introduced into the marsh cells, float-ons became a significant challenge for fill placement and overall fill management.

Figure 14. Float-ons obstructing the dewatering structures in one of the Marsh Creation Areas.

Solution – Creative Peat/Float-on Fill Management

With respect to ECD construction in peat conditions, improved performance was observed in areas where the centerline of the dike was aligned over existing, healthy marsh, providing a more stable foundation. Float-ons remained a persistent challenge throughout construction, intermittently isolating portions of the fill area and restricting slurry and water flow. While no single corrective method proved fully effective, the fill crew achieved limited success by using pontoon tanks and pontoon-mounted excavators to laterally displace float-ons, allowing slurry flow to resume in affected areas.

Recommendation – In-Situ Material in MCA

To the extent practicable, marsh creation areas with significant peat deposits should be avoided, and containment dikes should be designed along the margins of existing, intact marsh to provide improved foundation conditions.

Challenge – MCA As-Built and ECD Maintenance Surveys

As the marsh fill dried, surface conditions became too adhesive for airboat operation while remaining too unstable and unsafe for survey personnel to traverse on foot. In general, greater flexibility from the Owner in accepted survey techniques would have improved Contractor efficiency without compromising the outcome. Additionally, the required maintenance surveys of the dikes were extensive, taking nearly two weeks to complete every month, and putting personnel in unnecessary hazardous conditions.

Solution – Flexible Survey Techniques Permitted

Ultimately Manson was allowed to utilize drone surveys with LIDAR to supplement the as-built surveys of the MCAs. Admittedly, drone surveys are not totally without flaws. Utilizing drone surveys required that the project team merge the data with topographic data in areas to avoid picking up false marsh elevations from water and vegetation. Manson was also allowed to flood the cell again in some areas to regain access via airboat and survey.

Recommendation – Expedited Survey Access

To improve safety and efficiency, survey access should be provided as soon as practicable following completion of marsh fill activities. Final grades could then be verified using grade stakes after the required settlement period, or alternatively using drone surveys for final acceptance.

CONCLUSIONS

Early, proactive coordination and design decisions are critical to reducing risk, improving safety, and increasing efficiency on marsh creation projects. From the Contractor's perspective, the following items would enhance project performance during execution while also improving the overall quality, safety, and value of the Owner's final deliverable seen in Figure 14.

- Provide contractors with the best available utility information in the pre-bid phase to support effective planning, reduce bid risk, minimize schedule impacts, and potentially lower bid prices.
- Avoid marsh creation areas with significant peat deposits to the extent practicable.
    - Align containment dikes along the margins of existing, intact marsh to provide more stable foundation conditions and reduce float-on formation and fill management challenges.
- Allow greater flexibility in accepted survey techniques where traditional access is unsafe or impractical.
    - Utilize drone-based LiDAR surveys and/or grade stakes after settlement to verify final grades, reducing personnel exposure to hazardous conditions and minimizing the ongoing survey and maintenance burden.
- Facilitate survey access as soon as practicable following marsh fill completion.
    - Owners should consider including a dedicated contract line item for standby time during the final settlement period. This approach provides flexibility to accommodate actual settlement durations, reduces the need for contractors to carry large contingencies in their bids, and can ultimately result in cost savings to the Owner if settlement occurs more quickly than anticipated during design.

Figure 15. Completed Marsh Creation Area

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Markham, C., Valdez, L., Vazquez, N., Tennant, C., and Warwick, M. "LaBranche Marsh Creation Project," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

DATA AVAILABILITY

Some or all data, models, or code generated or used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

IDENTIFYING OPPORTUNITIES FOR BENEFICIAL USE OF DREDGED MATERIAL FOR HABITAT RESTORATION IN THE LOWER ST. MARYS RIVER, MICHIGAN

J.A. Miller[1], B.C. Suedel[2], S. C. Blackstock[3]

EXTENDED ABSTRACT

The St. Marys River is a commercial navigation artery and environmental corridor linking Lake Superior with Lake Huron and the lower Great Lakes. The lower river has been heavily modified over the years to develop and maintain a viable shipping channel which is a critical connecting channel in the Great Lakes navigation system. The original channel construction included blasting into bedrock rapids. Maintaining the channel requires routine dredging and strike removal, so that a combination of sand, silt and rock is continually available for beneficial use. The dredged materials are chemically clean and suitable for beneficial use, but historically the majority of this material has been stockpiled upland.

The St. Marys River is not only a shipping channel but is a traditional hunting and fishing area for Tribal Nations. Maintaining ecological functions in the river is a priority for supporting Treaty Rights activities including hunting and fishing. The on-going navigational maintenance has worked against ecological functions; comparison with historic maps shows the many changes in the area and documents the shoreline evolution and overall loss of wetland habitat. In-water habitat has also suffered with the removal of the rapids and a general loss of spawning and rearing habitat for native fish.

The beneficial use of dredged materials for ecological and shoreline restoration in the St. Marys River has the potential to address the shared needs of navigation and environmental protection. In this study, an analysis of historical mapping, hydrodynamic modeling, and ecological evaluation was used to identify areas where beneficial use of dredged material could be used to restore habitat and improve coastal resilience. Historical maps that identified habitat features were overlaid with present-day Google Earth imagery and wetland maps (NWI; USFWS 2025) to assess changes in shoreline configuration and vegetation. Both wetland and rocky shoreline areas were mapped, and areas which no longer include the historic habitat were highlighted. The focus of the evaluation was on Munuscong Bay area, which is a wide bay along the federally maintained channel in the Lower St. Marys River.

The restoration and establishment of habitat requires an understanding of the conditions under which the habitat will exist. Habitat types (submerged aquatic vegetation beds, emergent wetlands, and wild rice beds)

[1] Research Environmental Engineer, U.S. Army Corps of Engineers, Engineering Research and Development Center, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180, USA, T: 312-259-6826, Email: jennifer.miller@usace.army.mil
[2] Research Biologist, Engineer Research and Development Center - U.S. Army Corps of Engineers, 3909 Halls Ferry Rd, Vicksburg, Mississippi 39180, USA, T: 1-601-634-4578, Email: burton.suedel@usace.army.mil
[3] Deputy Resident Engineer, U.S. Army Corps of Engineers, Omaha District, ERDC Research Collaborator, 2125 Scott Drive, Ellsworth Air Force Base, South Dakota, 57706, USA, T: 770-315-8671, Email: scott.c.blackstock@usace.army.mil

were tied to physical conditions (velocity, shear stress, water depth) that would support the plants as stable features. The physical conditions were compiled from technical studies and guidance (Angradi et al. 2013; Kemp et al. 2004; Fischenich 2014; Wamsley et al. 2019; Meeker et al. 1993; MNFI 1997; Maynard 1997). The velocity, shear stress and depth information was also compared to sediment properties, to evaluate what type of materials would be stable under various conditions. Combined, these data sets allow the mapping and evaluation of areas of habitat loss, combined with what could be placed and stable in the area(s) based on the understanding of the existing conditions, the expected substrate, and habitat needs.

The results of the initial analysis identified five discrete locations that appear viable for habitat development (Figure 1). The characteristics and material requirements represent a range of conditions, with some areas requiring armoring to provide shelter and create stable habitat conditions. The Moon Island Habitat Reconnection would expand on an existing island that was created by previous dredged material placement, forming a protected embayment that could be filled with finer grained materials. This area could include a range of fish spawning habitat featuring gravel, and submergent and emergent wetlands that tie into the existing island that is currently used by birds. If desired, the upland portion of the existing island could be further modified to improve habitat conditions.

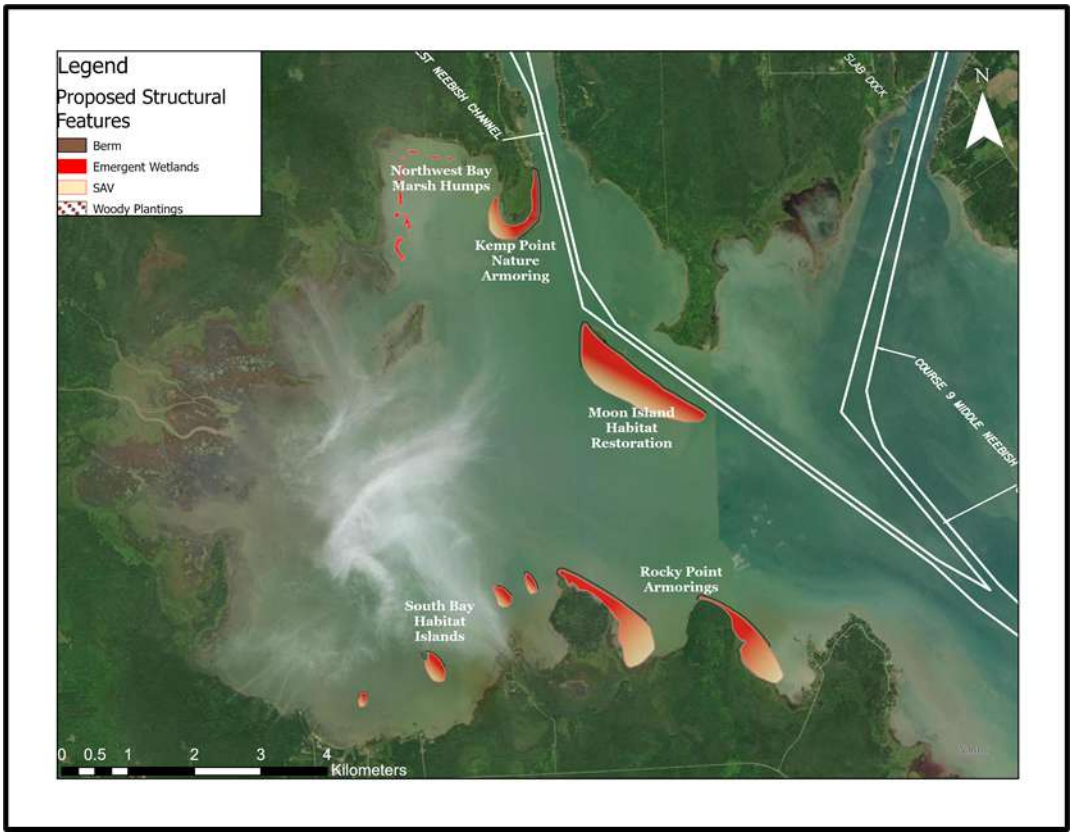

Figure 1. Map of five representative BU opportunities across the Munuscong Lake area of interest designed to restore historical habitats and serve as resilient nature-based solutions for the beneficial use of dredged materials (Image courtesy Vantor).

Kemp Point is an area with documented shoreline retreat. This site is in close proximity to the navigation channel, and it is likely that ship traffic has increased the wave energy in this area over the last century.

Kemp Point habitat would include constructing an armoring feature composed of an outer barrier of larger gravel or cobble to reduce erosion, while holding finer material behind. The goal would be to place materials at or above the water level to support species such as native black willow (*Salix nigra*) which historically grew in the area and anchored the shoreline.

Northwest Bay Marsh is located within a more sheltered portion of northwestern Munuscong Bay. Historic maps show extensive emergent and/or submerged vegetation, but these habitats are now mostly absent, with the area functioning as open water with soft substrate. The concept for this area involves creating irregularly spaced mounds of dredged material to mimic natural marsh hummocks and to increase bathymetric diversity. The mounds would be placed at elevations to support submerged vegetation, with the tops at a depth of 0.3 – 1 m depth compared to mean lake level. The placement would be unconfined, relying on natural consolidation and colonization, although wetland plantings could be done if needed.

The South Bay is an area where historic wetlands have been replaced by open water. The area experiences moderately high hydraulic energy and is influenced by the long fetch from the prevailing wind direction. Remnant islands exist, however the fringe wetlands that historically existed are no longer present. Habitat areas would be developed behind protective berms to ensure appropriate growing conditions for wetland plants.

Rocky Point is another exposed shoreline area; historical maps show rocky points interspersed with wetlands on the protected sides. The wetland features have degraded, possibly due to increased wave energy from navigation in the nearby channel. The construction of a protective berm along the nearshore, to stabilize the shoreline and reduce wave energy, would allow finer sediment to be placed behind the berm. The design would replicate the natural rocky outcrops and sheltered wetlands.

The initial concepts were shared with local Tribal Nations and stakeholders to obtain feedback. Coordination and design activities are on-going, as is a larger dredged material management plan for the federal channel. Finding viable beneficial uses of the rock and sediment (both stockpiled as well as future material generation) is a priority that will benefit all. The framework developed can inform future dredged material planning efforts while sustainably supporting USACE navigation and ecosystem restoration.

Keywords: beneficial use, habitat uplift, habitat restoration, dredging, Great Lakes

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CITATION

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RECONSTRUCTION OF A KILOMETER OF BEACH TO MITIGATE EROSION ON THE ÎLES-DE-LA-MADELEINE

J. Côté[1]

EXTENDED ABSTRACT

The Îles-de-la-Madeleine archipelago, located in the Golfe du Saint-Laurent (Gulf of St. Lawrence), is particularly vulnerable to coastal erosion, storm impacts and the effects of climate change. Its insular setting, limited local availability of suitable construction materials, and the exposure of critical transportation infrastructure pose major challenges for coastal protection and climate adaptation. For the Québec Ministère des Transports et de la Mobilité durable, Route 199 is a strategic asset. This approximately 85-km roadway connects the archipelago's main islands, with several segments running along narrow coastal barriers and low-lying areas exposed to both open-coast and lagoon dynamics.

Recent storm events have underscored the vulnerability of this road network. Severe wind events in November 2018, post-tropical storm Dorian in September 2019 and post-tropical storm Fiona in September 2022 caused significant erosion and damage in multiple locations across the islands. The Ministère currently monitors 44 vulnerable sites along Route 199, several of which have been affected repeatedly by storm impacts. These events have reinforced the need to test innovative coastal protection measures and to develop practical expertise in approaches that complement – or provide alternatives to – traditional hard-engineering solutions.

The Pointe-aux-Loups sector was identified as a priority area due to its high exposure to coastal processes and the proximity of Route 199 to the shoreline. Located within a dynamic hydro-sedimentary environment, the site is exposed to energetic wave and wind conditions, particularly from the northwest and northeast. Previous studies identified beach nourishment, combined with supplementary protection measures, as a suitable adaptation strategy for this sector. The project presented here involved the reconstruction of approximately one kilometre of beach using a large volume of dredged sand, together with the installation of geotextile tubes to provide additional landward protection behind the nourished area.

The nourishment required approximately 120,000 m³ of sand. Securing such a volume in the Îles-de-la-Madeleine posed one of the project's principal challenges. Local sources of granular material are scarce, while importing large quantities from the mainland would have entailed significant logistical complexity and high costs. The project therefore relied on the beneficial use of sand dredged from the Chenal de la Grande-Entrée as part of routine maintenance dredging operations. This approach made it possible to reuse compatible dredged material for coastal protection purposes while reducing reliance on external borrow sources.

[1] MANACC Coordinator, Ministère des Transports et de la Mobilité durable, 92, 2e Rue Ouest, Rimouski, Québec G5L 8E6, Canada, T: 418-896-3085, Email: jonathan.cote@transports.gouv.qc.ca.

Several options were assessed for transporting the dredged sand from the dredging site to the nourishment area. Direct maritime transport around the peninsula was considered but ultimately rejected due to excessive navigation time and operational inefficiencies. Transport through the lagoon was also evaluated, but insufficient water depth made it incompatible with the dredge draft. A third option, involving long-distance hydraulic pumping from the south side of the island, was analyzed but dismissed because of technical and operational constraints. The selected solution involved hydraulically pumping the dredged sediment to a temporary upland storage and dewatering site near the port facilities, followed by truck transport of the dewatered sand to the beach reconstruction area.

This approach required careful coordination of multiple successive operations, including dredging, slurry pumping, dewatering, trucking, geotextile tube installation and beach placement. The dredged sediment was conveyed as a slurry through a pipeline approximately 1.5 km long, with a booster pump installed to maintain sufficient energy in the system. At the temporary storage site, the layout was designed to promote rapid sand settling, optimize recovery of usable material and manage return water through a controlled settling sequence to limit suspended-sediment discharges to the receiving environment. Once dewatered, the sand was loaded onto trucks and transported to Pointe-aux-Loups, where it was placed to reconstruct the beach profile.

The installation of geotextile tubes introduced a buried structural element intended to enhance the resilience of the reconstructed shoreline, while allowing the nourished beach to act as the primary buffer against wave energy and erosion. This combined solution offered an alternative to a protection strategy based solely on rock armouring. It also enabled the Ministère to gain experience with a more flexible coastal protection approach, in which placed sand can be redistributed by natural coastal processes and contribute to the development of a gentler and more protective beach profile.

The project was implemented under significant time, regulatory and logistical constraints. Planning began in 2019, and the emergency context required completion by December 31, 2023. The construction phase coincided with the COVID-19 pandemic, which introduced additional uncertainty related to procurement, equipment availability, mobilization and coordination. The project also required close coordination with the entity responsible for channel maintenance, amendments to existing authorizations, land-access agreements and clear allocation of responsibilities among stakeholders. In total, up to 16 environmental authorizations from provincial and federal agencies were required prior to project completion.

This initiative provided the Ministère with its first large-scale experience in the Îles-de-la-Madeleine combining maintenance dredging, beneficial use of dredged sand, slurry pumping, temporary upland dewatering, truck transport, geotextile tube installation and beach nourishment. The project demonstrated the feasibility of using compatible dredged material to protect coastal road infrastructure in a remote, resource-limited island environment. It also yielded valuable practical lessons related to sediment sourcing, hydraulic transport, temporary storage design, environmental authorization, construction sequencing and coordination between infrastructure protection needs and dredging operations. These lessons are directly applicable to future coastal adaptation projects in island, remote or sediment-constrained settings where material availability, narrow construction windows and logistical limitations are key considerations.

Keywords: beneficial use, dredged sand, beach nourishment, slurry pumping, geotextile tubes, island logistics, sediment management, coastal adaptation.

CITATION

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Our thanks as well to WSP, Tetra Tech, LFG Construction, Les Entreprises PEC and ASDR for their valuable contributions to the success of this project.

DREDGING ENERGY TRANSITION & DECARBONIZATION

Earl Hersh[1]

ABSTRACT

Decarbonization is becoming a defining priority across the dredging and maritime sectors. Customers, regulators, investors, and communities are increasing expectations for lower emissions and improved fuel efficiency, while maintaining the performance required to support critical infrastructure, navigation, coastal resilience, and economic growth.

There is no single pathway to a lower-carbon future. The energy transition will require a coordinated mix of technologies, policy frameworks, and operational improvements. Organizations must advance environmental objectives while navigating the practical constraints of project economics, asset lifecycles, fuel availability, and operational reliability.

PANEL DISCUSSION

This panel convenes leaders in advanced battery technologies, naval architecture and fuel catalyst technology. Collectively, these perspectives offer both a long-term strategic view of industry transformation and practical insights into near-term actions that can be deployed today.

The discussion will focus on several strategic questions:

- How will advances in battery technology and electrification reshape marine operations over the coming decade?
- What “best designs” can dredgers include from other ocean fleets?
- What fuels are applicable for dredging both today and going forward?
- What role can fuel optimization and combustion-efficiency technologies play in reducing emissions from existing fleets as next-generation solutions continue to mature?
- What are customers asking?

The energy transition will not be achieved through a single technology. It will require multiple solutions working in concert to reduce emissions, improve efficiency, and strengthen long-term operational sustainability.

Keywords: Dredging, diesel, emissions, batteries, NetZero, biofuels

[1] Founder, No More Carbon USA, 1010 Kern Street, Houston, TX 77009, USA, T: 281-460-5968, Email: earl@nomorecarbonusa.com

Panelists

Maryam Ebrahimian	Corvus Energy	VP Canada
Earl Hersh	No More Carbon USA	CEO, Founder
Jennifer Ryan, P.E.	C-Job	Director of Engineering

Moderator

Paul Olander, PMP	ENTACT, LLC	Project Director

GEOTECHNICAL PROPERTIES OF BOTTOM SEDIMENTS AND THEIR SIGNIFICANCE FOR DREDGING AND SEDIMENT MANAGEMENT PROJECTS

D.F. Hayes[1] and K. Badu-Tweneboah[2]

ABSTRACT

People with a wide variety of professional background work on dredging and other sediment management projects. This meshing of expertise and experience helps produce successful dredging and other sediment management projects. One drawback, however, is that many have limited understanding of the geotechnical properties and characteristics of sediments and dredged materials. Yet geotechnical properties of these bottom sediments significantly impact almost every aspect of dredging projects, including dredge selection, transportation methods, and dredged material placement whether in water or on land. The geotechnical properties also affect the key design aspects of contaminated sediments management methods, such as dredging and excavations, sediment dewatering and consolidation and disposal in confined disposal facilities or landfills, and capping material type and thickness, and its overall stability. This paper is an attempt to summarize geotechnical properties useful for dredging and other sediment management projects. The paper provides fundamental definitions, field and laboratory procedures used to measure these properties, and typical values when possible. The paper discusses how these properties are utilized in the design and management of dredging and other sediment remediation projects and recommends the need for a short course that covers fundamental geotechnical properties and their application to dredging and other sediment material management projects.

Keywords: Dredgeability, in-situ properties, excavation properties, removal and transportation properties, disposal properties, soil/sediment descriptors.

INTRODUCTION

Dredging and sediment management projects require a diverse team with a variety of expertise and experience. Proper sediments characterization and assessment may be the most crucial ingredient for successful design and implementation. Project teams commonly include geotechnical engineers, geologists, environmental engineers, biologists, estimators, dredging equipment manufacturers, and dredging contractor personnel. Almost all team members have essential sediment-related knowledge, but it is rare for a single person to possess the breadth required to ensure success in all aspects of the project, from in-situ properties to post-placement stability. Further, different professions use different nomenclatures; since dredging projects include such a wide variety that it can be very confusing. This paper will attempt to summarize and synthesize important sediment properties to improve communications among team members. Typical values are provided where possible.

[1] CEO, The Dredging Professor, LLC, 9797 County Rd 420, Meridian, MS 39301, USA, T: 337.212.0127, Email: don@thedredgingprofessor.com (corresponding author).
[2] Senior Consultant, KBT Consultants, LLC, 91 Star Crossed Ln, Saint Johns, Florida, 32259, USA, T: 904-402-2169, kbadutweneboah@gmail.com.

PREVIOUS EFFORTS

Increased awareness and understanding of the key sediment properties will increase overall project efficiency and success. Spigolon (1993) attempted this by conducting a study consisting of a review of published literature and personal interviews with U.S. Army Corps of Engineers (USACE) personnel, dredging contractors, and dredging consultants. Spigolon's objective was to develop "standard descriptors for directly indicating or readily inferring the 'dredgeability' of in-situ material" (Spigolon, 1993). The term 'dredgeability', originally defined by Calhoun et al. (1986), was modified by Spigolon (1993) to mean "...the ability to excavate underwater, remove to the surface, transport, and deposit sediments with respect to known or assumed equipment, methods, and in-situ material characteristics…"

The dredgeability of a soil deposit depends on the type of equipment used to dredge. Based on the dredging mechanisms (Table 1 of Spigolon (1993), the dredgeability properties of soil sediments during the four stages of dredging operations are (Spigolon, 1993):

- *Excavation properties – suctionability, erodibility (scourability), cuttability (affected by friability), scoopability, and flowability (underwater instability)*;
- *Removal and transport properties - pumpability (affected by rheologic properties of slurry), abradability (abrasiveness in a pipeline), clay balling (affected by stickiness), sedimentation rate in a hopper, and amount of bulking*; and
- *Disposal properties – dumpability (affected by friability and stickiness), sedimentation rate in a disposal area, amount of bulking, and compactibility*."

Spigolon (1993) summarized significant geotechnical properties necessary for the engineering design of dredging projects and for the estimation, planning, and execution of dredging operations as shown in Table 1. He also proposed a new Dredging Classification System that considers all the dredging processes: excavation, removal, transport, and deposition and all types of dredging mechanisms and equipment. Eight sediment categories were assigned to soil groups as: Group R - rock and coral, Group S - shale and cemented soils, Group B - boulders and cobbles, Group G - clean granular soils, Group F - friable mix-grained soils, Group C - cohesive soils, Group O - highly organic soils and Group M - fluid mud. It was anticipated that maintenance dredging would primarily involve Groups G, F, and M categories whereas new work dredging could encounter any of the eight major categories. The author recommended additional research to define the geotechnical test criteria for each of the eight categories and definitions for sub-categories.

Spigolon and Bakeer (1994) followed up with a knowledge-based expert system (KBES) computer program "Geotechnical Factors in DREDGeABiLity" (DREDGABL) developed as part of the USACE Waterways Experiment Station's (WES) Dredging Research Program (DRP). The program was intended to serve the dredging community as a geotechnical engineering consultant. The program provides guidance in the suitability of various types of dredging equipment for specific sediment types whose properties are described in the contract documents. As pointed out by Spigolon and Bakeer (1994), dredging personnel often do not fully understand the geotechnical information in the manner that has been presented and its limitations. Geotechnical engineering descriptions of sediments do not indicate dredgeability properties and require analysis and interpretations. This could lead to misinterpretation of sediment-related risks with a resulting in higher costs and is often a cause of costly claims. The KBES computer program was therefore intended as a tool to develop standard dredging-related geotechnical descriptors for indicating, or inferring, the dredgeability of sediments. To the authors knowledge, this DREDGABL program and the Dredging Classification System proposed by Spigolon (1993) were not adopted and used by the USACE and other dredging personnel (including consultants) for dredging projects.

Table 1. Geotechnical soil properties for dredgeability estimation (*Table 3 from Spigolon, 1993*).

Geotechnical Property	**Applications to Dredgeability**
In-situ (Undisturbed) Soil Mass Properties	
In-situ shear strength	Extremely soft or loose soils can be suctioned; energy needed for cutting or scooping directly related to in-situ strength.
In-situ density	Used for calculation of in-situ solids content; density is correlated with shear strength.
Soil Material Properties	
Grain size distribution.	Clean granular soils can be easily scoured; energy for pumping slurry is related to median size; need maximum size for pump clearance; possibility of rheologic behavior in slurry related to fines content; amount of fines is indicator of settlement capability in hopper and in disposal area; indicator of compactability; correlated with shear strength.
Plasticity of the -no. 40 screen fraction	Indicator of friability; correlated (with water content) with in-situ strength and with potential stickiness; indicator of settlement capability in hopper and in disposal area; indicator of clay ball potential in pipeline; indicator of compactability.
Grain angularity, shape, and hardness	Factors affecting the in-situ shear strength of cohesionless soils; directly affect pumping energy and abrasiveness in a pipeline slurry.
Water content and specific gravity of grains	With bulk density, used in calculation of solids and gas content, either in-situ or in any other condition; used in settlement calculations.
Organics and type of cementation	Factors in evaluation of in-situ strength; indicators of potential for friability and for degradation during pumping; directly affect pipeline gas content and pumping energy.
Sedimentation rate – in fresh and salt water	Direct tests for sedimentation rate, or estimation using grain size distribution and plasticity: used for estimating settlement rate in hopper or in disposal area.
Rheological properties of slurry	For fines content greater than about 35%, the shear strength and viscosity of slurry are functions of slurry velocity, slurry density, fines content, and clay content.
Bulking capacity	Bulk volume change during manipulation of the soils is a function of initial density, grain size distribution, plasticity, organic content, water content, and method of deposition.

Costaras et al. (2011) emphasizes the importance of accurate and comprehensive dredging information when planning dredging projects. For any dredging project, the understanding of the bedding material, its variability, how it behaves when it is dredged, transported, and disposed of upland or in water is vital to determining how best to dredge and how best to mitigate any potential impacts (Costaras et al. 2011). Guidelines for planning a site investigation, sampling and testing are provided; existing laboratory test methods should be used with careful thought in the absence of specifically designed tests to properly represent the physical processes that materials are subject to during dredging. Particle-size distribution (and number of samples tested) of the sediments is one geotechnical property that could potentially affect the cost and execution of a dredging project especially when a trailing suction hopper dredger is used.

In an updated and revised edition of the paper by Johnson and Sraders (2003), Johnson (2005) describes the geotechnical information required by contractors for estimating, planning and performing dredging projects and the relationship of geotechnical properties to dredging production, costs, and performance. The geotechnical properties include soil classification, particle-size distribution, moisture content, Atterberg limits, in-situ density (unit weight), relative density (typically for sands), shear strength and rock quality index. These properties are the primary drivers of dredging equipment selection, methodology, production, project duration, and hence project cost. Johnson (2005) provides general guidelines and criteria for performing geotechnical site investigations for dredging projects and providing information in plans and specifications.

Following the general guidelines by Costaras et al. (2011) and Johnson and Sraders (2003), Dols (2012) discusses how every dredging project can benefit from geotechnical investigation tailored to the site and anticipated dredging process.

PIANC (2016) provides a comprehensive discussion of soil properties as they apply to dredging. It represents a significant update to PIANC (1984) which considered grain (particle) size and strength, but only limited consideration of Atterberg limits to distinguish between silts and clays as required by the Unified Soil Classification System (USCS). PIANC (2017) is a field version of the updated document (PIANC 2016) which summarizes as a series of useful tables and templates for field use.

It is apparent from the available literature that geotechnical properties of bottom sediments can significantly impact on almost every aspect of dredging projects, including dredge selection, transportation methods, and dredged material placement, whether in water or on land. The relevant geotechnical properties useful for dredging and sediment management projects are discussed below with focus on their fundamental definitions, laboratory test procedures used to measure the properties, and typical values when possible. Appropriate and relevant information (tables and figures) from the latest PIANC classification system (PIANC 2016, 2017) will be discussed when necessary.

RELEVANT GEOTECHNICAL PROPERTIES

In Table 1 (reproduced Table 3 from Spigolon 1993), the geotechnical soil properties and their applications to dredgeability are presented for the in-situ (undisturbed) soil mass properties and soil material properties. The in-situ or undisturbed soil mass properties refer to the properties of the in-situ soils or sediments at the bottom of the river that must be evaluated for dredging or other sediment management projects. PIANC presents a comprehensive table (*Table 3.4* of PIANC (2016) and *Table 2.2* of PIANC (2017) with the most common laboratory and in-situ tests that should be carried out for classification and description purposes.

Spigolon (1993) lists in-situ shear strength and density as the relevant properties. In-situ density is supposed to be used for calculation of in-situ solids content. Soil density (or unit weight) is the physical mass or weight of soil per unit volume (with typical units of lb/ft^3, g/cm^3, or kN/m^3), which varies based on how loosely or densely the soil is packed. Therefore, relative density is typically used to describe the in-situ density (see Table 1). The specific gravity of soil on the other hand is a dimensionless ratio comparing the density of soil solids to the density of water. Essentially, specific gravity is a constant property of the mineral particles themselves, whereas density is a variable state of the whole soil mass (including air and water). Unfortunately, some engineers and others often use density when they really mean specific gravity and vice versa.

This section describes the geotechnical properties of soils, based on the authors' experience, that are relevant to dredging and other sediment management projects. These properties are either determined in the field from soil borings with the standard penetration test (SPT), per American Society of Testing and Materials (ASTM) Test Method D1586, performed to estimate the penetration resistance (N-value) and also obtain disturbed and undisturbed samples for laboratory analyses. Vibracore sediment sampling is also routinely used to collect sediment samples for dredging and other sediment management projects. The rest of the paper will focus on soil sediment samples obtained in the field using soil borings with SPT and/or vibracore equipment.

Particle Size Distribution

Gradation (percent gravel, sand, silt, and clay) of the in-situ soils is useful in selecting the type of dredging equipment and in the case of hydraulic cutterhead dredging affects the pumping energy and hydraulic properties of the material to be dredged when slurried with water (Spigolon 1993, Johnson 2005). PIANC (2016) indicates that fines content will have an impact on the dredging process and the impact will be influenced by both particle size distribution and clay mineral composition (i.e., mineralogy). Different dredging processes have different levels of susceptibility to the cohesiveness of soils (PIANC 2016). These properties are typically determined in the laboratory by performing tests on samples collected from site investigations such as soil borings with SPT. ASTM D6913 provides gradation for coarse-grained soils using sieve analysis and ASTM D7928 for the gradation of fine-grained soils (silt and clay fractions) using hydrometer analysis. PIANC (2016) recommends including, whenever feasible, particle-size distribution (i.e., gradation) curves and with the computations of the coefficient of uniformity (C_u) and coefficient of curvature (C_c). If gradation curves are not given or are limited in extent, the percentage by weight of the several soil fractions shall be stated. Particle size distribution shall include an estimate of shell content, preferably broken down by particle size (PIANC 2016).

Below is the range of particle sizes for soil types as defined by the USACE on ENG Form 2087 (USACE 2022).

Sediment Descriptor	Grain Size (mm)
Coarse gravel	16 - 64
Fine gravel	4.8 - 16
Coarse sand	2.0 – 4.8
Medium sand	0.43 – 2.0
Fine sand	0.075 – 0.43
Silt	0.005 – 0.08
Clay	<0.005

The median particle size (D_{50}) is often used to estimate dredge production (O'Bourke et al. 2008). The typical median particle size of sediment is highly variable depending on the environment, but it frequently falls within the silt to fine sand range with the following values:

- 0.004 to 0.063 for suspended sediment from rivers that classify as silt or clay;
- 0.063 to 2 mm for bed load/bed material from rivers; and
- 0.125 to 0.5 mm for coastal/beach sediment, which is typically fine to medium sand.

O'Bourke et al. (2008) used D_{50} values of 0.03 mm and 0.2 mm for maintenance and new work dredging, respectively, to estimate production rates.

Natural Moisture Content

The natural moisture (water) content is a very useful indicator of the in-situ condition of soil. It is defined as the ratio of the weight of water to the weight of solid particles, calculated using the formula:

$$\omega = \frac{w_w}{w_s} \quad (1)$$

where ω = moisture (water) content (%); w_w = weight of water (lbs or N), and w_s = weight of dry solids (lbs or N).

PIANC (2016) states that the natural moisture content is an inexpensive test and a thorough profile of moisture with depth is recommended for boreholes. It is typically measured in the laboratory by using ASTM Test Method D2216 or D4959 and is generally accurate when relatively undisturbed specimens from SPT split-spoon and vibracore samples are used and therefore good for clays and silts. The natural moisture content of a bottom sediment may be used with specific gravity to calculate solids content to help estimate the volume of solids pumped via a pipeline to disposal cell in the case of hydraulic cutterhead dredging.

Atterberg Limits (Plasticity)

Atterberg Limits (liquid limit, plastic limit and plasticity index) are typically measured on cohesive soils (clays and silts) using ASTM Test Method D4318. The plasticity index (PI) which is the difference between the liquid limit and plastic is an indicator of friability of the dredged material, clay ball potential in a pipeline and settlement (or compactability) capability in a hopper or disposal area (Spigolon 1993). Table 2 (reproduced from Spigolon 1995) contains the descriptive word definitions currently used in geotechnical engineering in the United States and elsewhere. The well-known Atterberg liquid and plastic limits are used to distinguish silt from clay in fine-grained cohesive soils, thus providing important guidance on likely general material behavior during dredging, transport and placement. Note that liquid and plastic limits are of limited value without the accompanying natural moisture content.

Table 2. Plasticity terms to define cohesive soils (after Spigolon 1993).

Term	Liquid Limit	Plasticity Index
Silt	< 50	Plasticity Index (PI) less than 4 or less than the A-line[a] value corresponding to the Liquid Limit (LL)
Elastic clay	> 50	
Lean clay	< 50	Plasticity Index (PI) greater than 7 and equal to or greater than the A-line[a], and below the U-line[a], value corresponding to the Liquid Limit (LL)
Fat clay	> 50	
[a]The A-line has the equation: Horizontal at PI = 4 to LL = 25.5, then PI = 0.73*(LL-20). The U-line has the equation: Vertical at LL = 16 to PI = 7, then PI = 0.9*(LL-8).		

Classification

Even though PIANC (2016) states that soils and rocks shall be classified according to ISO, EN, BS, ASTM, DIN or other applicable national standards, it is not one of the soil properties listed in Table 3.4 of PIANC (2016). Geotechnical engineers in the United States use the USCS. The USCS, per ASTM D2487, uses laboratory tests (particle size analysis, liquid limit, and plasticity index) to classify soils into categories based on engineering properties. There are three major soil divisions: coarse-grained soils, fine-grained soils, and highly organic soils within the USCS. However, it provides a more descriptive description of the soil mass within the sediment bottom (e.g., well-graded sand (SW), poorly graded sand (SP), silty sand (SM), clayey sand (SC), and well-graded or poorly graded gravel (GW/GP). The USCS, Atterberg Limits, and moisture content test results can be presented on boring logs to help the contractor understand the type of material he is bidding for in the contract/project specifications.

Organic Content

ASTM Test Method D2974 is used for determining moisture, ash, and organic matter content in peats and organic soils, including mucks and clays. It evaluates organic matter for classification of soils and their suitability for construction. Soils with organic content above 30% by dry weight should be classified as "peats" or "organic soils" for dredging purposes (PIANC 2016). In the case of dredging, it can affect pipeline gas content and pumping energy (Spigolon 1993), and gas can create an environmental hazard to people on and near the dredging vessel (PIANC 2016). Many contaminated sediment sites have significant gas generation which could affect the physical stability of sediment caps if gas ebullition is not properly tested and accounted for in the design (Borrowman et al. 2013).

Specific Gravity

The specific gravity of soil particles (G_s) is an important measure of particle characteristics and settling rates:

$$G_s = \frac{\rho_s}{\rho_w} \tag{2}$$

where G_s = specific gravity (unitless), ρ_s = density of dry solids (kg/m^3), and ρ_w = density of water (kg/m^3). The specific gravity of soil solids is used to calculate the density of the soil solids. This is done by multiplying the specific gravity by the density of water at 20°C. Solids density is nearly independent of temperature. The term soil solids is typically assumed to mean naturally occurring mineral particles or soil-like particles that are not readily soluble in water. Therefore, the specific gravity of soil solids containing extraneous matter, such as cement, lime, and the like, water-soluble matter, such as sodium chloride, and soils containing matter with a specific gravity less than one, typically require special treatment or a qualified definition of their specific gravity. ASTM D854 is the standard test method for measuring specific gravity of soil solids using the water displacement method. For some soils containing a significant fraction of organic matter, kerosene is a better wetting agent than water and may be used in place of test water for oven-dried specimens. Kerosene is a flammable liquid that must be used with extreme caution. This standard should not be used when using kerosene as the test fluid (ASTM D854).

Table 3 is a summary of in-situ dry density values for various sediments (USACE 1985). The table shows that the specific gravity varies from 1.2 (for mud [clay] and silt) to 2.4 (for soft rock). These values appear

to be too low, in the opinion of the authors, since specific gravity of soil solids generally range from 2.65 to 2.80 for most inorganic soils with sand ranging from 2.66 to 2.68. PIANC (2016), however, reports specific gravity values of 1.3 to 1.7 for peat and other organic soils. A specific gravity value of 2.675 was measured from a composite sample containing 84 percent sand and 16 percent fines (silt and clay) collected from the St. Johns River in Jacksonville, Florida for a maintenance dredging project (Badu-Tweneboah et al. 2019).

Table 3. Material description versus average in-place density (USACE 1985).

Material Description	Average In-place Density*
Mud (clay) and silt	1200 g/l
Mud (clay) and silt	1300 g/l
Mud (clay) and silt	1400 g/l
Loose sand	1700 g/l
Loose sand	1900 g/l
Compacted (dense) sand	2000 g/l
Stiff clay	2000 g/l
Compacted shell	2300 g/l
Soft rock	2400 g/l
Blasted rock	2000 g/l

**Sediment density (g/l) divided by water density (~1,000 g/L) is equivalent to bulk specific gravity.*

As defined above, specific gravity can be used to calculate the density of soil solids. The volume of soil solids (V_s) is calculated using the specific gravity of solids (G_s), the dry weight of the soil solids (W_s), and the unit weight of water (γ_w):

$$V_s = \frac{w_s}{\gamma_w G_s} \tag{3}$$

where V_s = solids volume of soil (m^3) and γ_w = unit weight of water (N/m^3). The volume of sediment solids in a river bottom before dredging should be the same volume when placed in a disposal cell. Therefore, knowing the specific gravity of sediments can be used to confirm measurement and payment of dredged material. Finally, the specific gravity of soil solids can also be used to calculate the initial void ratio of sediments in the river and then used to estimate the final void ratio of the dredged material in the disposal cell and thereby estimate the bulking factor (discussed below).

Bulking Factor

Bulking factor is the ratio of the volume of material in the placement/disposal area compared to the volume in the original channel. It is a function of the initial density, particle -size distribution, plasticity, organic content, moisture content, and method of deposition. Factors that affect bulking of sediments include: (i) density changes (in-situ density and void ratio versus placement density and void ratio); (ii) water entrainment (dredging increases the water content, creating a slurry with a lower density than the original); (iii) degradation (clay balls breaks down over time, reducing the total volume in a containment area). Hydraulic dredging often results in higher initial bulking (more water) than mechanical methods, though hydraulic slurries may settle quickly. Bulking factors for dredged material typically range from 1.1 to >1.5 with 1.3 typically used for clay and 1.25 for other soil types.

Viscosity of Slurry

Viscosity is a fluid's internal resistance to flow, deformation, or shear, often described as its "thickness" or "stickiness". It measures the internal friction between fluid layers moving at different speeds. High-viscosity fluids (e.g., honey) flow slowly, while low-viscosity fluids (e.g., water) flow easily. Standard ASTM D2270 calculates viscosity index by measuring the kinetic viscosity of liquids at 40° and 100°C and ASTM D567 is used for calculating viscosity index from viscosity at 100ºF and 210ºF.

Slurry viscosity is a function of slurry velocity, slurry density, fines content and clay content (Spigolon 1993). Stokes' law for sedimentation is used to calculate the terminal settling velocity of a sphere falling through a viscous fluid. The equation is a function of particle radius (i.e. size), particle density, fluid density and fluid viscosity. For hydraulic dredging and transportation via pipeline, Johnson (2005) indicates that the hydraulic properties of the material to be dredged when slurried in water affect hydraulic production. For silts, the hydraulic properties can be calculated from the viscosity of the material and its in-situ density measured in the laboratory from undisturbed Shelby-tube samples obtained during soil borings (Johnson 2005).

In-situ Unit Weight (Density) of Sediments

As previously discussed in-situ density (and more preferably unit weight) of sediments is the physical mass or weight of soil per unit volume, which varies based on how loosely or densely the soil is packed. In-situ density measurement is sensitive to sample disturbance (PIANC 2016). Therefore, for cohesionless soils the term relative density is used to describe the "compactness" of the soil. The SPT N-value, when properly interpreted, is an index of soil strength, relative density (for granular soils), and consistency (for fine-grained soils). Table 4 shows examples of such correlations reported in the geotechnical literature. Therefore, SPT N-values correlation with relative density, as presented in Table 4, is one of the commonly used methods to estimate relative density of cohesionless soils. PIANC (2016) presents similar relative density terms using: the cone penetration test (CPT or CPTU) on the basis of tip resistance (q_c); the SPT N-value; dynamic probing heavy (DPH); dynamic probing light (DPL); borehole dynamic probing (BDP) on the basis of blow count (N_{10} or N_{30}); and the Swedish weight sounding test (WST) on the basis of half-turns/0.2 m. For cohesive soils, however, laboratory measurements using undisturbed Shelby-tube samples are performed in accordance with ASTM Test Method D7263. The in-situ density of bottom sediments can be used to calculate in-situ solids content and to correlate with shear strength (Table 4) and therefore can be used for dredge equipment type selection.

Shear Strength

The shear strength of bottom sediments is a good indicator of the dredgeability of the sediments and therefore the type of dredge equipment (mechanical or hydraulic) to use (Spigolon 1993). For contaminated sediments remediation, such as capping, the shear strength is an important design parameter especially regarding long-term stability assessment of the cap. SPT N-values correlations with shear strength (see Table 4) can be used to estimate shear strength especially for cohesionless soils. Laboratory triaxial and direct shear strength tests are used for cohesive soils where relatively undisturbed samples can be obtained from the geotechnical investigation. The cone penetration test (CPT) tip resistance and side friction measurements have also been correlated with shear strength of both cohesionless and cohesive soils. Undrained shear strength values for cohesive soils ranging from "extremely low" to "extremely high" based on results from field and laboratory tests are cited by PIANC (2016).

Table 4. SPT N-Values correlations with: (i) relative density and strength for cohesionless soils (from Meyerhoff 1956); and (ii) consistency for strength for cohesive soils (from Terzaghi and Peck 1967).

Meyerhoff (1956)		
Relative Density	**SPT N-values**	**Friction Angle, ϕ (degree)**
Very loose	< 4	25-30
Loose	4 - 10	27-32
Medium dense	10 - 30	30-35
Dense	30 - 50	35-40
Very dense	> 50	38-43

Terzaghi and Peck (1967)		
Consistency	**SPT-N**	**q_u (kPa)**
Very soft	< 2	< 25
Soft	2 - 4	25 – 50
Medium	4 - 8	50 – 100
Stiff	8 - 15	100 – 200
Very stiff	15 - 30	200 – 400
Hard	> 30	> 400

Compressibility

Compressibility properties of bottom sediments are more important for other sediment remediation projects, such as capping contaminated sediments than dredging. In such cases, settlement (primary consolidation and secondary compression) of the contaminated sediments would have to be accounted for in the thickness and stability design of the final cap. The compressibility properties are typically measured from laboratory tests, such as one-dimensional consolidation (odometer) test per ASTM D2435 and constant rate of strain (CRS) consolidation test per ASTM D4186, using undisturbed samples. For dredging projects, however, compressibility properties of the dredged material in a confined disposal facility (CDF) are useful in evaluating the life of the CDF. The "Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill" (PSDDF) model is used to predict the desiccation and consolidation of dredged materials deposited in a CDF (Stark 1996).

Other Properties

PIANC (2016) also lists carbonate content, mineralogy, and crushability as other important soil properties or characteristics that require testing in situ or laboratory for dredging purposes. Carbonate content is important to know for re-use of dredged materials and to assess the potential mechanical breakdown of sands during ground improvement activities involving compaction. The most commonly and easily tested is the calcium carbonate content, although it is noted that other carbonates can be present in soils. Mineralogy, along with particle shape, is used to assess the abrasivity of coarse-grained soil. Abrasive dredge slurries cause wear of cutterheads, dragheads, pumps, pipelines and fittings and their repair or replacement can be a significant dredging cost (PIANC 2016). Crushability is especially important for intermediate materials and materials with high shell or carbonate content. Intermediate materials refer to materials excavated during dredging that exhibit properties which are in a transition range between soils and rocks and frequently referred to as "hard soils" or "extremely weak rocks" (PIANC 2016). The potential for crushing of soils becomes important when the content of crushable materials exceeds 5% by weight.

Debris

Although not technically sediment properties, debris frequency and characteristics are critical information for successful dredging projects. Encountering debris usually reduces production and increases water quality impacts, sometimes significantly. Once removed, debris must be managed for disposal which may require additional, potentially specialized, equipment. Debris increases dredging costs and reduces

production, often leading to conflict between owners and dredging contractors. Beaver, et. al. (2022) summarizes debris characteristics and how they affect dredging operations.

Information from multiple survey methods such as multibeam sonar, magnetometer, and sidescan sonar can be combined to identify some debris, but not all. Methods have not yet been developed that synthesize this data to generate a useful quantitative debris measure.

PROPERTY CHANGES

Pre-project investigations focus, by necessity, on in-situ sediment characteristics and properties. However, sediment properties change as the result of dredging, transportation, and placement. In some cases, the in-situ sediment properties continue to apply; in other cases, changes in the physical makeup of the sediments at specific junctures may significantly change their behavior. This section describes property changes during dredging, loading, transportation, and placement. depending on the equipment used during each phase of the project. Density changes are the most obvious, but other changes occur as well.

Dredging

Hydraulic dredges add significant volumes of water to fluidize in-situ sediments, then pump the resulting slurry through a pipeline. Hydraulic dredges usually pump sand at 20% solids (by mass) or slightly higher. Fine sediments are more viscous and are typically pumped at about 10% solids (by mass). Slurry densities for mixed sediments can be estimated based on the proportional mass of sand and fines. Dilution factors can be computed by comparing slurry density to bulk density of the in-situ sediment. The sediment slurry properties are much different than those of the in-situ sediment.

The mechanical digging process destroys the in-situ sediment structure. Combined with extra water captured by the bucket, the bulk density in softer sediments typical of maintenance dredging projects may be slightly reduced. Enclosed buckets add more water than conventional buckets because of additional headspace. Partially filled dredge buckets can decrease bulk density even further. Except in unusual cases, however, density changes in soft sediments are modest and insufficient to dramatically alter the physical properties of the sediment.

Physical changes in stiff sediment, especially new work projects where the sediment structure has been forming for centuries, are typically more significant. Cohesive deposits with significant clay content often result in a combination of loose sediment and clumps of material that remain at in-situ density. Sediment clumps are “chunks” of in-situ sediment that remain together throughout the dredging process. Practically, they remain at (or very near) in-situ density and particle size distribution. Whether pumped hydraulically or mechanically loaded into a barge, clumps behave like rocks or boulders, settling rapidly and stacking with large void volumes between them.

The USACE open water placement model, STFATE, estimates the mass fraction of clumps formed during mechanical dredging based on the in-situ moisture content compared to the liquid limit of the sediment (Ousley *et al* 2016):

$$f_c = \frac{1}{0.8}\left(1.8 - \frac{\omega}{LL}\right) \quad (4)$$

where f_c = clumping fraction by mass (unitless), ω = in-situ water content (%), and LL = liquid limit of in-situ sediment (%). A similar physical change occurs during dredging of limestone and other soft, brittle sedimentary rock; the authors are not aware of any methods for estimating the fraction of clumping for these deposits.

Loading and Transportation

Maintenance sediments, and other soft sediments, usually retain their in-situ density and particle size distribution when dredged mechanically and placed in a barge. Some separation might occur if the barge were filled with water and the buckets emptied well above the water surface; this would be an unusual dredging situation. Extra water captured by the bucket along with water expelled from the sediment matrix due to weight-induced compression, forms a supernatant layer within the sediment barge. If the supernatant layer is removed from the barge through decanting or overflow, sediment properties will remain similar to in-situ conditions. If not, it may dilute the bulk density through mixing with sediment during the barge unloading process.

Clumps separate from other sediments and can usually be unloaded mechanically without major physical changes.

Hydraulically unloading of mechanically filled barges requires large water volumes for dilution. The resulting sediment slurries exhibit densities similar to those observed for hydraulic dredges discussed previously.

Hydraulically loaded barges, including spider barge systems[3], typically change particle size distribution dramatically which in turn alters most of other properties. Barges receive the dilute slurry pumped by hydraulic dredges requiring them to separate large volumes of water from the sediment particles. Since settling rates of different particle sizes vary dramatically, capture rates vary similarly. The retention of coarse particles (e.g., clumps, gravel, and sand) will be much greater than fine-grained sediment particles. In fact, almost all fine particles can sometimes be lost leaving only the coarse fraction and clumps in the barge.

As discussed previously, fluidizing sediment for hydraulic transport significantly reduces its density. Slurry density and the associated viscosity are important parameters for pipeline transport. Without site or dredge-specific information, slurry density can be estimated roughly as 20% solids (by weight) for the granular (sand) fraction and 10% solids (by weight) for the fines (silt and clay) fraction. For example, pumped slurry density would typically be about 15% solids (by weight) for an in-situ sediment with 50% sand and 50% fines.

Changes During Placement

Important changes can occur during the placement process, whether dredged sediment is used beneficially, placed in a confined or unconfined placement site, or released into open water. Mechanical placement of mechanically dredged sediment results in the least physical changes to the sediment. Hydraulic placement,

[3]A Spider Barge system distributes sediment slurry from a hydraulic dredge to multiple barges, reducing the loading rate to each barge which increases sediment retention. Spider barge systems may operate with continuous overflow or decant supernatant after a specified settling period.

however, results in dramatic changes in sediment properties whether it is directly from a hydraulic dredge or from hydraulically offloading of mechanically dredged sediment in a barge. Variations in the settling rates with particle size causes almost perfect segregation. Coarse particles, whether gravel, sand, or clumps, settle in the immediate vicinity of the discharge at their natural angle of repose, possibly 20% or more. Fine fine sediment particles will be transported further from the discharge location and may segregate further based on settling rates. Fine particles often settle on a slope of 1% or less. Settling rates and the initial settled density of each sediment fraction are different. This is why settling test protocols include a step to remove coarse particles prior to testing. The same segregation is necessary to get accurate measurements of other properties such as permeability and consolidation rates within a placement area.

Particle size segregation also occurs during open water placement operations. Surface discharges of hydraulically dredged slurries into open water segregate even more as water depth increases due to increased entrainment and settling time. Discharging closer to the bottom reduces segregation. Most of the sediment within a barge or hopper dredges usually settles as a mass, with some stripping of finer particles along the edges, and some release due to striking the bottom. These are not thought to significantly change bulk sediment properties.

Where Do Property Changes Matter?

Dredging processes are physically much more complicated than they may first appear. In-situ properties apply to many dredging and dredged material related analyses, but not all. In some cases, the physical changes described above change the sediment composition and, thus, behavior. In those cases, in-situ properties may not reflect the sediment properties of interest. Table 5 summarizes material properties of importance for various sub-processes that occur during dredging and dredged material transportation related activities presented by PIANC (2016); rock-related properties are excluded because they are beyond the scope of this paper. The properties in Table 5 are associated with in-situ soils. While in-situ soil properties may be appropriate for the placement of mechanically dredged and placed dredged material, they may not be appropriate for hydraulically placed dredged materials.

Once discharged, the disparity in settling velocities, by particle size and specific gravity, the composition of settled particles in the newly deposited sediment changes with distance and time. Granular particles usually settle rapidly, separating themselves from the fine particles which travel much farther before settling. Recently deposited granular sediments usually drain well; i.e., deposits not inundated will not remain saturated.

At very short distance from the discharge location, the slurry contains only the fine fraction of the in-situ sediment since all coarse particles settled previously. Column settling test procedures include a hydraulic sieving approach to achieve this modified composition. A similar approach is required for all analysis where the modified slurry is applicable. For example, initial density of the settled layer is usually around the liquid limit of the modified composition, not that associated with the in-situ sediment. Consolidation testing can provide density changes with time and loading conditions but should use sediment with the modified composition to provide the greatest accuracy.

Table 5. Important non-rock soil properties for dredging-related activities; modified from PIANC (2016).

ACTION		Soil Property												
		particle size distribution	**particle shape/angularity**	**particle density**	**min. and max density, relative density**	**permeability**	**internal angle of friction**	**mineralogy**	**unit weight and water content**	**Atterberg limits**	**rheology**	**undrained shear strength**	**non-organic content**	**decomposition**
EXCAVATION	(pure) hydraulic excavation	GCP	G		G	G	G		P	C	C		P	
	Hydraulic/mechanical excavation	G	G		G	G	G		CP	C		P	P	P
	Slurry density and clayballs	GCP							CP	C	C	CP	P	P
	Mixture formation while excavating	CP		G	G	G	G		CP	C	C	CP	P	P
	Wear and tear	G	G	G				GCP						
HYDRAULIC TRANSPORT	Critical velocity	GCP	G	G					CP	C	C		P	
	Pipeline resistance	GCP	G	G					CP	C	C		P	
	Slurry density and clayballs	CP					CP?		CP	C	C	CP	P	P
	Wear and tear	GCP	G	G				GCP	CP					
DEPOSITION	Bulking	GCP	G	G	G	C		CP	CP	C	C		P	P
	Overflow losses	GCP	G	G				CP	CP	C	C		P	
	(relative) density upon deposition	GCP	G	G	G			P	CP					
	Unloading hopper	GCP	G	G					CP	C	C	CP	P	

G = noncohesive soils (gravel, sand, and silt); C = cohesive soils (silt and clay); P = peat and organic soils

CONCLUSIONS

A clear understanding of sediment properties by all team members is critical to designing and managing successful dredging and sediment management projects. This paper synthesizes important sediment properties and describes how those properties influence dredging and sediment management operations. It also describes changes to sediment properties during phases of dredging and sediment management

operations. The purpose of the paper was to put this information into a single document where it could potentially be used as the basis for a short course covering fundamental geotechnical properties and their application to dredging and other sediment material management projects.

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DATA AVAILABILITY

All data, models, and code generated or used during the study are included in the manuscript.

CHALLENGES IN SITE INVESTIGATIONS, DESIGN, REMEDY IMPLEMENTATION, AND MONITORING IN SHORELINES WITH SHALLOW BEDROCK

J. Risinger[1], M. Bodman[2], R. Thomas[3], A. Corp[4], D. Ormerod[5], M. Woltman[6], M. Carey[7], N. Seyster[8]

ABSTRACT

Esquimalt Harbour is a large working harbour located on the southern end of Vancouver Island, British Columbia, with a long history of impacts from shipbuilding, mills, canneries, and naval activities. It was identified as a Class 1 Contaminated Site (high priority for action) and is being remediated by the Department of National Defence (DND) through the Federal Contaminated Sites Action Plan program. Currently, it is the home of the Royal Canadian Navy's Pacific Fleet, necessitating that remedial objectives align with operational considerations. Harbour remediation has been completed at 15 areas in the last 9 years, with eleven projects in areas with shallow bedrock.

The existence of shallow undulating bedrock in remedial areas posed numerous challenges in all phases of a project including site investigation, design, implementation of the remedy, and post-remediation monitoring. The approaches used to reduce uncertainty caused by these site subsurface conditions and to manage impacts to achieving remedial goals are discussed in this paper. Key lessons learned from implementing these eleven projects in areas of bedrock are shared in the following sections.

Site investigation challenges included determining the vertical extent of contamination and estimated elevations of bedrock. In all projects, these were largely determined through sediment coring and jet probing. Design considerations included developing the dredge prism based on sediment thickness delineation and the variability of data, addressing uncertainties with dredge volumes in measurement and payment approaches, and specifying appropriate dredging equipment. Additionally, remedial strategies had to balance dredging versus capping risks in achieving remedial and future operational objectives. During implementation, active change management was required to adapt to actual conditions encountered by the contractor, which at times varied significantly from predicted bedrock surface delineations. Post-

[1] Department of National Defence, Esquimalt, BC, Canada
[2] MARPAC Environment Officer CFB Esquimalt, Department of National Defence, PO Box 17000 Station Forces, Victoria, British Columbia, V9A 7N2, Canada, 250-363-4824 D199, Michael.bodman@forces.gc.ca.
[3] Senior Environmental Specialist, Environmental Services, Contaminated Sites, Vancouver Island Group, Public Services and Procurement Canada, 401-1230 Government Street, Victoria, British Columbia V8W 3X4, Canada, T: 250-418-5731, Email: Robert.thomas2@pwgsc-tpsgc.gc.ca.
[4] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.
[5] Principal Engineer. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2721, Email: dormerod@anchorqea.com.
[6] Principle Engineer, Anchor QEA, Inc., 1201 3rd Avenue, Suite 2600, Seattle, WA, USA, T: 206-903-3327, Email: mwoltman@anchorqea.com
[7] Managing Scientist, Anchor QEA, Inc., 12596 W. Bayaud Avenue, Suite 201, Lakewood, CO, USA, T: 303-984-6250, Email: mcarey@anchorqea.com
[8] Senior Scientist, Anchor QEA, Inc., 20 Bellwether Way, Suite 201, Bellingham, WA, USA, T: 360-733-4311, Email: nseyster@anchorqea.com

remediation performance monitoring plans were also designed to account for shallow bedrock during sampling. One project area additionally included bedrock blasting to support construction of a new jetty within a remedial action area, which required additional shallow bedrock considerations and adaptive management throughout the project phases to ensure remedial action objectives would be met.

Lessons learned from the completed remediation sites are discussed, including how accurate field measurements and predicted dredge volumes were compared to observations during construction, ways to mitigate uncertainty regarding bedrock elevation, strategies for managing residuals, and considerations when monitoring remedy effectiveness. Additionally, lessons learned from conducting bedrock blasting within a remedial area are briefly discussed.

Keywords: Dredging, bedrock, capping, delineation, adaptive management

INTRODUCTION

Esquimalt Harbour is located within the traditional territories of the Esquimalt Nation and Songhees Nation, whose members trace their ancestry to the Coast Salish lək'wəŋən (Lekwungen) people. The Lekwungen people have occupied southern Vancouver Island for thousands of years (Kennedy 2006) and harvested fish (particularly salmon and herring), shellfish, marine plants, waterfowl, marine mammals, deer, camas, berries, and other resources from the harbour and surrounding areas in their traditional territory (Esquimalt Nation 2014; Victoria Harbour History Project 2017). Urban and industrial development of the harbour began in the 1850s, and in 1855, the Royal Canadian Navy (RCN) established Esquimalt Harbour as a military installation. It has been classified as an active, working harbour for over 150 years, which has led to widespread contamination along the harbour's shoreline and throughout the sediments in the harbour.

Esquimalt Harbour is governed by the Canada Marine Act and Transport Canada's Natural and Man-Made Harbour Navigation and Use Regulations, which are administered by DND. Environment and Climate Change Canada (ECCC), Fisheries and Oceans Canada (DFO), and Health Canada have confirmed that Esquimalt Harbour is a Class 1 Contaminated Site (High Priority for Action), as per the DFO Aquatic Site Classification System. This Class 1 designation acknowledges that there are more than 25 known chemicals of potential concern in Esquimalt Harbour sediment, all of which exceed the Canadian Environmental Quality Guidelines for sediment. Collectively, the overall sediment remediation approach is managed under a Federal Contaminated Sites Action Plan (FCSAP)-eligible program.

The Government of Canada and the Department of National Defence (DND) have been working for over 30 years to address this contamination and improve the marine habitat as federal custodians of the harbour and on behalf of the Esquimalt Nation and Songhees Nation. As of May 2026, the remediation of 15 hot spots has been completed (Figure 1). Work on the planning and design for an additional five recently identified hot spot remediation projects is currently ongoing. Of those 15 hot spot remediations, 11 involved areas of shallow bedrock that impacted the planning, design, and implementation of the remediation. The existence of shallow bedrock in remedial areas impacts all phases of a project including site investigation, design, implementation of the remedy, and post-remediation monitoring requiring thoughtful consideration to reduce project uncertainties and achieve remedial goals. This paper discusses the unique challenges in site investigation, remedial design, remedy implementation, and monitoring associated with areas of shallow bedrock encountered in Esquimalt Harbour.

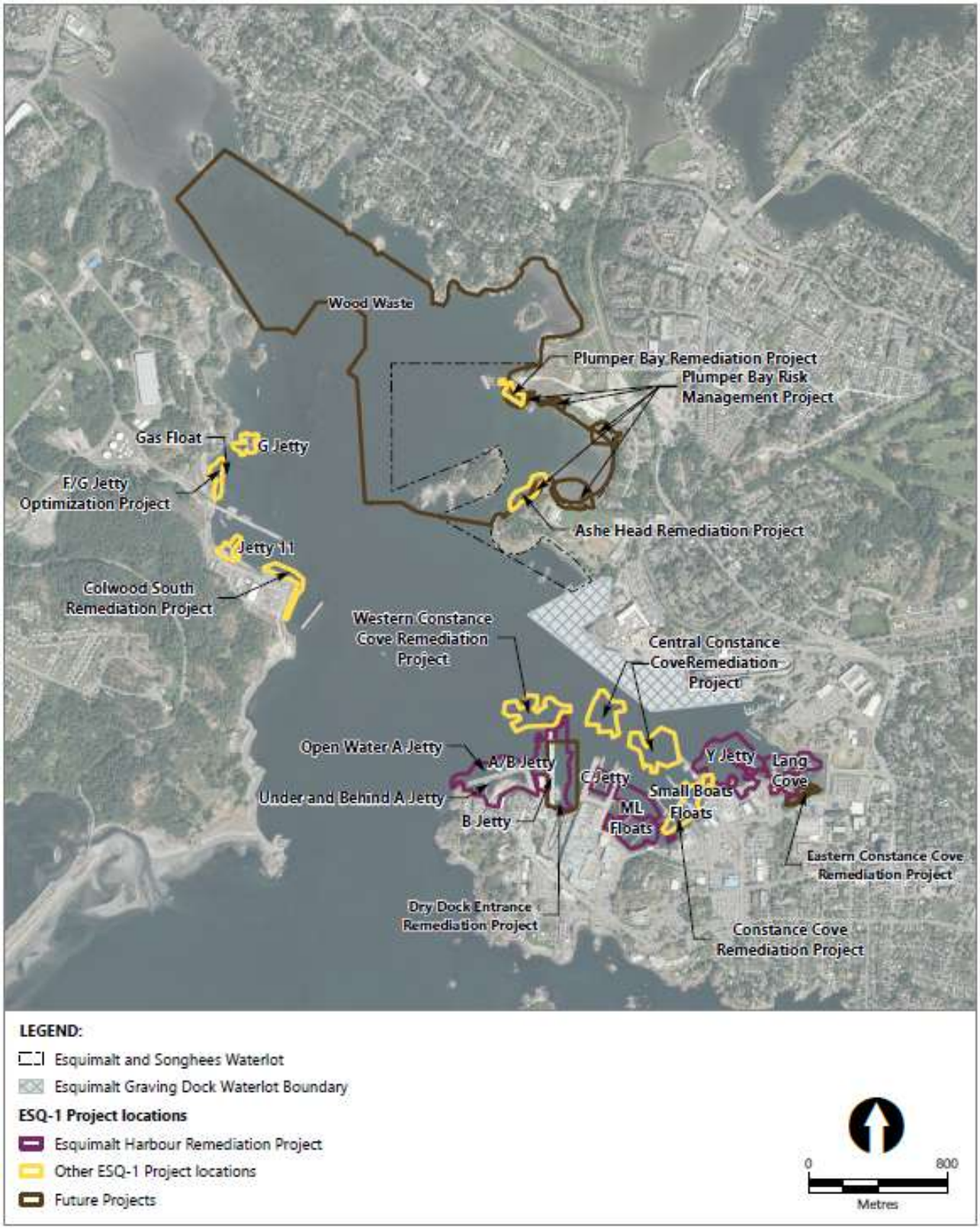

Figure 1. Esquimalt Harbour Sediment Remediation Projects

Harbour Background

Esquimalt Harbour is a relatively shallow, sheltered embayment adjacent to the Strait of Juan de Fuca. Hydrodynamically, under most conditions, the harbour behaves as a tidal estuary, with flows and currents driven by tidal exchange with the Strait of Juan de Fuca. Hydrodynamics (e.g., flows, water levels, and currents) in the harbour are tidally dominated, and there is minimal freshwater input. The sediment surface is generally flat with water depths ranging from -11 to -12 metres (m) below Chart Datum.

Esquimalt Harbour is net depositional, with net sedimentation rates ranging from 0.9 to 1.1 centimetres (cm) per year. Generally, the sediment stratigraphy in Esquimalt Harbour is variable due to natural depositional and erosional conditions, historical dredging or harbour filling activities, historical and current site uses, and a heterogeneous underlying bedrock surface. Bedrock is typically present at irregular shallow depths throughout the harbour, and in some cases, it occurs as outcroppings (islands), which is evident in the frequent exposed bedrock in the upper intertidal areas around the harbour and along varying portions of the harbour shorelines.

KEY CHALLENGES WORKING NEAR SHALLOW BEDROCK

Site Investigations

Within each remedial area, various investigation methods were implemented to determine the nature and extent of contamination and identify site features that would impact design and construction including the presence and extent of shallow bedrock. A variety of methods were used to support determination of bedrock extents within the sediment remedial areas. These included jet probing surveys to determine the extents of soft sediment over underlying refusal surfaces, interpreting results from sediment coring, and using visual clues and similar lines of evidence, such as mapping bedrock outcrops to gain a more complete indication of where bedrock could be encountered during dredging or excavation.

Jet probe surveys were the primary field investigation used to indicate the presence of a refusal surface (e.g. bedrock) underlying portions of the remedial area. The refusal surface for the purposes of sediment remediation was defined as a denser substrate, such as bedrock, riprap, glacial till, or clay material, underlying softer surficial sediment. The refusal surface is relevant for sediment remediation as below that it can be difficult to dredge or excavate into that material due to the hardness of the substrate and is also assumed to be uncontaminated, as typical contaminants of concern in the harbour are primarily associated with soft sediment. Jet probing consists of advancing a probe through the sediment until refusal is met. The probe also includes a water jet within the tip to facilitate penetrating denser sediment layers once initial refusal is encountered (photograph 1). Probing is typically completed along transects to determine the depth to refusal in pre-determined areas where bedrock may be anticipated based on visual observations of outcrops and shoreline bedrock (photograph 2). The results of the jet probing provide information on the depth of the refusal surface below the mudline, as documented by the dive team, that can then be translated into elevations based on available bathymetry.

Photographs 1 and 2: Jet probing in shallow water. Establishing a nearshore jet probe transect.

Sediment cores are an integral part of determining the vertical extent of sediment contamination and also provide a secondary source of information used to further refine the anticipated extents of bedrock and refusal surface within sediment remediation areas. Generally, this is completed though the interpretation of refusal depths from coring, and notes collected during the field effort regarding the refusal surface. Experienced contractors and field staff can infer subsurface characteristics through the sound of the vibracore at refusal, the type of "bounce" and the material in the bottom of the core, or lack of it. Similar to jet probing this provides a thickness of expected sediment in a location. As this method is more expensive and time consuming relative to jet probing, it is a secondary tool used to provide additional spatial distribution of data points when determining a bedrock surface.

Other methods of data collection included low tide visual observations, bank sediment sampling, and T-probe surveys. These visual and low tide surveys allow data collection in areas which may be inaccessible by boat or can provide better resolution of shallow features in intertidal areas with softer surficial sediment. Site features can be described in detail or mapped using a handheld GPS device. These methods were key in the Eastern Constance Cove Remediation Project design due to shallow water depths within Lang Cove (Photograph 3). Diver based jet probe surveys had been conducted during high tides, but visual observations and T-probe surveys at low tide were used as jet probe surveys were inconclusive and provided some false readings of the refusal surface. Subbottom profiling was also attempted in several projects but did not produce accurate depth-to-bedrock measurements due to interferences from cobble and other angular backfill materials, rendering the results inconclusive.

Photograph 3. Eastern Constance Cove at low tide, note T-probe in middle of photograph and bedrock outcrop in foreground and on right side of photograph

The refusal surface notes from jet probe surveys and sediment core collection are modelled in Computer Aided Design (CAD) softward where the information is interpolated to develop a continuous surface between data points. This interpolated surface can then be compared with intended dredging surfaces based on chemistry results, design parameters, or operational needs to inform design and provide context for expected dredging volumes and whether bedrock would expect to be encountered during dredging. For example, bedrock was found to be present within the footprint of a berthing area where dredging was planned to allow for berthing of deeper draught vessels (Figure 2). Based on this analysis, the requirement to conduct bedrock blasting was included in the project to facilitate reaching required berthing water depths.

With all of the site investigation methods, including coring and jet probing, there is always uncertainty about what is causing the actual refusal. For example, refusal could be occurring on a buried rock instead of bedrock. Additionally, bedrock, particularly on lower Vancouver Island, is known to have significant and dramatic undulations and outcrops that make it difficult to adequately map using a limited number of data points, as the irregularities in the surface would require more data than is feasible to collect. These uncertainties limit the ultimate utility of the interpolated surface created from site investigations, however these methods for in-water and nearshore bedrock delineation do provide valuable information regarding the expected presence/absence of bedrock and are indicative of depths that it can be expected during subsequent dredging.

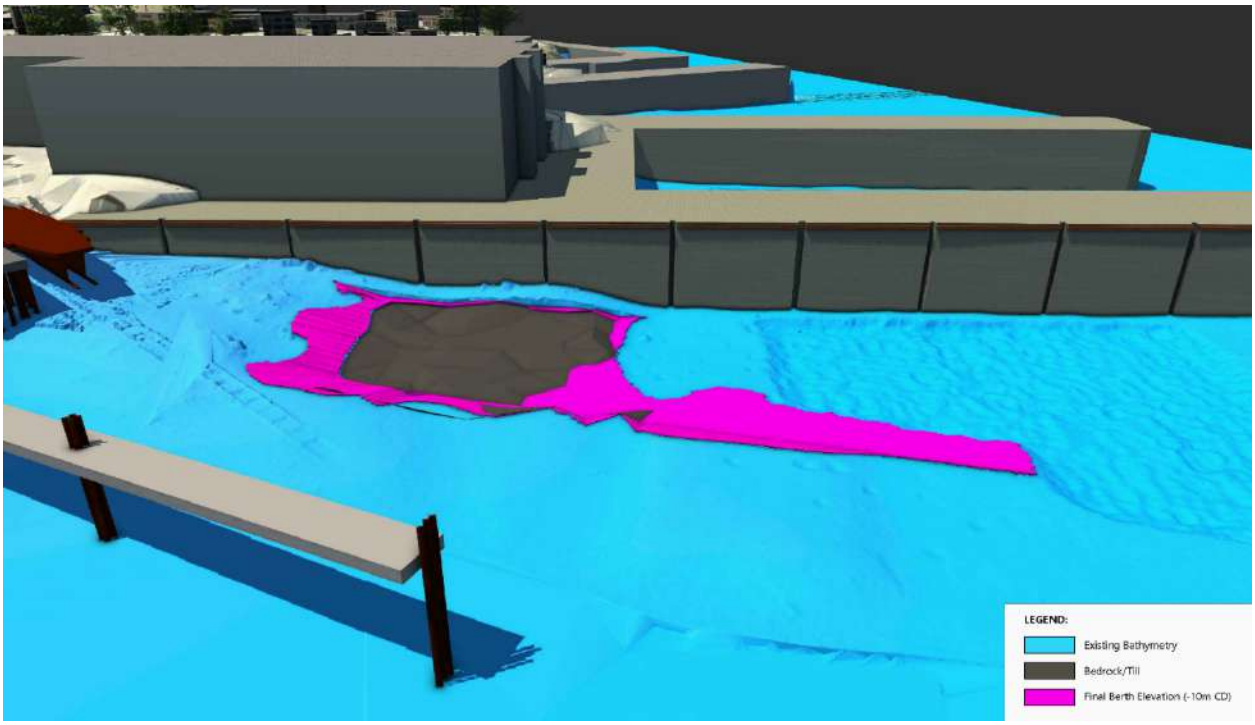

Figure 2. Simulated bedrock surface compared with a required berth dredging area

Remedial Design

The presence of shallow bedrock within sediment removal areas inevitably results in greater uncertainty regarding the actual dredge depth that can be achieved and will lead to greater residuals, both generated and missed inventory, which requires planning to address through pre-determined management methods to the extent practical. To account for these considerations, several strategies were implemented during design of Esquimalt Harbour sediment remediation projects:

- Planning for multiple dredge passes during initial dredging and including provisions for contingency re-dredging based on confirmatory sampling
- Allowing the contractor to use various equipment in intertidal areas, such excavators at low tide, and requiring use of as vacuum trucks on intertidal bedrock to address residuals, as long as water quality criteria and permit requirements were met
- Clear communication protocols and oversight when a refusal surface (i.e., bedrock, hard clay) was expected to incorporate verification by owner's representatives of refusal above design grades and to document bedrock locations on surveys for tracking purposes
- Additional consideration for estimating dredge volumes to more-accurately reflect expected removal outcomes instead of simply increasing the payable removal allowance to incentivize the contractor to remove material below the required depth. This was completed to decrease the likelihood of claims associated with a bid volume variance.
- Planning for potential active change management based on site conditions once dredging or excavation was underway

Residuals is one of the bigger challenges associated with the presence of bedrock given the difficulty of complete removal of contaminated sediment overlying a varying hard bedrock surface. A dredge bucket isn't capable of removing all sediment in cracks, fissures, and undulations. To support removal in these

challenging conditions, multiple dredge passes are often required over bedrock and generally built into design specifications. This includes initially requiring that the contractor demonstrate that sediment overlying bedrock has been thoroughly and methodically removed. This can be accomplished using a combination of oversight observations and dredging bucket maps to demonstrate full overlapping coverage in bedrock areas. Even then, this is often not sufficient to fully remove sediment. To support this, additional contingency re-dredging may be required based on confirmation sampling conducted by owner's representatives. These requirements must be built into contract documents so that contractors understand what will be required and are fairly compensated for the effort and uncertainty. Additional measures that have been employed are the use of excavators in intertidal areas, as these are expected to facilitate more-complete removal of sediment in hard-to-reach areas within bedrock surfaces. Also, in some instances, the additional requirement for the contractor to employ use of a vacuum truck or similar after all other excavation methods have been completed in intertidal areas in the dry is a final measure that can be used to facilitate the maximum removal of contaminated sediments to the extent possible.

A key lesson learned from implementing sediment removal projects in areas of bedrock is that during design planning and conferring with the owner and contracting authority (if different) is required regarding the dredging quantity provided to the contractor on the unit price table. Most contracts have clauses built into master specifications regarding a variation of the estimated quantity, allowing the contractor to renegotiate unit rates for work if the actual quantity during the work exceeds a certain percentage difference from expected quantities provided on the bid unit price table. For Esquimalt Harbour work, this percentage is +/-15% from the unit price table. In areas of bedrock this is complicated by uncertainty in how much bedrock may be encountered and at what elevations during dredging, limiting the potential for full removal to design grades with overdredge allowances and reducing expected volumes. As part of each project, available information gathered during site investigations was used in conjunction with best engineering judgement to inform an expected dredging volume. This expected volume was discussed with the project owner to coordinate a strategy for unit price volumes, as the owner ultimately takes on risks associated with a change in project costs.

Projects that also include planned bedrock blasting for operational requirements, pose their own set of unique challenges, due to the potential for blasting to suspend and redistribute remaining residuals. As part of the B Jetty project, the extent of redistribution was modeled in advance to inform design efforts and expected impacts. The design then included a second contingency re-dredge pass before blasting in an effort to reduce residuals further. A subsequent project introduced additional design sequencing requirements separating surficial environmental dredging with an additional contingency re-dredging pass, from subsequent underlying geotechnical dredging down to bedrock in preparation for bedrock blasting. It is intended that the multiple dredging passes will further reduce contaminated residuals prior to blasting to reduce the potential for redistribution. This same project has also included another round of contingency re-dredging over an expanded footprint built into the design after bedrock blasting and rock removal is complete to further mitigate the potential for redistribution of contaminated residuals after blasting. Then, after all of these dredging steps have been completed in full, residual management cover (RMC) will be placed over the full expanded footprint. The additional depth to accommodate the RMC placement was built into dredging and blasting depths so that ultimate berthing depth requirements can still be met.

Finally, regardless of the planning measures implemented, active change management measures may always be required to facilitate completion of a project and ultimately meet remedial objectives. This can range from redesigning removal depths and extents during construction, redesigning engineered cap locations, refining removal requirements, or implementing additional residuals management strategies

during the course of construction. To accomplish this, a design team must remain engaged and flexible during construction to support adaptations to achieve remedial objectives. Similarly, contracts and specification language should be prescriptive enough to ensure that work is completed as required but flexible enough to allow the contractor to choose appropriate means and methods. Contract documents must also provide sufficient information regarding the potential for the presence of bedrock so that a contractor is not able to file change of condition claims.

Implementation and Associated Challenges

As noted, variable conditions should be expected during remediation implementation in shallow bedrock areas. The contractor may elect to use different equipment to access a shallow bedrock area. Various solutions can be implemented to address the construction challenges posed by bedrock within dredging areas. Equipment choices have varied in Esquimalt Harbour sediment remediation projects, including the use of excavators in the intertidal areas, both on temporary mats (Photograph 4) and along constructed intertidal roads built of sacrificial material (e.g. road material requires disposal at a landfill). Other contractors have elected to employ shallow draft barges and sequence work so that it is only completed during higher portions of the tide cycle (Photograph 5). Both of these approaches limit the available work window during which removal can be completed and area influenced by seasonal tidal variations so that work may be completed during daylight hours versus night work. Through the variety of methods, it has been observed that more complete removal of contaminated sediment over bedrock can be conducted with excavators, as opposed to dredging equipment, due to the precision with which excavation can be completed in the dry versus a dredge bucket operating through the water column.

Photograph 4. Excavator in the intertidal area at the Lang Cove Site

Photograph 5. Dredging near exposed bedrock at F/G Jetty Site

As noted the presence of residuals, both generated residuals and missed inventory, in bedrock areas is a major challenge for projects with shallow bedrock. This can be mitigated during construction by close observation and coordination with the contractor to ensure methodical removal over bedrock areas, ensuring overlapping dredge bucket bites are conducted. Typically, however, the cracks, crevasses, and protrusions within bedrock make getting all contaminated material removed from a bedrock surface very difficult. One project used a vacuum truck operated from nearby shoreline areas after excavation was completed to try to remove additional generated residuals before tidal inundation of the bedrock areas. This achieved modest success but was limited by the capacity of the vacuum trucks and the proximity of the bedrock to accessible shoreline areas. All Esquimalt Harbour projects have placed a sand cover after dredging to mitigate for generated residuals, including in bedrock outcrop areas, unless engineered caps were warranted for other project-specific objectives. To access difficult locations, more than one contractor has elected to use a telebelt to place RMC materials where standard marine or land-based equipment could not gain access.

Active change management during the course of implementation is a key method for addressing construction challenges in areas of bedrock. Project design may need to be revised based on field conditions once dredging or excavation encounter bedrock, particularly in unexpected locations. For example, engineered cap layers may not fit within a given dredge unit as designed if the dredge cut is shallower during construction because of bedrock in the area. Adjusting and refining cap materials and layer thicknesses can be useful to address this complication, as well as reviewing the changes in the context of the project remedial objectives. For example, engineered caps may no longer be warranted in areas where shallow bedrock is encountered and changing to a residual management cover and surficial habitat/beach material may be better suited to meet project goals. During the Lang Cove project the contractor encountered bedrock in a beach area that was intended to be capped. The backfill types were adapted and backfill was placed to restore pre-construction grades instead of the originally intended engineered cap as removal over the bedrock in this intertidal area with an excavator was sufficient to meet remedial objectives. In another project the opposite happened in that the presence of residuals upon bedrock was too significant to meet remedial objectives, so an engineered cap in combination with placement of a concrete slab for structural reasons were implemented during construction in an under-dock area outside of berthing areas to mitigate the additional residuals. In adjacent berth areas, an amendment was added to the RMC to address

residuals with higher PAHs. In a separate project in an open water area, an unknown outcrop of bedrock was encountered under surficial sediment during dredging where no other indications of bedrock had previously been observed. This led to dredging volumes trending below the 15% variation in quantity from the unit price table volume which had implications for claims. In this instance, the dredging footprint was expanded laterally to an adjacent area that also had known sediment contamination and the volume from that area made up the difference in volume towards the unit price volume. This did require last-minute permit modifications to adapt to a slightly expanded footprint. This lesson learned was incorporated into future project planning efforts by expanding project footprints for permitting purposes to encompass the maximum potential footprint that could be completed. In most cases, planning and design can mitigate for the presence of bedrock in shallow areas, but being able to conduct active change management during the course of the work can support achieving remedial objectives when changes are encountered.

CONCLUSIONS

Through the work conducted to date within Esquimalt Harbour, a number of lessons have been learned through completing dredging projects within areas of shallow bedrock. Key lessons learned for remedial implementation include:

- Characterizing the potential for the presence of bedrock through conducting jet probing, shoreline surveys at low tide, and interpreting refusal encountered during core sampling can provide information regarding the presence and absence of bedrock for planning and design purposes
- Extra consideration should be given to estimating dredge volumes during design and coordinated with the site owner
- Additional residuals, both generated and missed inventory, should be expected in areas of dredging or excavation over bedrock
- When possible, it can be helpful to plan for multiple dredge passes in areas with significant bedrock, particularly if bedrock blasting is planned as part of subsequent project activities
- Allow the contractor flexibility in what equipment can be used to complete work can lead to innovation
- Employing full-time construction monitors on site and establishing clear communication pathways with the contractor can help verify the presence of bedrock during construction and supports documentation as well as facilitating change management
- Active change management should be planned for as part of implementation with design engineers available to support adjusting project elements to meet remedial objectives

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OPTIMIZED SEDIMENT CORING AND STRATIGRAPHIC LOGGING TO AVOID LOGISTICAL PITFALLS FOR DREDGING IN INDUSTRIALIZED ENVIRONMENTS

M. Ciarlo[1], J. Beaver[2], S. Goetz[3], C. Kiehl-Simpson[4] and M. Bowman[5]

ABSTRACT

Planning and design of remedial dredging projects relies heavily on sediment coring to characterize subsurface conditions. However, using sediment cores to characterize the subsurface faces numerous challenges in industrialized environments, including buried debris, disjointed sediment layers, scattered chemical impacts, and the legacy of past physical disturbance. Thus, coring often encounters refusal, variable recoveries, distorted stratigraphy, and obstacles from debris. This drives potential data gaps and uncertainties in design which may affect overall remedy effectiveness. This study seeks to develop a framework for systematically assessing and cataloguing practical information gained from sediment coring in industrialized settings and to apply this framework to several case studies. Sediment coring information was collected for each case study that included characteristics of the waterbody and its sediments; coring technologies; challenges to penetration and recovery associated with industrialized settings; relevance of these challenges to key vertical profile data quality; logistical factors affecting coring effectiveness; and adaptive measures used to overcome challenges. Coring effectiveness data were then reviewed to identify trends for industrial factors driving poor penetration and recovery or inconsistent capture of stratigraphy due to debris, impacted sediment, or industrial setting. They were also reviewed for how these impacts to sediment characterization may affect data quality as it relates to goal setting, planning/design, construction implementation, and dredging effectiveness. The study concludes that the method developed for compiling and standardizing sediment coring field experience proved easy to implement and effectively captured useful information. Evaluation of case studies found that challenges common to sediment coring in industrialized settings include human-made obstacles, the frequency and type of debris, complexity of depositional history reflected in stratigraphy, and presence of low-density surficial sediments. Effective adaptive measures include the deployment of more than one coring technology; thorough field identification of the sediment-water interface; collection and comparison of multiple replicate cores; and careful recording of penetration, recovery, and the challenges encountered. The study recommends applying the framework to evaluate additional case studies and incorporating successful adaptive measures for field application at other sites.

Keywords: Vibracoring, stratigraphy, debris, penetration, recovery.

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[1] Chief Scientist, EA Engineering, Science, Technology, Inc., PBC, 225 Schilling Circle, Suite 400, Hunt Valley, MD 21031, USA, T: 410-584-7000, Email: mciarlo@eaest.com.
[2] Senior Engineer, EA Engineering, Science, Technology, Inc., PBC, 5918 Meridian Boulevard, Suite 4, Brighton, MI 48116, USA, T: 410-584-7000, Email: jbeaver@eaest.com.
[3] Senior Geologist,EA Engineering, Science, Technology, Inc., PBC, 5918 Meridian Boulevard, Suite 4, Brighton, MI 48116, USA, T: 410-584-7000, Email: sgoetz@eaest.com.
[4] Senior Engineer, EA Engineering, Science, Technology, Inc., PBC, 5918 Meridian Boulevard, Suite 4, Brighton, MI 48116, USA, T: 410-584-7000, Email: ckiehlsimpson@eaest.com.
[5] Lead Construction Quality Engineer, EA Engineering, Science, Technology, Inc., PBC, 225 Schilling Circle, Suite 400, Hunt Valley, MD 21031, USA, T: 410-584-7000, Email: mbowman@eaest.com.

INTRODUCTION

Design of remediation dredging projects is dependent on the quality of subsurface characterization data, typically from sediment coring and sampling. Such data are typically used to define the vertical and horizontal extent of material requiring remediation based on chemistry, stratigraphy, and physical characteristics (Palermo et al. 2008). The data may also be used to determine how material will be removed, handled, treated, and placed. Therefore, the quality of subsurface sediment data influences many aspects of remedial design and construction, which may have significant impacts on dredging effectiveness, efficiency, protectiveness, and cost.

The need for high quality data stands in contrast to the logistical challenges associated with sediment characterization in industrialized environments. These environments often contain buried debris, scattered sources of impacts, repeatedly disturbed sediment beds, disjointed stratigraphy, obstacles to vessel access, and sediments of unusual consistency that complicate sampling and recovery/retention. Guidance from the U.S. Environmental Protection Agency (EPA), ASTM International (ASTM), academic texts, and individual states identifies suitable methods for collecting vertical cores of the sediment profile and provides helpful information for selecting the size and type of sampling technology based on type of waterbody, target depth of characterization, sediment type, and purpose of sampling (ASTM 1997, EPA 2001, International Atomic Energy Agency [IAEA] 2003, Murdoch 1994). However, industrialized settings provide challenges that are difficult to capture in generalized guidance, often requiring the use of multiple sampling methods, method modifications, and nuanced techniques to collect sediment profiles and samples that meet typical data quality objectives for remediation.

This study seeks to develop a framework for systematically assessing and cataloguing data regarding the practical application of coring technology gained from field investigations in industrialized settings and to apply this methodology to several case studies. This information is commonly held anecdotally and incidentally documented in field logs by environmental scientists, geologists, and drillers who have performed field data collection; however, it is rarely collected as an independent data set, as it is secondary to the goal of characterizing sediment. Recent studies have attempted to capture this data using new technologies during field investigation (i.e., Dreher et al. 2022). The specific purpose of this study is to develop a framework for collecting information regarding coring technology implementation from completed field efforts as it relates to accurately and completely capturing the sediment vertical profile, thereby, allowing representative sampling and stratigraphic logging of distinct vertical zones for recovered sediment. To achieve this, this study has the following objectives:

- Review the value of accurate, complete, and representative vertical profile capture and the specific coring variables (i.e., penetration, recovery, compaction, distortion, surface disturbance, expansion) affecting vertical profile data quality.
- Evaluate case studies based on site setting, coring technologies utilized, specific challenges of industrialized settings that affected coring success, and identify how challenges were overcome.
- Summarize findings to provide conclusions and recommendations for future study.

REVIEW OF FACTORS AFFECTING SEDIMENT VERTICAL PROFILE DATA QUALITY

Design of remediation via dredging relies on vertical profile data for subsurface sediments (Palermo et al. 2008). Typically, these data are captured through stratigraphic logs incorporating chemical and physical analyses of samples from distinct vertical intervals (EPA 2001). Stratigraphic logs are used to distinguish between deeper native sediments and more recently deposited sediments, as well as to document any visual

evidence of anthropogenic inputs, while sample results are used to produce spatial models of chemical concentrations based on exceedance of remedial goals (Murdoch and MacKnight 1994). Both are typically used to define dredge prisms and inform material handling and disposal decisions of the resulting dredge volume. Therefore, vertical profile accuracy, precision, representativeness, relevance, and completeness are key for dredging success. The following sections identify factors that are important for evaluating coring case studies, including: a review of the typical goals for vertical profile data quality; a discussion of key variables dictating coring effectiveness; and the major differentiators of coring technologies.

Typical Data Quality Goals for Sediment Coring

Vertical accuracy and precision goals for profile data are typically purpose fit, ranging from less than 1/8th inch to several inches (Job et al. 2021, Murdoch and MacKnight 1994). Vertical resolution of sample collection must account for the minimum volume required for analysis, as sampling smaller intervals may require combining material across multiple cores. Sampling near the sediment surface is typically higher resolution [i.e., the top 3 or 6 inches (9 cm to 18 cm) to provide the most relevance for biological exposure assessment (EPA 2015). Deeper sampling interval lengths are often 0.5 feet (ft), 1 ft, or 2 ft [0.15 meters (m), 0.30 m, or 0.60 m] each or more depending on the stratigraphy and goals of sampling (i.e., EPA 2001, Hawai'i Department of Health 2024). Dredging precision plays a role, for example, environmental dredging can achieve tolerances of several tenths of a foot (Nielsen et al. 2018, Palermo et al. 2008), although dredging in lifts typically targets a minimum of 0.5 ft or 1 ft (0.15 m or 0.30 m) as practical limitations. Consequently, standard dredge tolerances require precision of +0.5 ft ($\pm$ 0.15 m). Vertical data required for design of dredge prisms includes not only accurate thickness and relative depth of sediment layers but also accurate elevation, making accurate and precise bathymetry and geolocation data collection essential.

Recovering a continuous and undisturbed core provides the most relevant, representative, and complete profile of subsurface bedded sediments. This is due to gaps in the core, mixing of stratigraphic layers, and smearing or compression of layers all affect the ability to accurately vertically characterize chemicals of concern. A comparison of the length of the core recovered against the penetration depth is typically used as an indicator of representativeness and completeness, with recovery affected by many variables discussed below (ATSM 2019a). In practice, recovery of greater than 60% to 80% is common (Lamb et al. 2022).

Key Variables that Dictate Quality of Coring Data

A review of several standards and peer-reviewed sources regarding sediment coring identifies specific variables to consider when coring (i.e., ASTM 2019a; Blomqvist 1985, 1991; Weaver and Schultheiss 1983; Lamb et al. 2022). These variables are summarized in Table 1 together with common challenges and their effect on data quality. Review of these challenges indicate that target depth of coring, sediment grain size and consistency, water depth, presence of debris or obstacles, technology type, and access limitations all influence coring data quality.

Key Differentiators of Coring Technologies

Many guidance documents and studies have reviewed and evaluated vertical core capture technologies, including ASTM standards, EPA guidance, peer-reviewed articles, and other guidance documents (i.e., ASTM 2019a; Blomqvist 1985, 1991; IEAE 2003; Ohio EPA 2012; EPA 2001, etc.); this guidance emphasizes that technologies should be selected based on data quality objectives, and provide considerations for use. Technologies can be categorized using broad categories that relate to the variables in Table 1 as follows:

- **Piston core versus open barrel:** A piston corer uses an internal piston to minimize friction and sediment compaction, thereby preserving stratigraphic integrity, but typically requires deployment using drilling rods. Open-barrel corers lack a piston and are easier to deploy but may be susceptible to core shortening, disturbance, and loss of surficial sediments (ASTM 2019a; Blomqvist 1985).

Table 1. Variables affecting core vertical profile data quality.

Definition	Common Challenges	Effect on Data Quality
Penetration Depth Ability of the core barrel to advance to the target depth.[a]	Downward progress stopped (refusal) due to hard substrates, debris, or high friction.	Incomplete penetration results in missing deeper intervals, limiting stratigraphic completeness.
Recovery Length The measured length of sediment recovered in the core barrel.[a]	Summed effect of compaction, expansion, loss, bypass/exclusion, re-penetration, positioning.	Mismatch between penetration and recovery affects accuracy and representativeness of depth data.
Core Compaction Increase in sediment density caused by friction or vibration.[a]	Layer thickness reduced by internal barrel friction and vibration that expel water, especially in sand or silt.	Layer thicknesses are differentially reduced, affecting accuracy and representativeness of depth data.
Flow-In Distortion Stretching or mixing of sediment layers during entry into the barrel.[a]	Disruption due to barrel friction, differential compaction, debris blockage.	Stratigraphic boundaries become obscured, reducing representativeness of stratigraphic interpretation.
Expansion Increase in sediment volume after removal from in situ confinement or due to vibration.[b]	Expansion of tightly packed sediments due to vibration, removal from sediment bed, mixing with overlying water.	Over-recovery misrepresents stratigraphy.
Surface Disturbance Disruption or loss of sediment at the sediment-water interface during initial barrel contact.[a]	Barrel impact shifting sediment or punching through soft material without capture.	Loss or mixing causes incomplete data for surface layers.
Re-penetration Repeat capture of the same sediment interval.[a]	Duplicate capture due to partial withdrawal of barrel or slough within casings.	Duplication misrepresents stratigraphy, adds depth inaccuracies.
Deficient Entry/Exclusion Failure of sediment to enter the core barrel despite penetration.[a]	Debris, coarse grain size, mud wave pressure, or high-friction material blocking the barrel opening.	Produces missing intervals, causing incomplete stratigraphic continuity and depth assignment inaccuracy.
Loss Sediment falling from the bottom or pushed from the top of the barrel.[c]	Open-barrel designs, very soft surface sediment, or over-penetration.	Loss creates incomplete stratigraphy and inaccuracies in assigning stratigraphic thickness/depth.
Deployment Vertical Accuracy Accuracy geolocating sediment surface and maintaining vertical core alignment.[d]	Low density surface sediments (i.e., nepheloid layer), slopes, currents, waves, and cable sag may cause tilt or false start.	Tilt, movement, and sediment interface errors reduce accuracy of strata thickness data.
Retrieval and Sampling Methods used to extract, store, expose, and sample the recovered core.[a]	Need for extrusion, immediate handling, or liner removal; limited working time or space.	Improper handling can disturb structure and make stratigraphy non-representative or inaccurate.
Deployment Logistics Operational constraints on equipment, vessel, and access.[d]	Tradeoffs between penetration capability and portability; vessel size and stability limits.	Logistical constraints indirectly limit data quality by limiting coring technology.

Definitions adapted from the following sources:
[a] ASTM 2019a.
[b] Evans 2016; Weaver and Schultheiss 1983.
[c] Blomqvist 1985, 1991.
[d] ASTM 2019a, IEAE 2003, Ohio EPA 2012, EPA 2001.
Challenges and effects summaries are based on these sources and generalized information from the following case studies:

- **Barrel width and geometry:** Barrel width influences penetration resistance and sample volume, with larger diameters requiring greater force but yielding more material, whereas barrel geometry (including length, wall thickness, and nose shape) affects penetration efficiency, rigidity, and the degree of sediment disturbance. Barrel diameter and length also dictate frictional forces inside the core (ASTM 2019a; Mudroch and MacKnight 1994).
- **Direct-push versus vibrational coring:** Direct-push coring advances the barrel using static force or hammer blows for controlled penetration in cohesive sediments. Vibrational coring applies to high-frequency vibration to reduce friction and enable penetration in dense or coarse sediments, often with increased disturbance (ASTM 2019a; Palermo et al. 2008). Vibrational coring can be divided into vibracoring frequencies ranging from 1,500 to 3,000 vibrations per minute/25 to 50 Hertz (Ocean Instruments 2026) and sonic coring at frequencies of approximately 3,000 to 9,000 vibrations per minute/50 to 150 Hertz (Royal Eijkelkamp 2026; ASTM 2024).
- **Continuous versus drilled interval coring:** Continuous coring retrieves an uninterrupted sediment column that preserves vertical stratigraphy, whereas drilled interval coring collects discrete core sections from selected depths with unsampled gaps between augured intervals (ASTM 2019a, 2019b). Use of drilled intervals is typically reserved for deeper coring due to the friction associated with extended core barrel length versus diameter ratio.
- **Cable/rope versus rod/pole-deployed coring:** Cable- or rope-deployed coring suspends the core system from a flexible line and is suitable for deeper water but offers limited penetration and verticality control, whereas rod- or pole-deployed coring uses rigid connections to provide precise control over depth, alignment, and penetration (IAEA 2003; ASTM 2019a).
- **Lined versus unlined coring:** Lined coring captures sediment within an internal liner to preserve structure, reduce contamination risk, and facilitate transport subsampling. Unlined coring creates direct contact between sediment and barrel, increasing friction, potential contamination, and handling disturbance and requiring immediate processing (ASTM 2019a; Blomqvist 1991).
- **Vertical capture versus horizontal capture equipment:** Vertical capture equipment collects sediment while preserving true depositional order and stratigraphy; most coring and grab systems are vertical capture. Horizontal capture equipment samples sediment laterally to reduce the influence of down-pressure; such devices include Russian peat borers and freeze corers used for undisturbed surficial sampling (ASTM 2019a; Glew et al. 2001).

METHODOLOGY FOR CASE STUDY EVALUATION

Based on the reviews above, information was collected for each case studies that included the following:

- **Project Site Information:** Waterbody and location, water depth, sediment grain size, and character.
- **Coring Technology:** Description of coring technology with specific attention to piston core versus open barrel, barrel width and geometry, direct-push versus vibrational coring, continuous versus

drilled interval coring, cable/rope versus rod/pole deployed coring, lined versus unlined coring, vertical capture versus horizontal capture equipment, and vessel/access type.
- **Challenges Encountered:** Description of challenges encountered, including their cause, impact on coring, and effect on data quality.
- **Adaptive Measures:** Description of alternative and modified technologies to overcome challenges.

Over 25 projects from 10 different sediment remediation sites in the Great Lakes and mid-Atlantic were considered as potential case studies. The following three project sites were selected as the most complex examples of coring in industrialized environments: Manistique River, Lower Rouge River, and Grand Calumet River. Evaluation of coring experience is presented separately for each of these case studies in Table 2, 3 and 4 in the following sections.

MANISTIQUE RIVER CASE STUDY RESULTS

The Manistique River is located in the upper peninsula of Michigan on the north shore of Lake Michigan. Historically, sediments received inputs of polychlorinated biphenyl from paper recycling and manufacture (EA 2013a); this led to remediations performed by EPA in 2000 and National Oceanic and Atmospheric Administration (NOAA) in 2019 (EPA 2026). Sediment stratigraphy at the site was complex and included layers of limestone bedrock, sawdust, sand, gravel from a past capping remedy, plank wood, and high moisture floc (EA 2013a). Previous characterization and remediation efforts in the 1990s encountered challenges due to woody debris and sawdust.

This case study focuses specifically on cores collected in 2013 (EA 2013b). Sediment types varied widely, from sawdust and high moisture fines to clays and silts to gravel. Some cores consisted of a complex interbedding of materials, while others consisted mostly of fines and sawdust. In some cases, harder materials such as plank wood or gravel were encountered over softer materials. Figure 1 presents photographs of example core profiles. Water depths were less than 6 ft (1.8 m) but sufficient to allow barge access. Core collection was performed using a direct-push drilling rig mounted on a barge. The rig was capable of vertically driving open top lined 5 ft or 10 ft (1.5 m or 3.0 m) core barrels between 2 and 3 inches [6 centimeters (cm) to 9 cm] in diameter either via hydraulic direct push or via sonic vibration of a drilling rod assembly (EA 2013b). Minimum target depth was based on past chemistry results ranging from a few inches to over 3 ft (0.9 m), with a secondary goal of encountering refusal on bedrock at depths of 5 ft to 8 ft (1.5 m or 2.4 m). Goals for recovery were 70% to 80% (EA 2013c),

Overall, the effort was able to achieve coring at all the targeted locations; however, recovery was highly variable and representative stratigraphy difficult to capture as summarized in Table 2. Manistique River's complex sediment profiles produced numerous challenges for coring. Direct-push coring encountered refusal on wood, gravel, and compacted sawdust. Sonic coring was used to penetrate wood; however, wood and gravel often became bound in the core barrel, excluding or compressing deeper layers. Recovery varied widely between replicate cores, and often five coring attempts were required to capture sufficient recovery for sampling. In cores compressed of large amounts of sawdust, significant expansion was observed, resulting in recoveries greater than targeted. Coring also captured a nepheloid layer of black suspended material (possibly associated with thermal transfer ink wastes), at the sediment surface; this was difficult to capture and often ran out of the core liner when core processing because of its high moisture and lack of cohesion.

A number of adaptations were employed to overcome challenges at the Manistique River. Sonic coring was used to penetrate wood and make sure that either target depth or refusal on limestone was achieved. Multiple

replicate cores were collected. Stratigraphy was evaluated across replicates by comparing the depth at which distinct sediment beds were encountered to evaluate where compaction, exclusion, and distortion were likely occurring. At one location a nested coring device was used to collect a core from the 5 to 10 ft (1.5 m or 3.0 m) depth interval to avoid interference from surface layers.

Table 2. Manistique River Case Study Challenges and Adaptive Measures.

Challenge Encountered	Penetration	Recovery	Compaction	Distortion	Expansion	Surface Disturbance	Re-penetration	Exclusion	Loss	Deployment Accuracy	Retrieval and Sampling	Deployment Logistics	Adaptive Measures
Early refusal on wood or compacted sawdust instead of limestone	X												Sonic vibration to penetrate wood/collect limestone
Blockage by wood or gravel, compacting or excluding deeper sediments		X	X	X				X					Replicate cores to allow comparison; use of cased core to target deeper intervals
Expansion of sawdust in core barrel		X			X								Record of penetration versus recovery
Disturbance or loss of low density surface sediment layer		X				X			X		X		Lowering barrel slowly; careful opening of cores

For samples with significant sawdust, penetration versus recovery was examined to account for expansion. To address potential loss of the low-density surface sediment layer, careful attention was given when lowering cores to the suspected depth of the water-sediment interface to minimize disturbance and facilitate capture. Where distinguishable, material was captured for inclusion in surface interval samples during core processing.

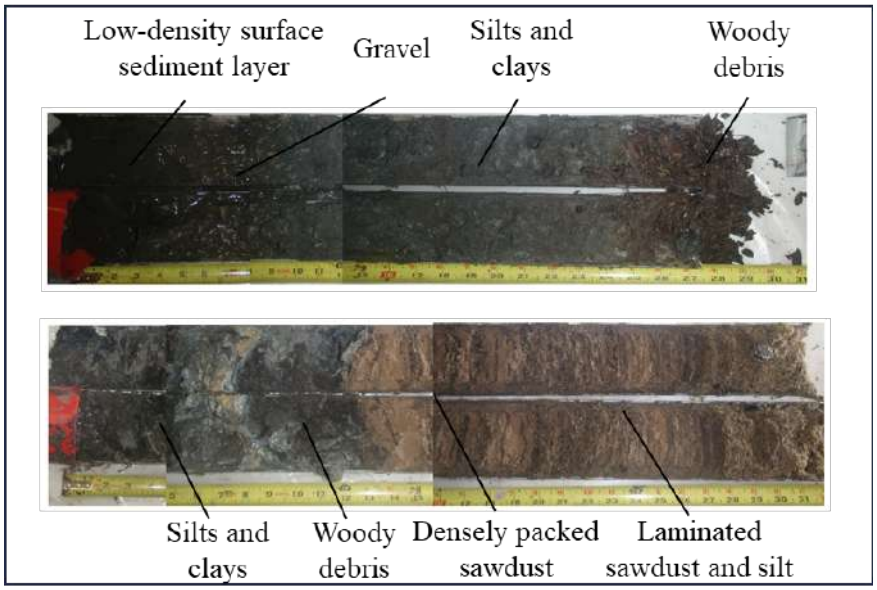

Figure 1. Manistique River Example Core Photographs

LOWER ROUGE RIVER CASE STUDY RESULTS

The Lower Rouge River Old Channel is located in Detroit, Michigan. Historically, sediments received inputs from industrial sites, outfalls, and combined sewer overflows that results in elevated polycyclic aromatic hydrocarbons in sediment (EA 2016); this lead to remediation via dredging initiated in 2019 (Great Lakes Mud 2026). This case study focuses specifically on cores collected in 2014 and 2015 (EA 2016). Sediments consisted of fines and sand over a thick layer of native clay; sediment stratigraphy was complicated by abundant debris, ranging from taconite and aggregate to wood waste to scrap metal and sunken vehicles. The sediment surface also contained coal tar, which when disturbed, would rise to the water surface entrained via ebullition. Figure 2 presents photographs of example core profiles. Water depths ranged from a few feet at the banks to over 20 feet in the channel center, with abundant stone, human-made structure and debris along the shoreline, and constant flows in the center channel. Core collection was performed using several methods. The primary method was a direct-push drilling rig mounted on a barge. The rig was capable of vertically driving open top lined 10 ft to 20 ft (3.0 m to 6.1 m) long core barrels between 2 and 3 inches (6 cm to 9 cm) in diameter either via hydraulic direct push, hammer, or via sonic vibration using a separate drilling rod assembly (EA 2016). A parallel effort included use of mudless, washed hollow stem auger drilling with 2-ft split spoons for geotechnical characterization; chemistry samples were collected from select intervals. Minimum target depth was based on past chemistry results and ranged from 5 to 15 ft (3.0 m to 6.0 m) with the overall goal of capturing the top several feet of native clays. Goals for recovery were greater than 70% (EA 2016).

The effort achieved coring at all the targeted locations with relatively high recovery, although some locations were moved to avoid obstacles and areas of refusal as summarized in Table 3. Access and logistics provided the first challenge to characterization of the Lower Rouge River Old Channel. Coring along the shoreline was limited by rip rap, debris, human-made structure, and water depth. The steep side channels and high current made accurate measurement of sediment surface elevation/water depth by lead line challenging; on the steep slope, even slight drift of the lead line away from the point of drilling could yield a change in recorded water depth of 0.5 ft to 1 ft (15 cm to 30 cm). This was exacerbated by the presence of low-density surface sediment layer at the sediment surface, which was readily disturbed and lost. Coal

tar adhered to barrels and liners, smearing along the inner surface of the liner across intervals, and at times making liner removal challenging by adhering sand grains between the liner and barrel. Small debris such as coal, taconite, gravel, and wood chips sometimes caused low recovery and potential stratigraphy distortion. Larger debris caused refusal, requiring movement of some locations,

A number of adaptations were employed to overcome challenges at the Lower Rouge River. Lead line measurements of water depth were conducted with extra weight and careful line management to reduce the influence of currents on line angle; also, bottom depth as encountered by drilling rods and bottom depths reported in bathymetry surveys were compared to depths measured by lead line to look for inconsistencies. To address potential loss of the low-density surface sediment layer, careful attention given when lowering cores to the suspected depth of the sediment-water interface to minimize disturbance and facilitate capture. Sonic coring was used to improve penetration and minimize compaction due to down pressure.

Table 3. Lower Rouge River Case Study Challenges and Adaptive Measures

Challenge Encountered	Penetration	Recovery	Compaction	Distortion	Expansion	Surface Disturbance	Re-penetration	Exclusion	Loss	Deployment Accuracy	Retrieval and Sampling	Deployment Logistics	Adaptive Measures
Early refusal on clay and debris	X	X											Sonic vibration to penetrate deeper
Refusal or blockage of barrel by gravel, debris; debris limits to access nearshore	X	X	X	X				X					Multiple core replicates, movement of locations to avoid debris
Steeply sloped side channel and high currents										X		X	Careful lead line management, comparison to rod depth
Coal tar non-aqueous phase liquid near sediment surface						X			X		X		Pressure washing of core barrel; caution in lowering barrel, sampling inner core material to avoid draw down
Low-density surface sediment layer often missed or lost		X				X			X	X	X		Lowering barrel carefully to sediment-water interface

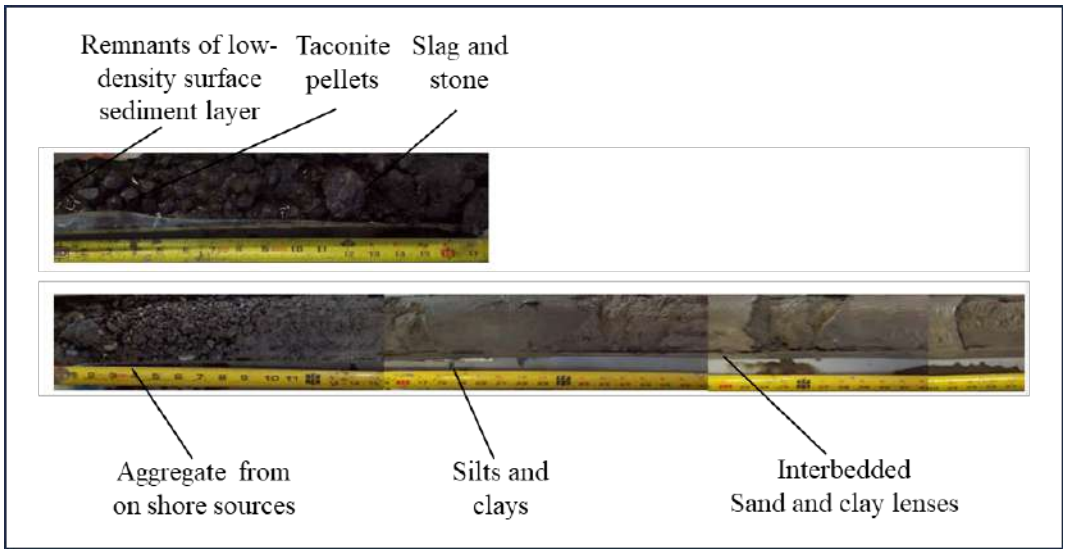

Figure 2. Lower Rouge River Example Core Photographs

To address debris, multiple cores were often collected at each location to improve recovery and allow comparison between core strata to determine if compaction or distortion were issues. Coring locations were often shifted to avoid refusal on large debris. To address coal tar, pressure washing was used to clear barrels between insertion of liners and only the innermost material of cores was used for stratigraphic logging and sampling to avoid potential impacts of coal tar smearing across intervals.

Collection of samples via hollow stem auger with split spoons had many disadvantages and one distinct advantage. Slough, heaving sand, and draw down of non-aqueous phase liquid of soft sediments produced challenges for distinguishing whether material in split spoons was from the newly collected interval or was residual from intervals above. Also, the narrow diameter of the split spoon compared to a core barrel resulted in frequent exclusion as debris or the pressure wave from the nose of the spoon pushed soft material aside. The one advantage was that in deeper consolidated sediments, the influence of compaction on intervals above did not obscure depth relationships compared to the sediment surface,

GRAND CALUMET RIVER CASE STUDY RESULTS

The Grand Calumet River is located in Gary, Indiana. Historically, sediments received inputs from multiple industrial sites (EA 2026a). This case study focuses specifically on cores collected in 2024 and 2025 from the river channel and an associated marsh (EA 2026a, 2026b). Sediment types vary but tend to consist of fines over native sand. Water depths ranged from less than a foot in marshy areas to over 15 ft in the main channel. The site setting is complex; in some areas the river is wide and fringed by emergent marsh. In others, it is narrow, shallow, and has steep and wooded banks with and without infrastructure from nearby industrial properties. The length of the river is divided by numerous bridge crossings, a weir structure, booms, and a culvert. A wide range of coring methods were utilized. The primary method was a vessel mounted open barrel vibracore rig. The rig was capable of vertically driving open top lined 10 ft to 20 ft (3.0 m to 6.1 m) long core barrels between 2 and 3 inches (6 cm to 9 cm) in diameter; these were attached to a steel tube so they could be driven by hand through a moon pool and removed via winch (EA 2026a, 2026b). A secondary approach was to use a similar vibracore assembly mounted between two Jon boats connected by an A-frame. In marshes, a mobile vibracore was deployed using an A-frame. Where water was too deep for the A-frame but to shallow or inaccessible for the Jon-boat assembly, a single Jon boat

was deployed and manual push cores or grab samples collected. Target depth was 10 ft (3 m) below sediment surface or at least 1 ft (0.3 m) into native sands, whichever was achieved first. Goals for recovery were greater than 70% (EA 2026a, 2026b).

The effort achieved coring within the targeted reaches with relatively good recovery at locations that could be sampled. However, some locations were abandoned for refusal on stone or dense sand, and some were moved to avoid obstacles and debris as summarized in Table 4. The greatest challenges associated with sampling the Grand Calumet River were associated with access. Deployment of vibracore via large vessel was infeasible in many areas due to low bridge crossings and steep banks that would have required crane lifts into at least six different reaches. As described for other case studies in this paper, the presence of low-density surface sediment layer presented challenges to both capture and retention during processing. This was particularly challenging to capture in cores where this layer was underlain by aggregate. In many cases, this presented as refusal or material was lost from the bottom of the barrel due to lack of cohesion or plug of sediment to retain the overlying soft material. Occasionally, debris caused challenges for penetration and retrieval. In some cases, non-aqueous phase liquids in sediment caused grit to adhere between the inner core barrel and liner, making liner extraction challenging.

A number of adaptations were employed to overcome challenges. Multiple coring technologies were mobilized for the effort and the most robust technology feasible was selected for each location. Issues with encountering aggregate and debris were addressed by conducting numerous cores and grabs within a 30-ft radius of the sampling location. This was used to avoid distinct pieces of debris or aggregate. In this case study, shallow push cores and grabs were used to explore the thickness of low-density sediment layers so that coring could better target the sediment-water interface. Careful attention was given when lowering cores to the suspected depth of the low-density surface sediment layer to minimize disturbance and facilitate capture. At some locations, vegetative root mats and woody debris caused refusal; these were cleared using a grab or rake to facilitate penetration. In the few cases, where there were concerns liners could not be extracted from the core barrel due to hydrocarbons, single-use aluminum core barrels were used.

DISCUSSION

A key objective of this study was to develop a methodology for consistently and comprehensively capturing information on coring technology effectiveness. The framework developed for specific site characteristics, variables, technologies, challenges, and expectations proved easy to assess and intuitively useful for converting anecdotal information on coring experience into a standardized data set. Both factors specific to industrialized environments (i.e., debris, access, complex stratification) and factors generally common to coring (i.e., refusal on dense sand, low-density surface sediments) proved easy to catalogue and assign to variables relevant to data quality. Reviewing the three case studies together, several themes are common regarding frequent challenges and how they may be overcome.

Table 4. Grand Calumet River Case Study Challenges and Adaptive Measures

Challenge Encountered	Penetration	Recovery	Compaction	Distortion	Expansion	Surface Disturbance	Re-penetration	Exclusion	Loss	Deployment Accuracy	Retrieval and Sampling	Deployment Logistics	Adaptive Measures
Structures, shoreline, and depth limited access	X	X									X	X	Deployed multiple technologies on multiple platforms
Refusal on vegetative mat or aggregate with loss of overlying sediment	X	X							X		X		Multiple attempts with core grab samplers; clearing of bottom vegetation before coring
Exclusion or refusal on debris	X	X	X	X		X		X			X		Address debris as separate issue
Hydrocarbon material in surface sediments						X			X		X		Deploy single-use barrels; careful capture of sediment-water interface
Low-density surface sediment layer often missed or lost		X				X			X	X	X		Lowering barrel carefully to suspected layer surface; careful opening of cores

Low-density surface sediments: All three sites encountered challenges with capture of low-density surface sediments composing a nepheloid layer. This is key to chemical characterization, as in all three cases these were associated with potential sources of chemicals of concern. This challenge included the difficulty determining the depth of the surface water interface to accurate assign start of coring; the ease with which these sediments can be disturbed and lost during deployment; and the difficulty capturing them when core processing. Overcoming this challenge required careful measurement of water depth, comparison of depth against bathymetry survey information, cautious deployment of the core barrel, use of grabs and push cores to explore the sediment surface, and special preparations to capture liquid from the top interval of cores during core handling and processing.

Debris, including woody material: The challenging nature of debris at remedial dredging sites has been previously documented and bears special challenges for sediment coring. Large debris halts penetration entirely while small debris may become entrained in the core and cause blockages to inflow, resulting in

compaction and distortion. Sonic coring proved helpful in two case studies for penetrating debris but did still encountered challenges with entrained debris. The best adaptation for entrained debris was repeated coring and comparison across cores. Woody material constitutes a specific category of debris with unique effects on coring. Sawdust was observed to expand in cores, while fibrous material caused refusal or compaction. Repeat coring and vegetation clearing before core collection were key to effective coring.

Complexity of stratigraphy: Several case studies exhibited unusual stratigraphy due to anthropogenic impacts. This included layers of hard material over soft material, interbedded strata of sediment and debris, and complex mixtures of materials. This complexity both increases the need for vertical accuracy in profiling and makes coring more challenging due to variable density and compressibility. Collection and comparison of multiple cores was the most effective adaptive measure for capturing these effects.

Access: At two of three sites, access was a significant issue. In one case this was due to shoreline obstacles, while in the other, it was largely due to steep slopes and cross-river obstructions to passage. In both cases, this drastically affected the feasibility of deploying coring equipment requiring larger vessels and limited collection to grab samplers or push cores. The most effective adaptive measure was to have multiple sampling and coring technologies on hand suitable for wading, shallow water, and deepwater deployment; this allowed use of the most robust coring technology practical for the setting.

Vertical accuracy: In all three cases, fixed drill strings (i.e., drill rods or tubes) were used to deploy coring devices. This provided vertical accuracy despite slopes and currents. At one site, sediment surface elevation/water depth was recorded by cabled lead line; this proved challenging and required cable management and comparison against drilling records to account for line drag. This demonstrates the uncertainties that can be associated with cable deployment of equipment. Availability of independent elevation information from nearby tide gauges and bathymetry surveys was useful for comparison.

CONCLUSIONS

A method was developed for compiling and standardizing information regarding challenges and successes for sediment coring, sampling, and vertical profile delineation at industrialized sites to support remedial design. This method draws from published literature and guidance on the common variables that determine quality of data achieved by coring as well as typical data quality objectives for remediation dredging projects. When applied to three case studies as a pilot effort, this methodology proved easy to implement and effectively captured useful information. Given the use of new field technologies to quantify some of the variables discussed in this paper (i.e., Dreher et al. 2022), use of such a framework is expected to produce valuable results for optimizing sediment investigation practices. The data fields recommended for future use are presented in Table 5 along with additional fields identified as potentially useful based on the case study. Given the success of the data collection framework presented in this study, it is recommended that the framework be used to collect and evaluate information from additional field efforts across a range of both remediation and navigation projects in industrialized settings. Using this framework across multiple studies would provide the information needed to develop guidelines and best management practices for technology selection for future sediment investigations and could benefit scientists and engineers as they collected the data needed for future dredging designs.

Review of three case studies indicates that many of the challenges common to sediment coring in general are exacerbated by factors specific to industrialized settings, including human-made obstacles, the frequency and type of debris, complexity of depositional history reflected in stratigraphy, and presence of oily, low-density sediments. Effective adaptive measures include deployment of a variety of technologies

Table 5. Data Collection Fields for Future Use in Evaluating Success of Coring Methods[(a)]

PROJECT SITE INFORMATION	CORING TECHNOLOGY	CHALLENGES	ADAPTIVE MEASURES
• Waterbody • Geographic location • Water depth range • Coring target depth • Coring target penetration • Chemicals of interest • General stratigraphy/ sediment grain size	• Piston versus open barrel • Barrel width, geometry • Drive (direct-push, vibrational, sonic) • Continuous versus drilled interval • Cable/rope versus fixed rod • Lined versus unlined • Vertical versus horizontal capture • Vessel/access type • *Capture devices*	• *Low-density sediments (i.e., nepheloid layer)* • *Chemical impacts that affect coring* • *Debris type, size, and frequency, using categories from Hayes et al. 2022* • *Complex stratigraphy* • *Vertical deployment accuracy* • *Limits to vessel and equipment access*	• Adaptive measures to better gauge depths and elevation • Adaptation of coring equipment • Adaptation of coring methods/process • Adaptation of core processing methods • Comparison of cores • Use of multiple coring technologies • Adaptation of access/deployment

[(a)] New data fields that were added to the methodology based on the framework are shown in *italics*.

to provide options for difficult situations and settings; careful attention to the sediment-water interface when measuring water depth and lower core barrels; collection and comparison of multiple collocated cores to identify effects of distortion and compaction; and careful recording of penetration, recovery, and challenges encountered during core collection and processing. The adaptive measures that proved successful in these case studies should be considered when planning future investigations. General recommendations include preparing for diverse field conditions via an adaptive management approach that includes a range of technologies and approaches; assess drilling conditions and core penetration and recovery patterns frequently; use multiple lines of evidence to assess recovery and integrity of cores; evaluate influence of field outcomes on data quality and usability. Additional recommendations include assessment of more case studies using the same framework and review of conditions encountered during dredging to identify whether these confirm the type and frequency of debris.

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DATA AVAILABILITY

Some data used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

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GEOTECHNICAL INSTRUMENTATION SUPPORTING LARGE-SCALE DREDGING AND MARINE CONSTRUCTION AT THE SOO LOCKS

J.W. Caryl[1], B. L. Rohrbach[2] and J. S. Matus[3]

EXTENDED ABSTRACT

The Soo Locks at Sault Ste. Marie, Michigan, are among the most critical lock and dam infrastructure assets in North America, conveying nearly all domestically produced iron ore and supporting a substantial portion of U.S. steel manufacturing. To address aging infrastructure and eliminate reliance on a single Poe-sized lock, the U.S. Army Corps of Engineers (USACE), Detroit District, is executing the multi-phase New Lock at the Soo megaproject. This work includes deepening the upstream approach channel, reconstructing deteriorated approach walls, and constructing a new Poe-sized lock within an active and highly constrained navigation corridor.

This presentation describes the role of geotechnical instrumentation and monitoring as a risk-management tool during Phase 1 upstream approach channel deepening, Phase 2 upstream approach wall construction, and Phase 3 construction of the new lock. These phases required extensive dredging, underwater rock removal, controlled blasting, and heavy marine construction adjacent to critical lock, dam, bridge, and powerhouse infrastructure. Construction activities were constrained by ongoing vessel traffic, international rail and highway bridges, and strict movement and vibration limits established by USACE.

GEI Consultants served as the contractor's geotechnical instrumentation engineer, providing continuous monitoring support throughout all phases. The instrumentation program included automated total stations monitoring hundreds of survey prisms on existing and reconstructed approach walls, manual and automated inclinometers and shape arrays, vibrating wire tiltmeters and piezometers, vibration and blast monitoring, and centralized automated data acquisition systems. Real-time data were made available to contractors and USACE to support construction sequencing, blasting controls, excavation limits, and response actions when threshold values were approached.

The presentation highlights how instrumentation data directly informed dredging and marine construction decisions, reduced risk to lock and dam assets, and enabled safe project execution in a complex operating environment. Lessons learned from implementing long-term monitoring across multiple construction phases will be discussed, with emphasis on coordination between dredging operations, marine contractors, and instrumentation engineers. These experiences provide practical insight for similar large-scale dredging and navigation infrastructure projects where ground movement, vibration, and structural risk must be actively managed.

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[1] Senior Vice President, Construction Services, GEI Consultants, Inc., 1215 North Street, Cleveland, Ohio 61456, USA, T: 216-456-5896, Email: jcaryl@geiconsultants.com.
[2] Senior Consultant, GEI Consultants, Inc., 401 South Washington Square, Suite 103, Lansing, MI, 48933, USA, 517-974-5530, 615-830-6688, brohrbach@geiconsultants.com. (corresponding author).
[3] Senior Vice President, GEI Consultants, Inc., 401 South Washington Square, Suite 103, Lansing, MI, 48933, USA, 517-974-5530, jmatus@geiconsultants.com. (corresponding author).

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TRANSFER INNOVATION FOR SUBSEA ROCK INSTALLATION AND SELF-UNLOADING VESSELS

C. Augustin[1], R. Turner[2], G. Donnelly[3], R. Tadros[4] and J. Pierre[5]

ABSTRACT

The transfer of proven industrial sensing technologies into the marine domain offers significant potential for improving operational efficiency, automation, and safety in subsea rock installation and self-unloading vessel operations. This paper describes the adaptation of 77 GHz industrial radar systems, originally developed for harsh mining environments, to maritime bulk material handling and vessel monitoring applications. The objective of the work is to demonstrate how robust radar technologies can provide reliable, maintenance-free measurement solutions under demanding marine conditions such as dust, spray, fog, vibration, and corrosive atmospheres. The presented systems include 2D and 3D radar sensors for material flow measurement, hopper level monitoring, and vessel draft measurement. In subsea rock installation applications, radar sensors mounted above conveyors or apron feeders continuously measure volumetric rock flow into fall pipes, enabling precise tracking of deployed material quantities, detection of inconsistent flow conditions, and improved bunker management. Additional radar systems monitor hopper filling levels and material distribution, allowing operators to identify potential blockages and overflow situations before operational disruptions occur. The radar data is integrated into existing vessel automation and control infrastructures using standard industrial interfaces. The paper further discusses the development of integrated digital twin concepts that combine radar-derived volumetric measurements with vessel positioning systems to create spatially resolved deployment visibility during subsea rock installation operations. Initial deployments with major marine industry operators have demonstrated the feasibility and operational benefits of the transferred technology, including simplified installation, reduced maintenance requirements, and improved operational transparency compared to conventional measurement approaches. Furthermore, radar-based draft measurement systems for self-discharging vessels are introduced, enabling continuous monitoring of vessel movement and loading conditions during operation. The results show that radar technologies developed for mining automation can be successfully transferred into marine environments and provide a scalable foundation for future intelligent vessel monitoring and automation solutions.

[1] Director Radar & RTLS Technology, NovAtel Positioning Division, Veripos Ltd., 1B Farburn Terrace, Dyce, Aberdeen, AB21 7DT, Scotland UK, +49 179 1212818, christian.augustin@hexagon.com (corresponding author).
[2] VP Marine Business Unit, NovAtel Positioning Division, Veripos Ltd., 1B Farburn Terrace, Dyce, Aberdeen, AB21 7DT, Scotland UK, +44 7734 494812, richard.turner@hexagon.com.
[3] Business Development Manager – Marine, NovAtel Positioning Division, Veripos Ltd., 1B Farburn Terrace, Dyce, Aberdeen, AB21 7DT, Scotland UK, +44 1224 59800, graham.donnelly@hexagon.com.
[4] Marine Business Development & Portfolio Manager, NovAtel Positioning Division, Veripos (US) LLC, 5775 North Sam Houston Parkway West. Suite 500, Houston, Texas 77086 United States, + 1 281 966 7903, rami.tadros@hexagon.com.
[5] Business Development Manager, indurad GmbH, Belvedereallee 5, Aachen, 52070, Germany, +49 241 53 80 700, julien.pierre@indurad.com.

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INTRODUCTION

Transfer innovation describes the adaptation of technologies, methodologies, and operational concepts from one industrial domain into another. Innovation research has shown that transformative progress often emerges not only from entirely new inventions, but from transferring and recombining existing technologies in new application environments (Schumpeter 1934; Rogers 2003). A prominent example is the transfer of Global Positioning System (GPS) technology from military navigation into civilian applications, such as automotive navigation, logistics, agriculture, autonomous systems, and smartphones, and thereby fundamentally transforming industries and everyday life (Kaplan and Hegarty 2005). Similar transfer mechanisms can be observed today in industrial automation, digital sensing, and autonomous operations.

In industries characterized by harsh environmental conditions and complex workflows, the transfer of proven technologies can reduce development risk while accelerating implementation and operational acceptance (Chesbrough 2003). Rather than developing isolated solutions for individual sectors, transfer innovation enables scalable platform technologies that benefit from operational experience across multiple industries. In industrial sensing, this became increasingly relevant as advances in semiconductor technology, radar systems, and digital processing capabilities from consumer electronics and automotive markets became available for industrial use.

This paper follows this transfer innovation approach by describing how industrial radar technologies originally developed for harsh mining environments were adapted for subsea rock installation and self-unloading vessel operations. Radar systems designed for dust, vibration, and corrosive mining conditions are transferred into marine environments characterized by spray, fog, vessel movement, and adverse weather. The paper demonstrates how these technologies enable volumetric material flow measurement, hopper monitoring, draft measurement, and digital twin generation in maritime operations, thereby improving operational transparency, automation, and safety.

FROM AUTOMOTIVE AND SMARTPHONE MARKETS

Between approximately 2005 and 2009, several technological and regulatory developments converged to create the foundation for a new generation of industrial radar systems. Three factors were particularly important: advances in mobile phone semiconductor technologies, the emergence of automotive radar systems, and the international harmonization of the 77 GHz frequency band, a millimeter-wave spectrum primarily utilized for high-resolution automotive and industrial radar systems.

The rapid growth of the mobile phone market drove major investment into highly integrated, low-cost, and low-power semiconductor components designed to generate, process and receive high-frequency radio signals (RF chipsets). Technologies such as silicon-germanium (SiGe) based semiconductors, which enabled better and more compact chipsets, and later complementary metal-oxide-semiconductor (CMOS) high-frequency electronics matured quickly due to consumer-scale production volumes, making compact radar systems economically viable beyond military and scientific applications, allowing integration of radar functions into increasingly compact and affordable chipsets (Floyd et al. 2004).

At the same time, the automotive industry invested heavily in radar technologies for adaptive cruise control, collision avoidance and blind spot detection. These applications demanded robust sensors capable of

operating reliably in rain, fog, dust and changing light conditions. In particular, the transition to 77 GHz radar significantly improved spatial resolution and measurement precision compared to earlier 24 GHz systems (Wenger 2005; Skolnik 2008).

A further enabling factor was the regulatory harmonization of the 76–77 GHz and later 77–81 GHz frequency bands by organizations such as the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC). This internationally standardized “free-to-operate” spectrum reduced development risk and accelerated adoption (FCC 2004; ETSI 2005).

Together, these developments enabled companies to transfer radar technologies into industrial automation and mining applications. Technologies originally developed for consumer electronics and automotive safety could now be adapted for harsh industrial environments involving dust, vibration, moisture, and extreme operational conditions. This transfer innovation enabled applications such as volumetric flow measurement, stockpile monitoring, collision avoidance, and later marine sensing systems.

TECHNOLOGY TRANSFER TO MINING

For decades, the mining industry has faced major challenges in deploying reliable sensor technologies under harsh environmental conditions. Open-pit and underground mines are characterized by dust, mud, vibration, humidity, extreme temperatures and poor visibility. Conventional optical sensing systems such as cameras and laser scanners often suffer severe performance degradation in these environments. Cameras depend heavily on ambient lighting, while laser systems are sensitive to dust, spray, and contamination of optical surfaces. As a result, the reliability of optical systems in continuous mining operations has historically been limited, particularly in bulk material handling and autonomous machine applications (Roberts et al. 2007).

Against this background, early experimental work by Nienhaus et al. (2007) and Augustin et al. (2009) explored whether imaging radar technologies could be adapted for industrial mining environments. The investigations aimed to transfer radar principles from aerospace, defense, and automotive applications into industrial process monitoring and automation. The central hypothesis was that millimeter-wave radar sensors (primarily at 77 Ghz and also at 24 Ghz) could provide robust sensing capabilities largely unaffected by dust, fog, or changing lighting conditions.

Imaging radar systems are capable not only of detecting object presence or distance, but also of generating spatially resolved representations of surfaces and material distributions. Unlike simple point-measurement radar systems, imaging radar reconstructs geometric information using approaches such as rotating antennas, phased arrays, and mechanically scanned architectures (Skolnik 2008; Brookner 1991; Hansen 1998).

These investigations laid the technological foundation for later 2D and 3D industrial radar solutions used in mining automation, volumetric material flow measurement, collision avoidance, and stockpile monitoring under harsh environmental conditions.

The operational advantages of radar-based sensing technologies become particularly apparent when compared with alternative industrial measurement approaches commonly used in mining and marine bulk material handling environments. Many conventional sensing technologies suffer from reduced reliability under dust, fog, spray, vibration, and continuously changing environmental conditions. These limitations were already a major challenge in mining applications and later became equally relevant during the transfer of the technology into marine and offshore operations.

The robustness of industrial radar systems under harsh environmental conditions therefore represented one of the key enabling factors for the successful transfer from mining into subsea rock installation and vessel monitoring applications. Table 1 compares radar-based sensing systems with conventional industrial measurement technologies regarding environmental robustness, maintenance requirements, and suitability for marine bulk material handling applications.

Table 1. Technology comparison.

Technology	Dust Resistance	Fog / Spray Resistance	Non-contact	Maintenance Effort	Suitable for Short Conveyors	Calibration Requirement	Volumetric Measurement Capability	Typical Limitations
77 GHz Industrial Radar	Excellent	Excellent	Yes	Low	Excellent	Low	Excellent	Multipath reflections on metallic structures may require filtering
Laser Scanner / LiDAR	Limited	Limited	Yes	Medium to High	Good	Medium	Excellent	Reduced performance due to dust, spray, and contaminated optics
Optical Camera Systems	Poor	Poor	Yes	Medium	Good	High	Limited	Strong dependence on lighting and visibility conditions
Ultrasonic Sensors	Moderate	Moderate	Yes	Low	Moderate	Medium	Limited	Sensitive to wind, temperature, and irregular surfaces
Conventional Belt Scales	Good	Good	No	High	Poor	High	Limited (mass flow only)	Require stable mechanical reference conditions
Mechanical Level Sensors	Good	Good	No	High	Not Applicable	Medium	Limited	Mechanical wear and direct material contact
Load Cells / Weighing Systems	Good	Good	No	Medium to High	Poor	High	Limited (mass only)	Sensitive to vessel inclination and structural deformation

COMMERCIAL AVAILABILITY FOR MINING

The introduction of 2D and 3D radar technology into the mining industry did not follow a predefined roadmap, but evolved through continuous interaction between technological capability, operational challenges, and customer-driven adaptation. Initial radar systems were introduced to solve sensing problems in harsh mining environments where conventional optical technologies repeatedly failed. Early applications focused on bulk material monitoring, conveyor measurements, and machine positioning under dust, fog, and vibration conditions. Once the first systems proved reliable in practice, operators quickly identified additional use cases that had previously been considered technically impractical.

This process represents a characteristic example of transfer innovation. Rather than transferring a fully mature product into a new industry, the technology evolved through close interaction between developers and users. Additional applications continuously emerged, including stockpile monitoring, collision avoidance, volumetric flow measurement, and machine automation.

Innovation research has shown that important innovations often emerge during the practical use of technologies rather than during their original conception (Rosenberg 1982; von Hippel 1986). In mining environments, customer interaction became a key driver for discovering new applications and refining the technology.

At the same time, the transition from individual customer solutions to scalable industrial products required continuous commercial selection. While many technically promising applications emerged, only a subset justified long-term productization and global support. The evolution of industrial radar technology in

mining therefore illustrates not only a successful transfer innovation, but also the interaction between scientific exploration, customer-driven adaptation, and commercial selection processes.

SPIN OFFS INTO OTHER INDUSTRIES

The further evolution of industrial radar technology led to specialized spin-offs aimed at making the technology available to certain specialized markets, such as intermodal terminal automation (Augustin 2019) and autonomous haulage systems (Riedel 2022). These examples demonstrate that successful technologies often create new application domains requiring dedicated organizational structures.

At the same time, they highlight that technology is never an isolated endeavor. Technologies must be developed, adapted, and operationalized by people within real industrial environments. Innovation therefore depends not only on technical capabilities, but also on their integration into existing operational and organizational systems. Socio-technical systems theory has long emphasized that technological success depends on the interaction between technology, organizational structures, and human acceptance (Trist 1981; Bijker et al. 1987). The long-term success of industrial radar technologies was therefore shaped as much by user interaction and organizational adaptation as by the sensor technology itself.

EXPANSION INTO MARINE APPLICATIONS

The further development of industrial radar technologies into marine and offshore applications represents another step in the broader process of transfer innovation and technological scaling. The maritime domain has historically been closely connected to radar technology. Since the pioneering work, including the development of the “Telemobiloskop” in 1904 (Hülsmeyer 1904), radar has played a central role in maritime navigation, collision avoidance, and vessel safety (Skolnik 2008). Conventional marine radar systems typically operate in the S-band around 3 GHz and the X-band around 9–10 GHz, frequencies that are optimized for long-range navigation, weather penetration, and reliable target detection under maritime conditions (Skolnik 2008). Due to the comparatively long wavelengths at these frequencies, conventional marine radar systems provide limited spatial resolution and are therefore less suitable for precise industrial sensing tasks such as detailed surface profiling, volumetric material measurement, or high-resolution object contour detection.

In contrast, 77 GHz radar systems operate at significantly shorter wavelengths of approximately 3.9 mm, enabling substantially higher spatial resolution, smaller antenna dimensions, and more precise distance and contour measurements (Brookner 1991; Wenger 2005). These characteristics allow 77 GHz radar technologies to address sensing applications that were previously not feasible with conventional marine navigation radar systems. The expansion into marine applications was enabled by combining radar sensing technologies with complementary positioning, automation, and digital infrastructure systems. This integration allowed existing expertise in material flow measurement, stockpile monitoring, and machine automation to be transferred into offshore and subsea operational contexts (Winkel et al. 2011). At the same time, the combination with positioning systems, navigation technologies, and digital twin architectures created opportunities for new operational concepts such as spatial deployment mapping, integrated vessel monitoring, and digitally assisted offshore operations (Kaplan and Hegarty 2005).

The following sections present examples of how industrial radar technologies have been successfully deployed in mining and marine environments, illustrating how transfer innovation continuously generates new operational applications, technological capabilities, and integrated sensing architectures.

SUBSEA ROCK INSTALLATION – MATERIAL FLOW

Accurate measurement and control of material flow are critical for subsea rock installation vessels, where rock material is continuously transferred from onboard bunkers into fall pipes for subsea deployment. Conventional belt scale systems are often difficult to install in marine environments due to limited installation space, short conveyor sections, and harsh environmental conditions, including spray, vibration, fog, and material contamination. In addition, conventional belt scales require stable mechanical reference conditions and regular recalibration, which becomes challenging under continuous vessel motion and changing inclination angles. Furthermore, belt scales primarily measure mass flow, whereas offshore rock deployment operations often require precise volumetric information for operational planning and contractual verification. To address these challenges, a radar-based volumetric flow measurement system was deployed on several customer vessels. Figure 1 shows a typical installation deployed in 2012 on a fallpipe vessel operated by a major offshore contractor. The system is still operational.

Figure 1. Radar sensor installation above conveyor and transfer point (source: indurad GmbH).

Figure 2 illustrates the radar-based volumetric flow visualization integrated into the operational vessel interface. The system continuously displays measured material flow rates and bunker utilization states during unloading operations, enabling operators to detect irregular flow conditions and estimate remaining bunker capacity in real time.

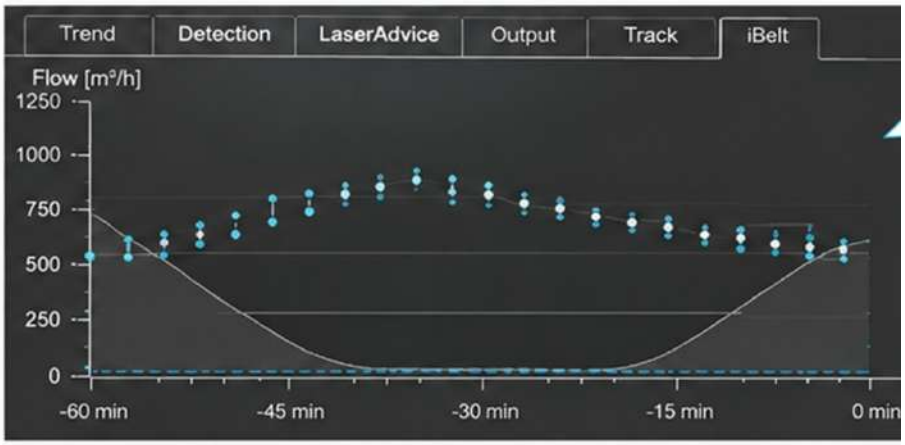

Figure 2. Data visualization in existing customer system (source: screenshot indurad GmbH).

The system architecture consists of multiple industrial radar sensors connected to a dedicated radar processing unit (iRPU-F), as shown in Figure 3. The underlying radar technology platform is identical to the system architecture used in the following section. The sensors are mounted above the conveyor or apron feeder transporting rock material toward the fall pipe. A 2D radar sensor continuously measures the cross-sectional profile of the material stream across the conveyor width while simultaneously determining material velocity using Doppler-based measurement principles. By combining these parameters, the system calculates the volumetric material flow in real time and outputs continuous flow data in m³/h.

Figure 3. Example sensor heads (left) and processing unit (right).

The volumetric material flow can be described as the product of the material cross-sectional area and the material velocity. For conveyor-based installations, the cross-sectional area is derived from the radar-measured material profile across the conveyor width. The volumetric flow rate can be calculated as

$$Q_v = v \int_0^w \big(h(x) - g(x)\big)dx \qquad (1)$$

where Q_v is the volumetric flow rate [m³/s] which is for operator visualization typically converted in m³/h, v is the measured material velocity [m/s], w denotes the effective conveyor width [m], h(x) is the radar-measured profile of the loaded conveyor [m], and g(x) is the reference profile of the empty conveyor belt [m], including its trough geometry. The difference h(x) − g(x) therefore represents the material height above the empty belt profile, and the integral corresponds to the material cross-sectional area transported by the conveyor [m²].

The modular architecture allows integration into existing programmable logic controller (PLC), supervisory control and data acquisition (SCADA), and vessel automation systems through standardized industrial communication interfaces. At the same time, the system also supports dedicated local or remote visualization interfaces for operators and process monitoring.

Compared to conventional belt scales, the radar-based approach provides several operational advantages. Since the system contains no moving parts in contact with the conveyed material, maintenance requirements are significantly reduced. In addition, the radar measurement is largely independent of belt tension, material

adhesion, varying visibility conditions, and contamination of optical surfaces. The compact sensor design enables installation on short conveyor sections where conventional belt scales cannot be implemented. Importantly, installation and maintenance can be performed directly by vessel crews without major mechanical modifications to the conveyor infrastructure.

The generated flow information is integrated into the vessel control and monitoring system and supports operational decision-making in several areas. Accurate volumetric measurements improve accounting and contractual verification of deployed rock quantities. Continuous monitoring allows early detection of inconsistent flow conditions, partial blockages or process disturbances before operational interruptions occur. The system also supports bunker management by estimating remaining onboard material quantities and calculating expected bunker depletion times.

Field operation under rough sea conditions demonstrated that radar-based volumetric measurement provides a robust and reliable sensing solution for marine bulk material handling applications. Benchmark measurements against conventional belt scales showed deviations below ±3% under operational sea conditions. The system operated continuously for more than 2,000 operating hours without sensor maintenance. The radar sensors remained fully operational under spray, dust, vibration, fog and changing weather conditions, demonstrating the robustness of the transferred mining radar technology to maritime environments.

SUBSEA ROCK INSTALLATION – HOPPER MONITORING AND MATERIAL DISTRIBUTION

Reliable monitoring of hopper filling levels is essential for maintaining stable material flow during subsea rock installation operations. In marine bulk handling environments, irregular material distribution, bridging effects, or uncontrolled overfilling can lead to operational interruptions, unscheduled downtime, and potentially hazardous overflow situations. Conventional level measurement technologies often struggle under these conditions due to dust generation, vibration, material reflections, and continuously changing material geometries. To address these challenges, radar-based hopper monitoring systems using 2D and 3D radar sensors were deployed on fallpipe vessels.

The radar sensors are mounted above the hopper structure and continuously scan the rock material surface during operation. Depending on the application requirements, either 2D profile scanners or full 3D radar systems are used to monitor filling height, material distribution, and surface geometry inside the hopper. The resulting measurement data enables real-time supervision of material accumulation and transfer behavior. Figure 4 shows the installation of the sensors on the vessel. The sensors were installed back in 2012 and have been in operation since then.

Figure 4. Hopper monitoring installation (right panel shows installed sensors, looking sideways to the material).

Figure 5 shows the internal processing of the radar measurement data. The radar sensors generate distance-, angle-, and intensity-based measurement points across the hopper cross-section. The predefined empty hopper geometry is represented as the "Container Shape," while detected radar reflections are grouped into clusters that form the reconstructed 2D material profile. For data reduction and control system integration, the profile is discretized into virtual 2D bins. An average material height is calculated for each bin and transferred to the higher-level control system together with the absolute filling value.

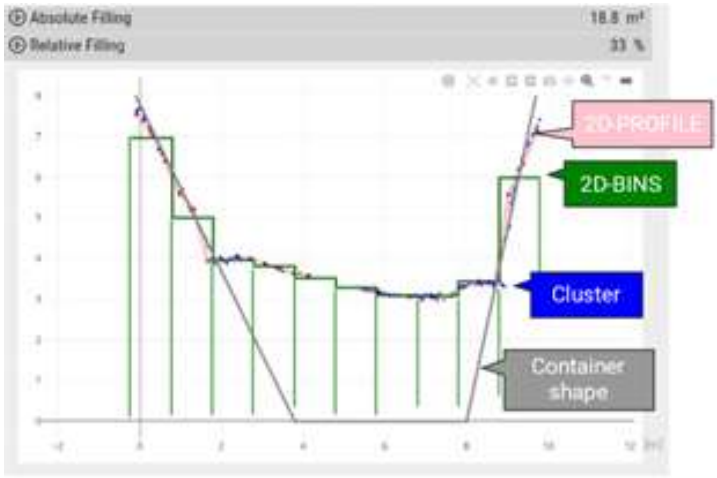

Figure 5. Hopper profile visualization.

Equation (2) represents a discrete numerical approximation of the hopper volume obtained from multiple measured cross-sections:

$$V_h = \sum_{\{i=1\}}^{\{n\}} \quad A_i \cdot \Delta x_i \tag{2}$$

where V_h is the estimated hopper volume [m³], A_i is the measured cross-sectional material area in section i [m²], and Δx_i is the corresponding section length [m].

For fully resolved 3D radar systems, the hopper volume can be calculated directly from the difference between the measured material surface and the known hopper geometry:

$$V_h = \iint \left(z_{m(x,y)} - z_{c(x,y)}\right) dA \quad (3)$$

where (A) denotes the horizontal hopper footprint area, ($z_{m(x,y)}$) is the measured material surface elevation (subscript m = material), and ($z_{c(x,y)}$) is the known hopper or container geometry (subscript c = container). The difference ($z_{m(x,y)}$-$z_{c(x,y)}$) represents the local material depth. The equation follows directly from standard volume integration principles, where the local material depth is integrated over the entire hopper area to obtain the total contained volume. A major advantage of the radar-based approach is the ability to detect developing blockages, uneven material distribution, or critical filling conditions before operational disruptions occur. This allows vessel operators to proactively adjust conveyor speeds, feeder rates, or material handling processes in order to maintain stable operation and avoid uncontrolled overflow events. In addition, continuous monitoring improves utilization of hopper capacity and contributes to more predictable material flow toward the fall pipe deployment system.

The radar systems operate reliably under harsh marine conditions, including spray, fog, vibration, and highly irregular rock surfaces. Since the sensors perform non-contact measurements and contain no moving mechanical components, maintenance requirements are significantly reduced compared to conventional mechanical level measurement systems.

The generated measurement data is integrated into the vessel automation environment using standard industrial communication interfaces. This allows direct integration into existing PLC, SCADA, and vessel control infrastructures that enables operators to use radar-derived filling level information within established operational workflows and control strategies.

DIGITAL TWIN INTEGRATION AND SPATIAL MATERIAL DEPLOYMENT MAPPING

Building upon the successful transfer of radar technologies from mining into marine applications, the technology platform is being further extended toward integrated 3D bunker volume control and digital twin systems for subsea rock installation operations. The objective of these developments is not only to measure local material flow conditions, but to create a continuously updated spatial representation of the complete material handling and deployment process.

The radar systems described in the previous sections are combined into an integrated sensing architecture that continuously captures volumetric flow, hopper filling levels and material transfer dynamics throughout vessel operation. By integrating these radar-derived measurements into a digital twin environment, operators obtain a real-time operational model of the onboard rock handling process and bunker utilization state.

A key extension of the system is the integration with positioning technologies. By combining precise vessel positioning data with radar-based material flow measurements, the deployed rock material can be spatially mapped during subsea installation operations. This enables the generation of georeferenced deployment

maps and provides operators with full visibility regarding where and, in what quantities, material has been deployed during offshore operations.

The integration of radar sensing, positioning systems, and digital twin technologies illustrates the next evolutionary step of transfer innovation within industrial sensing systems. Technologies originally developed for industrial process monitoring are thereby transformed into broader operational intelligence platforms capable of supporting automation, process optimization and future autonomous marine operations.

RADAR-BASED DRAFT AND VESSEL MOVEMENT MEASUREMENT

In addition to material flow and hopper monitoring applications, radar technology has also been deployed for draft and vessel movement measurement on self-discharging vessels. In the current system configuration, six radar sensors are distributed across the vessel structure to continuously monitor vessel draft, trim, and relative vessel movement during loading and unloading operations. The measurement principle is based on contactless distance measurements between predefined sensor positions and the water surface, enabling continuous calculation of vessel draft and inclination states.

The local draft at each radar position can be calculated from the known sensor reference height and the measured distance to the water surface. Since the absolute sensor position relative to the vessel structure is fixed and known, the instantaneous local draft can be derived geometrically from the difference between the sensor reference height and the radar-measured air gap to the water surface, as shown below in Figure 6 and Equation 4.

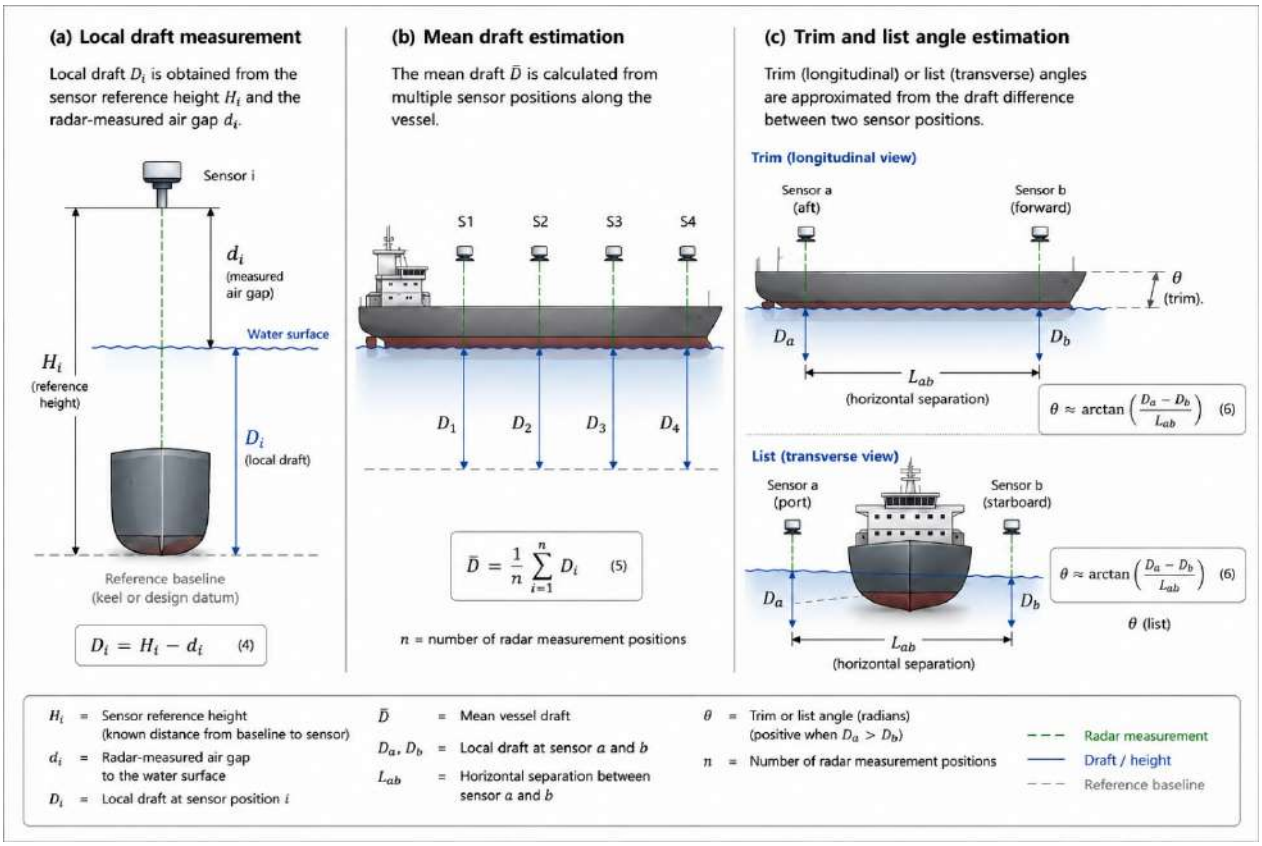

Figure 6. Graphical abstract to conceptualize the mathematical model

$$D_{\mathrm{i}} = H_{\mathrm{i}} - d_{\mathrm{i}} \tag{4}$$

where D_i is the local draft [m], H_i is the vertical distance between the sensor reference position and the vessel baseline [m], and d_i is the radar-measured distance to the water surface [m].

For vessels with approximately uniform sensor distribution, the mean draft can be approximated by the arithmetic average of the local draft values:

$$\bar{D} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} D_{\mathrm{i}} \tag{5}$$

where $\bar{D}$ is the estimated mean vessel draft, n is the number of radar measurement positions, and D is the local draft [m].

Trim and list angles can be approximated from the draft difference between two sensor positions:

$$\Theta = \arctan\left(\frac{\mathrm{D_a} - \mathrm{D_b}}{\mathrm{L_{ab}}}\right) \tag{6}$$

where θ is the calculated trim or list angle [rad], D_a and D_b are the local draft values at two sensor positions [m], and L_{ab} is the horizontal separation between these positions.

The radar sensors themselves operate with millimeter-level distance measurement precision and measurement rates of up to 16,000 Hz. While instantaneous measurements are influenced by wave motion and dynamic sea-state conditions, the oscillatory nature of wave patterns enables mathematical filtering and averaging approaches that allow stable draft estimations to be calculated over time. Calibration and validation of the system are performed using conventional manual draft surveys conducted during vessel operations, allowing the radar measurements to be benchmarked against established maritime reference procedures.

The radar-based approach provides several advantages compared to conventional draft measurement methods. Since the sensors operate contact-free and are largely unaffected by environmental visibility conditions, reliable measurements can be obtained even under rain, fog, spray, and varying sea-state conditions. Furthermore, the system does not require mechanically moving components or extensive calibration against fixed mechanical reference structures, thereby improving operational robustness and reducing maintenance requirements during loading and unloading procedures.

At the current stage of development, the installation represents a semi-permanent operational setup. While the radar infrastructure remains assigned to the vessel, the sensors still need to be manually mounted and positioned prior to operation. Although this approach enabled rapid deployment and validation of the technology under real operational conditions, it is not considered an optimal long-term industrial solution from an operational and maintenance perspective.

Current development activities therefore focus on permanently integrated sensor concepts that can be retrofitted into existing vessel structures with minimal mechanical modification requirements. The objective is to create a scalable and operationally efficient monitoring solution without requiring major vessel conversions. The successful long-term field deployment and validation for over 4 years against manual draft surveys demonstrate that the system already represents a validated engineering solution under

operational conditions. Current activities therefore focus less on validating the measurement principle itself and more on transforming the proven engineering setup into a fully integrated industrial product platform suitable for scalable fleet-wide deployment.

This development again illustrates the iterative nature of transfer innovation, where early prototype installations evolve step-by-step into fully integrated industrial systems adapted to operational and customer requirements. Figure 7 illustrates the measurement principle and system output of the radar-based draft monitoring solution. Multiple radar sensors continuously measure the distance between predefined sensor positions on the vessel and the water surface. Based on these measurements, the system calculates vessel draft, trim, and inclination states in real time. The right-hand side of the figure shows a typical operator visualization displaying draft values and trim conditions across different vessel sections.

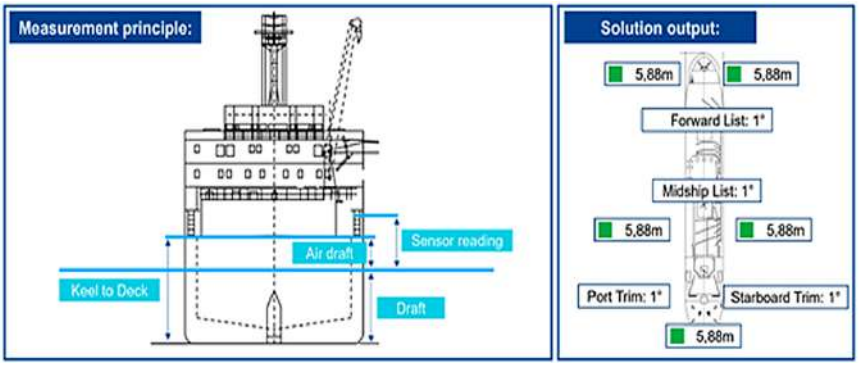

Figure 7. Enhanced draft measurement concept.

CONCLUSIONS

This paper demonstrates how high-precision industrial radar systems, originally developed for harsh mining environments, can be successfully transferred into marine and offshore applications. While the underlying radar technologies represent important technological innovations, the presented work particularly highlights the role of transfer innovation — the adaptation of existing technologies into adjacent industrial domains with new operational requirements and application scenarios.

Advances in semiconductor technology, automotive radar development, and internationally harmonized 77 GHz frequency regulations enabled the emergence of compact, robust, and highly accurate radar sensing systems. Initially introduced into mining operations to overcome the limitations of optical sensors under dust, fog, vibration, and harsh weather conditions, these systems have evolved into versatile industrial sensing platforms capable of supporting material flow monitoring, hopper supervision, volumetric measurements, automation, collision avoidance, and digital twin generation.

The transfer of these technologies into marine environments demonstrates significant potential to improve offshore and vessel operations. Applications such as subsea rock installation, self-unloading vessel monitoring, hopper filling supervision, and draft measurement show that radar-based systems can provide reliable, maintenance-reduced, and contactless measurement solutions under demanding operational conditions. In addition, the same sensing principles can support berthing assistance and vessel positioning applications, where robust environmental perception is required independent of visibility conditions.

The presented developments further illustrate the broader convergence of radar sensing, positioning systems, and operational automation. By combining radar measurements with georeferenced positioning technologies, new forms of operational intelligence and digital twin architectures become possible, supporting both process optimization and future autonomous operations.

As innovation in this field continues, several further developments are currently under investigation. One example is the use of Doppler radar technologies to measure speed over water, enabling partial compensation and stabilization of vessel positioning information in situations where satellite-based navigation systems are unavailable, degraded, or unreliable. Such developments indicate that high-precision radar systems may become an increasingly important component of resilient and autonomous marine navigation and industrial operation systems in the future.

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DATA AVAILABILITY

Some data, models, or code generated or used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

SOUTHERN CALIFORNIA'S EMERGING BEACH FILL DEMAND

J. Finegold[1], K. Garvey[2], and C. Webb[3]

EXTENDED ABSTRACT

Coastal agencies throughout Southern California are increasingly focused on developing and implementing resilience projects that rely on the nourishment of beaches as a key adaptation strategy to address coastal erosion. Across the region, multiple jurisdictions are independently advancing efforts to address persistent coastal erosion, protect sensitive infrastructure, and proactively mitigate future risks associated with sea level rise. These initiatives share a common reliance on dredging, beach nourishment, and sand-retention strategies, reflecting a regional understanding that sediment management, and specifically the sourcing of sufficient quantities of sand to meet beach nourishment demand, will play a central role in sustaining Southern California's coastline in the coming decades.

Several agencies are currently pursuing major projects that involve the placement of sand or the construction of sand-retention structures. The Cities of Oceanside and San Clemente are each exploring approaches that combine nourishment with structural measures to retain sediment. Los Angeles County, the South Orange County Coastal Coalition, the San Diego Association of Governments (SANDAG), the Beach Erosion Authority for Clean Oceans and Nourishment, the County of Orange, and the Orange County Transportation Authority are all advancing nourishment-focused efforts. Although these agencies operate across different jurisdictions and have distinct, locally-driven project objectives and desired outcomes, they share a common strategy: using dredging and beach nourishment as a primary tool to counteract ongoing erosion and enhance shoreline resilience.

To support these projects, offshore sand investigations are underway to identify suitable borrow sites capable of supplying the volumes and sand quality required for nourishment. These investigations represent an important step toward building a sustainable sediment pipeline for the region. As these efforts progress, these agencies have begun coordinating their activities amongst each other. Coordination between Cities, Counties, and agencies intending to implement a beach nourishment project is critical to regional success, primarily with respect to the allocation of sand sources available along the California coast. Following the shared allocation of resources, supporting goals of inter-agency coordination may be an improved likelihood of securing State and Federal funding, as well as a reduction in cost where project timelines may be aligned to reduce mobilizations and downtime between efforts.

The momentum behind these initiatives is supported by State-funded studies, completed and ongoing, that highlight the urgency of addressing future sea level rise. These studies consistently identify a significant regional deficit in beach sand quantities and emphasize the need for replenishment to maintain shoreline stability. The findings have helped build consensus among agencies that large-scale sediment placement

[1] Senior Construction Manager, Moffatt & Nichol, 4225 E Conant Street, Long Beach, California 90808, USA, T: (562) 590-6500, Email: jfinegold@moffattnichol.com
[2] Project Manager, Moffatt & Nichol, 4225 E Conant Street, Long Beach, California 90808, USA, T: (562) 590-6500, Email: kgarvey@moffattnichol.com
[3] Principal Coastal Scientist, Moffatt & Nichol, 555 Anton Blvd. Suite 400, Costa Mesa, California 92626, USA, T: (562) 810-3664, Email: cwebb@moffattnichol.com

will be necessary to protect coastal communities and infrastructure. If agencies continue to align their efforts, the delivered benefit to the Southern California region could be substantial. Combined, these agencies could realize projects that may deliver over 10 MCY of beach fill in Southern California over the next five to ten years to restore beaches, and could repeat regularly thereafter at some appropriate interval to maintain shorelines. This scale of activity would represent a major regional investment in sediment management and could significantly influence the future condition of many beaches.

Despite the potential for future public benefit, agencies must navigate a challenging regulatory climate. Permitting requirements for dredging, offshore sand extraction, and beach nourishment projects are complex, requiring a lengthy regulatory approval process. As the need for beach nourishment projects in Southern California become a more common occurrence and the scale of placement increases, permit-seekers may find a clearer pathway to approvals and funding to implement hopper-dredge beach fills. Although hopper dredging is commonly used for nourishment projects on the Gulf and East Coasts, it has historically been rare on the West Coast. The challenges facing hopper dredging in Southern California stem from environmental requirements for the protection of ESA listed species or sensitive marine ecosystems during in-water construction, the physical characteristics of the Pacific Ocean and the continental shelf off of the California coast, and the lack of presence of hopper dredging equipment on the West Coast due to a lack of demand. The emerging interest in hopper-dredge-based nourishment represents a potential shift in regional practice, driven by the scale of sediment needs and the desire to adopt proven methods used elsewhere in the United States.

SANDAG's upcoming Regional Beach Sand Project (RBSP) III is a strong example of large-scale nourishment demand in Southern California in the immediate future. The proposed RBSP III project represents approximately 4.3 MCY of dredged material, eclipsing the 3.64 MCY of nourishment material placed during the previous two phases. In addition to SANDAG's efforts, Orange and Los Angeles Counties are also investigating beach fill projects and pursuing new borrow site permitting to support future nourishment. Beyond traditional beach nourishment applications, a significant hopper dredge opportunity may emerge through the future construction of Pier Wind at the Port of Long Beach. The project's current design includes approximately 8 MCY of hopper dredge work to be completed over the next ten years, which will be contingent on locating and permitting the dredging of suitable sand sources in Southern California. If implemented, this project would represent a major dredging effort and could further increase regional demand for hopper dredge capacity.

As coastal erosion continues and as private and public entities evolve to support and protect infrastructure, including potential new marine construction development, the need for hopper dredges in Southern California is expected to grow. The anticipated increase in dredging activity over the next decade would exceed levels experienced in the region over the past twenty years. This shift underscores the importance of coordinated planning, strategic permitting, and sustained investment in sediment management to support both coastal resilience and port development.

CITATION

Finegold, J., Garvey, K., and Webb, C. "Southern California's Emerging Beach Fill Demand," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

STRATEGIC USE OF INTRA-PORT MATERIAL FOR SLIP FILL AT PORT OF LONG BEACH PIER G

K.R. Ewert[1] and P. Allen[2]

EXTENDED ABSTRACT

International Transportation Services, LLC. (ITS), in partnership with the Port of Long Beach (Port), has elected to invest in the future of the Port by filling the Pier G Slip in the Port's Southeast Basin. The Port's objective is to double its terminal throughput by 2050 (Port of Long Beach, 2026). This decision to increase the cargo capacity at the ITS terminal is planned to be accomplished through the infill of Pier G and the creation of 19 acres of new laydown space and a 3,400-foot continuous wharf. This is one step towards achieving greater terminal performance and overall trade objectives in the coming decades. The infill of Pier G Slip will require approximately 2.5 MCY of material to be dredged electrically, which will be sourced from within the Port boundaries, as identified in a separate US Army Corps of Engineers (USACE) Deep Draft Navigation Feasibility Study (2019). The Deep Draft Navigation Feasibility Study (Feasibility Study) identified areas within the Port which may be deepened, widened, or newly dredged to improve accessibility of deep draft vessels to terminal facilities with material placement at nearshore sites or a regional Offshore Dredge Material Disposal Site (ODMDS). ITS and the Port recognized the beneficial use opportunity presented by the Feasibility Study to achieve additional operational and accessibility improvements for the Port and its growth initiatives, readily sourcing the quantity of material required for the fill while simultaneously deepening Pier J, the West Basin, and the Southeast Basin (i.e. Pier G), and improving Port-wide access for deep draft vessels through the widening of the Main Channel.

The design of Pier G's slip-fill required sediment characterization across the Port's Main Channel, West Basin, Pier J, and Southeast Basin to understand the material's geotechnical and chemical properties. The characterization effort resulted in approximately 45% of the available material being characterized as unsuitable for open-water placement due to elevated levels of contaminants of concern. Additionally, approximately 80% of all material was determined to have a sand content of 60% or less. The results of the sediment characterization required that dredged material be strategically placed within the fill to beneficially re-use the maximum quantity of poor-quality and contaminated material as possible, followed by the installation of uncontaminated, high-quality material to provide geotechnical stability and create an effective cap within the fill to prevent the migration of contaminants back into the marine environment.

The total quantity of material presented by the Feasibility Study, Port maintenance needs, and regional USACE projects exceed the capacity of the fill, requiring material to be prioritized for selection. The prioritization considered placement suitability of the material, sand content, operational importance to the Port, and the placement needs of USACE. Material of low sand content that was not suitable for open-water

[1] Coastal Scientist, Moffatt & Nichol, 4700 Falls of Neuse Road Ste. 300, Raleigh, North Carolina 27609, USA, T: 661-342-9153, Email: kewert@moffattnichol.com.
[2] Head of Capital Projects, International Transportation Services, LLC., 1281 Pier G Way E, Long Beach, California 90802, USA, T: 562-221-6665, Email: Paul.Allen@itslb.com.

placement typically represents the highest disposal cost if it cannot be beneficially used, offering the greatest positive impact to cost and schedule for the Pier G fill when placed below EL -10' MLLW. This material included 1.15 MCY from Pier J, Port maintenance, regional USACE projects, and portions of the West Basin. The character of the material placed below EL -10' MLLW required a balance of dredging and placement production speed, means, and methods. Placement needed to be coordinated with the timing for concurrent construction of the solid rock containment dike. Material placed below EL -10' MLLW had to be mechanically placed, and material placement could not exceed the height of the rock dike as it was raised to prevent material loss into the Southeast Basin. Above EL -10', approximately 910,000 CY of material suitable for open-water placement and of increasing quality could be placed using more flexible means and methods to provide the fill's geotechnical stability. Further methods to increase the stability of the fill and minimize risk include the permitting of a Contractor-designed sediment trap to manage losses from hydraulically placed material, required placement of the highest quality material (80% sand or greater) between EL 0' and +16' MLLW, installation of wick drains at EL +11', and surcharging of the fill.

Using this strategy, the Port, ITS, and USACE have provided a pathway for the beneficial reuse of 1.15 MCY of contaminated material from within the Port and nearby USACE projects, which would otherwise require costly upland placement. By following unsuitable, low-quality material with the placement of a clean, sandy layer of dredged material, contaminants may be effectively capped within the fill. While the Pier G Slip fill project has elected to utilize material in its immediate vicinity, this strategy could also be expanded to allow contaminated materials from other regional projects completed for Ports, USACE, cities, and counties to be deposited in a fill as a cost-effective alternative to material placement in CDFs or upland disposal. This strategy relies on the availability of a sufficient quantity of uncontaminated, sandy material that could be dredged or imported to produce an environmentally effective, geotechnically stable fill. Use of intra-Port or regional material for fill applications may be repeated in future fill projects with significant quantity needs, such as the future development of Pier Wind, as the Port continues its growth objectives towards 2050.

Keywords: Dredging, maintenance dredging, beneficial uses, dredged material disposal, contaminated sediment.

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CITATION

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SEDIMENT INVESTIGATION AND MANAGEMENT FOR HUMBOLDT REDWOOD MARINE MULTIPURPOSE REPLACEMENT PROJECT

S. Anghera[1] and R. Holmlund[2]

EXTENDED ABSTRACT

The federal government has established a goal of deploying 30 gigawatts (GW) of offshore wind energy by the year 2030 and 110 GW by the year 2050. The State of California has established goals of deploying five GW of offshore wind energy by 2030 and 25 GW by 2045. Studies by the Federal Bureau of Ocean Energy Management (BOEM), the National Renewable Energy Laboratory (NREL), and the California Energy Commission (CEC) have indicated that major port development will be required throughout California for the federal and State goals to be realized. BOEM has leased three sites near Morro Bay, California, and two sites near Humboldt Bay, California to private offshore wind (OSW) energy developers. The Humboldt Bay Harbor, Recreation, and Conservation District (Harbor District) is designing a new terminal to support OSW energy development for these leases.

The Humboldt Bay Offshore Wind Heavy Lift Marine Terminal Project (Project) would redevelop a marine terminal on an approximately 180-acre (73-hectare) site at the Port of Humboldt Bay, California. The terminal will primarily serve as a facility for vertical integration, launching, and long-term maintenance of fully assembled offshore wind turbines. The terminal will also serve as a facility for the manufacturing, import, staging, and preassembly of various components. Marine infrastructure and upland improvements are required to prepare the terminal for use by offshore wind developers to conduct the above activities. The Project includes demolition of existing structures, site preparation, marine terminal construction, new wharves, new dredging to accommodate berths for vessels, wet storage for floating foundations, a sinking basin, and habitat restoration as shown in Figure 1.

This presentation will share the sediment quality, proposed sediment management strategies being considered, and a summary of the anticipated environmental constraints and conditions for construction. Material will be removed using hydraulic and mechanical dredging methods depending on placement/disposal location site(s). Dredging activities will include creation of a new berth pocket, three wet storage areas and a sinking basin. The new dredge design depth will be -40 feet (ft) (12.2 m) mean lower low water (MLLW) at the berths and -38 ft (11.6 m) MLLW at the wet storage areas. A sinking basin will be dredged to -60 ft (-18.3 m) MLLW. Approximately 6,000,000 cubic yards [CY] (4,587,000 cubic meters [CM]) of material will be dredged. Approximately 5,000,000 CY (3,823,000 CM) of sand will be placed either as temporary surcharge for ground improvements or directly placed at Samoa Beach (outside of Humboldt Bay) for beneficial use. If placed as surcharge, material will be hauled to the beach for

[1] Principal Scientist, Moffatt & Nichol, 630 Grand Avenue, Carlsbad, California, 92008, USA, T: 714-296-9017, Email: sanghera@moffattnichol.com. (corresponding author).
[2] Development Director, Humboldt Bay Harbor, Recreation and Conservation District, 601 Startare Drive, Eureka, California, USA. T: 707-443-0801, Email: rholmlund@humboldtbay.org.

beneficial use after surcharge is complete. A portion may remain on site as fill. Approximately 1,000,000 CY (765,000 CM) of fine-grained material will be disposed offshore at an approved ocean disposal site if suitable and upland if not suitable. Other potential beneficial reuse options include nearshore nourishment adjacent to Samoa Beach, use as permanent fill at the Project site, or to raise elevations at nearby salt marshes to support habitat restoration efforts.

Figure 1. Conceptual site layout with dredging areas.

Keywords: Dredging, beneficial uses, capital dredging, sediment management strategies, offshore wind energy.

CITATION

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JAMES RIVER DREDGED MATERIAL SEDIMENT TRANSPORT STUDY: LESSONS LEARNED

T.C. Lackey[1], E. Hayter[2] and S. Bailey[3]

ABSTRACT

The Engineer Research and Development Center (ERDC) has developed a regional operational model for sediment transport at the request of the USACE Norfolk District to improve sediment management in the entire lower James River initiative. The goal of this work is to ultimately help reduce economic costs and maintain navigation while protecting environmental concerns. The fate of material placed during dredging operations within the James River at the channel adjacent placement mounds is described within this article. The study focuses on the potential migration of the placement mound into the channel as well as the transport of sediment resuspended during placement at the Dancing Point - Swann Point, Tribell Shoals, Goose Hill, Jordan Point, and City Point Shoal locations. A select combination of ERDC developed models was utilized to appropriately simulate hydrodynamic conditions, pipeline discharge near field suspended sediment estimates, far field transport of the pipeline discharge source term, and mound migration. Results show that for the likely conditions simulated, maximum predicted levels of increased SSC remain ~100 mg/l or less above background at all sites and deposition levels from resuspended material remain less than 1cm. The life cycle of all placement areas is 19-26 years (+/- 6 yrs). It was also shown that in all placement sites, 5% or less of the placed material is migrating back into the navigation channel within 2 years of dredging. Ultimately, the goal of this article is to summarize a process used to understand regional sediment transport of dredged material that may be extended to other locations and describe lessons learned.

Keywords: Dredging, sediment transport, numerical modeling, dredged material placement, contaminated sediment.

INTRODUCTION

Over the last decade, the U.S. Army Engineer Research and Development Center (ERDC) and USACE Norfolk District (NAO) have worked together to gain a better understanding of sediment transport within the lower James River area (Figure 1). This work is a part of a Regional Sediment Management (RSM) initiative to comprehend and support navigation challenges by looking at systems holistically and scientifically. Increased dredging costs over recent years along with Operations and Maintenance budget cuts have decreased the amount of dredging that can be accomplished to maintain the navigation project to meet navigation needs and the goal of unrestricted navigation on the James River. Supporting decision making with quantitative analysis is essential to making effective decisions. Utilizing numerical modeling,this work addresses questions that, if answered, will support RSM goals for the James River. This

[1] US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road Vicksburg, MS 39180-6199. 601-634-3552 Tahirih.C.Lackey@usace.army.mil
[2] US Army Engineer Research and Development Center Environmental Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199. 864-280-0935 Earl.Hayter@usace.army.mil
[3] US Army Engineer Research and Development Center Environmental Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199l. 601-634-3932 Susan.E.Bailey@usace.army.mil

paper is designed to outline methods applied, emphasize results and conclusions, and finally describe lessons learned.

Figure 1. James River RSM initiative study area.

The James River Federal Navigation Project was congressionally authorized by the River and Harbors Act of 5 July 1884 and modified by the River and Harbor Act of 13 June 1902, 3 March 1905, 3 July 1930, 26 August 1937, 2 March 1945, 17 May 1950, and 23 October 1962. The federal navigation channel in the James River runs from Hampton Roads to Richmond, Virginia, a distance of approximately 90 miles (Figure 1). The project provides for a channel 35 ft deep and 300 ft wide from Hampton Roads to Richmond Deepwater Terminal, approximately 86 miles in length. However, the channel is currently maintained to a maximum dredging depth of 28 ft and 300 ft wide. One million cubic yards (CY) of material are currently dredged per year in the James River. In some areas, dredging must occur twice yearly. When dredging is not performed, load restrictions are placed on vessels, ultimately resulting in economic losses. A better understanding of the impact of strategically placed dredged material and sediment transport patterns in the system is required to evaluate efficient operational strategies which control dredging costs and reduce load restrictions.

Dredging placement operations in the area utilize pipeline placement methods. Material is pumped from the dredge and placed within multiple channel adjacent placement sites (see orange locations in Figure 1). Current questions exist regarding the length of time (years) the placement sites will be available for placement. In most cases, the cost of transporting the material to offshore coastal placement areas would be significant. In addition, there is a question of whether dredged material placed at the sites is migrating back into the channel. Removing the same dredge material multiple times is a concern.

OBJECTIVES

The general goal of this work was to develop and communicate an understanding of the sediment-transport processes and the alternative sediment management strategies in the James River system. However, specifically this paper addresses the following questions asked by NAO:

- What are exposure (suspended sediment concentration, deposition, etc.) levels during placement? Is there significant risk to nearby critical environmental receptors (habitat, species, etc.) due to resuspended dredged material?
- What is the life cycle of the dredged material placement areas?
- Is material that is placed during dredging operations migrating back into the channel?
- Are there risks from PCB contaminated sediment, primarily at City Point Shoal.

In addition to these primary questions, sediment transport sensitivity with respect to location of the material placed within the placement sites was also investigated. The hope was to determine if specific locations within the placement site might yield lower exposure values for critical environmental receptors such as habitat and fish migration areas.

These objectives were accomplished using models developed by the ERDC that can predict hydrodynamics and sediment transport for the area. Understanding the fate of material placed in approved shallow-water sites (Figure 1) should provide vital information to the James River operations and maintenance (O&M) team. The results should help the James River O&M team optimize budget, minimize ecological risk as well as the risk from the contaminated sediment, and prepare for future years of dredging.

APPROACH

Numerical modeling was used to address the previously described sediment transport questions. Utilizing data either collected in the field specifically for this project (hydrodynamic information, sediment characterization information, etc.) or supplied by NAO (dredging operation parameters) numerical models were utilized to predict resuspension and transport of sediment in the area. The modeling was divided into short-term concerns which might focus on 2-4 weeks and long-term concerns which focused on timeframes six months - decades. From the hydrodynamic modeling, it was determined the typical hydrodynamic conditions such as velocity, water surface elevation, and salinity. The pipeline placement model predicts how much sediment is resuspended during placement and is available for transport. Far-field fate modeling was used to determine where immediately available sediment is transported in the short term. Morphology modeling was used to predict the life cycle of the placement site and potential migration of material from the placement site back into the channel.

The following specific models were applied in this effort:

Continuous Discharge Fate of Dredged Material (CDFATE)

Discharge of dredged sediment into a receiving body, results in the formation of a plume. The size, location, and vertical and horizontal movement of the plume in the water column, and hence the impact on the receiving water, can be estimated using the Continuous Discharge Fate of Dredged Material (CDFATE) model and its component models (Continuous Dredge Disposal Mixing Zone [D-CORMIX] and Disposal from a Continuous Discharge [DIFCD]). These models can be used to determine the extent of the nearfield mixing zone; that is, that area in the immediate vicinity of the discharge point where water-quality parameters may exceed established criteria. Information describing the receiving water environment, the dredged-material disposal method, and the mixing zone is provided to the model. The model will use these data in concert with numerical computations to generate output describing the plume location, plume geometry, and pollutant concentrations within the plume as a function of time.

Particle Tracking Model (PTM)

The PTM is a Lagrangian particle tracker designed to simulate particle-transport processes (McDonald et al. 2005, Gailani et al. 2016, Lackey et al 2020). PTM has been developed for application to dredging and coastal projects, including dredged-material dispersion and fate, sediment pathway and fate, and constituent transport. The model contains algorithms that appropriately represent transport, settling, deposition, mixing, and resuspension processes in nearshore wave and current conditions. It uses waves and currents developed through other models and input directly to PTM as forcing functions.

Geophysical Scale Transport Multiblock Modeling System (GSMB)

The Geophysical Scale Transport Multiblock Modeling System (GSMB) is a modeling system that includes the Curvilinear-Grid Hydrodynamics Model in Three Dimensions (CH3D) hydrodynamic model and the Sediment Transport—Ziegler, Lick, and Jones (SEDZLJ) mixed sediment-transport model (Hayter et al. 2018; LaBuhn et al. 2018). SEDZLJ is dynamically linked to CH3D so that simulated changes in bed morphology (that is, spatially varying bed elevation) due to erosion and deposition are automatically accounted for during a model run in predicting the new flow field using CH3D. GSMB can be used as a site-evaluation tool to estimate the dispersion characteristics of a dredged-material placement site over long periods of time, ranging from several days for storm events to a year or more for ambient conditions. SEDZLJ has the capability of simulating both noncohesive and cohesive sediment transport. In addition, avalanching of noncohesive sediments and consolidation of cohesive sediments are simulated to accurately predict physical processes that occur at the site.

These models were used at each of the James River placement sites to evaluate sediment transport and water column impacts resulting from dredged material placement.

RESULTS

Predicted Exposure Levels

General Exposure

The first question addresses the level of exposure at each of the placement sites based on material that has been resuspended during dredging. This was accomplished utilizing GSMB for hydrodynamics, CDFATE to predict the amount of sediment resuspended during placement, and PTM to ultimately determine the fate of the resuspended dredged material (Lackey et al 2020, Lackey et al 2022, Lackey et al 2025a, Lackey et al 2025b).

Placements at multiple locations within each placement area were simulated to determine which location yielded the highest expected exposure (suspended sediment concentration and deposition). It should be noted that in most cases, the exposure level was independent of changes of location within the placement site. Tribell Shoals proved to be an exception to this trend. At that placement site, exposure was dependent on location of the material placed within the site. More information regarding that exposure investigation can be found in next section of this article.

Results are shown for exposure values of suspended sediment concentration and accumulation at the Dancing Point-Swann Point placement site (Figure 2). This site was chosen because it shows the maximum values of exposure for the James River study area. At Dancing Point - Swann Point, separate one-month PTM simulations were performed at three release positions. PTM release/source points 2, 4 and 6 are located on the placement site adjacent to channel stations 59+00, 205+00, and 342+00 respectively. Results

of the CDFATE modeling for this work suggest the amount of sediment resuspended during placement ranges between 3 and 7 percent, which agrees with what is generally thought to occur in the field. These results were used to generate PTM source terms for discharge at the three locations within the placement area.

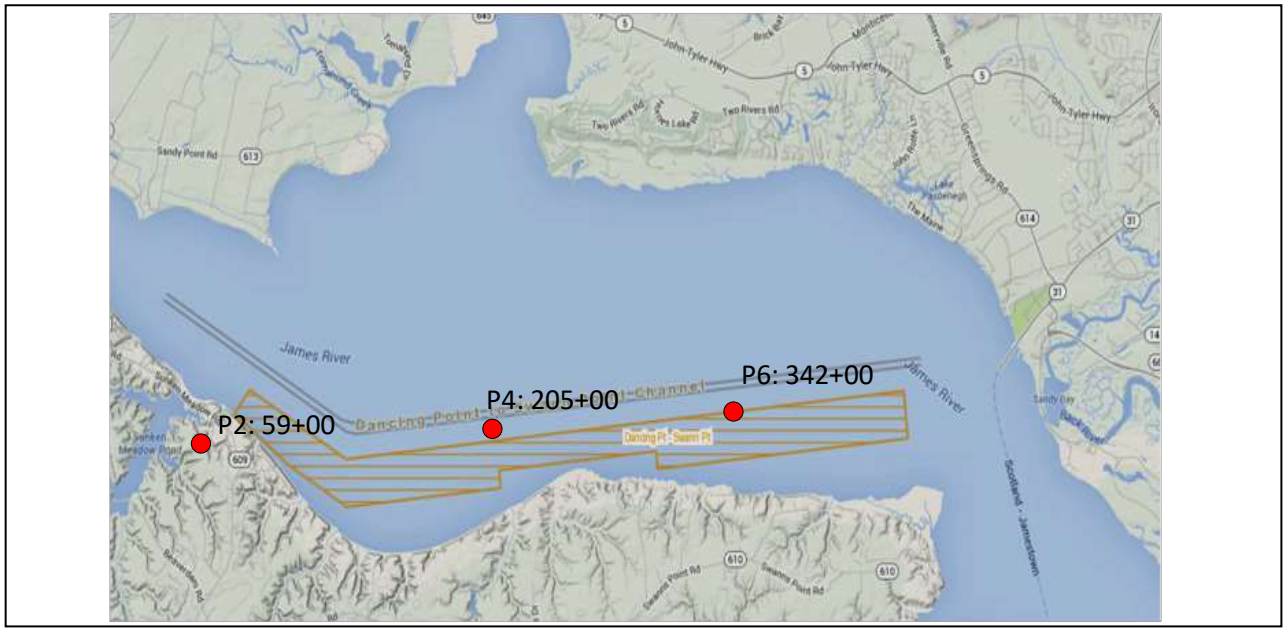

Figure 2 Dancing Point - Swann Point placement site and modeled placement locations 2, 4, and 6.

PTM results show that the maximum suspended sediment concentration (Figure 3) for all three locations was on the order of 100 mg/l. However, in areas outside of the placement site, suspended sediment concentration values were less than 40 mg/l. These values are relatively modest in comparison to background suspended sediment for this area which can range from 5 mg/l to 300 mg/l depending on the meteorological and hydrodynamic conditions.

It was determined that sediment placed on the upstream end tended to deposit and remain near the placement site. The maximum depth of deposited material (0.50 cm) occurred in that scenario (Figure 4a). The largest predicted mass rate of material released to the water column was from the release point near the middle of the placement site. The footprint of deposited material was the most extensive for that case (Figure 4b). The least amount of deposited material was modeled from the downstream release point. In comparison to the other two release points, more sediment is transported away from the area of interest for that scenario.

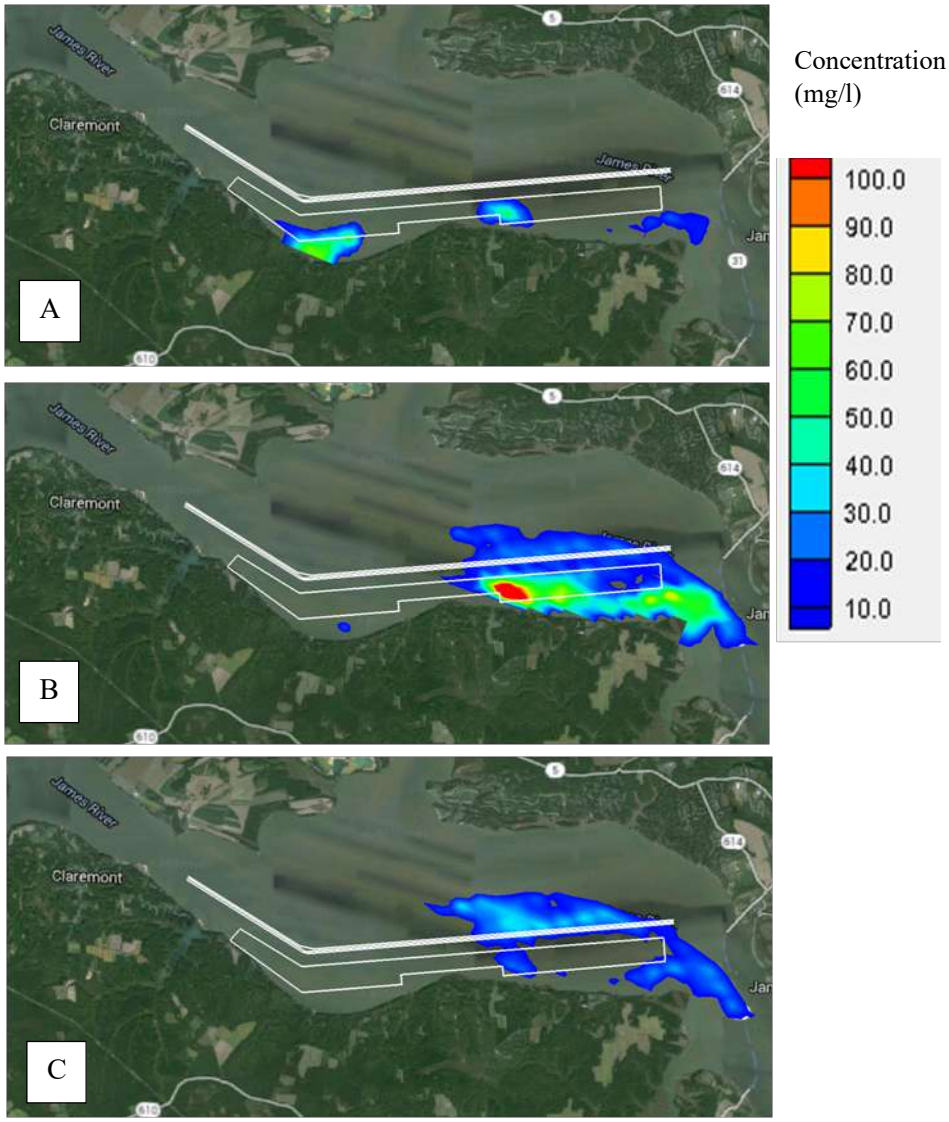

Figure 3 Dancing Point – Swann Point Suspended Sediment concentration (mg/L) for a) placement location 2, b) placement location 4, and c) placement location 6 after 2 weeks.

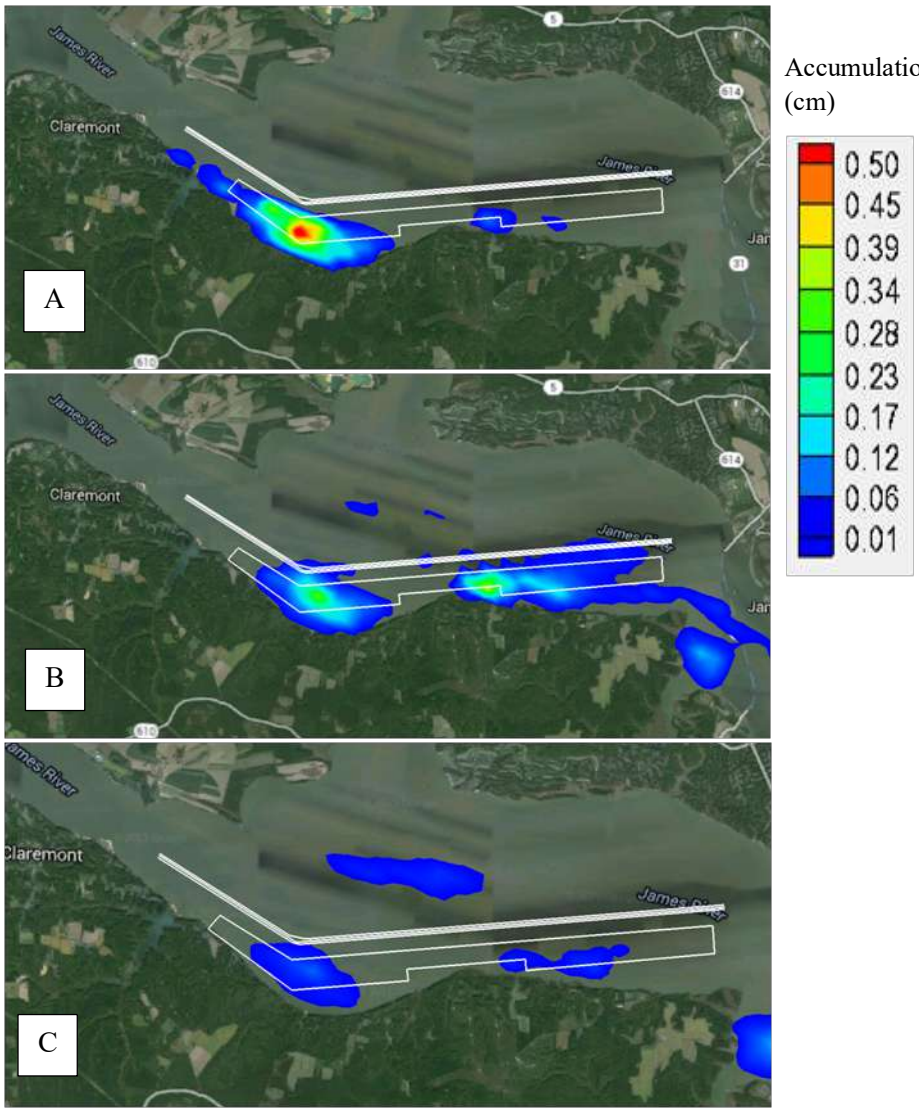

Figure 4 Dancing Point – Swann Point Accumulation (cm) for a) placement location 2, b) placement location 4, and c) placement location 6 after 2 weeks.

Tribell Shoals Placement (Oyster Leases)

The Tribell Shoals area (Figure 5) of the James River, located near the middle James River study area, has special considerations. When sediment is dredged from the channel (shown in red) and then placed utilizing pipelines at adjacent placement sites (shown in yellow), it may provide risk to nearby oyster leases (shown in blue). Currently sediment is pumped to the upstream placement site (location 1 on the map). Due to a longer pipeline pumping distance, placing material at that location is expensive. However, there is a concern that if material is placed further downstream, there may be a negative impact to the nearby oyster leases.

Figure 5 Tribell Shoals placement site

It should be mentioned that to discuss the risk to the oysters due to dredging, a general understanding of effects characterization must be performed as well. Risk assessment in dredging combines the information of the strength, duration, and location of dredge material that enters the water column (exposure) with an understanding of the critical levels that will have a negative impact on the receptor (effects). Therefore, in the case of the James River, it is not enough to know how much sediment is introduced into the water column and to predict its fate. There must also be an assessment of the critical levels needed to impact the oysters.

In an effort to understand the critical levels which may impact the eastern oyster (*Crassostrea virginica Gmelin*) found in the James River, Suedel et al (2015) performed a laboratory study mimicking sediment resuspension during annual dredging operations in the James River. Field-collected oysters were exposed for 7 days to total suspended solid levels up to 500-mg/L. Results indicated no significant negative effects of suspended sediment at those levels after 7 days of exposure.

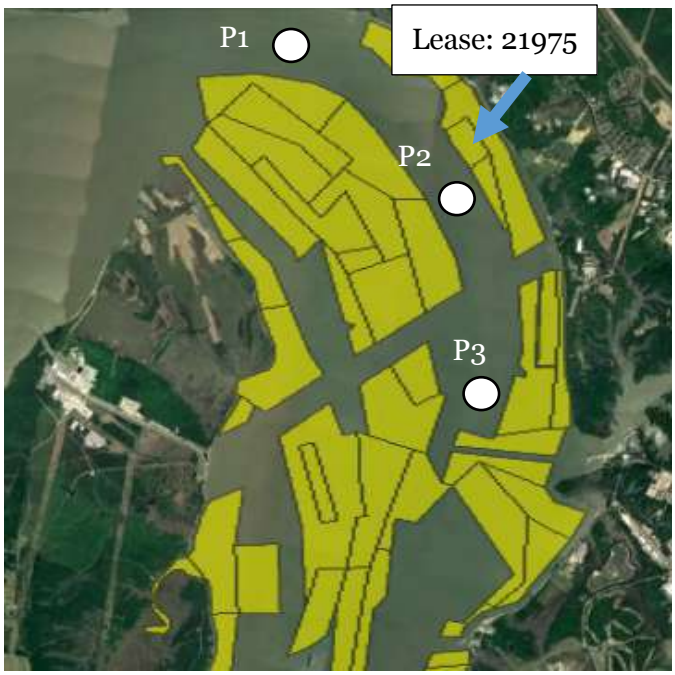

Figure 6 Oyster lease locations.

An example of results is in Figure 7 which shows predicted suspended sediment concentration time (mg/l) series at oyster lease 21975 (Figure 6). The location of oyster lease 21975 is very close to placement location 2. Despite the proximity, the middle location shows less resuspension of sediment and lower values of SSC (less than 10 mg/l SSC), most likely due to the lower velocities predicted in that area.

Generally, for the parameters (velocities, production rates, etc.) explored in this work, the predicted values of resuspended sediment is less than 50 mg/l which is a tenth of the values the oysters were shown to tolerate (Suedel et al. 2015). The model parameters, described in detail in Lackey et al 2023, are based on the most reasonable characterization of resuspended sediment amounts during placements. However, it should be noted that extensive sensitivity studies were run to determine the impact of increased amount of total sediment resuspended during placement or a decrease in parameters such as settling rate. It was determined that when these values were adjusted to most conservative values possible (maximum erosion rates and lowest possible settling rates), the maximum values of suspended sediment concentration at the oyster leases increased significantly to >250 mg/L. However, the overall trend stayed the same, in which the middle location showed the least amount of resuspension and the lowest values of SSC for those parameters. Therefore, the middle location remains the best placement location with respect to risk to the oyster leases.

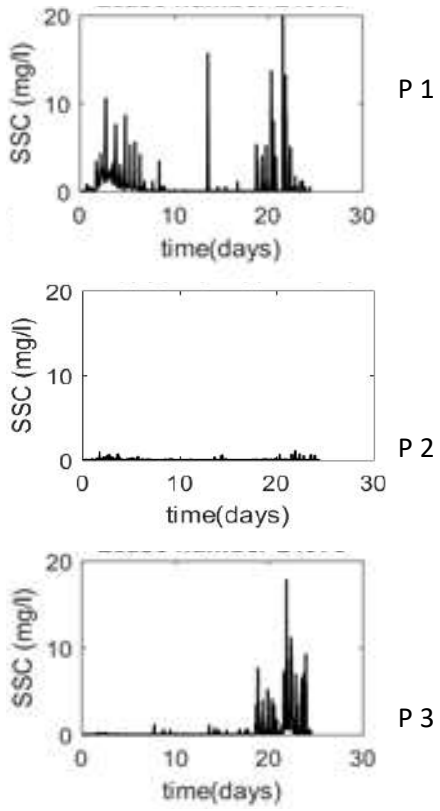

Figure 7 Comparison of SSC time series for each placement site at an oyster lease

Determination of Channel Shoaling Source and Lifecycle of Place Site

The next focus for this work was to determine if NAO redredged the same material due to sediment transporting from the placement site back into the navigation channel over time. Modeling was performed to determine the source of the sediment depositing in the navigation channel within the study area. The GSMB-SEDZLJ model simulated the two-year period 01 Jan 2011 – 31 Dec 2012 during which the sediment loads from the Upper James and Chickahominy Rivers as well as eroded sediment from the dredged material placement sites were traced using different sediment size classes.

Table 1

	Jordan Point		Dancing Point – Swann Point		Goose Hill		Tribell Shoals	
	After 1 year	After 2 years	After 1 year	After 2 years	After 1 year	After 2 years	After 1 year	After 2 years
Total Channel Deposition (CY)	35,000	72,000	440,000	820,000	360,000	680,000	140,000	265,000
Upstream Source	98%	97%	93%	92%	95%	95%	90%	90%

	Jordan Point		Dancing Point – Swann Point		Goose Hill		Tribell Shoals	
	After 1 year	After 2 years	After 1 year	After 2 years	After 1 year	After 2 years	After 1 year	After 2 years
From Placement Site	1%	1%	2%	2%	1.4%	1.3%	3%	3%
Other sources	1%	2%	5%	6%	3.6%	3.6%	7%	7%

Table 1 shows the initial location of the sediment that is ultimately deposited into the channel near the placement side after 1 year and after 2 years. As can be seen in the table for each of the four sites investigated, most of the material (>90 %) is transport from upstream and less than 5% of material within the channel comes from the placement sites. This suggests that NAO is not redredging the same material to a significant extent.

Table 2 Life Cycle Analysis at Dredge Material Placement Sites

Placement Site	**Life Time (yrs)**
Dancing Point – Swann Point	19
Goose Hill	21
Tribell Shoal	22
Jordan Point	26

Life cycle analysis was performed by extending the simulations to 10 years. The results (i.e., change in bathymetry in each of the dredge material placement sites) at the end of the 10-year simulation were used to estimate the usable lifetime of these sites by extrapolating the results to 20+ years. Using this method, predicted placement site lifetimes were found to range from 19 to 26 years.

Based on the analysis performed at other sites that semi-quantified the uncertainties of this analysis, the estimated uncertainty bound associated with these estimates is +/- six years. The largest sources of uncertainty for this type of analysis are: 1) the assumption that the annual maintenance dredge volumes in the navigation channel reaches will remain the same as they were in 2017-2018; 2) the constructed 10-year meteorological and hydrological conditions are reasonably representative of those over an actual decade; and 3) the sediment loads from the tributaries will follow the same regression relationships as used in this study.

Contaminant Transport at City Point Shoals

City Point Shoal differs from the other sites in that it is only dredged once a decade and the dredged material has potential PCB contaminants associated with it. The purpose of the two-year simulation of PCB transport for the City Point Shoal Placement Site was to determine the fate of the PCB contaminated sediment after

it was eroded from the placement site. Previous work at the site has shown that there is the potential for the contaminated sediment to be transported away from the site during dredging.

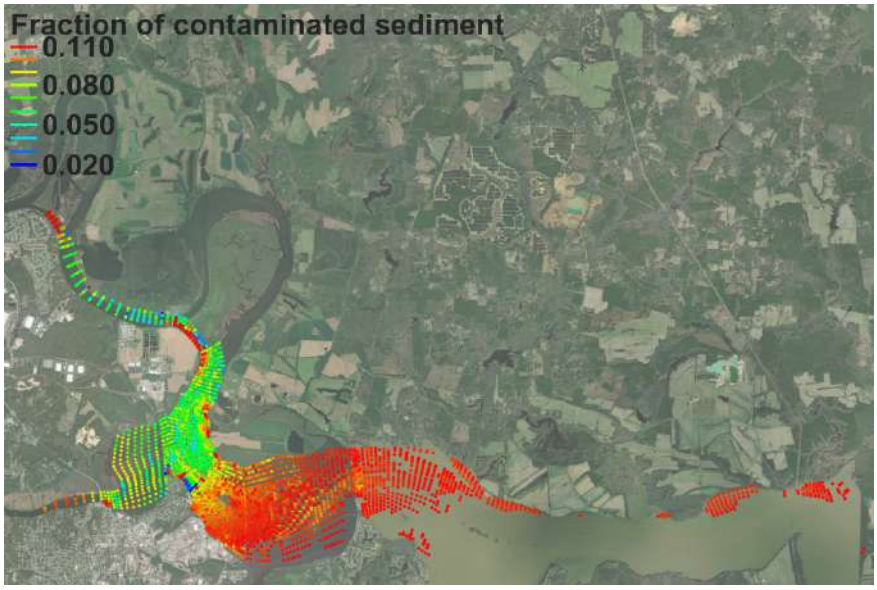

Figure 8 Location of contaminated sediment at the end of the two-year simulation

Figure 8 shows that the contaminated sediment was transported upstream in both the James and Appomattox Rivers during flood tides as well as downstream from the City Point shoal site during ebb tides. At the start of the simulation 70 percent of the sediment within the City Point Shoal Placement Site was composed of the contaminated sediment, whereas at the end of the two-year simulation the maximum percentage of the contaminated sediment anywhere was 10 percent. This indicates a net export of the PCB contaminated sediment from the City Point Shoal site to locations both upstream and downstream of the site. The PCB concentration in each grid cell has units of mass of PCBs per bed volume (e.g., kg/m^3) where the bed volume is equal to the thickness of the second bed layer times the surface area of each grid cell. So as the percentage of the contaminated sediment decreases, the PCB concentration decreases as well.

CONCLUSIONS

The following are conclusions and lessons learned during the process of modeling and analysis of the lower and middle James River Regional Sediment Management project. Conclusions based on specific placement sites are included, followed by general analysis of the overall system.

Dancing Point – Swann Point

- Most of the material released into the water column remains in the placement area or is transported out of the area of interest downstream, rather than re-entering the channel.
- Mound migration results indicate that little of sediment from the placement mound moves into the channel. The fine-grained nature of these sediments precludes these small volumes of sediment from depositing in the channel where the currents are strong. These results suggest that channel sedimentation is most likely caused by upstream sediment sources not represented in this study.

Tribell Shoals

- Results show that exposure is largest towards the downstream or southern end of the placement site. The middle location, most likely due to the lower velocities predicted in that area, shows less resuspension of sediment (less than 10 mg/l) and overall lower exposure.

- Predicted suspended sediment concentration when utilizing expected modeling parameters is less than 50 mg/l, which is much less than values that may be critical to the oysters. Previous work (Suedel et al. 2015) suggest that values would need to be maintained at well over 500 mg/l for weeks to impact the oysters. The values seen in this analysis are all acute (peak values that quickly dissipate).

Goose Hill

- The GSMB model provided a clear indication of the source of the channel shoaling. Results showed that the vast majority of the shoaling at this site is the result of deposition of a portion of the suspended sediment load.

Jordan Point

- Material placed at Jordan Point appears to quickly disperse through the system, depositing in thin layers at specific areas. The areas of deposition can most likely be attributed to the strong curvature of the James River near Jordan Point. Results seem to be independent of any specific location within the placement site.

City Point

- The two-year GSMB sediment transport simulation showed that the annual average net shoaling thickness at the City Point Shoal Placement Site was 2.5 cm, and was 2.6 cm in the City Point navigation channel. The average annual shoaling rates were 18,600 CY and 13,000 CY, respectively, in the City Point Shoal Placement Site and City Point navigation channel.
- The two-year simulation showed that there was a net export of the PCBs from the City Point Shoal to locations both upstream and downstream of the site. The concentrations of the PCB contaminated sediment varied with distance from the City Point Shoal site, i.e., they did not consistently decrease with increasing distance from the site.

General Conclusions for all sites

- For the one-month PTM simulations, maximum predicted levels of increased SSC remain ~100 mg/l or less above background at all sites.
- For the one-month PTM simulations, maximum increased deposition remains below 1cm.
- Predicted placement site lifetimes were found to range from 19 to 26 years.
- Less than 5% of material within the channel comes from the placement sites. This indicates that we are not re-dredging the same material.

General Lesson's Learned

- This work was accomplished over a decade through the perseverance of multiple agencies and collaborators. While understanding sediment transport within areas such as the James River is essential, it requires a great deal of expertise and support.
- Even with this level of effort, there is generally more work to be done and more questions to be answered. Creating conditions of collaboration is essential to accomplishing this work.

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CITATION

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DATA AVAILABILITY

All models, or code generated or used during the study are available in a repository or online in accordance with data retention policies of USACE.

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CUTTERHEAD DREDGING ON THE USACE PORTFOLIO: HISTORICAL DATA ANALYSIS

M. Asborno[1], B. Emery[2], A. Gharagozlou[3], A.D. Godfrey[4], C. Phillips[5], and K.N. Mitchell[6]

ABSTRACT

The U.S. Army Corps of Engineers (USACE) oversee the operations and maintenance of all Federal Navigation Channels, totaling over 25,000 miles of navigable waterways. To maintain channels at Congressionally authorized dimensions, the USACE dredges on average 230 MCY of sediment per year. Multiple types of dredges are used in these operations, such as Mechanical, Hopper, and Cutterhead Suction Dredges (CSD). Annually, USACE has solicited an average of 250 dredging contracts, with CSD accounting for 42% of these. Due to the gap in literature about CSD dredging, this paper provides an insight into the US CSD fleet and historical productivity across several metrics. Sample metrics include time spent in standardized dredging cycle activities (categorized into effective, non-effective, and lost time), discharge pipe length, cubic yards dredged, fuel consumed, type of material dredged, etc. Insights are mined from over 114,500 daily dredge logs of roughly 1,000 contracts broken down into 3,700 dredging events, or "projects" recorded across 15 years (between 2010 and 2025) on the Resident Management System (RMS), a database developed by USACE for construction management purposes. Findings are presented by region and dredge size. The trends and observations provided in this paper are intended to assist practitioners with real world data for planning and assessing future dredge projects.

Keywords: Dredging, Cutterhead Suction Dredges (CSD) fleet, productivity, dredged material disposal.

INTRODUCTION

The U.S. Army Corps of Engineers oversee the operations and maintenance of all Federal Navigation Channels, totaling over 25,000 miles of active waterways. These projects span across the nation, with projects representing 41 of the 50 U.S. states. These projects, differing in authorized depths and widths, sediment type, and physical conditions/constraints, require different methods of maintenance to ensure they remain at congressionally authorized dimensions. While engineered structures such as training dikes and

[1] Research Civil Engineer, Applied Research Associates, 119 Monument Pl, Vicksburg, MS 39180, USA, t: 601-634-2010, Email: masborno@ara.com; magdalena.asborno@usace.army.mil; (corresponding author).
[2] Research Civil Engineer, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, T: 601-842-4632, Email: benjamin.e.emery@usace.army.mil
[3] Coastal Engineer, Taylor Engineering, 10199 Southside Blvd STE 310, Jacksonville, FL 32256, USA, T: 904-731-7040, Email: agharagozlou@taylorengineering.com
[4] Research Civil Engineer, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, T: 912-805-9033, Email: anna.d.godfrey@usace.army.mil
[5] Jr Software Engineer, Applied Research Associates, 119 Monument Pl, Vicksburg, MS 39180, USA, t: 601-634-9410, Email: cjphillips@ara.com.
[6] Research Civil Engineer, US Army Corps of Engineers Research and Development Center, 3909 Halls Ferry Rd, Vicksburg, MS 39180, USA, T: 601-529-9005, Email: kenneth.n.mitchell@usace.army.mil

levees help to maintain depths in certain portions of waterways, dredging remains the most effective tool for the Army Corps of Engineers. Annually, the USACE removes over 230 MCY of sediment from these Federal Navigation Channels. To do so, the USACE relies on multiple types of dredges such as Mechanical, Hopper, and Cutterhead Suction Dredges (CSD). This paper will focus on the CSD, providing an insight into the U.S. CSD fleet and historical productivity across several metrics. The observations provided in this paper are intended to assist practitioners with real world data for planning and assessing future dredge projects.

What is cutterhead dredging?

The vast majority of USACE dredging is contracted to and performed by the private dredging industry. Annually, USACE has solicited an average of over 250 dredging contracts, with CSD accounting for roughly 42% of these solicitations (based on DQM data between years 2021-2023). Although CSDs make up a large portion of the dredging within the U.S., many are unfamiliar with this type of dredge and how it works.

Differing from Mechanical Dredges, which rely on barges or scows to transport material after mechanically excavating it, or from self-propelled Traction Suction Hopper Dredges (TSHD), which hydraulically load material into their hopper bins and then transport it to a designated placement site, CSD mechanically excavates material and hydraulically transport it via a pipeline to a placement area. CSDs use a rotating head equipped with blades to loosen sediment and a pump system to directly transport sediment slurry via pipeline to its designated placement site, allowing for continuous sediment removal. The dredge itself is a non-self-propelled vessel that relies on an attendant fleet for operations. A typical Cutterhead Suction Plant will include the Dredge, Anchor Barge(s), Fuel Barge(s), Work Barges(s), Tows/Tugs, and often, a separate crew, known as a “bull-gang crew”, responsible for setting up and taking down pipeline (Figure 1). During operation, the dredge moves (“swings”) around a spud pole, to cover a “cut”.

The theoretical estimation of productivity for CSDs relies heavily on pump slurry curves, designed specifically for the type of pump employed by the dredge. These curves provide pump output capabilities based off Horsepower (HP) and Head Differential (depth) in varying sediments (Randall 2022). Although these curves can provide estimated rates of transport, this does not necessarily equate to the productivity seen at the jobsite. Beyond pump capabilities, there are other CSD ship characteristics that influence productivity, such as the type of cutterhead, step speed ahead, swing speed and force, and spud system. In addition, boundary work conditions like water velocity, the type of soil to be dredged, the cutting pattern, possible slopes to be dredged, and the material excavation process itself influence production rates (Vlasblom, 2003). Moreover, activities such as moving anchor, moving out of the way of traffic, moving pipelines; coupled with adverse weather conditions, changing sediment types, and elevation/distance changes all contribute to work delays, and reduce actual productivity achieved. Understanding how these aspects affect the total productivity of the dredge operation can assist practitioners such as planners, cost engineers, and operations managers in refining project cost and schedules.

While there are many publications that offer insight on ways to estimate or increase productivity within CSDs, to the authors’ knowledge, there has not been an effort made to evaluate historical CSD productivity on a large scale. The USACE Engineer Research and Development Center (ERDC) has compiled over 114,500 individual daily dredge records, accessed through the Resident Management System (RMS), from USACE CSD contracts from 2010 to 2025, to provide a productivity analysis and fleet summary. While several factors that influence CSD productivity cannot be assessed with the variables tracked by RMS (such as step speed ahead, swing speed and force, spud system, water velocity, etc.), RMS does provide insights

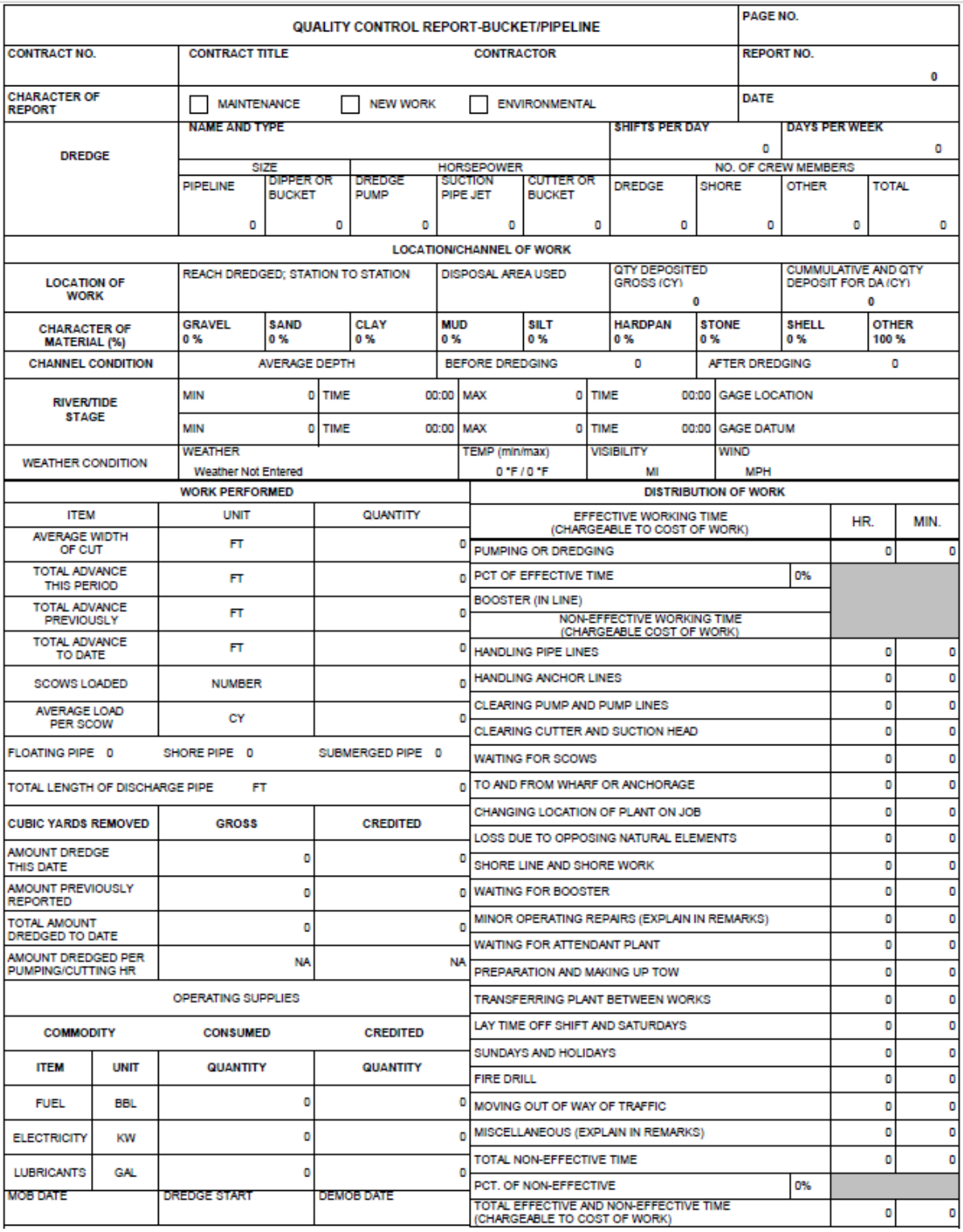
into cycle time activities, discharge pipeline, fuel consumption, sediment type and volumes, and many others. This paper mines and analyzes RMS data to address CSD fleet and productivity trends.

Figure 1. CSD with beach placement (Frabotta, 2012)

Resident Management System (RMS) Dataset

The Resident Management System is used by the USACE for construction oversight and contract execution for all types of construction projects (USACE, 2021; USACE, 2025). For dredging contracts, the RMS requires contractors to fill out daily production worksheets, which are reviewed by USACE quality assurance personnel for progress payments. These daily production worksheets contain a multitude of data points ranging from specific cycle time activities and non-effective time breakouts to length of discharge pipeline, daily quantities and type of sediment removed, which dredge plant and placement areas are being used, weather, fuel usage, and more (Emery et al, 2022). Figure 2 shows a sample daily production worksheet. While most USACE Districts are using this system, it does not have a full accounting of every dredging project in the nation. The ERDC has been able to compile over 260,000 individual daily productivity reports (including CSD, TSHD, and mechanical dredges), from which 44% (114,500) correspond to 982 contracts where approximately 215 CSDs worked at 28 USACE Civil Works Districts between 1 January 2010 and 17 September 2025 (Figure 3). RMS records were subjected to data preparation to mitigate reporting inconsistencies that hindered automated data mining. This process involved standardizing dredge name identifiers and correcting evident erroneous entries related to daily volumes, discharge pipe lengths, and other critical attributes. Those records spanning 15 years of historical data are used to generate figures and analysis in this work.

The RMS has been leveraged to assess broad productivity trends for hoppers and cutterhead dredges across the USACE portfolio (Emery et al, 2022), and to characterize the type of sediment dredged (Caldwell et al, 2024).



QUALITY CONTROL REPORT-BUCKET/PIPELINE									PAGE NO.
CONTRACT NO.	CONTRACT TITLE		CONTRACTOR						REPORT NO. 0
CHARACTER OF REPORT	☐ MAINTENANCE	☐ NEW WORK	☐ ENVIRONMENTAL						DATE
DREDGE	NAME AND TYPE					SHIFTS PER DAY 0		DAYS PER WEEK 0	
	SIZE		HORSEPOWER			NO. OF CREW MEMBERS			
	PIPELINE 0	DIPPER OR BUCKET 0	DREDGE PUMP 0	SUCTION PIPE JET 0	CUTTER OR BUCKET 0	DREDGE 0	SHORE 0	OTHER 0	TOTAL 0
LOCATION/CHANNEL OF WORK									
LOCATION OF WORK	REACH DREDGED; STATION TO STATION		DISPOSAL AREA USED			QTY DEPOSITED GROSS (CY) 0		CUMMULATIVE AND QTY DEPOSIT FOR DA (CY) 0	
CHARACTER OF MATERIAL (%)	GRAVEL 0 %	SAND 0 %	CLAY 0 %	MUD 0 %	SILT 0 %	HARDPAN 0 %	STONE 0 %	SHELL 0 %	OTHER 100 %
CHANNEL CONDITION	AVERAGE DEPTH		BEFORE DREDGING 0			AFTER DREDGING 0			
RIVER/TIDE STAGE	MIN 0	TIME 00:00	MAX 0	TIME 00:00	GAGE LOCATION				
	MIN 0	TIME 00:00	MAX 0	TIME 00:00	GAGE DATUM				
WEATHER CONDITION	WEATHER Weather Not Entered		TEMP (min/max) 0 °F / 0 °F	VISIBILITY MI	WIND MPH				

WORK PERFORMED

ITEM	UNIT	QUANTITY
AVERAGE WIDTH OF CUT	FT	0
TOTAL ADVANCE THIS PERIOD	FT	0
TOTAL ADVANCE PREVIOUSLY	FT	0
TOTAL ADVANCE TO DATE	FT	0
SCOWS LOADED	NUMBER	0
AVERAGE LOAD PER SCOW	CY	0

FLOATING PIPE 0 SHORE PIPE 0 SUBMERGED PIPE 0

TOTAL LENGTH OF DISCHARGE PIPE FT 0

CUBIC YARDS REMOVED	GROSS	CREDITED
AMOUNT DREDGE THIS DATE	0	0
AMOUNT PREVIOUSLY REPORTED	0	0
TOTAL AMOUNT DREDGED TO DATE	0	0
AMOUNT DREDGED PER PUMPING/CUTTING HR	NA	NA

OPERATING SUPPLIES

COMMODITY		CONSUMED	CREDITED
ITEM	UNIT	QUANTITY	QUANTITY
FUEL	BBL	0	0
ELECTRICITY	KW	0	0
LUBRICANTS	GAL	0	0

MOB DATE	DREDGE START	DEMOB DATE

DISTRIBUTION OF WORK

EFFECTIVE WORKING TIME (CHARGEABLE TO COST OF WORK)		HR.	MIN.
PUMPING OR DREDGING		0	0
PCT OF EFFECTIVE TIME	0%		
BOOSTER (IN LINE)			
NON-EFFECTIVE WORKING TIME (CHARGEABLE COST OF WORK)			
HANDLING PIPE LINES		0	0
HANDLING ANCHOR LINES		0	0
CLEARING PUMP AND PUMP LINES		0	0
CLEARING CUTTER AND SUCTION HEAD		0	0
WAITING FOR SCOWS		0	0
TO AND FROM WHARF OR ANCHORAGE		0	0
CHANGING LOCATION OF PLANT ON JOB		0	0
LOSS DUE TO OPPOSING NATURAL ELEMENTS		0	0
SHORE LINE AND SHORE WORK		0	0
WAITING FOR BOOSTER		0	0
MINOR OPERATING REPAIRS (EXPLAIN IN REMARKS)		0	0
WAITING FOR ATTENDANT PLANT		0	0
PREPARATION AND MAKING UP TOW		0	0
TRANSFERRING PLANT BETWEEN WORKS		0	0
LAY TIME OFF SHIFT AND SATURDAYS		0	0
SUNDAYS AND HOLIDAYS		0	0
FIRE DRILL		0	0
MOVING OUT OF WAY OF TRAFFIC		0	0
MISCELLANEOUS (EXPLAIN IN REMARKS)		0	0
TOTAL NON-EFFECTIVE TIME		0	0
PCT. OF NON-EFFECTIVE	0%		
TOTAL EFFECTIVE AND NON-EFFECTIVE TIME (CHARGEABLE TO COST OF WORK)		0	0

Figure 2. RMS daily CSD dredge log (Form 4267).

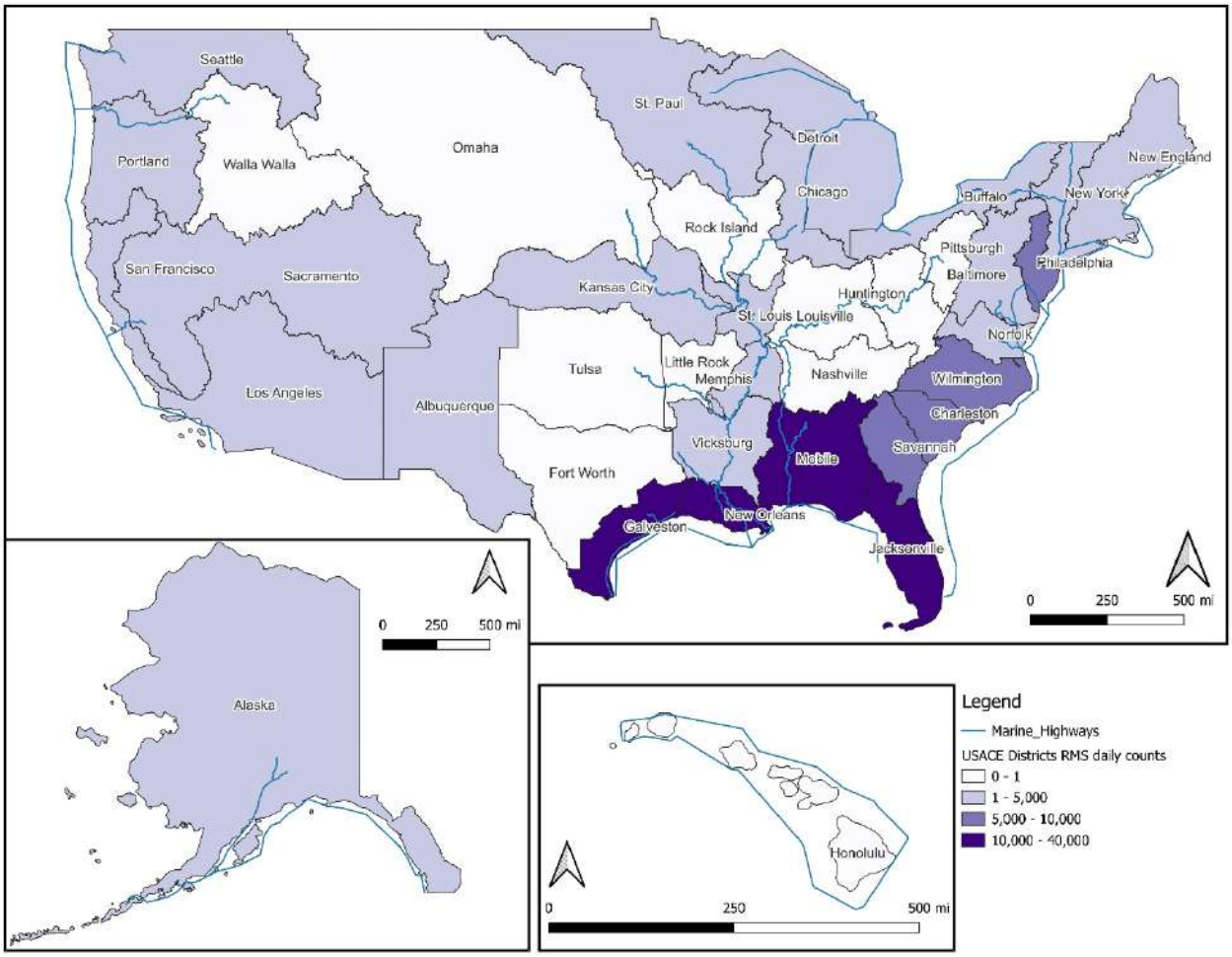


Figure 3. Count of RMS daily records by USACE Civil Works District. RMS dredging records in Albuquerque (SPA), located away from navigable waterways, belong to dredging in reservoirs and dams.

NATIONAL DATA ANALYSIS OF CUTTERHEAD DREDGING WITH HISTORICAL RMS DATA

Dredging Projects Delivered With CSD, by Region and Plant Size

RMS includes in the order of 114,500 daily records where dredging activity was performed by CSDs within the period of analysis. Those days correspond to 982 contracts. In some cases, multiple dredges work for the same contract, leading to 1,039 unique combinations of [contract ID – dredge size]. Moreover, contracts are broken down into 3,651 dredging events, or "projects". For the purpose of this work, a "project" is defined as a succession of consecutive days where a single dredge is working under a unique Contract ID and "Project Name" in RMS. Records have been grouped into regions as shown in Figure 4, based on the USACE Civil Works district reported. The following paragraph presents the proportion of those projects and days by region and dredge size.

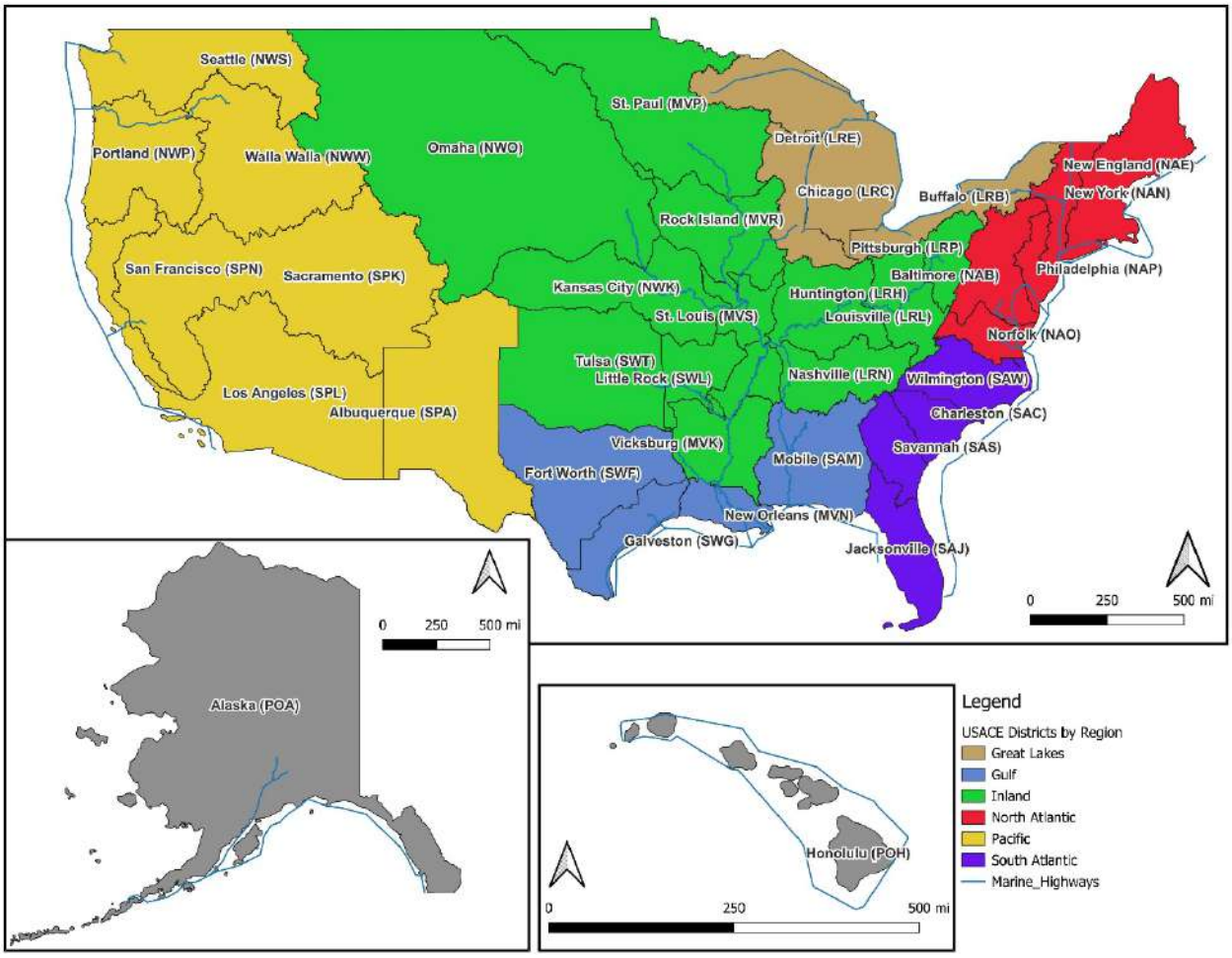


Figure 4. USACE districts by Region.

Figure 5 illustrates the proportion of dredging projects (left) and daily RMS records (right) by region (inner rings) and plant size (outer rings). Plant sizes are categorized in Large (discharge pipeline diameter greater than 24 inches), Medium (discharge pipeline diameter between 14 and 24 inches), and Small (diameter smaller or equal than 14 inches). The Gulf region dominates the use of CSDs. The South Atlantic region records longer time (in days) when CSDs worked than the North Atlantic region; however, in terms of number of projects, the rank is reversed. This indicates that in the South Atlantic, projects have longer duration than in the North Atlantic, on average.

Dredging Projects Delivered with CSD Annually by Type of Project

Furthermore, dredging projects can be characterized by purpose, as identified by the "Report Character" field in RMS. The most frequent operation consists of removing accumulated sediment from channel beds to maintain channel dimensions. Those activities are categorized as "Maintenance" (MT). Less frequently, channels may be deepened or widened, and very infrequently, dredging of new channels occur; all of those activities being categorized as "new work" (NW). Lastly, beach nourishment and other congress-authorized projects where its main purpose is not to achieve given channel dimensions are categorized as "environmental" (EN). Figure 6 shows the proportion of projects and days pertaining to each category, per year; maintenance work is further disaggregated by plant size (small, medium, large).

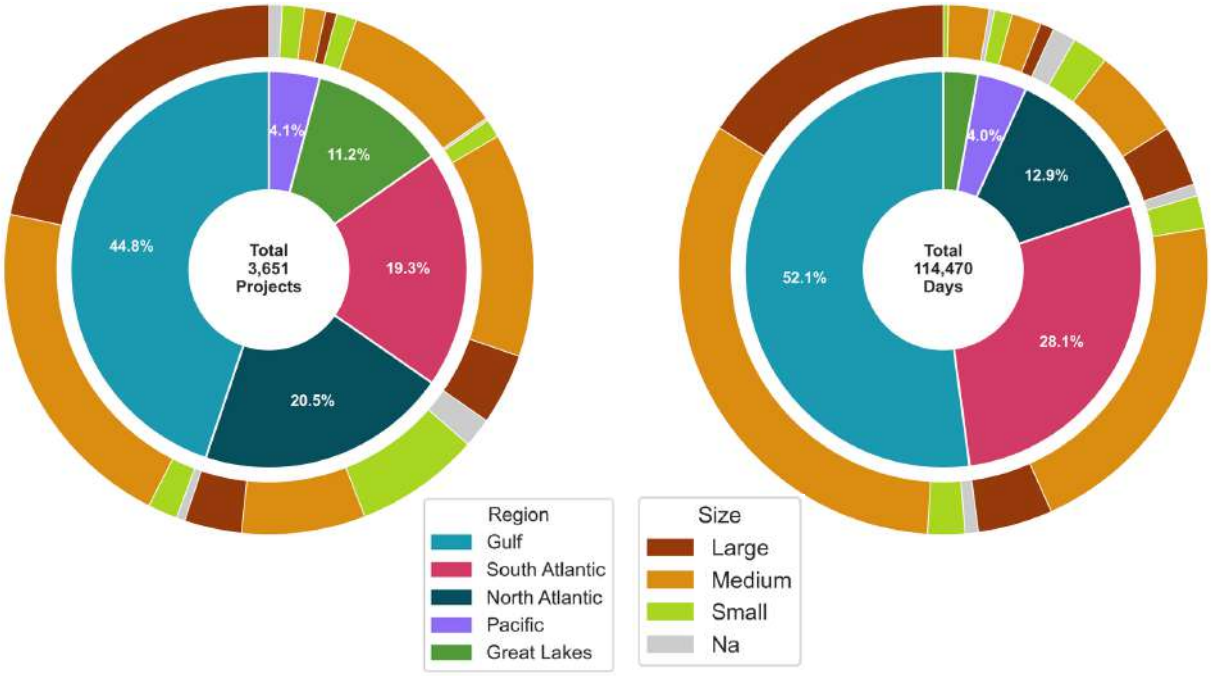


Figure 5. Pie chart illustrates the regional distribution of projects by region and plant size (left) and their duration (right).

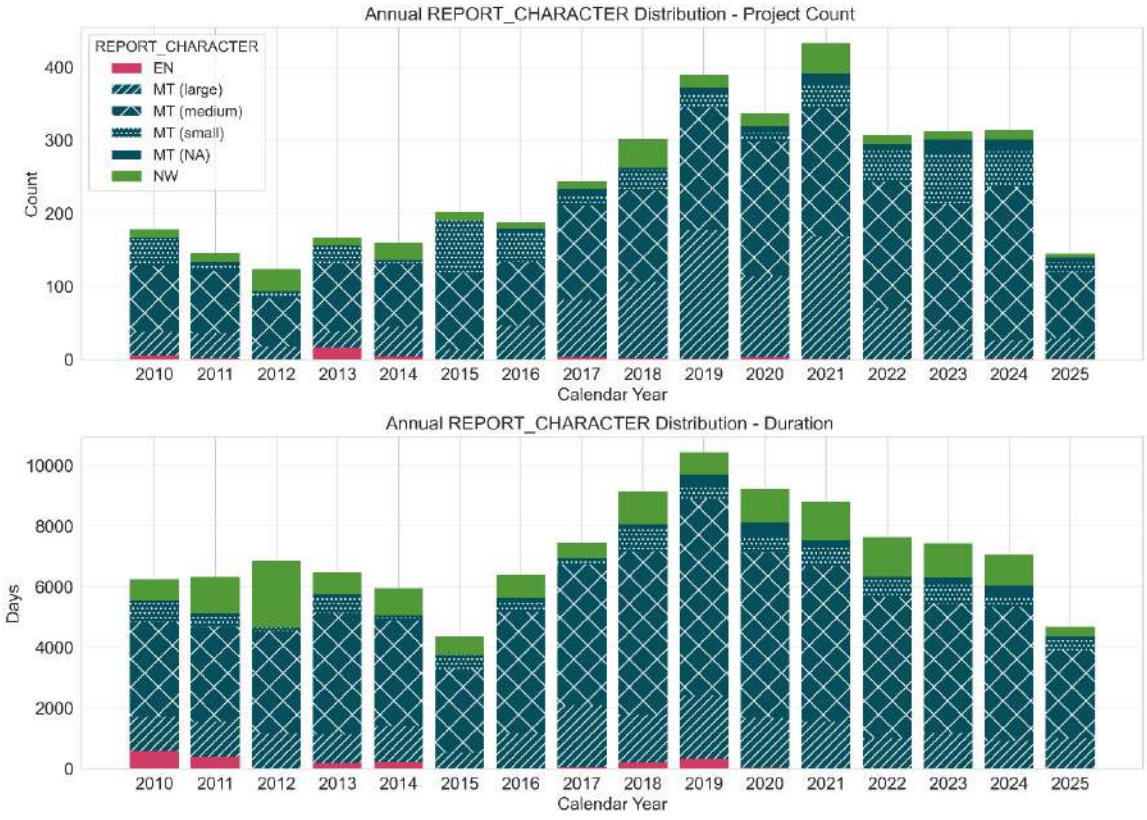


Figure 6. Number of projects and days delivered annually by CSDs, by type of project. EN: Environmental; MT: Maintenance; NW: New Work. Maintenance work is further disaggregated by plant size (small, medium, large).

CSD Size and Production

CSD dredges operate by "cutting" the waterway bed material through a rotating cutterhead positioned at the suction inlet. The cutterhead loosens the material, which is mixed with water to form a slurry, suctioned through a pipeline with the help of pumps, and discharged through a long, flexible pipe. The efficiency of CSDs to remove material depends on several factors, including site conditions, material type dredged, atmospheric conditions, the design and characteristics of the dredge, support equipment, skill of management and operations staff, etc., (Wetta, 2010). With respect to dredge characteristics, one of the main factors that influence dredge production is the discharge pipeline size. Approximated by its diameter, the discharge pipeline size of the U.S. CSD fleet varies between 8 and 32 inches. For this work, CSDs are classified by their discharge pipeline diameter in the categories shown in Table 1. Most of the fleet (at least 105 dredges) is comprised of medium dredges, followed by small (48), then large (27). Note that for some dredges, as identified by their unique standardized name in RMS, their size is unknown or not available on the dataset.

In terms of production, CSD with larger discharge pipe diameters have the capacity to remove material faster. For a slurry concentration of approximately 13% by dry weight (145 ppt), a CSD with a 24-inch diameter pipeline would remove material at a production rate of 515-1615 CY per hour; while a 16-inch diameter would remove material at a rate of between 240-875 CY per hour (Marine Construction, N.D.).

Table 1. CSD fleet size categories.

CSD size category	Discharge pipeline diameter (d, inches)	Number of dredges in RMS
Small	d <= 14"	48
Medium	14" < d <=24"	105
Large	d > 24"	27
Not available		35
Total		215

Sizes of the CSD U.S. Fleet

The CSD U.S. fleet, as recorded in RMS between 2010 and 2025, consists of approximately 215 individually named dredges of varied sizes. The authors are aware that some of these dredges have been sold and are operating under a different name. In these cases, each dredge name is considered as a separate dredge.

Moreover, these dredges have performed work in more than 28 (out of 41) USACE Civil Works districts. The number and proportion of unique medium and large dredges observed in each district, by size of discharge pipeline diameter, is shown in Figures 7 and 8. For both figures, only dredges bigger than 16-inch discharge pipeline diameter are shown.

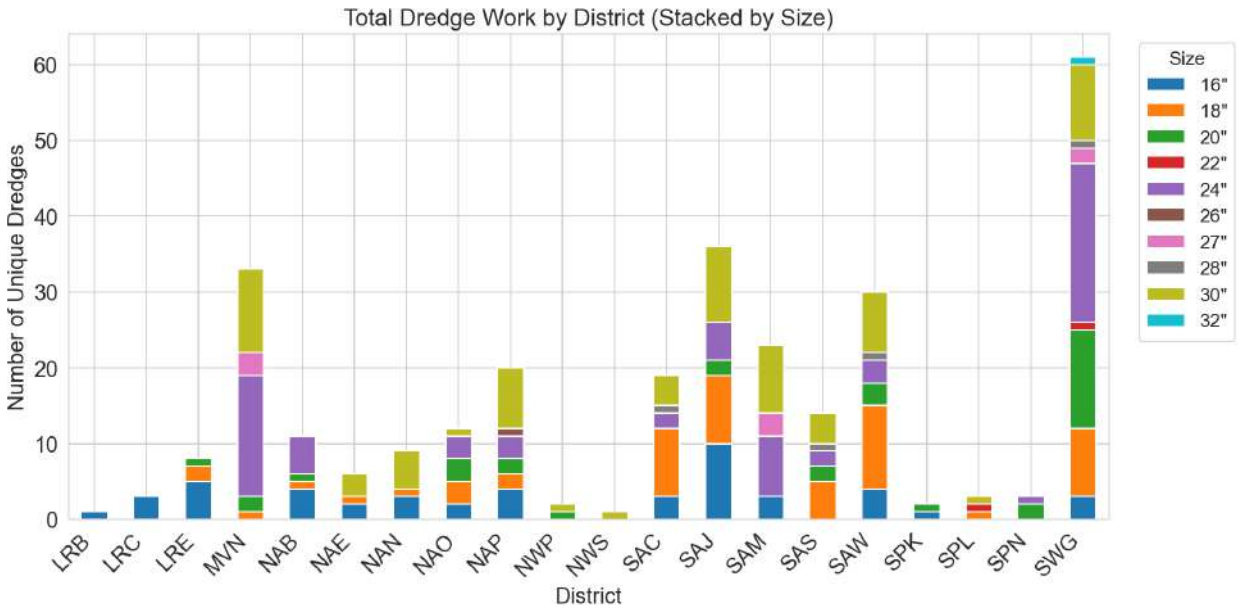


Figure 7. Number of unique CSD dredges observed per USACE Civil Works District in RMS, by size.

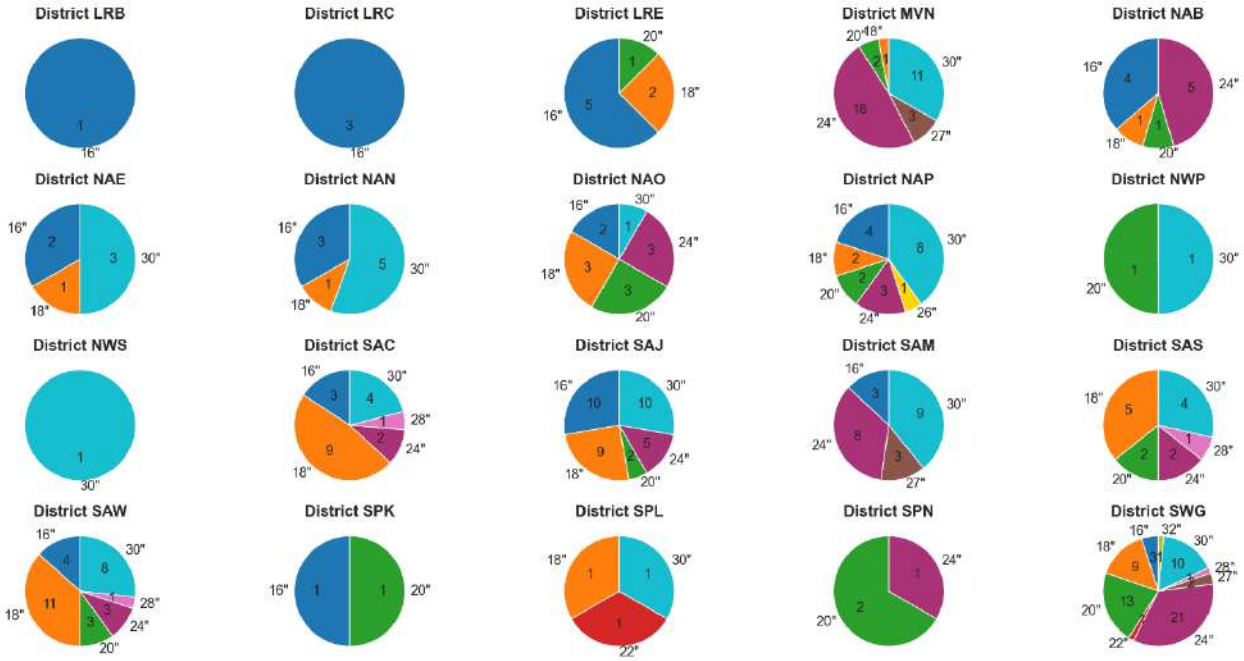


Figure 8. CSD size distribution by USACE Civil Works District.

Channel depths dredged by CSDs of different sizes, by region

Figures 9 to 11 show the distribution of channel depths before and after CSD dredging, by region. The bottom portion of each graph shows a "violin" plot, the wider the shape, the greater number of daily records at any given depth. These violin plots indicate with a horizontal line the mean channel depth dredged by

CSDs in each region. For the violin plots, minimum and maximum values represent the full extent of the dataset (outliers are not removed by the python library used to create the violin graphs). The top portion of the graphs are box-and-whisker plots, offering a simplified version of the channel depth distributions. In the box plots, the lowest whisker indicates the minimum channel depth dredged, the colored box indicates the interquartile range (channel depths within the 25th and 75th percentile values), and the top whisker indicates the maximum depth dredged, after removing outliers (thus the differences in minimum and maximums when comparing with violin plots). Outliers are defined as a function of the inter-quartile range (Waskom, 2024). The horizontal black line within the colored box is the median depth dredged (50% of data points are shallower and 50% are deeper than this value). Median values are less affected by extreme values than the mean, thus considered more representative to characterize central tendency.

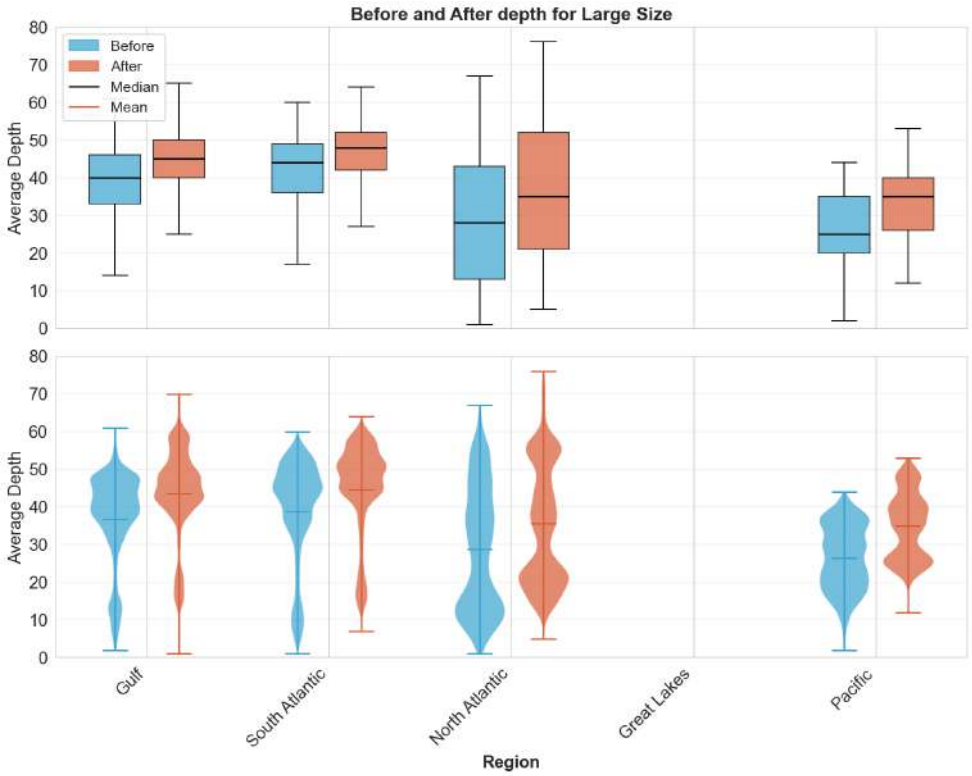


Figure 9. Distribution of channel depths before and after dredging with large CSDs.

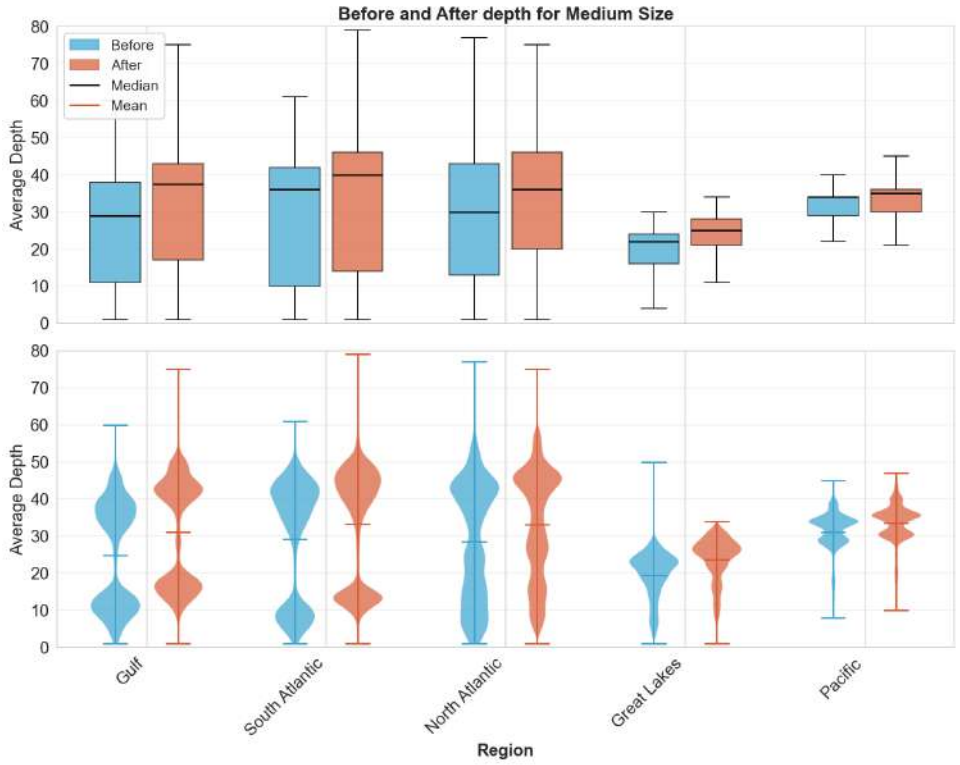


Figure 10. Distribution of channel depths before and after dredging with medium CSDs.

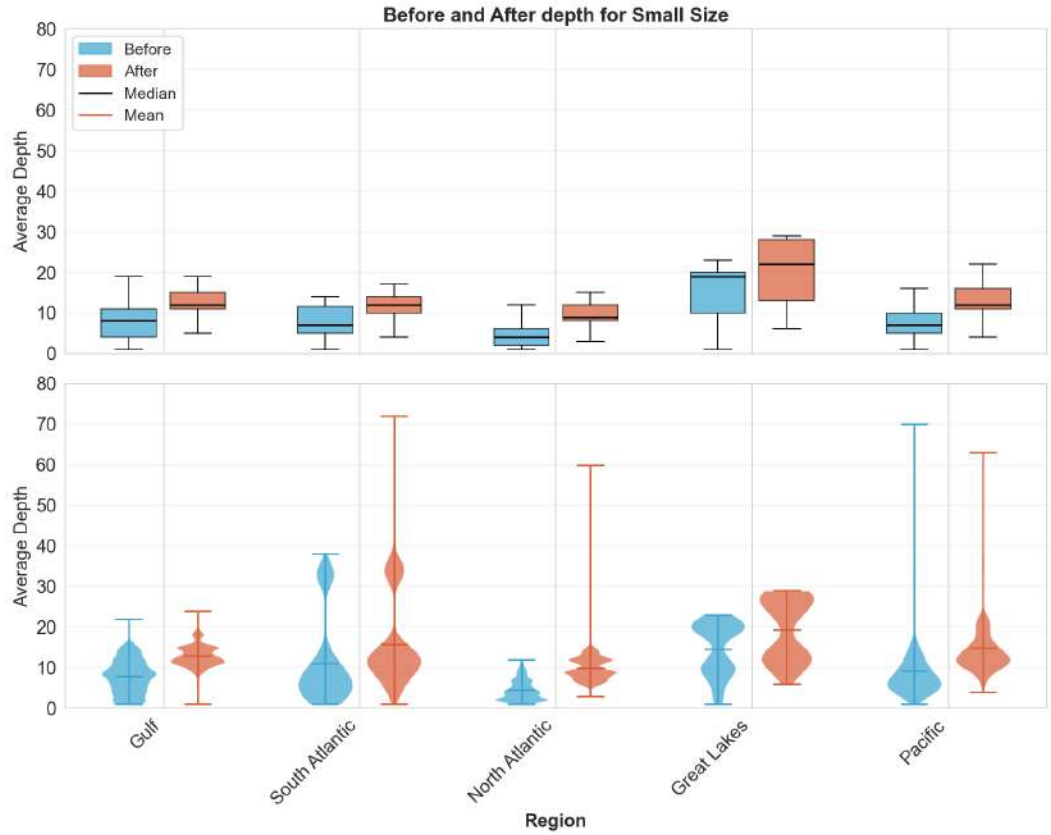


Figure 11. Distribution of channel depths before and after dredging with small CSDs.

Figures 12 to 14 show the cut depth, calculated as the difference in depth before and after dredging performed by a given CSD, at a given location, on a given day for large, medium, and small dredges, respectively.

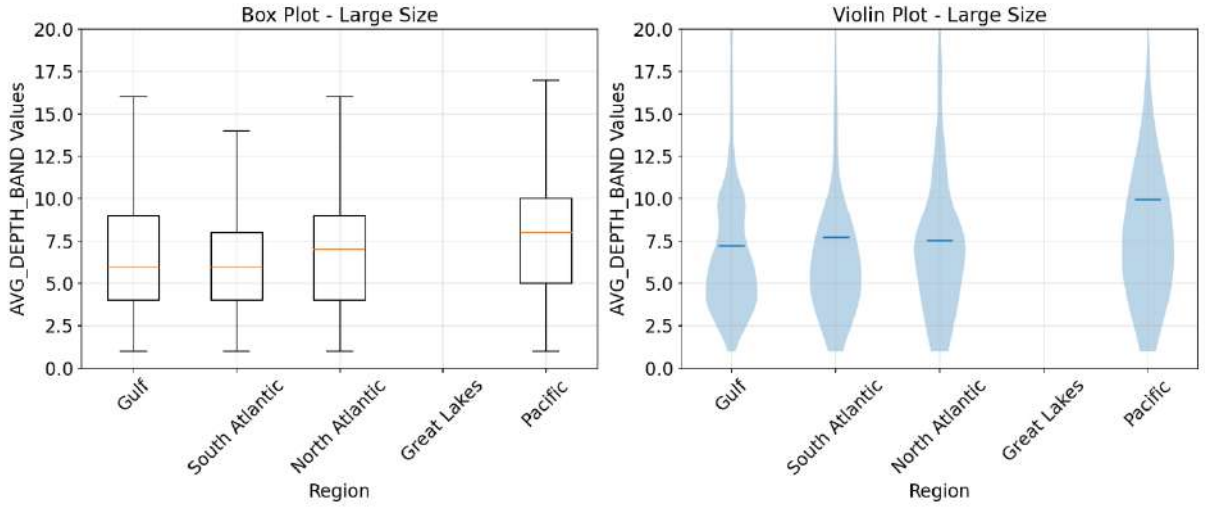


Figure 12. Difference in channel depth before and after daily dredging, by region, for large CSDs.

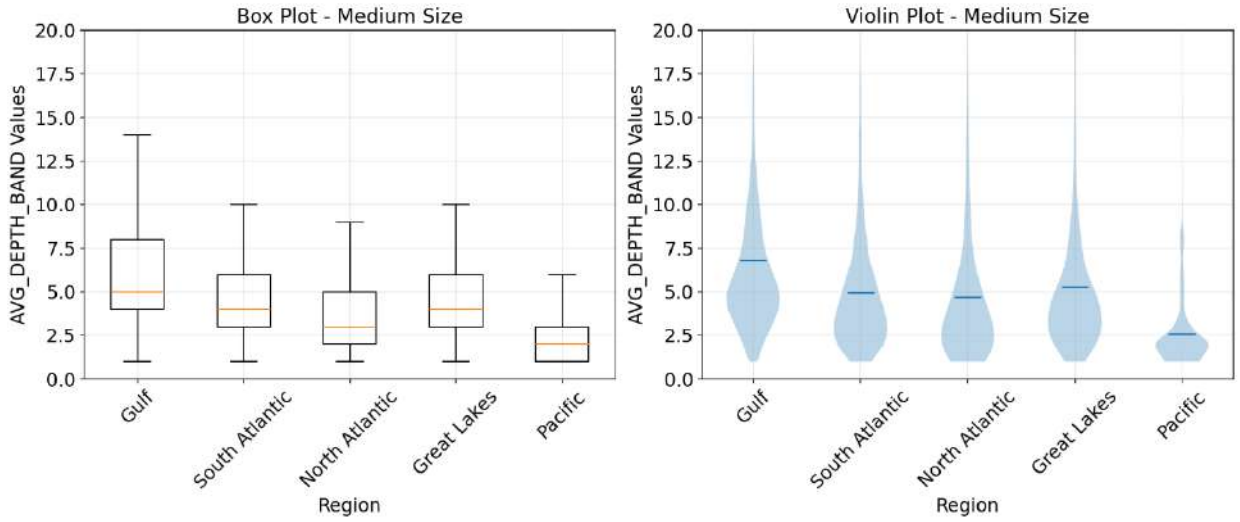


Figure 13. Difference in channel depth before and after daily dredging, by region, for medium CSDs.

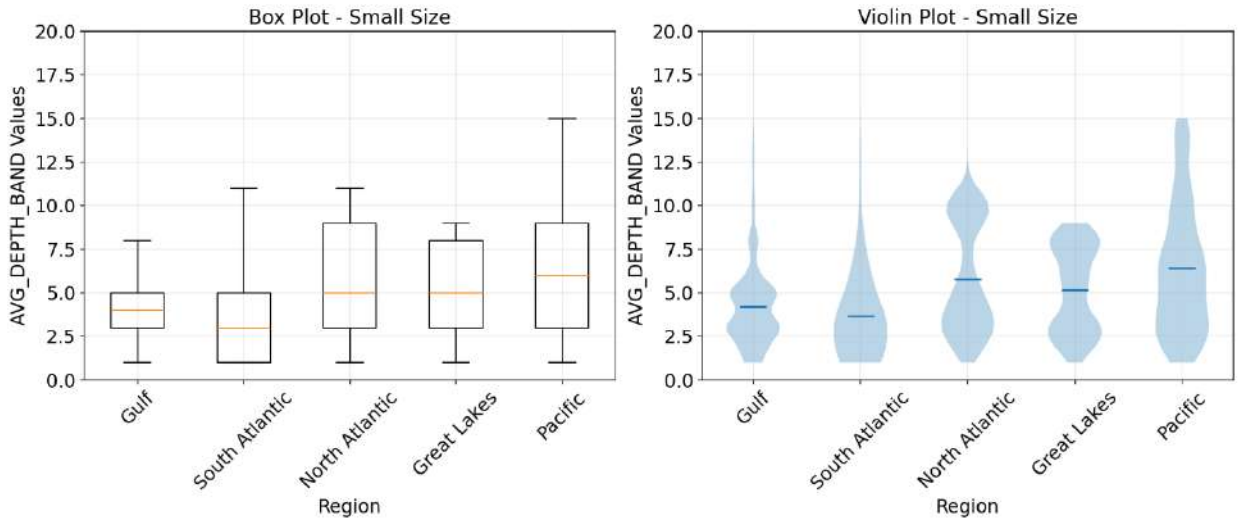


Figure 14. Difference in channel depth before and after daily dredging, by region, for small CSDs.

Cycle Time Analysis and Productivity

Arguably, one of the most valuable pieces of information in RMS is the dredging cycle time breakdown. One cycle is typically one full day (24 hours). The cycle time is broken down into three components: effective, non-effective, and lost time, depending on the activities the dredge is involved in. The cycle time components are measured in units of time (minutes).

The Effective Working Time (EWT) or pumping time refers to the portion of the cutterhead cycle time when actual production is taking place, such as material moving through the pipeline, and it is chargeable to cost of work (USACE, 2008).

While CSDs are designed for continuous sediment removal, and operate on-site 24/7, dredging operations do not achieve a 100% effective working time (Emery, 2024). Non-effective cycle time activities are chargeable to cost of work, and include: handling pipelines, handling anchor lines, clearing pump and pump lines, clearing cutter and suction head, waiting for scows, going to and from wharf or anchorage, transferring plant between works, moving away of traffic, loss of time due to natural elements, shoreline and shore work, minor repairs, waiting for booster pump, waiting for attendant plant preparation and making up tow.

Lost time, on the other hand, considers time spent on major repairs, collisions, cessation, and miscellaneous, and it is not chargeable to cost of work.

Figure 15 shows a breakdown of cycle time into its three components, by plant size. The graph indicates the percentage of cycle time the dredge was involved in effective, non-effective, and lost time activities, average of all daily RMS records. Small CSDs tend to have, on average, a smaller percentage of effective time and a higher percentage of lost time than medium and large CSDs. Figure 16 shows the proportion of CSD cycle time activities by region. The Gulf region shows a higher proportion of time spent moving away from traffic, and lost time due to weather and repairs, than other regions. On average, roughly 43-50% of the time CSDs are involved in removing material from the channel bed.

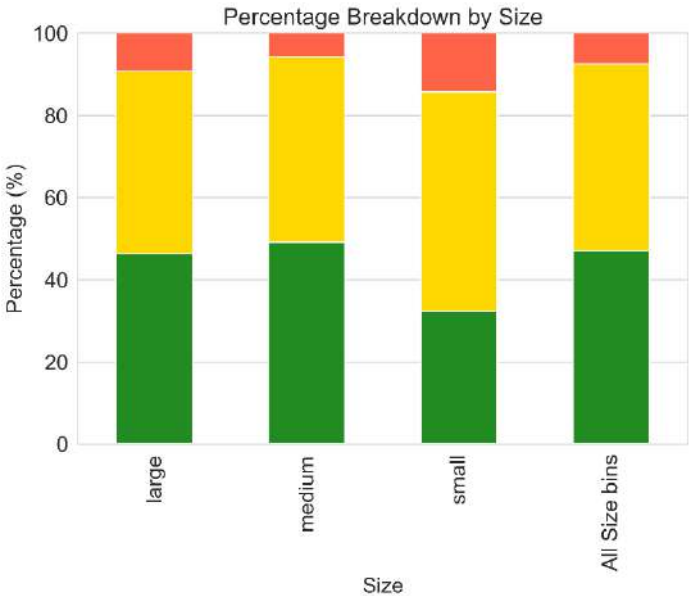


Figure 15. CSD Cycle time breakdown by plant size.

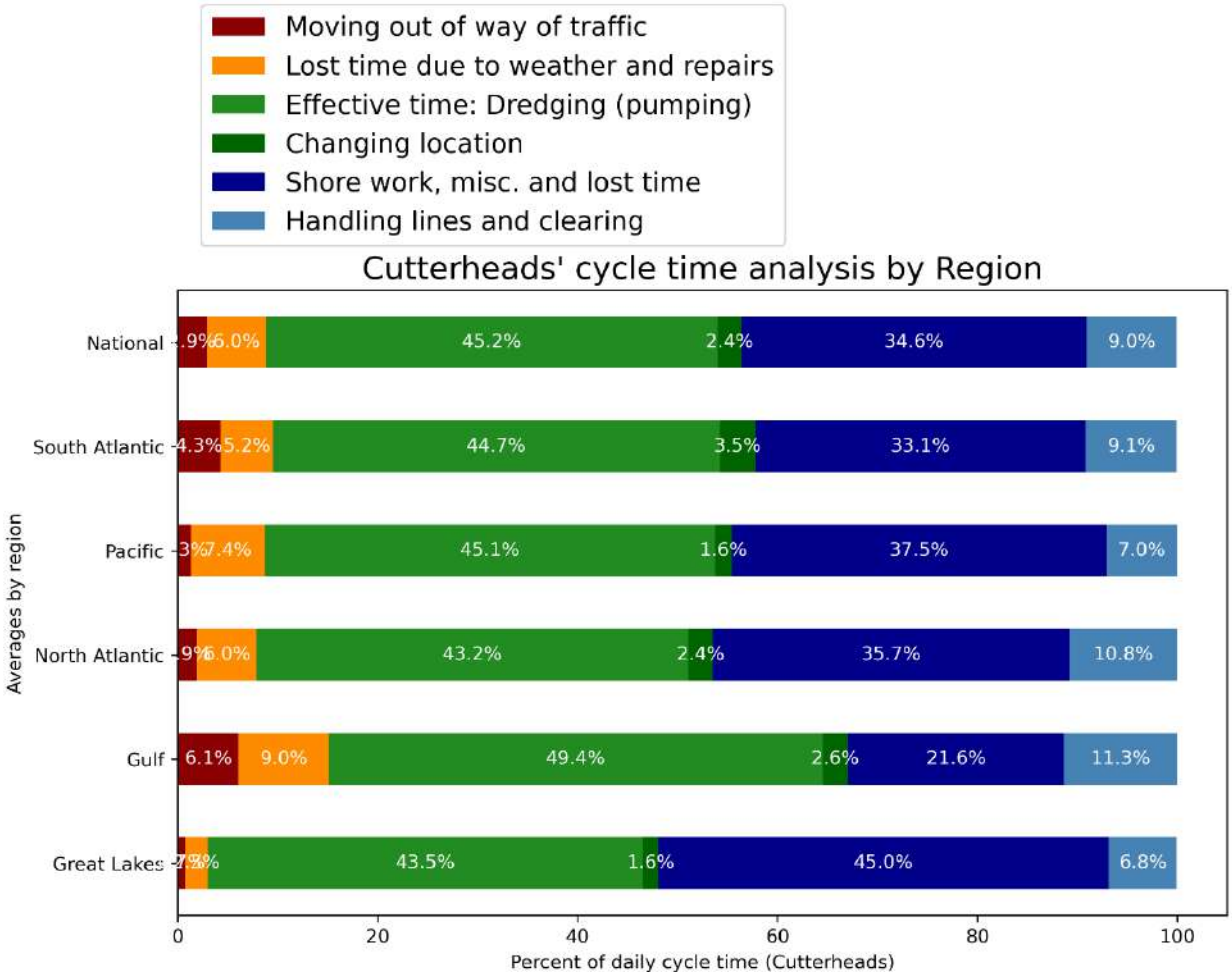


Figure 16. CSD Cycle time breakdown by region.

Focusing on lost time, Figure 17 shows the Kernel Density Estimation (KDE, a smoothed estimation of the probability density function) of percentage of lost time per day by dredge size (small, medium, large) and region. Notably, in the North Atlantic region, for medium and small dredges, if lost time occurs on a given day, the full day is more frequently recorded as lost, when compared to other regions.

In Figure 18, the KDE of nation-wide daily lost time is presented by CSD size in more detail, with dredge size measured as discharge pipeline diameter, in inches. In both Figures 17 and 18, each ridge is independently rescaled to that its peak height is the same, which lets the shapes of the distributions be comparable regardless of sample size.

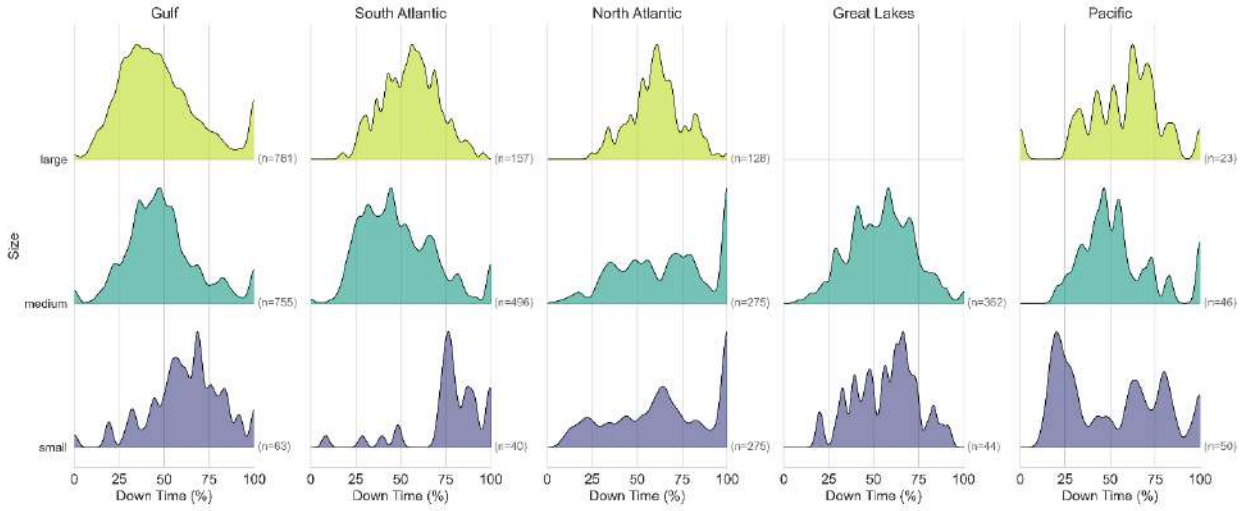


Figure 17. Distribution of lost time (as percentage of a day) by region and CSD size.

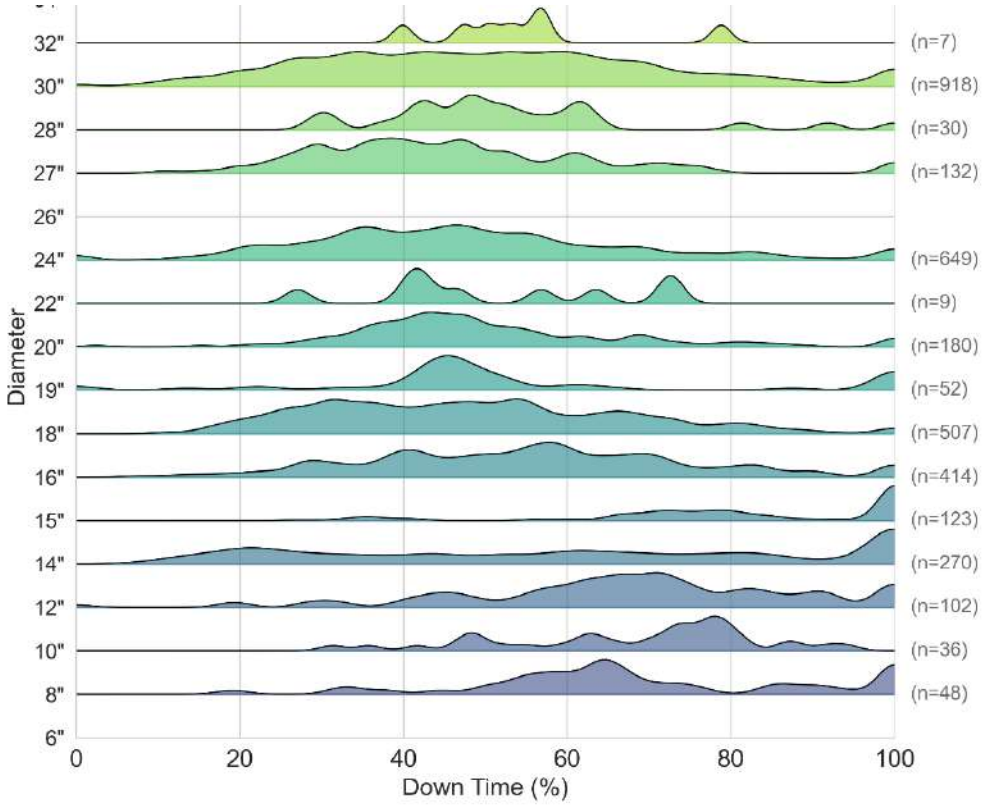


Figure 18. Distribution of daily lost time by CSD size (discharge pipeline diameter, in inches).

Disposal of Dredged Material

The disposal of sediment dredged by CSDs is made through pipeline discharge. The distance of such pipeline varies with the location of approved disposal areas, influenced by environmental restrictions. As the dredge progresses its work through the channel, new sections of pipeline are added, increasing the final length. Longer discharge distances require the utilization of assistant pumps. The discharge pipe can be placed submerged (to allow for navigation), floating on the channel, and/or installed on shore. A combination of those three is typically observed on a single project site. Pipeline plans and materials are influenced by project location, channel location, shoal sizes, and cost. For example, floating lines or hoses tend to be more expensive than steel or plastic lines. Pipelines have their own pressure limits which also dictate what type of pipeline should be used. This section discusses the CSD discharge pipeline lengths observed, with a breakdown in submerged, floating, and shore pipe. The discharge pipe length and type are observed by region in Figure 19, by plant size in Figure 20, and by type of material dredged in Figure 21.

Figures 19-21 present box-whisker plots (left) and violin plots (right) showing the distribution of discharge length, for on shore (top), submerged (center), and floating pipelines (bottom). These graphs were developed with project-level data, meaning each data points constitute a project. Conceptually, the maximum length of the discharge pipe for each project should be considered. However, to prevent capturing outliers, the 95th percentile of discharge pipe length was used as proxy.

Notably, from Figure 19, median submerged discharge pipelines are in the order of 5,000-10,000 ft long, and maximums can be as long as 35,000 ft long in the Atlantic region. Submerged lines are much longer than lines onshore (5,000 ft median length or less; maximums around 15,000 ft), followed by floating

portions (median between 2,000-5,000 ft; maximums around 15,000 ft in the Gulf, but less than half elsewhere). Floating lines may be more adequate in ports and access channels (like in the Pacific region) because of traffic conditions, material placement, and depths. For places with wider gaps in shoals and more vessel traffic, possibly in the Gulf region, moving or staging multiple sublines may be more suitable to help reduce non effective times for moving lines. Shore and floating discharge pipeline lengths are considerably shorter in Great Lakes than in other regions.

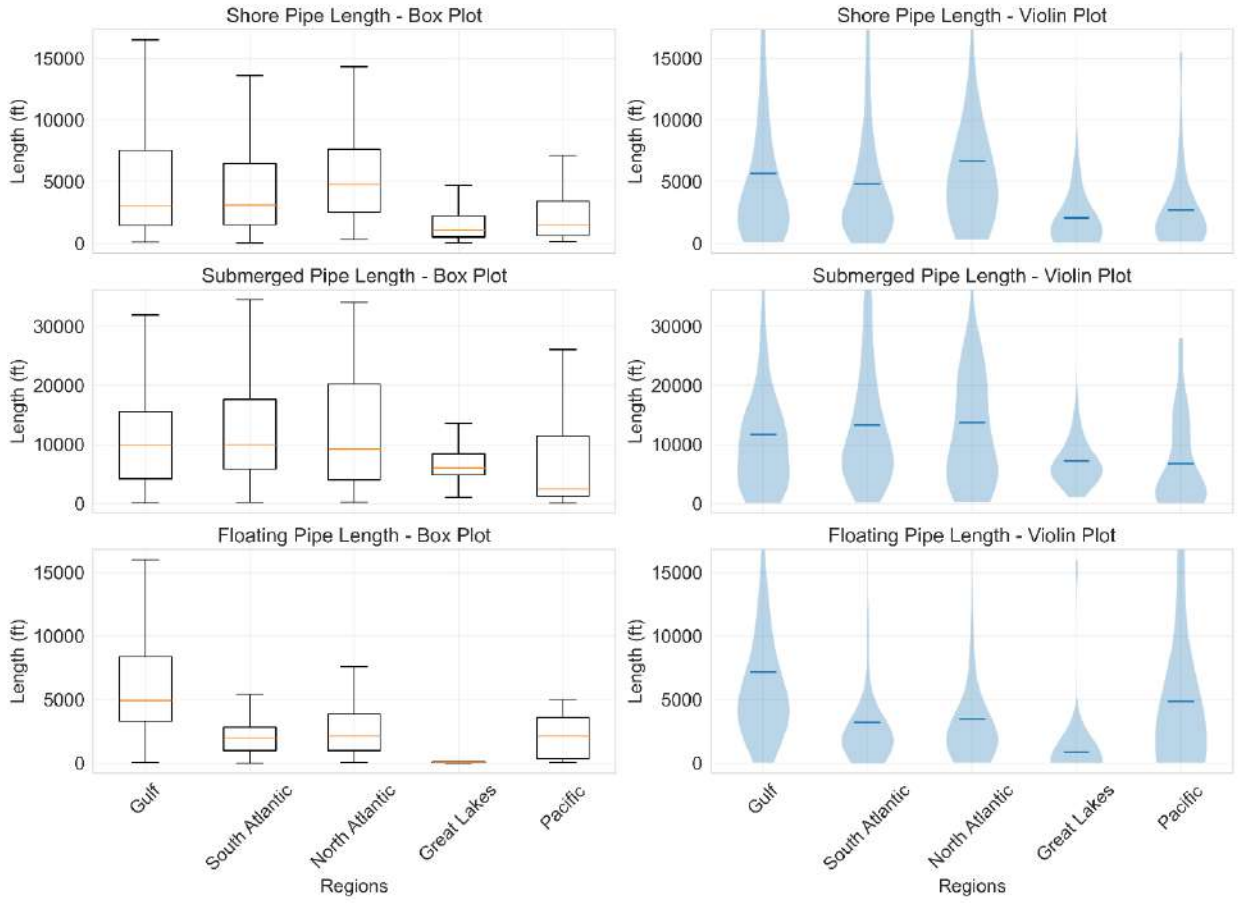


Figure 19. Shore, submerged, and floating discharge pipeline lengths observed per region.

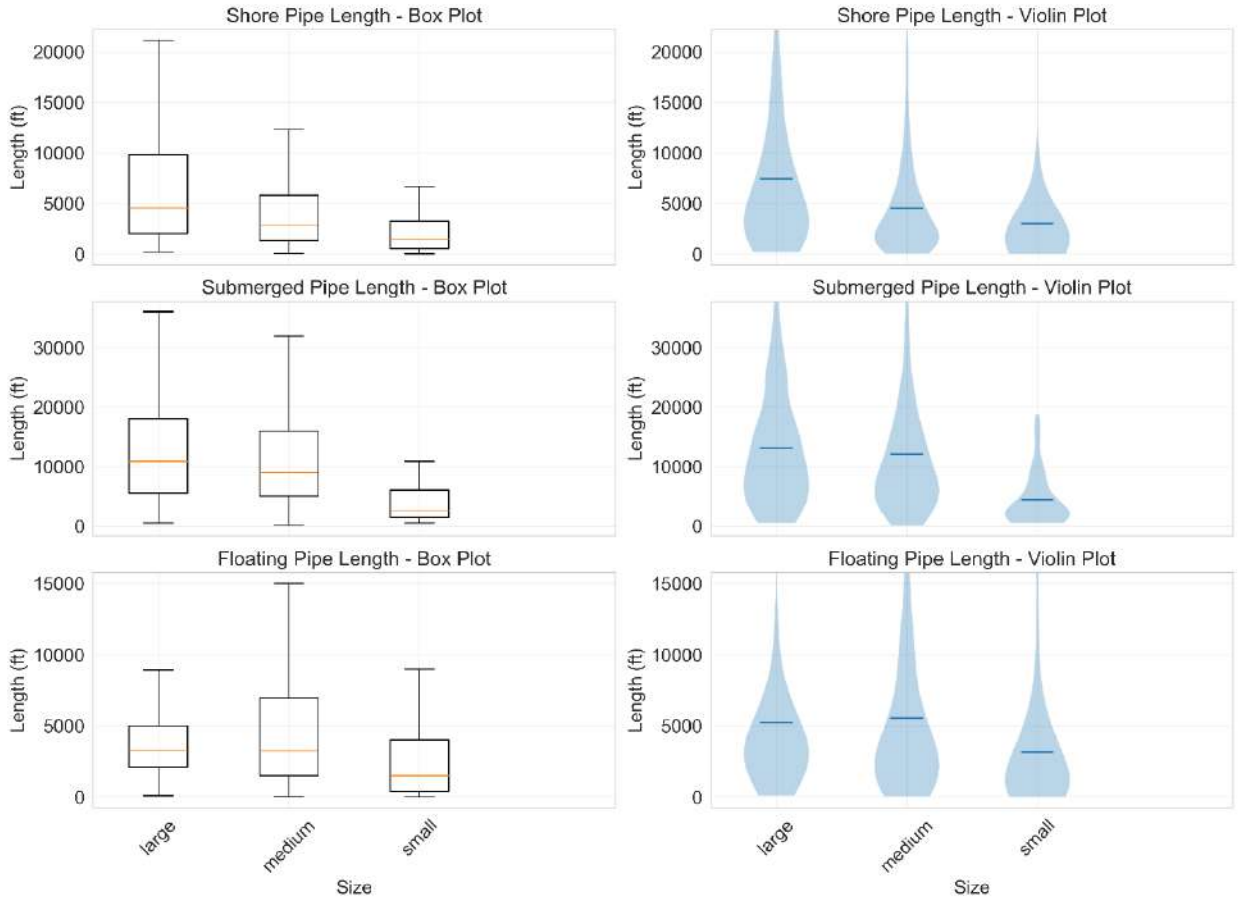


Figure 20. Shore, submerged, and floating discharge pipeline lengths observed per plant size.

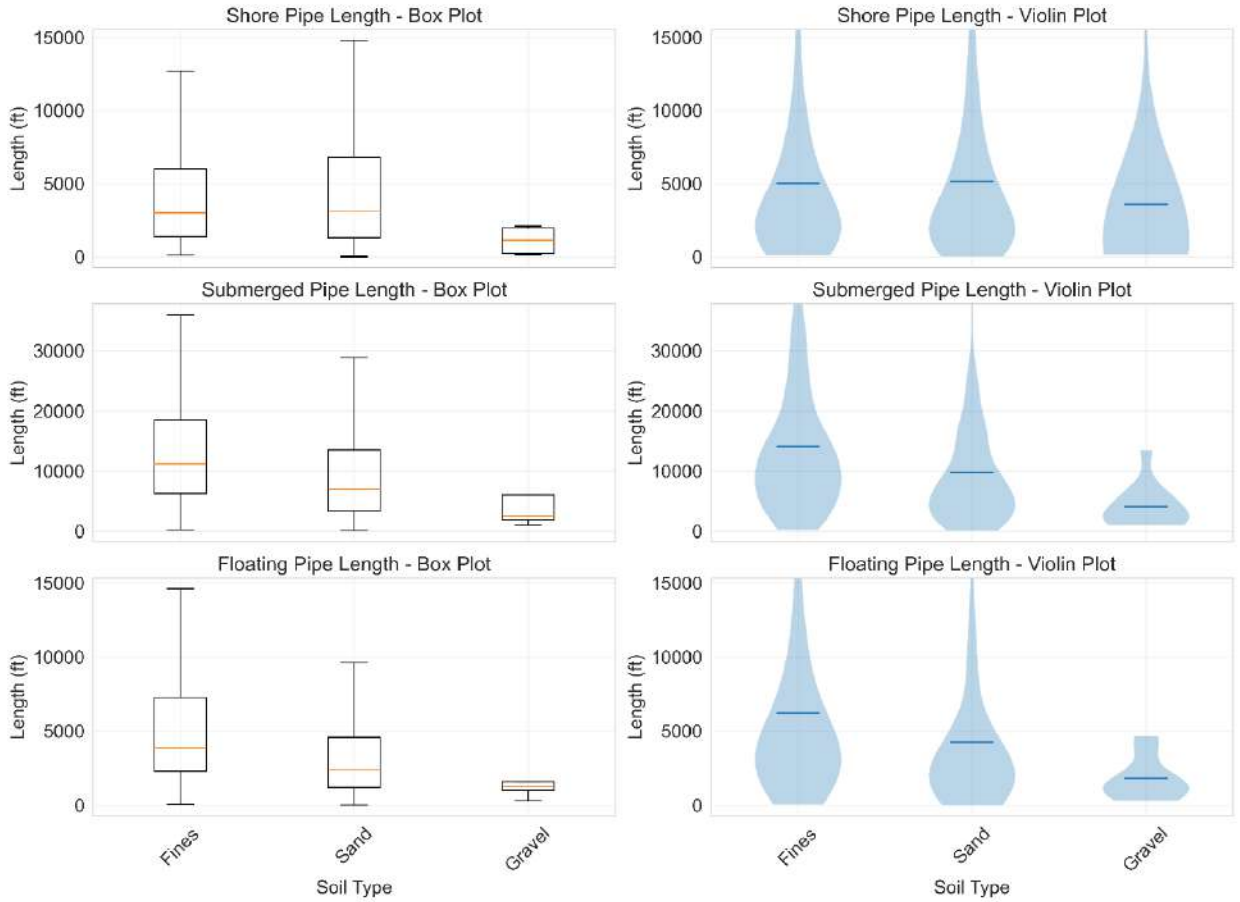


Figure 21. Shore, submerged, and floating discharge pipeline lengths observed per sediment type.

Regionalization and Time-series

Time-series of CSD Plant Usage Across the Portfolio

Figure 22 shows the utilization of CSDs as recorded in RMS, for all dredge sizes, colored by region. The horizontal axis is the time (days), and the vertical axis represents the number of dredge plants used each date. Each colored "box" is a dredge plant; the length of the box being the duration (in days) that the plant was associated to a given project (dredging event). The color of the box represents the region where the dredge was working. While regional utilization is better visualized in Figure 23, Figure 22 provides an idea of historical times when the utilization of CSDs were higher than others. CSD utilization peaks occurred in the first quarter of 2019, and in the last quarter of 2020; 2019 being the busiest year. Valleys occur in the first quarter of 2015 and by mid-2022.

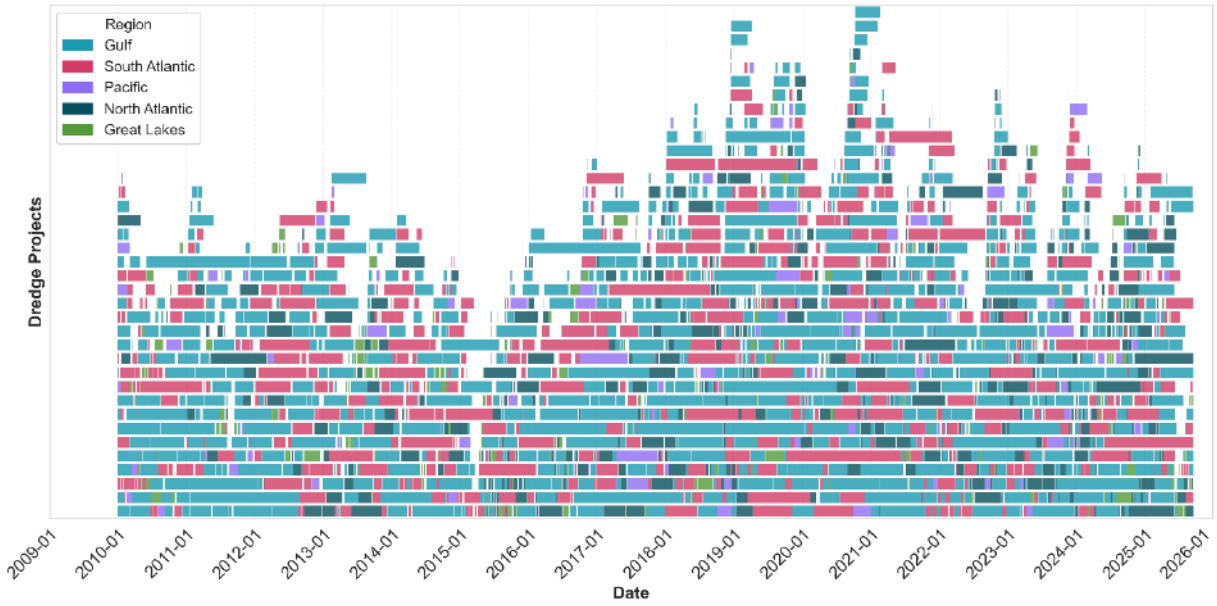


Figure 22. Timeline of Cutterhead dredges' use on USACE projects (all sizes, colored by region).

Figure 23 is similar to Figure 22, but each region is shown separately. Thus, the utilization of CSDs by region can be better visualized. The Gulf region is the region that uses CSDs the most at all times, followed by the South Atlantic, and North Atlantic.

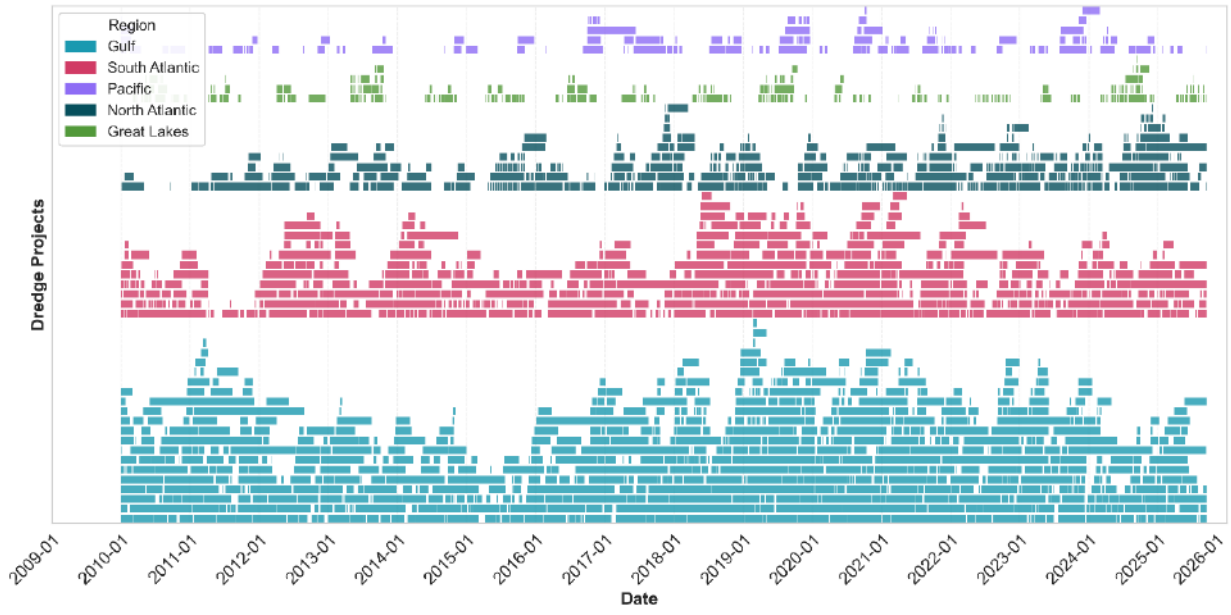


Figure 23. Timeline of CSDs' use on USACE projects by region.

Figure 24 shows the utilization of CSDs recorded in RMS by dredge size. Medium sized dredges are mostly used, followed by large, and then small sized CSDs. Only for a small number of records the dredge size was missing ("N/A", grey bars).

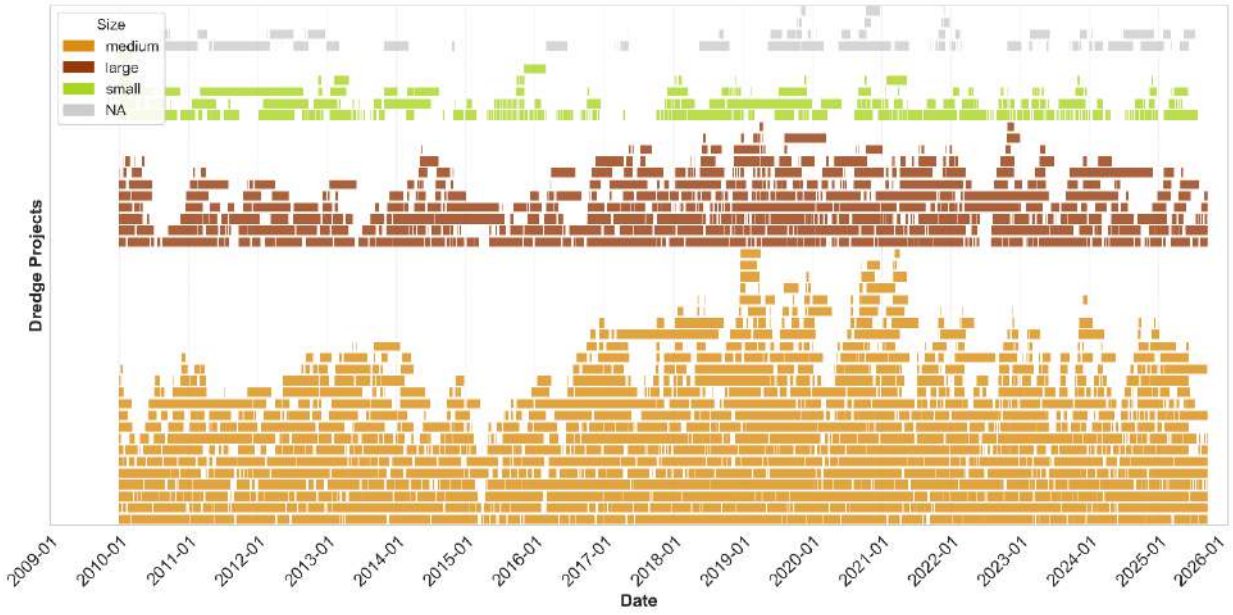


Figure 24. Timeline of CSDs' use on USACE projects by size.

Visualization of How CSDs Move Across the Continental U.S.

This section presents a map depicting USACE Civil Work Districts, connected by lines that represent the movement of CSD dredges as they transition from one project into another, following a temporal line between 2010 and 2025. Connecting lines do not consider travel to/from yards nor dredge maintenance locations in-between two temporally adjacent projects. The mobilization is simplified by connecting district centroids, not actual project locations. Line thickness is an indication of the number of movements made by several dredges, in any direction (i.e. each line is not an individual dredge; Figure 25). It can be observed that most movements occur within regions (i.e. lines connecting districts within the Gulf, and within the Atlantic coast, are thicker than those connecting districts located in different regions). The thinner lines that connect regions located far away from one another (for example, between Pacific and Gulf or North Atlantic regions) represent one-time movements by a single dredge; they may occur on rare occasions when a dredge is sold and relocated, or it may be an artifact of missing or erroneous data. Notably, relatively longer movements between the Gulf and North Atlantic (in no particular direction) were observed on a handful of occasions, and made by large dredges, indicating their participation in specific project types when a certain size or vessel characteristics are required. In addition, it was observed that approximately half the fleet transitioned between districts, while the other 50% remained always within the same district.

For a more detailed analysis of dredge movements, the Automatic Identification System (AIS) tracks timestamped vessel locations. AIS traces are publicly available through Marine Cadaster and other services (Kress, 2023). AIS identifies "Dredging" as a type of vessel (separated from cargo, tankers, tug/tows, etc.); however, it does not discriminate by dredge type. The identification of CSDs could be made by matching of MMSI codes, and heat-maps may be used to explore this in future efforts.

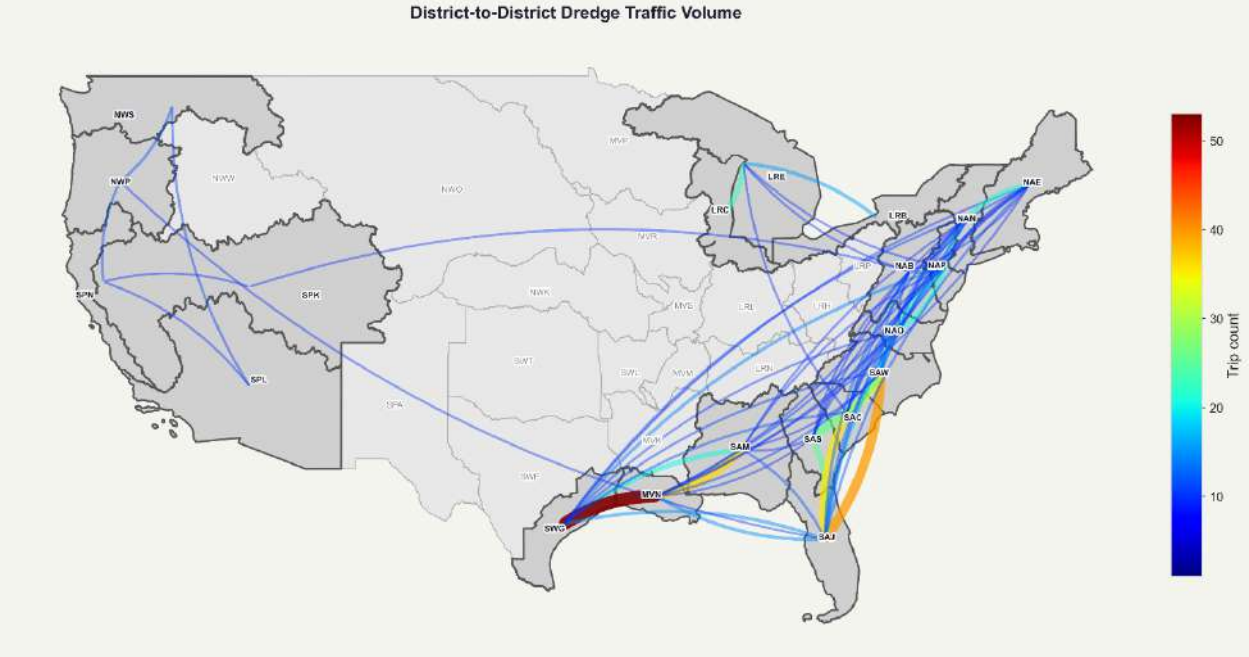


Figure 25. Movement of CSD plant across USACE CW Districts.

Fuel Consumption

Fuel costs can account for approximately 30% of a dredging project cost (Murphy, 2012). Thus, fuel efficiency is a driver to reduce dredging cost. For a CSD, the rate of fuel consumed typically depends on its main engine power, the type of material dredged, and output of the dredger (iTECH, 2025). Other factors affect the volume of fuel consumed at project level. For example, the presence of attendant plant, and the distance to placement site for removed sediment may require the use of booster pumps along the discharge pipeline, increasing the volume of fuel needed. RMS records may include exclusively the fuel consumed by the dredge itself; however it is unclear if the reporting procedure may change across regions or contracts, including in some cases fuel utilization by attendant plant. Fuel consumption (gallons/day) statistics associated with dredging operations within each region are depicted in Figure 26, by dredge size.

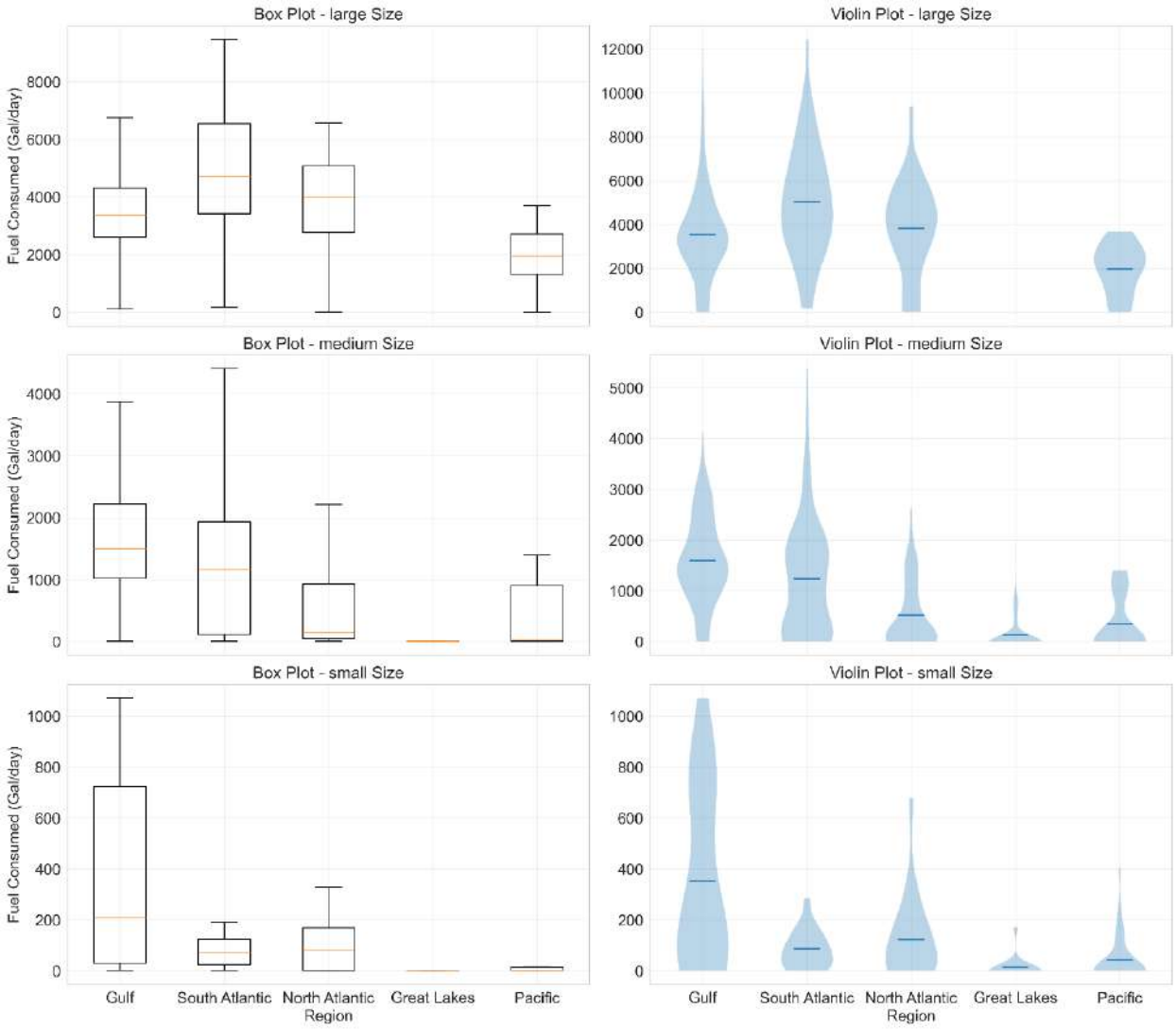


Figure 26. Fuel consumption of CSDs by region and plant size.

Cost Analysis

This section first presents an analysis of cost of CSD dredging, per unit of sediment volume dredged (CY) (Figure 27), effective time worked (hours) (Figure 28), and duration (days) (Figure 29) at contract level, by region and plant size. Next, unit cost (USD/CY) is compared to discharge pipeline lengths per region and CSD size (Figure 30). The cost considers the full contract award amount (including mobilization/demobilization, dredging rate, monitoring, etc.). The duration is the number of days reported on RMS for each contract. Outliers have not been removed from the data.

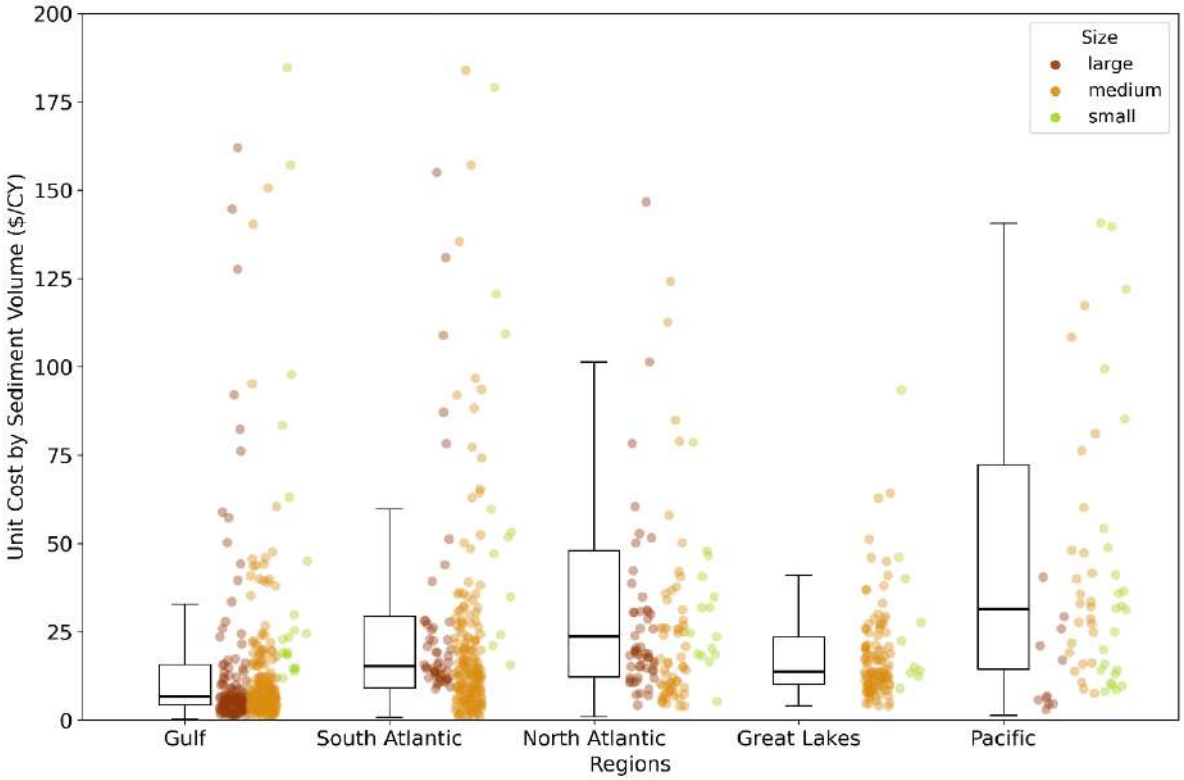


Figure 27. Unit cost of CSD dredging by sediment volume dredged, by region and plant size.

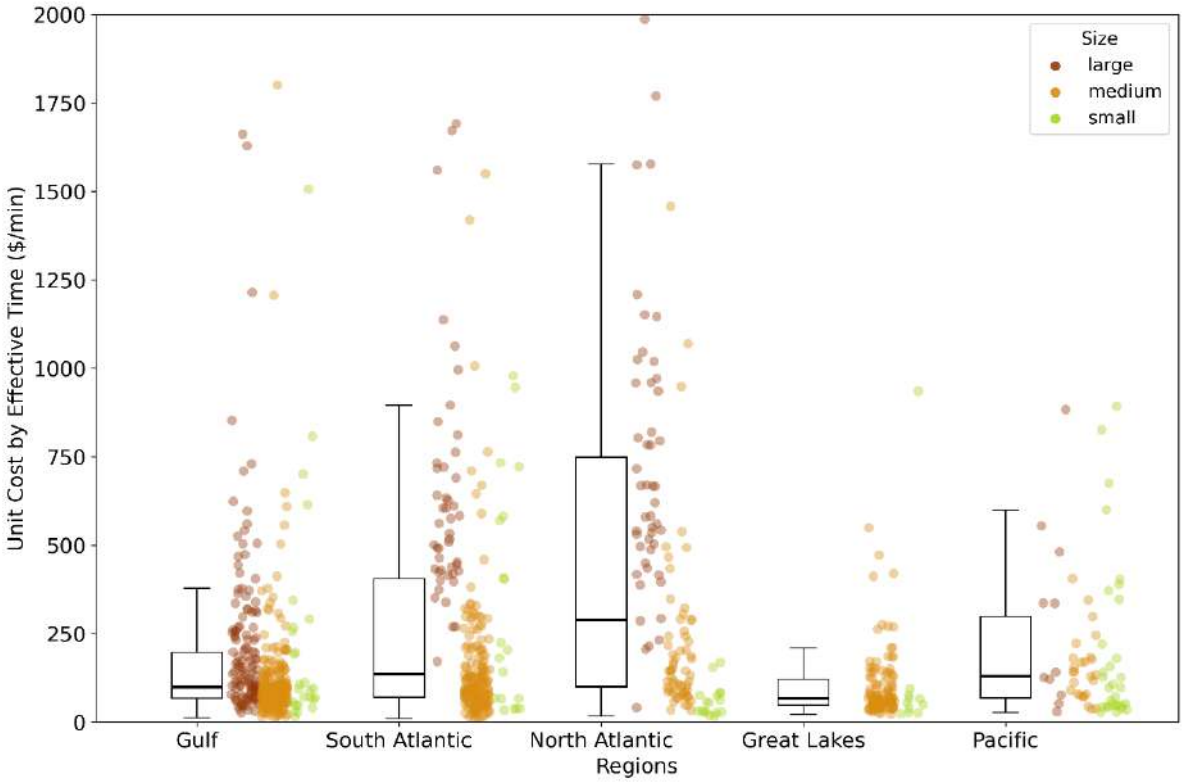


Figure 28. Unit cost of CSD dredging by effective time, by region and plant size.

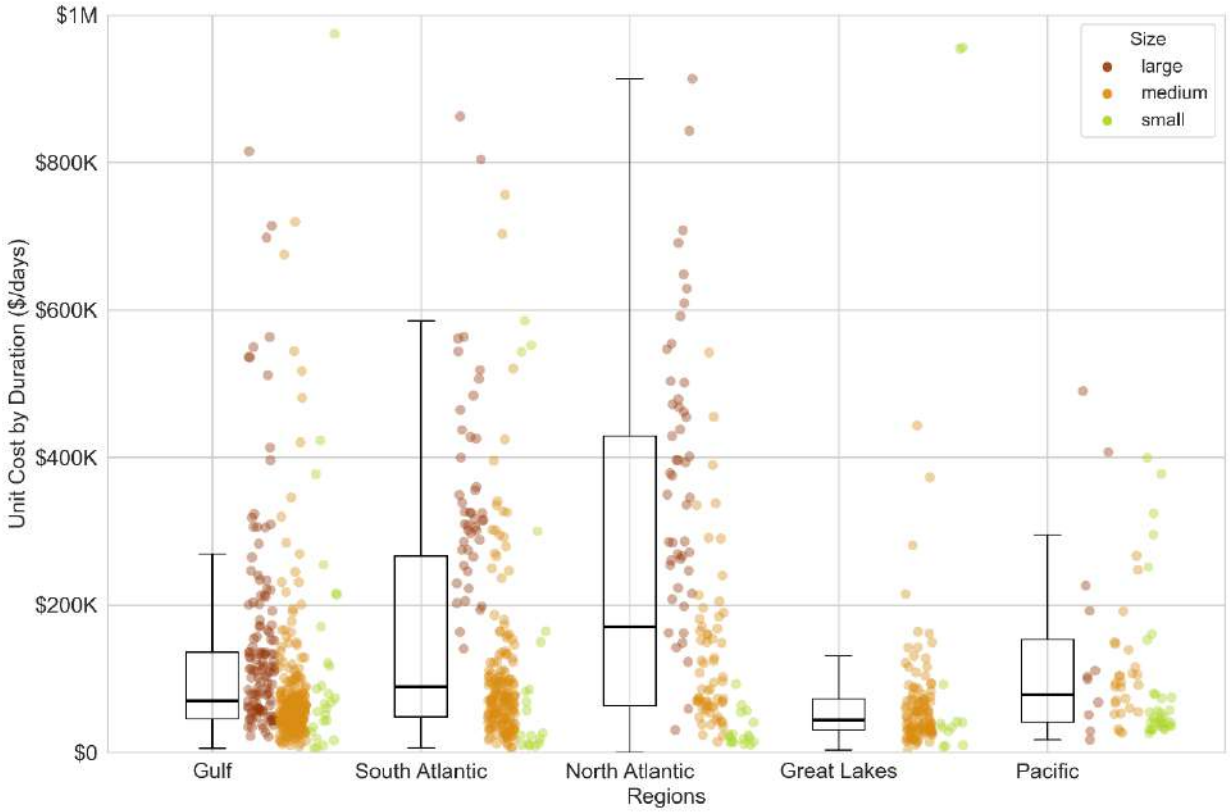


Figure 29. Unit cost of CSD dredging by project duration (days), by region and plant size.

Unit Cost and Discharge Pipe Length

Figure 30 shows the unit cost (vertical axis, USD/CY) as a function of discharge pipe length (horizontal axis, ft), per region and nation-wide, by dredge size. Each point represents a project. RMS records the length of the discharge pipeline daily. Since the discharge pipeline length may vary throughout the project duration, the 90th percentile value was used (considering all days pertaining to a given project). Trend lines (dashed black lines) do not evidence a clear increase or decrease in unit cost as a function of discharge pipeline length. Nationwide, the y-intercept (point of the graph where the trend line crosses the y-axis) decreases as the CSD size increases. Future work may include an analysis of unit cost by sediment type dredged by CSD.

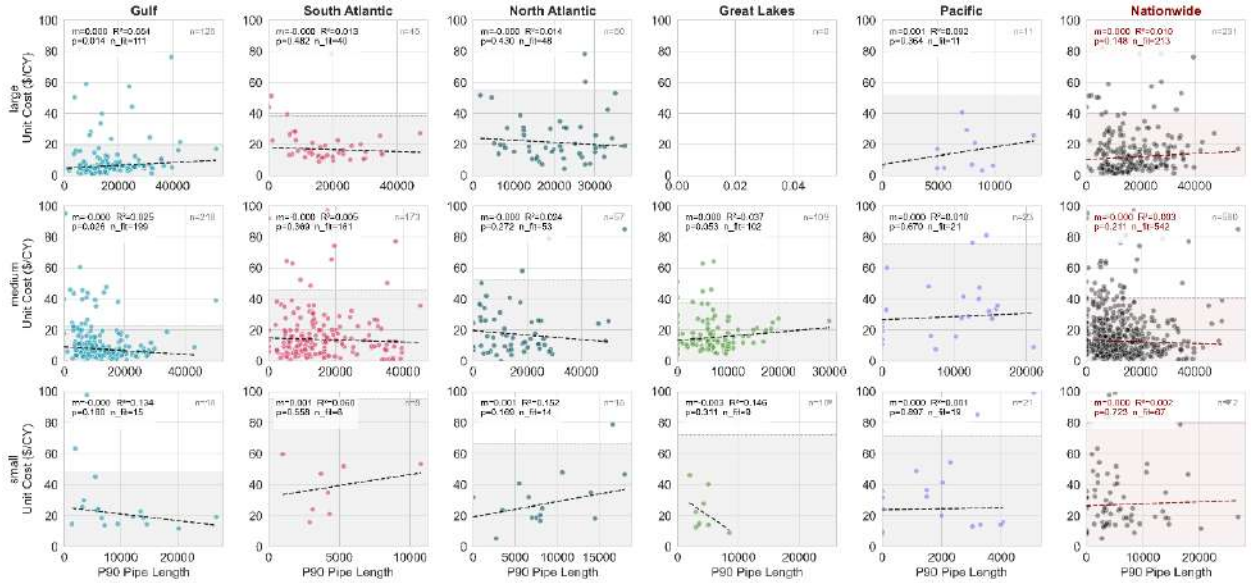


Figure 30. Unit cost (USD/CY) of CSD dredging by length of discharge pipeline (ft).

Mobilization / Demobilization Cost

This section explores the mobilization/demobilization costs as percentage of total contract award, per contract, as extracted from bid data. Figure 31 shows the distribution of such variable for each region and dredge size. A further analysis shows no apparent correlation between the percentage of mobilization in contract award and the discharge pipeline length. This may be related to how the use of equipment is sequenced. In contrast, the type of placement may influence mobilization costs. An open cell placement without the need of building dikes would reduce equipment needs or borrow site maintenance, versus a marsh or beach placement or confined cell. This hypothesis cannot be confirmed with RMS data alone, because it does not consistently inform the type of placement utilized. Future research including other datasets may elaborate on this matter. Moreover, based on Figure 25, there seems to be a pattern of shorter regional moves, which help control CSD pipeline mobilization costs. Increased coordination of contracting and scheduling efforts across the USACE portfolio may help to further reduce mobilization costs (Hanowsky et al., 2024)

CONCURRENT EFFORTS AND NEXT STEPS

Concurrent work by the authors focuses on utilizing RMS CSD records, together with other dredge types, in combination with timestamped dredge location data, to characterize dredging operations geo-spatially and derive historical activity patterns to inform future dredging program selection, scheduling and cost estimation efforts for the USACE portfolio. Future work may focus on a more granular analysis of the factors influencing lost time and non-effective work to identify opportunities for efficiency improvements, as well as a multi-variate analysis of factors that drive dredging cost and productivity. Papers similar to this work, but for other types of dredges may be developed.

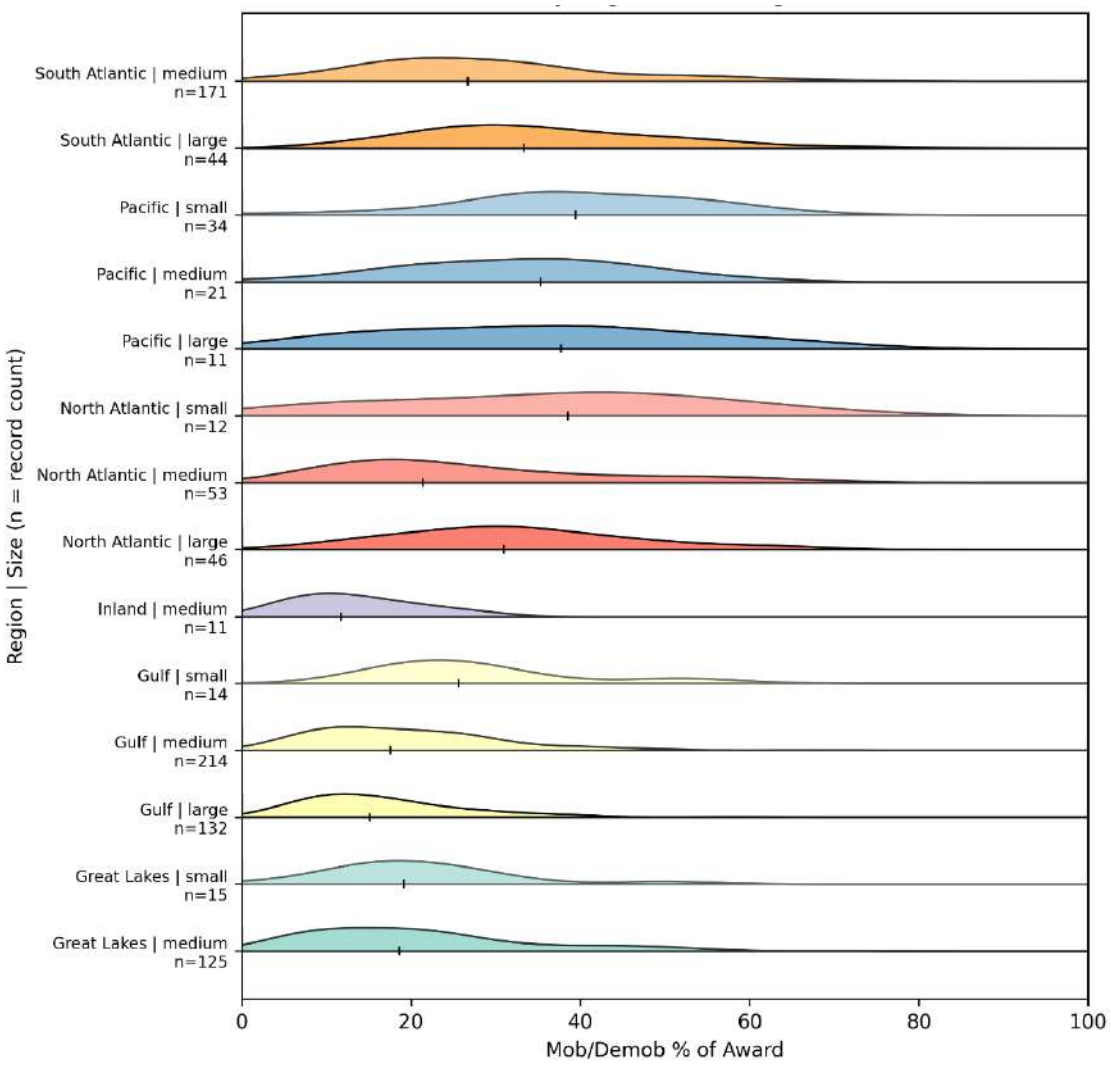


Figure 31. Mobilization and demobilization costs as a percentage of contract award for contracts involving CSD dredges by region and dredge size.

CONCLUSION

This paper presents a comprehensive analysis of the cutterhead suction dredge (CSD) fleet that has worked for the U.S. Army Corps of Engineers. The analysis focuses on productivity, drawing upon an extensive 15-year dataset from the Resident Management System (RMS) (between 2010-2025). The analysis of over 114,500 daily dredge logs reveal significant trends and provides valuable benchmarks for practitioners.

Key findings indicate that CSD dredging is a critical component of the USACE's maintenance strategy, accounting for 42% of its dredging contracts, performed by a fleet of over 200 plants. The Gulf region is the most active, dominating in both the number and duration of CSD projects. The data shows distinct regional variations in project characteristics, including dredge size, project duration, channel depths, cycle time efficiencies, and costs. The analysis highlights that, on average, dredges are actively pumping sediment from channels (effective work) only about 43-50% of the time, with the remaining time dedicated to non-effective but necessary activities or lost time due to repairs and other delays. This cycle time

breakdown varies significantly by region, with the Gulf region experiencing the highest efficiency. Productivity and unit costs show considerable variability, influenced by dredge size, region, and project specific conditions. The study found no clear correlation between unit cost and discharge pipeline length, suggesting that other factors play a more significant role in determining project costs. Furthermore, the analysis of dredge utilization over time reveals patterns in demand, with peak usage observed in 2019. An analysis of USACE districts where individual CSDs have worked through time shows that most movements occur with regions (i.e. districts within the Gulf, and within the Atlantic coast, unlike districts located in different regions).

The insights and data-driven trends presented in this work offer a foundational resource for planners, cost engineers, and operations managers. By providing real-world data on dredge performance, cycle times, fuel consumption, and costs, this paper equips practitioners to make more informed decisions in planning, estimating, and managing future dredging projects.

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DATA AVAILABILITY

All data, models, or code generated or used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

NAVIGATING PFAS IN SEDIMENTS: REGULATORY DRIVERS, DECISION TRIGGERS, AND DATA GAPS

E. Thomas[1], J. Benaman[2], and J. Holden[3]

ABSTRACT

Regardless of (or perhaps because of) the fits and starts of federal perfluoroalkyl and polyfluoroalkyl substances (PFAS) regulations, many states are pushing forward with regulating PFAS. As focus on the potential impact of PFAS in sediments increases, understanding possible risks and decision paths is becoming critical to proactive and thoughtful environmental management. This paper presents a decision framework to support strategy decisions for managing PFAS-impacted sediment. The framework is organized around the following three possible risk-based "decision lanes" that commonly drive management outcomes: 1) fish consumption advisory implications; 2) impacts to existing or new remedial sites; and 3) impacts to beneficial use or disposal of dredged sediment. We will overview the current state of knowledge and regulations, critical decision points along that path, and data gaps. While all three decision lanes are mentioned, this paper will expand more on the third "decision lane"—beneficial use or disposal of dredged sediment—because that is of particular interest to the dredging community. For the third lane, the framework examines how PFAS influences dredged material management decisions, including characterization, facility acceptance criteria, leaching and treatment during dewatering, and secondary-release risks across placement options (e.g., confined disposal, landfill, treatment, in-water disposal, and upland reuse). The framework highlights that national concentration-based sediment disposal triggers remain limited and inconsistent, and disposal and destruction guidance is still developing, requiring project-specific lines of evidence and stakeholder engagement—especially for dredging programs operating under tight schedules. Across all three lanes, we summarize what is known (e.g., federal monitoring recommendations, aquatic life criteria and benchmarks, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) hazardous-substance designation for perfluorooctanoic acid; perfluorooctanoate (PFOA) and perfluorooctanesulfonic acid; perfluorooctane sulfonate (PFOS), and advancing analytical methods) and what is still forthcoming (e.g., broader PFAS sediment criteria, harmonized beneficial use and disposal thresholds, and consistent tissue-to-sediment decision linkages). We conclude by identifying priority data gaps needed for defensible decisions and strategies for navigating these uncertainties as federal, state, and technical guidance continue to be developed.

Keywords: dredging, beneficial use, disposal, material management, adaptive management

INTRODUCTION

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) management for sediment and dredged material projects is emerging in a regulatory environment characterized by "fits and starts" at the federal level

[1] Senior Managing Engineer, Anchor QEA, 660 West Washington Avenue, Suite 302, Madison, WI 53703, USA, T: 248-228-6293, Email: ethomas@anchorqea.com (corresponding author).
[2] Principal, Anchor QEA, 68 Excelsior Avenue, Suite 101, Saratoga Springs, NY 12866, USA, T: 503-972-5016, Email: jbenaman@anchorqea.com.
[3] Principal, Anchor QEA, 54 Genesee Street, Suite 100A, Camillus, NY 13031, USA, T: 315-414-2009, Email:jholden@anchorqea.com.

alongside accelerating and highly variable state actions. The practical outcome is PFAS-related requirements are increasingly project-specific, driven by the combination of local regulatory programs, receiving facility expectations, and the specific exposure pathways implicated by a sediment management action.

Regulatory attention to PFAS initially centered on drinking water, but in recent years has broadened to address wastewater discharges, surface water, biosolids, and fish consumption advisory concerns. As these programs mature, they increasingly find connections to sediment systems—both because sediments may act as reservoirs of PFAS to the water column (depending on the nature and behavior of PFAS precursors) and because sediment handling can create water-release pathways (return water, runoff, leachate) that are regulated through water quality and discharge programs. As a result, PFAS is now affecting decisions at sites and projects that were historically considered routine, including navigation and maintenance dredging where placement and water management constraints can become decisive.

Dredging projects are uniquely exposed to these dynamics. They often operate under compressed schedules and seasonal windows, involve large material volumes, and must navigate multiple permitting regimes spanning dredging authorization, water quality certification, discharge permitting for dewatering and return flows, and approvals for disposal or beneficial reuse. These conditions amplify the consequences of late-breaking PFAS requirements, inconsistent thresholds across jurisdictions, and facility acceptance uncertainty.

To support proactive planning under this uncertainty, this paper presents a decision framework organized into the following three risk-based "decision lanes" that commonly drive sediment management outcomes: 1) fish consumption advisory implications; 2) impacts to existing or new remedial sites; and 3) impacts to sediment disposal and/or beneficial use. While each lane is introduced in the paper, Lane 3 is expanded due to its direct relevance to dredging and material management decisions.

REGULATORY DRIVERS AND DECISION TRIGGERS

Sediment management projects are often governed by federal and state regulatory drivers that create "decision triggers" that drive project actions. These decision triggers can result in new sampling, changes to disposal or beneficial use, additional treatment, or expanded monitoring. Additionally, these projects are adapting to a continually evolving set of regulatory drivers, while federal and state policies are being established. The following sections summarize the current regulatory drivers and their respective decision triggers as of April 2026.

Federal Drivers

Starting in 2016, the first federal driver was established by the U.S. Environmental Protection Agency (EPA) setting lifetime health advisories for perfluorooctanoic acid; perfluorooctanoate (PFOA) and perfluorooctanesulfonic acid; perfluorooctane sulfonate (PFOS). Since that time, federal drivers have advanced, shifted, and in some cases been reconsidered across administrations, creating uncertainty in how quickly and consistently federal policy translates into enforceable requirements. Recently, the federal government has advanced the following drivers:

- **Analytical method standardization:** December 2024, EPA's Office of Water published Method 1633A to improve data defensibility across aqueous, solid, biosolids, and tissue matrices (EPA 2024a).
- **Drinking water:** April 2024, EPA finalized enforceable standards for six PFAS (EPA 2024b). However, in May 2025, under new administration, EPA announced its intent to rescind standards for four of the six PFAS (EPA 2025a).

- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)**: July 2024, EPA finalize the rule establishing PFOA and PFOS as hazardous substances (EPA 2024c), increasing the potential for PFAS to be considered as contaminant of potential concern, and for PFAS to be considered in remedy reviews and liability assessments. While this rule was being finalized, in April 2024, EPA announced enforcement discretion policy to focus on parties that "significantly contributed" rather than passive receivers (EPA 2024d).
- **Clean Water Act (CWA) aquatic life criteria**: September 2024, EPA published its final recommended water quality criteria and benchmarks for several PFAS, providing a technical basis for states and tribes to develop water quality standards (EPA 2024e).
- **Disposal and destruction guidance:** April 2024, EPA updated the 2020 interim guidance on PFAS destruction and disposal summarizing the acceptability for landfills, thermal destruction approaches, and management of treatment residuals (EPA 2024f).
- **Wastewater:** December 2024, EPA's published Preliminary Effluent Guidelines Program Plan 16 summarizing ongoing effluent guideline studies and ongoing effluent rulemakings (EPA 2024g).
- **Resource Conservation and Recovery Act:** February 2024, EPA proposed to add nine PFAS to the Resource Conservation and Recovery Act's hazardous constituents list (EPA 2024h).
- **Biosolids:** January 2025, EPA issued draft risk assessment indicating that even low PFOS and PFOA concentrations may create unacceptable human health risks (EPA 2025b).

Collectively, these federal actions span methods, health and ecological benchmarks, cleanup liability, and waste management, creating multiple decision triggers for sediment projects. These drivers will expand and be periodically revised as PFAS science, policy priorities, and implementation tools continue to evolve.

State Drivers

Because federal PFAS policy has shifted over time, and national rules for sediments and dredge material remain slow to standardize, states have moved at different speeds and in different directions, creating a diverse set of state-specific triggers that often determine how PFAS is managed in practice. State programs also evolve to changing federal requirements and to implement federal recommendations through state authorities. For example, under CWA Section 401, states and authorized Tribes decide whether to grant, grant with conditions, or deny certification based on compliance with applicable water quality requirements. This authority provides the state ability to require PFAS-related sampling, monitoring, or controls for sediment projects even if dredging activities are permitted under federal rule. States similarly translate EPA's recommended aquatic life criteria into water quality standards, permit expectations, or screening practices that can become decision triggers for dredging projects.

One example where state drivers had direct and overriding impact on a dredging project is the Grand Haven Inner Harbor federal navigation channel (WGVU 2025). In April 2025, the U.S. Army Corps of Engineers (USACE) Detroit District had planned to conduct navigational dredging of the inner harbor, but the project was delayed after the Michigan Department of Environment, Great Lakes, and Energy (EGLE) expressed concern about potential drinking water impacts based on where dredged material was placed. In June 2025, EGLE published Sediment Dredging Guidance (EGLE 2025), which establishes sediment testing requirements, disposal options, and sediment dewatering requirements. The Grand Haven Inner Harbor project was completed in November 2025 after USACE addressed requirements set forth in EGLE's Sediment Dredging Guidance.

THE THREE DECISION LANES

Considering the complexities of federal and state drivers, we propose evaluating PFAS issues in sediments across three decision lanes:

- **Lane 1: Human and/or ecological risk due to fish consumption.** Lane 1 focuses on whether PFAS in sediment may translate into fish tissue concentrations that could affect human consumption risk, ecological exposure, or advisory and outreach decisions. The key decisions revolve around whether fish tissue is the controlling endpoint, what lines of evidence are needed (tissue, food-web context, supporting sediment and porewater), and how to interpret uncertainty in tissue–sediment linkages.
- **Lane 2: Impacts to existing or new remedial sites.** Lane 2 addresses how PFAS can change decision-making at active or proposed cleanup sites, including whether PFAS becomes a contaminant of concern, alters remedial action objectives, affects remedy selection (dredging, capping, MNR, amendments), or significantly affects project costs. The key decisions revolve around integrating PFAS into the conceptual site model and remedy performance framework, including what designates a PFAS-related risk and what media should be monitored to demonstrate protectiveness and long-term effectiveness.
- **Lane 3: Impacts to beneficial use and/or disposal of dredged sediment.** Lane 3 focuses on how PFAS affects where dredged material can go and what controls are needed to manage release pathways (return water/decant, runoff, leachate) across placement options such as confined disposal facilities (CDFs), landfills, treatment, in-water disposal areas, and upland use. The key decisions revolve around option feasibility and acceptance—often driven by permits, facility criteria, and discharge and leaching potential—because these constraints can drive cost and schedule even when PFAS is not the primary risk driver.

A practical approach is to start with the lane most aligned to your project type: advisory or ecological investigations start in Lane 1, remedial projects start in Lane 2, and navigation dredging often starts in Lane 3. Then apply a "controlling lane" check based on: 1) the dominant endpoint; 2) the decision authority; and 3) the pathway that constrains feasibility. A lane becomes controlling when it determines the project's key outcome (e.g., fish tissue concerns drive the required scope or stakeholder acceptance (Lane 1), cleanup program obligations set the remedy requirements (Lane 2), or disposal/dewatering/acceptance constraints dictate what can be implemented on schedule (Lane 3). More than one lane can apply, but the controlling lane is the one that dictates the minimum defensible dataset and the critical path for decisions; the others typically become "secondary lanes" that add targeted data needs or stakeholder coordination. While Lanes 1 and 2 can be critical to the success of a project, the remainder of this paper addresses the details of Lane 3.

LANE 3: DISPOSAL AND BENEFICIAL USE

Lane 3 Framework

Lane 3 is the material management lane that is triggered when decisions relate to how dredged material will be managed and/or disposed. In practice, Lane 3 decisions answer four related questions: 1) where the material can go; 2) which permits and receiving-site acceptance requirements apply; 3) which water-release pathways must be managed (return water, runoff, leachate); and 4) whether and where beneficial use may be feasible and defensible.

Under Lane 3, PFAS introduces release- and pathway-based constraints into decisions that are often otherwise driven by logistics and cost. This is why Lane 3 can become the "critical path" even when PFAS is not the dominant risk driver in the broader site setting.

The following subsections offer a suggested approach for navigating Lane 3 issues for a typical dredging project.

Step 1: Assess Federal and State PFAS Requirements and Regulatory Precedence

Projects should first assess the current federal PFAS regulatory landscape (rules, guidance, and program expectations) and determine whether new or revised guidance is likely to emerge during the project timeline that could change decision gates (e.g., analyte lists, discharge expectations, disposal and destruction considerations). In parallel, teams should evaluate applicable state (or multi-state) PFAS requirements, recognizing that state programs often define the practical triggers for dredging approvals, dewatering and return-water compliance, and disposal or beneficial reuse acceptability. This upfront assessment should also incorporate regulatory precedence by reviewing how similar projects have been handled locally and, where useful, nationally (e.g., projects delayed or modified due to PFAS testing or placement constraints), to anticipate likely data needs, schedule risks, and stakeholder expectations before finalizing the sampling and alternatives evaluation approach.

Step 2: Define Feasible Placement and Beneficial Use Options Early

Step 2 should begin with an explicit, project-specific definition of feasible placement options (e.g., open-water placement where allowed, CDF or dredge management material facility (DMDF) placement, landfill disposal, treatment for limited volumes, beach nourishment and similar protective applications, and upland beneficial use scenarios). This "options-first" framing matters because each option implies different exposure pathways and therefore different PFAS data needs. It also creates an early basis for aligning regulators and receiving facilities on what the decision process will require (i.e., what evidence must be developed to support each option).

Step 3: Build a Characterization Program That is Fit-For-Purpose

Once placement options are defined, Lane 3 proceeds with a characterization strategy that is aligned to those options and to material handling realities. Key elements include dredging method implications (mechanical versus hydraulic dredging), the ability to segregate or manage "hot" areas, sampling designs that directly support placement decisions, and method/quality assurance considerations (cross-contamination controls, detection limits, and analyte list rationale). A practical way to implement this is to develop a placement-option crosswalk that states, in advance, the minimum PFAS dataset needed for each candidate option (e.g., CDF vs landfill vs beneficial use) and how results will be interpreted.

Sediment PFAS data may be interpreted in the context of background concentrations, particularly where naturally occurring or regionally widespread inputs could influence what is considered elevated relative to ambient conditions. When evaluating upland placement or beneficial use, background PFAS conditions at candidate placement locations (e.g., soil, groundwater, and nearby surface water) may also be relevant for establishing baseline conditions, assessing incremental impact, and selecting monitoring triggers for potential secondary releases.

Step 4: Translate Bulk Sediment Results Into Release Potential

Because PFAS-specific bulk sediment concentration criteria are limited and inconsistent, placement decisions often shift from "What is in the sediment?" to "What might be released under the conditions of the proposed management option?" This naturally leads to a tiered sampling and testing approach that is tailored to the contaminant pathways of concern and the disposal and placement alternative under evaluation. The USACE/USEPA Technical Framework ("Technical Framework") emphasizes that contaminant testing should focus on pathways where contaminants may be of concern, and that testing should be tailored to the disposal site and option being evaluated (EPA and USACE 2004).

With that context, the option-specific logic is as follows:

- **Open-water placement:** If PFAS is detected in sediment, evaluation may focus on what could dissolve or mobilize into the water column during placement. The Technical Framework describes evaluating potential water column contaminant effects by comparing contaminant release in an elutriate to applicable water quality criteria or standards, and notes that for CWA-authorized disposal, water quality standards and allowances for initial mixing are specified by states as part of Section 401 certification requirements. In practice, this means elutriate results are typically interpreted against state water quality standards and values (and any applicable mixing-zone assumptions), and, where needed, supplemented by toxicity testing or risk-based evaluation where criteria are uncertain or not definitive.
- **Upland placement**: For upland placement options, bulk sediment PFAS concentrations may not be sufficient to address groundwater and surface-water protection questions, so the evaluation would turn to leachate-style testing and/or partitioning-based prediction of leachate quality. The Technical Framework identifies key CDF pathways as effluent discharges, surface runoff, and groundwater leachate, and indicates that predicted effluent and runoff concentrations can be compared to water quality standards, while leachate quality is evaluated relative to applicable criteria (or through risk assessment where criteria are unavailable). Thus, for PFAS, leachate results are generally evaluated using the most relevant state and federal groundwater or drinking-water benchmarks adopted or applied by the jurisdiction (and, where necessary, a risk-based narrative to address uncertainty).
- **Beneficial use:** Beneficial use evaluations often remain leachate-focused but require additional, project-specific lines of evidence tied to the use scenario and exposure assumptions (e.g., frequency of water contact, proximity to receptors, stewardship and monitoring). The Technical Framework highlights the lack of clear, uniform guidance for beneficial use suitability and emphasizes that applicable standards and criteria are commonly determined by state or local authorities and may draw from multiple existing frameworks depending on how dredged material is regulated and where or how it will be used. As a result, beneficial use decisions frequently rely on a structured weight-of-evidence that integrates bulk sediment characterization, leaching potential under expected conditions, and scenario-specific controls and monitoring commitments.

Step 5: Treat Dewatering and Return-Water Management as a First-Order Design Constraint

For upland placement or beneficial use projects, water discharge compliance can become the controlling constraint when return water, filtrate, or decant is released to surface waters under water-quality-based requirements and monitoring expectations. In many states, these releases are regulated through the state-administered National Pollutant Discharge Elimination System (NPDES) program (or state equivalent), meaning PFAS can become a reportable parameter and, where warranted, a basis for effluent limits, best management practices, and operational controls (e.g., treatment, reuse of water on site, or modified dewatering configurations). States may also incorporate PFAS-related conditions through CWA Section 401 certification for federally permitted activities, but in practice the day-to-day compliance burden often runs through NPDES permit terms for dewatering discharges. As a result, dewatering approaches, and the feasibility of treatment and residuals management at dredging scale, are not implementation details; they frequently determine whether a disposal or beneficial use pathway is feasible, approvable, and schedulable.

Step 6: Evaluate Secondary-Release Risk and Long-Term Stewardship by Option

After near-term handling and discharge pathways are addressed, Lane 3 must evaluate whether a placement option introduces unacceptable secondary-release risk and what long-term obligations it implies. For CDFs, this typically includes seepage and leachate controls, long-term operations and maintenance, and

monitoring commitments. For landfills, leachate management and evolving acceptance policies can be material constraints, and liability concerns may dominate feasibility. For upland or in-water uses, the analysis often turns on defensible exposure scenarios, water contact assumptions, institutional controls, and whether the use narrative remains durable over time and across stakeholders.

Step 7: Manage Permitting, Stakeholder Alignment, and Schedule Risk Deliberately

Because Lane 3 decisions are frequently shaped by multiple approval gates and third-party requirements, early coordination is essential. A practical expectation for Lane 3 is "permit stack mapping" (e.g., 401/404, NPDES for dewatering, solid waste approvals), early engagement with regulators and receiving facilities, and a communication strategy when beneficial use is proposed (including sensitivity to community and fish program concerns). This emphasis is not administrative; it is technical and cost risk management. Navigation dredging projects, in particular, can be constrained by seasonal windows and funding cycles, so PFAS testing lead times, lab capacity, late-stage scope changes, and disposal facility negotiations can become schedule and cost drivers even when the broader PFAS risk story is still evolving.

Challenges and Solutions

The following subsections apply the staged decision structure to the real-world challenges that commonly disrupt sediment projects and outlines practical mitigation actions that can be implemented at each step to keep decisions defensible and projects on track.

Multiple Regulatory Programs

Lane 3 decisions often sit at the intersection of multiple programs such as CWA 404/401 (dredging and placement approvals), state-administered NPDES (dewatering and return water), state solid waste and materials management requirements (upland placement, landfill, and CDF), and in some cases cleanup program expectations. The result is a "multi-gate" process where different agencies can require different datasets, and where one late-emerging requirement can invalidate an otherwise workable placement plan.

Mitigation plan:

- **Permit stack mapping early (Step 1/Step 6):** Create a one-page "permit stack" diagram identifying the controlling authority for: a) dredging and placement; b) water releases (dewatering, decant, and runoff); and c) final disposition (landfill, CDF, and reuse).
- **Single decision log:** Maintain a living table of decision gates, required submittals, and "acceptance tests" (what evidence satisfies each gate).
- **Early regulator and facility alignment meeting:** Hold a short alignment meeting with the state water program, materials management and solid waste program, and the likely receiving facility to confirm the minimum dataset for each option and avoid rework prior to initiating any investigations or sampling.

Evolving and Non-Harmonized PFAS Criteria

In the absence of widely adopted bulk sediment criteria, PFAS management is commonly anchored to media-specific and pathway-specific benchmarks (water quality, groundwater and drinking water, fish and bioaccumulation considerations), and these vary by jurisdiction. States may also differ in PFAS analyte lists, COPC expectations, and how they interpret "total PFAS," precursors, and mixtures. This variability creates uncertainty, especially for projects that cross jurisdictions or depend on disposal sites with their own policies.

Mitigation plan:

- **Benchmark crosswalk (Step 2/Step 3):** Develop a project-specific "benchmark crosswalk" that lists the applicable (or likely-to-be-applied) water, groundwater, and tissue benchmarks and identifies which pathways each benchmark governs (return water, runoff, leachate, fish).
- **Design for change:** Build contingency triggers into the plan (e.g., "if PFAS suite expands, analyze archived extracts or retain sample mass for add-on analytes") and include a change-management protocol.
- **Use a weight-of-evidence narrative:** Document how decisions are made when criteria are absent or inconsistent (e.g., background, lines of evidence, sensitivity analyses, conservative assumptions).

Option-Specific Testing: Bulk Sediment is Not Enough

Bulk sediment data often supports initial screening and facility discussions, but it rarely answers the Lane 3 question of release potential under management conditions. Open-water placement raises water-column mobilization concerns (potentially requiring elutriate-style testing), while upland placement and beneficial use raise groundwater and surface-water protection questions (potentially requiring leachate-style testing). Dewatering adds another layer of complexity and compliance is frequently determined by what's in return water and filtrate rather than the sediment.

Mitigation plan:

- **Branching test plan (Step 3):** Write the sampling and analysis plan as a tiered decision tree:
  - Tier 1: bulk sediment PFAS plus basic material properties to support screening and segregation.
  - Tier 2A (open-water): elutriate- and effluent-like evaluation, if that option remains on the table.
  - Tier 2B (upland and reuse): leachate-style evaluation, if upland pathways remain on the table.
  - Tier 2C (dewatering): decant and filtrate characterization aligned to the discharge mechanism and permit expectations.
- **"Option holds" to avoid wasted testing:** Only execute Tier 2 tests for options still viable after Tier 1 screening and early regulator and facility feedback.
- **Matrix-to-decision linkage:** Explicitly state and gain agreement on how each test will be interpreted and what action it triggers prior to collecting data.

Facility Acceptance Criteria and Long-Term Liability

Receiving facilities (e.g., landfills, CDF/DMDF operators, beneficial use site owners) may impose acceptance criteria that are independent of regulatory thresholds and can change quickly. Liability concerns (e.g., future leachate management, long-term monitoring, public perception) can dominate feasibility even when technical risk appears manageable.

Mitigation process.

- **Secure conditional acceptance early (Step 1/Step 6):** Obtain written, conditional acceptance from the likely receiving facility based on a defined dataset and decision logic (what they need to see, and under what conditions they would refuse).

- **Define stewardship and "who owns it":** Explicitly assign long-term responsibilities for monitoring, operations and maintenance, and contingency actions (especially for CDFs and reuse sites).
- **Material management plan with "off-ramps":** Include alternative disposal pathways if acceptance changes (e.g., secondary landfill option, modified CDF operations, or treatment contingency for a limited fraction).

Schedule and Cost Risk (Especially for Navigation Dredging)

PFAS can create schedule risk through late-breaking testing requirements, laboratory capacity constraints, longer turnaround times, and iterative reviews with agencies and facilities. Cost risk is driven by additional sampling rounds, option-specific testing, water management and treatment requirements, and losing the least-cost placement option late in design.

Mitigation process.

- **Front-load the critical path:** Treat PFAS sampling and analytics and facility and regulator alignment as early critical path tasks, not "nice-to-have" add-ons.
- **Parallel path planning:** Advance at least one backup placement option (and associated testing plan) in parallel until acceptance is secured.
- **Schedule contingencies tied to triggers:** Build time allowances for Tier 2 testing and permit modifications, and define decision deadlines (e.g., "by X date, if open-water placement remains uncertain, pivot to upland/CDF option and execute Tier 2B tests").
- **Cost containment via segregation:** Use spatial modeling and segregation to reduce the volume requiring the most constrained management pathway.

Across these challenges, the consistent mitigation strategy is to treat Lane 3 as a sequenced set of decision gates—align early on the gate requirements, design tiered testing that maps to specific pathways and options and maintain contingencies so evolving criteria or acceptance constraints do not become late-stage project blockers.

CONCLUSIONS AND PATH FORWARD

Lane 3 remains challenging because several key elements needed for predictable, repeatable decision-making are still developing, including harmonized reuse/disposal thresholds, standardized release testing and interpretation that clearly map results to decisions, long-term performance monitoring best practices for CDFs and reuse sites, and more consistent linkage between sediment PFAS and tissue outcomes that often shape stakeholder acceptance of disposal and reuse pathways. Looking ahead, projects should also anticipate that additional PFAS may be elevated from "parameters of interest" to COPCs as analytical capabilities, toxicity information, and regulatory programs expand. This means today's PFAS datasets may not fully bound tomorrow's decision space. In parallel, evolving federal and state actions (and related litigation and policy) are likely to increase the importance of long-term liability considerations for dredged material placement, including how residuals are managed, how releases are monitored over time, and how responsibilities are defined among dredging sponsors, receiving facilities, and other stakeholders. As a result, even when PFAS is not the initial driver for a sediment project, it will increasingly need to be addressed at some stage of planning, permitting, implementation, or long-term stewardship.

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DATA AVAILABILITY

No data, models, or code were generated or used during the study.

BEAR CREEK DREDGING-CAPPING REMEDY: MANAGEMENT OF TECHNICAL CHALLENGES DURING PRE-DESIGN AND REMEDIAL DESIGN

J. Beaver[1] and C. Kiehl-Simpson[2]

EXTENDED ABSTRACT

EA Engineering, Science and Technology, Inc., PBC is supporting U.S. Environmental Protection Agency (EPA) during pre-design investigations, preliminary evaluations, and removal action remediation design (RD) for the Beer Creek Sediment Remediation Dredging and Subaqueous Capping Project. Constituents of concern (COCs) include polychlorinated biphenyls (PCBs), heavy metals, and total oil and grease. The Site includes approximately 60 acres in Bear Creek at the former discharge area of Tin Mill Canal. Relict structures from a former trolley and deteriorated timber wall, abandoned and active utilities, and debris within the Site will be a component of the remedial design. An existing heavily trafficked bridge isolates a small area of the remedy footprint. Pre-design investigations (PDI) included bathymetric/topographic surveys, sampling, geotechnical evaluations, groundwater and surface water flow studies, and other field activities. Data interpretation and pre-design evaluations are underway and planned for completion this year in 2026, while the RD is presently planned for 2027.

The Site is located southeast of the main span of the former Francis Scott Key bridge on Interstate 695 and adjacent to the western shoreline of the Sparrows Point Facility (SPF) owned and operated by Tradepoint Atlantic (TPA). The SPF is located on an approximately 3,100-acre peninsula in Baltimore Harbor, generally bounded by the Back River, Bear Creek, and the Northwest Branch of the Patapsco River. More than 100 years of steelmaking and related activities conducted by various owners at SPF resulted in releases of hazardous substances into the environment, including Bear Creek. PAHs, PCBs, and metals have been analyzed, as well as oil and grease, which will be factored into the subaqueous cap and removal action design.

Hydraulic dredging will remove sediment and convey the slurry to geotextile tubes for dewatering, management, and disposal. Demolition debris and other debris will be removed and managed before and during dredging. Capping will include requirements to address challenging site conditions for geotechnical engineering aspects of the RD. Pre-design investigations have confirmed the presence of thick, highly compressible, and very low shear strength highly sensitive sediment, both in terms of potential for significant loss of strength with physical disturbance and potential for porewater expression into the lower portion of the cap from consolidation. Elevated concentrations in pore water are currently under evaluation. Groundwater flow modeling and direct measurements using seepage meters have been completed, and pre-design CAPSIM modeling scenarios to determine the cap's chemical isolation requirements are planned.

Pre-design has identified the following challenges that will be summarized in the presentation: management of resuspended solids during hydraulic dredging; management of sheen during dredging and water

[1] Dredging Engineer, EA Engineering, Science, and Technology, Inc., PBC, 225 Schilling Circle, Suite 400 Hunt Valley, Maryland, 20131, USA, T: 410-584-7000, Email: jbeaver@eaest.com.
[2] Project Manager/Senior Engineer, EA Engineering, Science, and Technology, Inc., PBC, 10321 East Grand River Avenue, Brighton, Michigan, 48116, USA, T: 810-206-3048, Email: ckiehlsimpson@eaest.com.

treatment; management of space limitations for geotextile tube dewatering; mudwaving risk and mitigating low slope stability safety factors for capping; management of significant consolidation during both cap placement and for many years following construction; groundwater flux and the advection versus chemical diffusion components of chemical isolation; use of mixing zone for the cap design given fluid-like conditions in surficial sediment; implications for acceptable placement technologies, including anticipated placement requirements to manage slopes stability and differential settlement during cap placement; and long-term monitoring for both chemical isolation and cap integrity. Pre-design evaluations that have been completed or have progressed to initial findings will be summarized; however, materials included in the presentation will not be finalized and approved by EPA at the time of the conference. As such, the information in the presentation is not endorsed by EPA and reflects the opinions and experience of the authors.

Keywords: Environmental dredging, subaqueous capping, sediment consolidation, mud-waving, cap bearing stability

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A TARGETED APPROACH TO SEDIMENT REMEDIATION IN A HERITAGE-RICH NATIONAL PARK (QUÉBEC, CANADA)

M. Audet Daigle[1]

EXTENDED ABSTRACT

Opémican National Park was created in 2013 in the Témiscamingue region to honor and preserve the rich history and natural beauty of this area. With Indigenous presence dating back to around 6500 years, the Bay of Opémican (figure 1) was an important fur trade location in the 17th century and later became an operation center for the forestry and log driving activities between the 1860s and 1980s.

Figure 1. Bay of Opémican (Photo credit Louis Jalbert)

The historical commercial and industrial use of the site has left its mark on the area through the presence of numerous remains and buildings from that period, as well as clear signs of PAHs and metals contamination in certain portions of the territory.

The initial project call included complete remediation of the bay to enable safe recreational use (swimming and non-motorized water activities) while ensuring the preservation of heritage remains and aquatic ecosystems. With the aim of proposing sustainable remediation interventions compatible with the park's future use, WSP carried out multiple field studies to better define contamination, hydrodynamic conditions and biological habitats within the bay.

[1] Project Manager-Dredging and Sediment Management, WSP Canada inc., Maxim.AudetDaigle@wsp.com

These campaigns showed that the contamination was confined to sediments and that water quality was not an issue except for suspended solids. These results indicated that the primary environmental risk was associated with the resuspension of fine sediments during storm events, rather than chemical exchange between water and sediments. As a result, a three-part strategy was implemented:

- Targeted dredging and capping in areas used for swimming;
- Capping in sectors at risk of resuspension;
- Monitored natural recovery in all other zones.

The project site includes remains of historical industrial activity, severe water-level fluctuations, and low bearing capacity/strong wave climate in some areas. Instead of fighting these technical constraints, WSP adapted the project design to leverage them. Low water level periods were used to complete part of the project with land-based equipment, reducing risks related to floating machinery near the numerous remains in this area. Further offshore, important volumes of capping material were strategically placed so that it could be naturally redistributed across the low bearing capacity areas through wave and current action. This natural process will ensure a slow and even distribution of the capping material, while generating minimal pressure on existing sediments.

Keywords: Environmental capping, Environment Dredging, Nature Based Solutions, Shoreline Restoration

CITATION

Audet Daigle, M. “A Targeted Approach to Sediment Remediation in a Heritage-Rich National Park (Québec, Canada),” *Proceedings of the Western Dredging Association Dredging Summit & Exposition ‘26, Montreal, Quebec, CA*, July 20-23, 2026

PORTLAND HARBOR SUPERFUND SITE: ENVIRONMENTAL REMEDIATION CONSIDERATIONS AND CONSTRAINTS

T.M. Dreher[1], R.S. Webb[2], J. Bale[3]

ABSTRACT

In 2000, the U.S. Environmental Protection Agency (EPA) added the Portland Harbor Superfund Site (PHSS) to the National Priorities List pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The remedial investigation and feasibility study (RI/FS) for the PHSS was completed in 2016 and the EPA issued a Record of Decision (ROD) for the PHSS in January 2017. The PHSS is an approximately 10-mile (16-kilometer) segment of the Willamette River in Portland, Oregon, that is currently undergoing remedial design for future remedial actions to address sediment contamination within the waterway. The PHSS area is currently a mix of industrial uses including marine terminals, manufacturing facilities, railroad and utility crossings, commercial and residential uses along shoreline properties, and public property including parks and open spaces.

PHSS remedial designs must be consistent with overall PHSS ROD requirements and address technical issues related to the ROD. The PHSS section of the Willamette River has been heavily industrialized for over a century, serving a wide variety of industries over time including considerable shipbuilding during WWII. The industrial history and related cycle of development and redevelopment in the waterway have created challenges typical of many urban, industrialized rivers including significant debris, a mix of active and remnant structures, areas of significant infilling and erosive over steepened slopes, often held in place by a variety of non-engineered shoreline materials and/or established vegetation. This paper highlights several critical design considerations and constraints and the corresponding technologies or approaches being evaluated to address these design challenges. The design considerations and constraints discussed in this paper include the following: structures, transload and disposal, shallow bedrock, buried contamination, slope stability, and seismic considerations.

Keywords: Dredging, sediment characterization, dredge equipment selection, dredging Best Management Practices (BMP), contaminated sediment, diver dredging

INTRODUCTION

In 2000 the Environmental Protection Agency (EPA) added 10 miles (16 kilometers) of the Lower Willamette River to the National Priorities List (NPL) creating the area designated the Portland Harbor

[1] Senior Engineer, DOF – Dalton, Olmsted & Fuglevand, Inc., 2601 Cherry Ave., Suite 300, Bremerton, WA, USA, 360-710-8180, tdreher@dofnw.com
[2] Principal Engineer, DOF – Dalton, Olmsted & Fuglevand, Inc., 1317 Front Street, Leavenworth, WA, USA, 360-908-1386, rwebb@dofnw.com
[3] Senior Engineer, DOF – Dalton, Olmsted & Fuglevand, Inc., 3121 South Moody Ave., Ste 180, Portland, OR, jbale@dofnw.com

Superfund Site (PHSS). The PHSS is an approximately 10-mile segment of the Willamette River in Portland, Oregon, that is currently undergoing remedial design for future remedial actions to address sediment contamination within the waterway. The PHSS area has a mix of industrial uses including marine terminals, manufacturing facilities, railroad and utility crossings, commercial and residential uses along shoreline properties, and public property including parks and open spaces, and was added to the NPL by EPA in 2000. The overall PHSS is divided into various Project Areas where remedial design work is being performed by various parties. Due to the location, site history, and uses, there are several factors and design considerations that add complexity to the remedial design and implementation. This paper will discuss several of these factors.

STRUCTURES

Marine infrastructure such as wharfs, piers, floating docks, and pilings, are common in the PHSS, both active and remnant. Active overwater structures largely support vessel loading and unloading operations and/or mooring. Shoreline structures stabilize the riverbanks from urban development (EPA 2017). Throughout the PHSS these structures are in various levels of functionality and condition. The PHSS ROD (EPA 2017) states that structures must be removed to access contaminated media unless the structure is permanent, functional, and required to support current or future property and waterway uses. The Remedial Design Guidelines and Considerations (EPA 2021) is an EPA document that adds context and detail to the PHSS ROD. In 2019, EPA issued their initial RDGC (EPA 2019) document to provide further clarity to the PHSS ROD requirements and later issued a revised RDGC (EPA 2021). The RDGC defines functional structures as either in use for site operations or being used to stabilize the riverbank, and with a current service life of greater than 50 years. It is stated that minor structures such as outfalls will be temporarily or permanently moved to accommodate dredging and backfill, as necessary.

To address this design consideration detailed in the PHSS ROD (EPA 2017), PHSS Project Areas are required to perform a functional structures evaluation for any structures that fall within active remediation areas to determine if structure can remain or will require removal to support the remedial action. Per the RDGC (EPA 2021), in order to determine if a structure can be deemed a “Functional Structure”, it is expected that pre-remedial design activities will include site surveys to determine the functionality and stability of site structures to determine which must be removed prior to the construction of the selected remedy and to understand the effect of the selected remedy on the stability of structures that are expected to remain. If the structures are deemed to have less than a 50-year remaining functional life, the structure must be removed to prevent impeding the remedial action, and in some cases, replaced.

Only those structures that meet the criteria for a Functional Structure may be left in place during remediation. In which case, a remedial technology must be selected that won’t destabilize the structure or riverbanks. Where standard dredging can’t be completed around and underneath a structure to remove contaminated sediment, the following options could be considered:

- **Diver Dredging.** Diver dredging may be used to remove contaminated sediment underneath and around structures that may stay in place where other methods of removal may not be feasible. This option must be evaluated for diver safety concerns, impacts to the structures stability, and whether it may result in destabilization of the riverbanks.
- **Capping.** Capping may be considered in areas with structures that will remain in place, specifically if dredging or other remedial methods may risk destabilization of the structure, assuming the cap is physically stable and chemically isolates the underlying contaminants. Evaluations must be conducted to determine if capping material may surcharge structures and risk destabilization or whether it will result in a net-rise in the Project Area.

Additionally, leaving remnant non-functional structures, even outside of active remediation areas, can have a negative impact on mitigation requirements per the PHSS ROD and accompanying PHSS Biological Opinion (BiOp) (National Marine Fisheries Service [NMFS] 2025).

TRANSLOAD AND DISPOSAL

The transport, transload, and disposal of dredge material are critical parts of environmental remediation projects and are typically some of the most costly aspects of remediation. Once dredged and on a barge the dredge material is typically dewatered as necessary and then transloaded from the sediment barge to upland trucks or rail cars for transportation to an approved landfill for disposal. Care must be taken during these transloading activities to avoid contaminant releases to the environment. Currently there are no operating transload facilities located within or near the PHSS, requiring dredge material to be transported via barge to a farther transload facility. Currently, the nearest transload facilities to the PHSS is located in the Dalles, Oregon, could require a 30-hour or longer duration of a round trip per barge to go to the transload facility and back to the Project Area with an empty barge. Additionally, this transload facility primarily services one of three potential landfills in Washington or Oregon typically considered for disposal of PHSS dredge material. The construction of a suitable transload facility within the PHSS would reduce potential environmental impacts, reduce risks and reduce costs for dredge material disposal to upland landfill. A transload facility within the PHSS could expand the number of landfills that could potentially receive PHSS dredge material. This could help improve schedule if disposal is a limiting factor to project completion.

Without a transload facility within the PHSS, cost, schedule, and remedial action implementation complexity will be increased. Dredge material from the PHSS that is barged to a regional transload facility in the Dalles or elsewhere along the Columbia River will require larger river barges to safely transport the dredge material. Some transportation considerations include:

- Depending on Project Area removal approaches, locations, and subsurface conditions, sediment may need to be initially loaded into a smaller barge and then rehandled within the PHSS onto a larger barge for river transport to the transload location.
- Sediment being transported via barge up the Columbia River will need to be more aggressively dewatered and/or stabilized prior to transport, to not decrease barge stability and reduce potential for dredge material loss during transport.
- To reduce the potential for dredge material shifting during transport, barges may need to be light-loaded due to the greater travel rough water conditions often encountered in the Columbia River. In addition, uncovered barges must account for the potential of additional water spray entering the barge during tug pushes in high wave conditions, which is not uncommon in the Columbia River gorge.
- Significant coordination and detailed advance planning are needed for a more distant transload facility as a variety of contractors and parties must be engaged to ensure smooth operations between barge suppliers, scow loading operations, transport, and offloading operations at a transload facility.
- The number of total barges required and the capacity for staging loaded barges at the transload location must be considered to avoid work stoppages.

A suitable transload facility within the PHSS has the potential to:

- Reduce risks associated with barging dredge material up the Columbia River including anticipated need to transload dredge material to larger haul barges than are used for actual dredging.
- Reduce impacts due to significant number of barge trips up and down Columbia River including travel thru locks and potential impacts of new I5 bridge construction over the Columbia River.

- Reduce project schedule by reducing dredge material throughput capacity and allowing additional landfills to receive the dredge material.

BIOLOGICAL OPINION PROJECT DESIGN CRITERIA

The BiOp (NMFS 2025) was issued to detail the Programmatic Consultation on PHSS Cleanup Activities. The BiOp adds requirements to the remedial design and implementation of the cleanup action in accordance with section 7(b) of the Endangered Species Act (ESA), which are defined as Project Design Criteria (PDCs). The PDCs listed in the BiOp cover many different categories, including: general in-water construction, dredging, barge loading and transport, capping and treatment, piling installation and removal, riverbank construction and stabilization, transload facility operation, monitoring, and habitat impact minimization and offsets/restoration.

In general, the PDCs are akin to best management practices applied to other projects, but there are some that add additional complexity to the remedial design. Some of the most impactful PDCs include the following (NMFS 2025):

- Armoring of riverbanks may not solely use riprap or large rock, but should use vegetated riprap with large wood, which must incorporate a minimum amount of wood for the treated area to mitigate the riprap such that the amount of wood is equal to 20 percent of the treated area of riverbank.
- Following dredging in shallow water areas, backfill must be down to restore pre-dredging elevation to avoid a loss of shallow-water habitat.
- Lay back or extend out riverbank slopes to as close as a 5H:1V slope as practicable given site-specific conditions.

Additionally, the BiOp states the total amount of dredging will not exceed 366,000 cubic yards per season, based on 3,000 cubic yard per day production rate and up to three remedial action areas may be dewatered, dredged, or capped simultaneously.

These additional factors and criteria further complicate the remedy and will add cost and schedule to the project implementation.

BURIED CONTAMINATION

Many contaminated sites have top-down contamination where contamination starts at the mudline surface and continues vertically to an interface with clean or native material. This scenario allows for the creation of dredge prisms where contaminated material is removed and disposed of without significant removal of cleaner material. However, there are multiple areas within the PHSS where subsurface sediment exceeding active cleanup levels is overlain by shallower sediment below these thresholds. In some cases, the cleaner overburden material is greater than 20 feet in depth. The concentration trends at the PHSS are largely due to the timing of when most of the contamination occurred (pre-1970s) and the fact that the PHSS of the Lower Willamette has significant depositional areas or has changed shape and depths via filling and dredging throughout the years.

One of the primary remedies in the PHSS is to reduce the contamination levels in the surface sediment, thus improving fish tissue concentrations over time and the overall health of the waterway. Dredging clean material to access and remove contaminated material above the remediation thresholds would re-exposure these buried deposits, generating resuspension and would be a costly approach that may not actually help in achieving this goal. The EPA has allowed for consideration of “Buried Contamination” not requiring active remediation if certain criteria is met, but it would require ongoing monitoring. Whether or not buried contamination will be included in an SMA depends on the stability of the buried material and reasonably

anticipated future site uses. This requires an evaluation to reasonable demonstrate the contaminated material is both physically and chemically stable and is unlikely to be exposed at the sediment surface in the future. The evaluation must include fate and transport modeling and address factors such as erosion/scour potential, chemical concentration gradient compared to active remediation thresholds, the thickness of the overlying layer with concentrations below active remediation thresholds, and advective transport. If EPA supports the outcomes of an evaluation indicating stability over time, monitored natural recovery would be approved.

SHALLOW BEDROCK

There are areas of the PHSS where undulating, shallow basaltic bedrock exists, increasing the challenges of implementing a remedial action where contaminated sediment lies directly atop the bedrock.

In these locations, removal is difficult with traditional remediation technologies. At the PHSS, some SMAs have been defined in areas where bedrock is overlain by only a few feet of softer sediment and/or have contaminated sediment directly overtop of the bedrock surface. The bedrock undulation and the material hardness present challenges to full removal of softer, overlying sediment. Removal with a dredge bucket is not considered a feasible approach, which was verified by the United States Army Corps of Engineers (USACE) when deepened a portion of the Columbia River with similar bedrock conditions. After unsuccessfully attempting removal using a large clamshell dredge, underwater blasting was performed to remove the bedrock (USACE 2011). Hydraulic dredging is also not a feasible option due to the undulating surface, which could cause damage to the cutterhead and would also leave a layer of residual contaminated material. Due to the bedrock conditions, contaminated material may need to be left in place over the surface of the bedrock.

Remedial options considered for these areas include dredging to within a couple feet of the bedrock surface and then placing a cap above the remaining contaminated sediment or, in areas where capping isn't feasible, using diver dredging to attempt to remove as much material as possible, but would come at a high cost per cubic yard, especially in deeper areas of the channel. The remedial options complications increase where shallow bedrock occurs within the federally authorized navigation channel, as described below.

NAVIGATION CHANNEL

A federal navigation channel, with an authorized depth of -40 feet (ft) Columbia River datum (CRD), extends from the confluence of the lower Willamette River with the Columbia River to River Mile 11.6 within the Willamette. Portions of the river require periodic maintenance dredging to maintain the navigation channel at its authorized depth. Additionally, Congress has authorized the Willamette River to be deepened to -43 ft CRD; however, this has not yet occurred and is planned to be completed following remediation of the PHSS (EPA 2017).

The PHSS ROD (EPA 2017) states that material exceeding remediation thresholds and/or capping material may not be left above the authorized navigation depths within the federal navigation channel, including a two-foot overdredge allowance and a 50-ft horizontal buffer on either side of the navigation channel. Any cap located in this area must have a final elevation that is below the future overdredge allowance, so as not to interfere with future navigation dredging and elevated contaminant concentrations cannot be left within these limits.

Due to these guidelines, there are areas in the PHSS where material that could be considered "Buried Contamination" will have to be removed due to the elevation of the material in relation to the navigation channel authorized depth if it falls within the navigation channel or in the adjacent buffer area.

SEISMIC CONSIDERATIONS AND SLOPE STABILITY

Discussion of seismic design considerations in the PHSS ROD (EPA 2017) was limited to sediment capping requirements and did not discuss seismic requirements for structures. The PHSS ROD stated that "*Caps will also factor in appropriate earthquake design elements for contingency level events.*" The RDGC then included the definition of a contingency level event (CLE). As stated in the RDGC, "*The seismic hazard level for the CLE is defined as a ground motion with a 10% probability of exceedance in 50 years (i.e., a return period of 475 years). Seismic cap design should include analysis of the likelihood that the cap will be damaged to the extent that underlying contaminated sediment is exposed during the CLE hazard level.*"

Each PHSS Project Area is independently evaluating how their projects will integrate seismic considerations into the design process if the area includes docks, wharves, or retaining walls. The proposed approaches will then be presented to EPA, who will provide the design to a team of reviewers at the City of Portland (City) to obtain feedback as to whether the proposed design is in conformance with City codes. The City's response will be provided to EPA to determine what CERCLA's position is on any non-conformance statements by the City. Then EPA will relay their assessment of the City's position to the PHSS Project Area designers. This process has yet to be initiated by any Project Area so EPA position is not clear, results insignificant uncertainty on design approval of a particular approach, and may result in overdesigning structures to minimize uncertainty.

Further, a temporary structure is typically approved by the City when being utilized for 180 days or less but most PHSS dredging projects require consideration of temporary retaining walls which may be needed well beyond this timeframe if the cleanup work cannot be completed in a single in-water construction season. As temporary structures do not typically need to be designed to meet seismic design requirements, understanding of whether a temporary condition on longer duration projects will trigger the requirement for designing the structure as "permanent", which increases cost and structural complexity.

EPA guidance around in-water caps require the evaluation of liquefaction, lateral spreading, and seismic slope stability and other factors. The surficial and shallow soil types present in the PHSS primarily consist of unclassified fill placed over silt and sandy alluvium. The fill and alluvium are susceptible to liquefaction and lateral spreading during a CLE event for which in-water caps must be designed for. As such, EPA's expectations are that caps are designed to prevent exposure of underlying sediment that could result from lateral spreading. In addition, much of the fill materials placed over time were placed at slope angles that are over steepened and have a minimal or no factor of safety. In this scenario, even minimal dredging could result in slopes with much lower than traditional static factors of safety even when matching existing slopes. These factors are making it very challenging to design a remedy that meets the seismic criteria without flattening the existing slopes, which can result in loss of uplands and have a large impact on facility operations.

CONCLUSIONS

The PHSS is a complex Superfund Site due to both its location near downtown Portland, Oregon, and the history of the industrial waterway. Some of the unique considerations are due to physical features within the PHSS, like the current lack of a transload facility which could result in a 30-hour round trip for a clean sediment barge to return to the project area after sending off a loaded barge; Buried Contamination which, if removed, would result in disposal of a large volume of material that does not exceed the remediation thresholds; and shallow basalt that makes traditional remediation technologies challenging to achieving full removal of the target material.

There are also many complexities with regards to the remedial design that will make for a very costly and complex remedy that are driven by the various guidance documents including the PHSS ROD (EPA 2017), RDGC (EPA 2021), and the BiOp (NMFS 2025) which lay out EPA's criteria for remediation. The expansive PDCs included in the BiOp add more mitigation requirements than is typical of a remedial design, including the need to add large woody debris to an armored shoreline, even in the event that that shoreline was previously armored prior to remediation.

The combination of the physical and regulatory complexities of the PHSS will create the need for unique remedial design solutions.

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Dreher, T.M., Webb, R, and Bale, J. "Portland Harbor Superfund Site: Environmental Remediation Considerations and Constraints," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

DATA AVAILABILITY

No data, models, or code were generated or used during the study.

ANALYSIS OF THE USE OF GEOTUBES® IN NJDOT MAINTENANCE DREDGING PROJECTS ON THE NEW JERSEY COAST

I. Abrahamsen[1], W.S. Douglas[2], and J. Heeren[3]

ABSTRACT

The NJ Department of Transportation (NJDOT) is responsible for the operations and maintenance of 200 nautical miles (370 kilometers) of shallow draft navigation channels in the Atlantic coastal region. Proper maintenance of this system requires the dredging of 300,000 to 500,000 cubic yards (230,000 to 380,000 cubic meters) per year of mostly clean sand and silt. Traditionally, dredged material has been placed on beaches (coarse-grained) or in confined disposal facilities (CDFs) (fine-grained) located in nearby marshes. While beach replenishment continues to be a viable option for coarse-grained material, the capacity in CDFs is limited, and siting of new facilities continues to be problematic.

The NJDOT Office of Maritime Resources (OMR) has explored numerous options for dredged material management including marsh restoration, confined and unconfined benthic restoration, and shoreline stabilization. In those places where these innovative techniques are not possible, the material must be beneficially used upland, sometimes at significant distance from the channel. Dewatering of sediment prior to transportation and placement is accomplished using geotextile tubes, usually on sites limited by size and season. Other challenges include proper polymer selection and dosage, water management, debris, quality of discharge, and community relations. Following dewatering, material is often used as daily landfill cover, amongst other beneficial use applications.

A sediment sampling and testing program was conducted for seven maintenance dredging projects along the Atlantic coast, from Sandy Hook Bay to Cape May, with geotextile tubes used for dewatering. The program occurred from 2021 to 2024. The seven projects included the successful dredging of 21 channels and dewatering of approximately 430,000 cubic yards (330,000 cubic meters) utilizing geotextile tubes.

Polymer types, site conditions, and sediments varied across projects. The objectives of the program were to evaluate the efficacy of the geotextile tubes, to measure the impact of the polymers, and to identify the best testing parameters for determining when dredged material is suitable for transportation and/or beneficial use. The program included seven testing protocols: grain size distribution, paint filter, percent moisture, percent solids, Atterberg limits, plasticity index, and modified Proctor test. Each of the projects provided takeaways, with even more learned by comparing all seven projects. Summaries of these projects

[1] Senior Engineer, Dewberry Engineers Inc., 6 Campus Drive, Suite 203, Parsippany, New Jersey, USA, corresponding author, 973-780-9267, email: IAbrahamsen@dewberry.com
[2] Dredging Program Manager (retired), NJ Dept. of Transportation, Office of Maritime Resources, 1035 Parkway Avenue, Trenton, USA, 609-963-2108, email: scott.douglas@dot.nj.gov
[3] Associate Vice President, Dewberry Engineers Inc., 600 Parsippany Road, Suite 301, Parsippany, New Jersey, USA, 973-576-0149, email: JHeeren@dewberry.com

and the overall evaluation program will be presented. Conclusions include recommended thresholds for percent solids and percent moisture with consideration of grain size distribution.

Keywords: geotextile tubes, dewatering, sampling program, sediment treatment, sediment testing

INTRODUCTION

The New Jersey Department of Transportation Office of Maritime Resources (NJDOT OMR) completed seven dredging projects from 2021 to 2024 in which Solmax® Geotubes® were utilized to dewater the dredged material. These projects/sites included Absecon (Gateway Confined Disposal Facility [CDF]), West Creek (West Creek CDF), Manasquan Phase 2 (Municipal Parking Lot), Keansburg (Keansburg CDF), Wildwood Phase 1 (26th Avenue Site), Wildwood Phase 1 (DPW Site), and Patcong (Beesley's Pt. CDF).

Each of these projects was conducted by multiple NJDOT-approved contractors utilizing different means and methods. During dredging operations, select polymers at various concentrations were added to the dredged material before the material entered the Geotubes®. To evaluate the effectiveness of the Geotubes® and the various types and dosages of polymer in the dewatering, a sediment sampling and testing program was implemented at each site.

This report presents the results of this sediment sampling program and draws conclusions for NJDOT and their engineers to consider for future projects that utilize Geotubes® to dewater dredged material.

SAMPLING AND ANALYSIS

The Geotube® sediment sampling and testing program took place from 2021 through 2024. Samples were collected post dredging and, in most instances, once Geotube® capacity was reached. An objective of the program was to determine the best test(s) for determining when dredged material was suitable for transportation and off-site beneficial use. Table 1 presents the tests performed at the sites.

Table 1. Tests performed at each of the seven sites.

Test	Absecon	West Creek	Mana-squan	Keans-burg	Wildwood 26th Ave	Wildwood DPW	Patcong
Grain Size Distr.	In Situ	In Situ	In Situ	At Site	At Site	At Site	At Site
Paint Filter Test	NA	X	X	NA	NA	NA	NA
Percent Moisture[1]	X	X	X	X	X	X	X
Percent Solids	X	X	X	X	X	X	X
Atterberg Limits[2]	X	X	X	X	X	X	X
Modified Proctor[3]	X	X	X	NA	NA	NA	NA

[1]H_2O as % dry weight; [2]Final sampling event with a suitable sample only (average liquid limit: moisture content as % of dry weight, average plastic limit: moisture content as % of dry weight, average plasticity index: liquid limit minus plastic limit); [3]Average maximum dry density (pounds per cubic foot), average optimum moisture (%); NA: Not analyzed.

Samples of sediment were taken via “stinger ports” located on top of the Geotubes®. For Geotubes® without accessible stinger ports, a narrow access hole was manually cut into the fabric using a utility knife. Samples were collected using varying equipment, including a push core sampler with a rigid polycarbonate liner, hand augers, and shovels. To account for variability within a Geotube®, three samples were collected from each Geotube® and composited for analysis. Each of the composites was prepared by mixing a sample taken from three stinger ports (ends and middle) of the Geotube®.

The tests performed are as follows:

- Grain Size Distribution (ASTM 422): the distribution of particle sizes within a sample.
- Paint Filter Test (SW-846 Test Method 9095B): the presence of free liquids in a sample determined by whether liquid drips through a standard mesh paint filter within a specified time frame. This testing was conducted only at Manasquan, West Creek, and Absecon during the first round of Geotube® sampling. In the case of a passing result, the material remains in the filter for a minimum of 5.0 minutes, the liquid passing through is collected, and no free liquids are detected. This indicates that the material can be transported for beneficial use or additional treatment. In the case of a failing result, free liquids are collected. This indicates that the material requires additional dewatering time or further treatment prior to transport.
- Percent Moisture (ASTM D2216): the mass lost after drying to a constant weight at a specified temperature.
- Percent Solids (ASTM 5907): the percentage of solid material, by weight, present in a sample (typically a liquid or slurry) after the sample has been dried to a constant weight.
- Atterberg Limits (ASTM D4318): the Liquid Limit (LL) and Plastic Limit (PL), which indicate the moisture content of the soil when it transitions between different states. PL indicates the moisture content when a fine-grained soil sample transitions from a plastic state to a semi-solid state, which is the point when a sample can no longer be molded without cracking/crumbling. The LL indicates the moisture content when a soil sample transitions from a plastic state to a liquid state, which is when a groove cut into the soil closes upon dropping the soil. The Plasticity Index (PI) is the laboratory-determined numerical difference between LL and PL, representing the range of moisture contents at which the soil sample remains plastic.
- Modified Proctor Test (ASTM D698): determines a sample's Maximum Dry Density and Optimum Moisture when compacted using a higher compaction effort than in the Standard Proctor Test. Maximum Dry Density is the highest dry density of a soil under a given compaction effort as determined from the soil's compaction curve. Optimum Moisture is the water content when a soil can be compacted to its Maximum Dry Density using a given compaction effort.

DEWATERING OPERATION SPECIFICS

Dredging and Material Delivery

All projects were dredged with a shallow draft hydraulic cutterhead pipeline dredge and delivered to the site through 10, 12- or 16-inch pipeline.

Dewatering Means and Methods

During dredging, the contractors on the Absecon, Manasquan, Keansburg, Wildwood 26th Avenue, Wildwood DPW, and Patcong sites utilized similar methods, usually with two crews: one managing the Geotube® field and one managing the automated polymer treatment system. Samples of the slurried

dredged material were taken regularly at the processing site. The two crews stayed in regular contact with the dredging crew throughout the project to adjust the dredging or polymer dosage rate as needed.

In contrast, one of the contractors on the West Creek project had only one team to manage the Geotube® field and monitor polymer dosage. The contractor relied on the automated polymer system to adjust the polymer dosage rates. Very few slurry samples were taken during the project, and there was no regular communication between the processing site and the dredge. This strategy was not effective in producing dredged material suitable for construction, stockpiling, or trucking in a timely manner.

Regarding contractor methodology, the Wildwood DPW and 26th Avenue contractors used a sand separator to remove debris and sand and a thickener tank (to incorporate the polymer solution within the dredged material) before sending the treated dredged material to the Geotubes®. The Keansburg contractor did not utilize a sand separator and instead pumped the dredged material directly into the Geotubes®, where the polymer solution was directly injected into the dredge pipeline/manifold prior to entering the Geotubes®.

In comparison to Keansburg, the Wildwood DPW and 26th Avenue sites allowed additional material to be placed within the Geotubes® because of the additional capacity provided by the sand separator's removal of the sand. The footprint of the sand separator should be considered when evaluating the staging site layout.

Table 2 provides a summary of the polymer and coagulant types and feed rates for the sites. The polymer feed rates for Wildwood are likely higher than those for Manasquan, Keansburg, and Patcong because of the manual operations of blending the polymer.

Table 2. Summary of polymer and coagulant types and feed rates.

Project	Polymer Type	Polymer Feed Rate (lbs/dry ton)	Coagulant Type	Coagulant Feed Rate (lbs/dry ton)
Absecon	HEXAFLOC 139H	Unable to Confirm	N/A	
	MAGNAFLOC 292	Unable to Confirm	N/A	
West Creek	Unable to Confirm	Unable to Confirm	Unable to Confirm	Unable to Confirm
Manasquan	SOLVE 9330	1.20	SOLVE 426	Unable to Confirm
Keansburg	SOLVE 9330	1.06	SOLVE 7118	0.31
Wildwood 26th Ave	Unable to Confirm	27.46	N/A	
Wildwood DPW	Flopam EM-533	DPW Phase 1: 34.15 DPW Phase 2: 16.74	N/A	
	Flopam A-12321			
	SOLVE 9330			
	FLOPAM A-9320			
	CLARIFLOC A-3320			
Patcong	SOLVE 2230C	1.01	SOLVE 7118	0.52

Absecon

The dredged material was dewatered in 46 Geotubes® arranged in a single layer at the Gateway CDF. An automated, in-line polymer injection system delivered and blended the dewatering polymer. Dredging was completed in October 2021. When last inspected in January 2022, the sediment was effectively dewatered,

with minimal remaining moisture. One round of sampling, including six samples, was performed on March 2, 2022. These samples represent the beginning, middle, and end of dredging.

West Creek

The dredged material was dewatered in 42 Geotubes® arranged in two layers at the West Creek CDF. A polymer injection system delivered and blended the dewatering polymer. Dredging was completed in December 2021. When last inspected in January 2022, the sediment was not adequately dewatered. Two rounds of sampling were conducted: six composite samples each on February 24, 2022, and April 18, 2022.

Manasquan

The dredged material was dewatered in 21 Geotubes® arranged in four layers within the municipal parking lot. An automated, in-line polymer injection system delivered and blended the dewatering polymer. Dredging was completed in January 2022. When last inspected in January 2022, the sediment appeared to be effectively dewatered. Two rounds of sampling were conducted: six composite samples on February 11, 2022, and four composite samples on March 29, 2022.

Keansburg

The contractor used three distinct dewatering polymer dosage rates: "no polymer", "partial polymer dosage," and "full polymer dosage." The dredged material was dewatered in 16 Geotubes® arranged in two layers within the Keansburg CDF. An automated, in-line polymer injection system delivered and blended the dewatering polymer. Dredging was completed in early January 2024. When last inspected in mid-January 2024, the sediment was effectively dewatering. Four rounds of sampling were conducted, each including four composite samples, on January 18 and 24 and February 1 and 8, 2024. Each sampling event included one sample from the first/bottom layer and three from the second layer.

Wildwood 26th Ave

The dredged material was dewatered in 34 Geotubes® arranged in four layers. A sand separator removed debris and sand, and a thickener tank blended the polymer with the dredged material prior to injection into Geotubes®. Dredging was completed in June 2024, and when last inspected in June 2024, the sediment was effectively dewatering. Four rounds of sampling were conducted, each with five composite samples, on July 17, July 31, August 22, and September 12, 2024. During each sampling event, all samples were collected from the third layer.

Wildwood Department of Public Works (DPW)

The dredged material was dewatered in 54 Geotubes® arranged in four layers. A sand separator removed debris and sand, and a thickener tank blended the polymer with the dredged material prior to injecting it into the Geotubes®. Dredging was completed in mid-August 2024. When last inspected in August 2024, the sediment was being effectively dewatered. Transportation of the dewatered material was ongoing during the final sampling event. Four rounds of sampling were conducted, each with five composite samples, on September 12 and 20 and October 4 and 24, 2024. Samples were collected from the third layer.

Patcong

The dredged material was dewatered in 42 Geotubes® arranged in four layers. An automated, in-line polymer injection system delivered and blended the polymer. Dredging was completed in October 2024. When last inspected in October 2024, the sediment was effectively dewatering. Four rounds of sampling

were conducted, each with five composite samples, on November 6 and 21 and December 6 and 20, 2024. During the first sampling event, two samples were collected from the first layer, two from the second layer, and one from the third layer. This was repeated for the subsequent three events.

RESULTS

Grain Size Distribution

The grain size distribution of Geotube® samples was determined at the Keansburg, Wildwood 26th Ave, Wildwood DPW, and Patcong sites. For the other sites (Absecon, West Creek, and Manasquan), the grain size distributions of in situ samples obtained from the dredged channels are provided. The sites (except Keansburg) generally showed greater than 70% fines. Keansburg had the coarsest sediment, whereas West Creek had the finest sediment.

Paint Filter Test

Paint filter tests were conducted at the West Creek and Manasquan processing sites. Some of the results indicated a passing paint filter test, while others indicated a failed paint filter test. During their first rounds of sampling, West Creek (55 days post dredging) had six out of six samples fail, and Manasquan (29 days post dredging) had two out of six samples fail. In contrast, Absecon (134 days post dredging) had zero out of six samples fail. No tests were conducted at Keansburg, Patcong, or Wildwood (either site) because the material was either not immediately trucked or already too dry at the time of sampling. No paint filter tests were performed during the second round of sampling.

Percent Moisture and Percent Solids

The rate of dewatering and percent solids at each of the seven project sites were assessed by taking two or more samples from selected Geotubes® over several weeks to months. The results are presented in Figure 1, which has an x-axis in days post dredging. Please note that in this and other figures, 95% confidence intervals were not developed for columns with fewer than three samples.

Atterberg Limits

To assess the quality and suitability for beneficial use of the dewatered material, Atterberg Limits (LL, PL, and PI) were determined for dredged material dewatered in Geotubes® at each project/site (Figure 2).

Plastic Limit

West Creek had the highest average PL of 49.5 percent, followed by Manasquan at 43.3 percent, Patcong at 40 percent, Absecon at 39.6 percent, Keansburg (Geotubes® with polymer) at 38.3 percent, Wildwood 26th Avenue at 36.5 percent, Wildwood DPW at 32 percent, Keansburg (Geotube® with partial polymer) at 25 percent, and Keansburg (Geotube® with no polymer) at 22 percent (Figure 3).

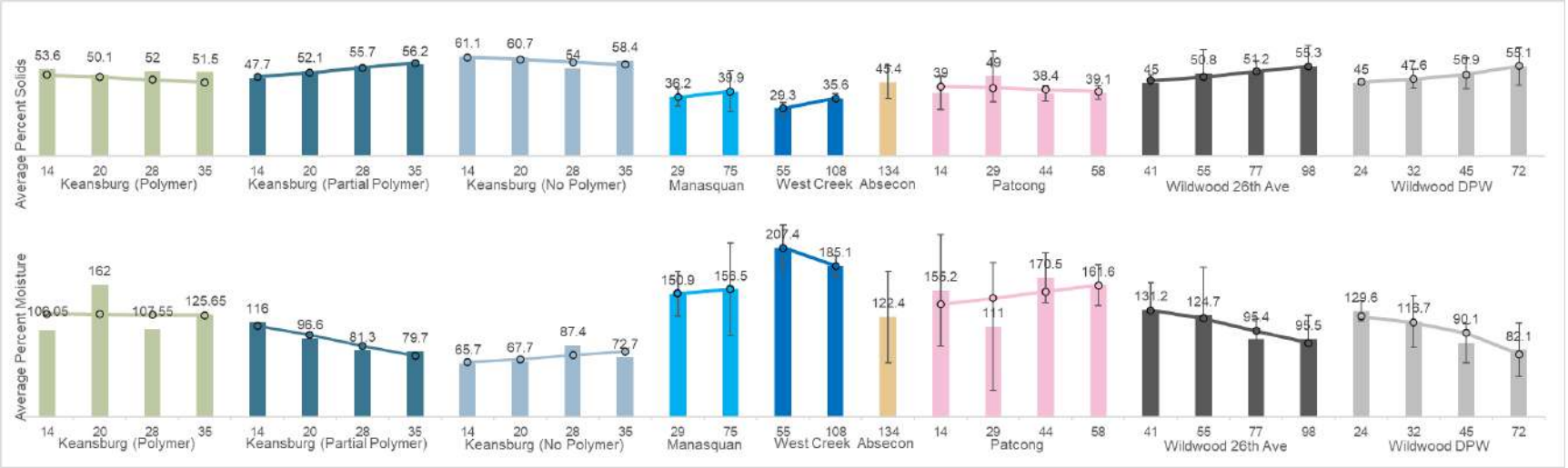

Figure 1. Average percent solids (top row) and percent moisture (bottom row) per sampling event

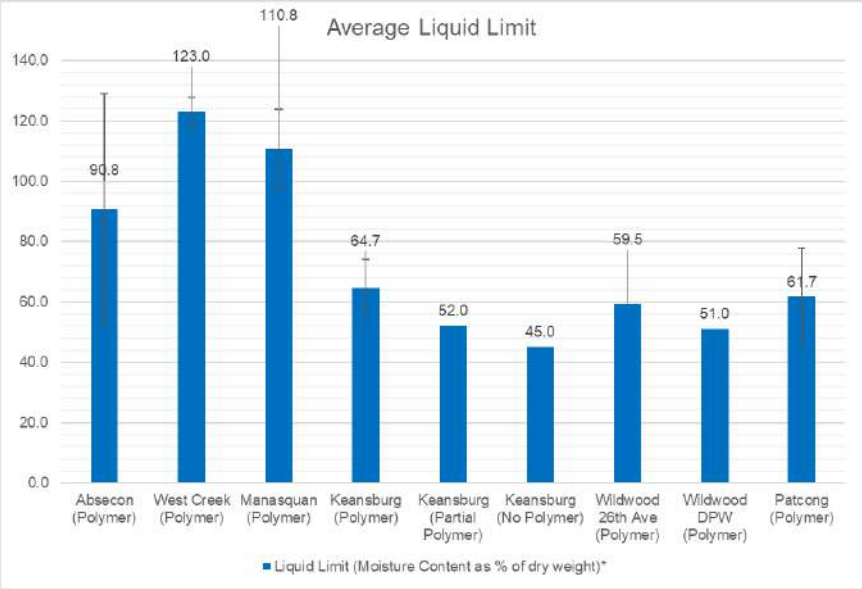

Figure 2. Average liquid limit

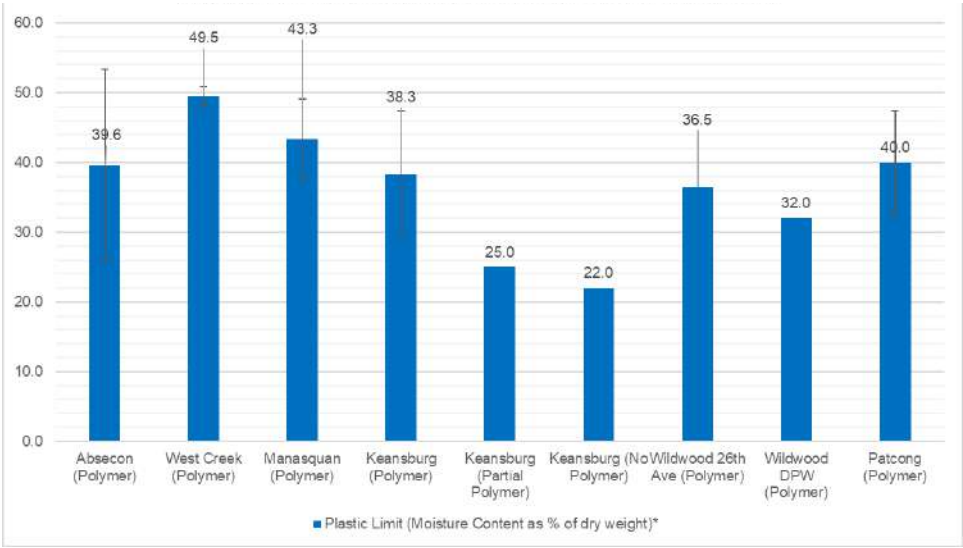

Figure 3. Average plastic limit

Plasticity Index

West Creek had the highest average PI of 73.5 percent, followed by Manasquan at 67.5 percent, Absecon at 51.2 percent, Keansburg (Geotube® with partial polymer) at 27 percent, Keansburg (Geotubes® with polymer) at 26.3 percent, Keansburg (Geotube® with no polymer) at 23 percent, Wildwood 26th Avenue at 23 percent, Patcong at 21.7 percent, and Wildwood DPW at 19 percent (Figure 4).

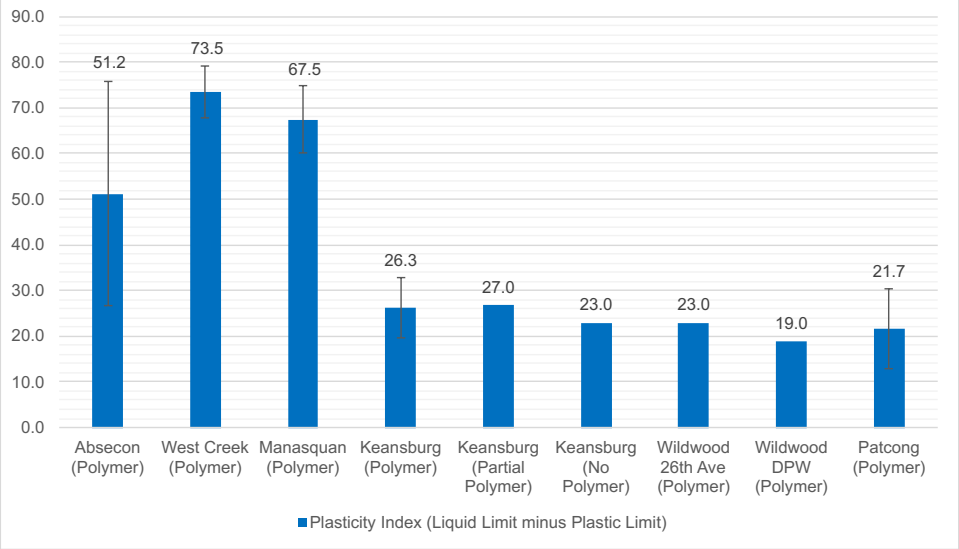

Figure 4. Average plasticity index

Modified Proctor Test

To further assess the quality of the material for compactability for cap and fill projects, the dredged material dewatered in Geotubes® at three of the sites (Absecon, West Creek, and Manasquan) was subjected to a Modified Proctor Test. The results of these tests are presented in Figures 5 and 6 below.

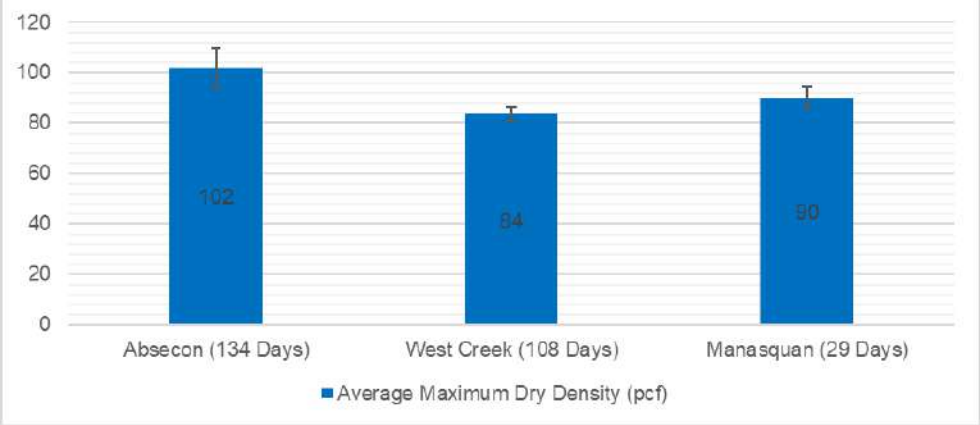

Figure 5. Average maximum dry density

When evaluating the dewatering process, the results from Manasquan were used as a benchmark to evaluate if the dredged material had been effectively dewatered. The dredged material was considered effectively dewatered if the sediment had a lower average percent moisture result than the Manasquan data, a higher average percent solids result, or a lower average PI within 75 days.

Paint Filter Test

Paint filter testing was limited to the Manasquan, West Creek, and Absecon locations during the first sampling event. The dewatering process used at Manasquan and Absecon Geotubes® was more efficient than the process used at West Creek. All six West Creek samples failed the paint filter test 55 days after

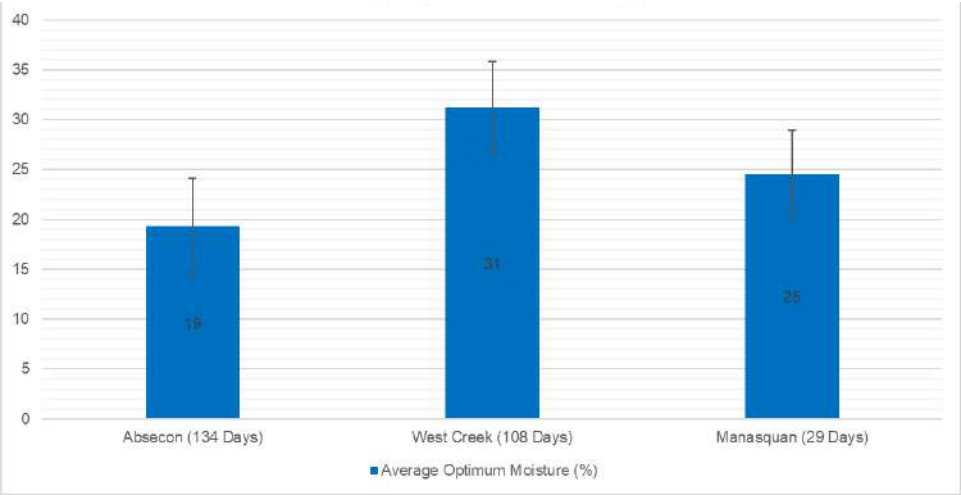

Figure 6. Average optimum moisture

dredging was completed. The dredged material at West Creek was much slower to solidify, possibly due to more liquid being present or a lack of effective dewatering.

DISCUSSION

Percent Moisture and Percent Solids

Absecon

The dredged material was effectively dewatered and could be stockpiled and transported via truck 134 days after dredging was completed. The dewatering process at Absecon performed well and achieved sufficient results.

West Creek

The dewatering process used at West Creek did not perform as well as those at the other six sites. The percent moisture content was significantly higher and the percent solids significantly lower at 55 and 108 days after dredging than those observed at the other six sites. Furthermore, the average percent solids at West Creek, 55 and 108 days after dredging ceased, had not surpassed that observed at the other six sites. Thus, the dredged material in the West Creek Geotubes® could not have been stockpiled and trucked due to the significantly higher percent moisture and lower percent solids, dewatering at a significantly lower rate, or lack of dewatering. These issues imply an improper polymer dosage during dredging operations at West Creek.

Manasquan

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 29 and 75 days after dredging was completed. The dewatering process used at Manasquan performed well and achieved sufficient results. Although percent solids and percent moisture in dredged sediment are inversely correlated, specific environmental and physical factors can cause the trend seen at Manasquan, leading to increases in both percent solids and percent moisture. Examples include new solid material being introduced to the Geotubes®, organic decomposition releasing water while increasing byproducts, capillary

action wicking moisture into sediment layers, and compaction trapping water in fine-grained sediments. Although the percent moisture content increased slightly over time, the Geotubes® still achieved sufficient results.

Keansburg (No Polymer)

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 14 and 35 days after dredging. The no-polymer process used at Keansburg performed well and achieved sufficient results. Even though the percent moisture content steadily increased over time, the Geotube® showed the lowest content (72.7 percent) in Round 4 after 35 days post dredging. Even with the percent solids steadily decreased over time, the Geotube® achieved the highest percentage (58.4) in Round 4 after 35 days post dredging. The no-polymer dewatering process achieved the highest percent solids and lowest percent moisture in both Round 1 (14 days post dredging) and Round 4 (35 days post dredging), without any polymer, even with environmental and physical factors reversing the relationship between percent solids and percent moisture. Keansburg (no polymer) sediment had a larger coarse grain size than the Wildwood 26th Avenue, Wildwood DPW, and Patcong sites.

Keansburg (Partial Polymer)

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 14 and 35 days after dredging was completed. The Keansburg partial-polymer process performed well in comparison to those at the six other sites. The percent moisture content steadily decreased over time and had the second lowest value (79.7) in Round 4 after 35 days. The dredged material observed in the Geotube® could have been stockpiled and trucked any time after Round 1 because of the significantly higher percent solids and lower percent moisture than at Manasquan. The Keansburg partial-polymer process dewatered faster than the Geotubes® at the other sites that received a complete dosage of polymer. Thus, the partial dosage may have been a proper dosage during dredging operations.

Keansburg (Polymer)

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 14 and 35 days after dredging. The Keansburg full-polymer process indicates that it performed well in comparison to those at the six other sites. Even though the percent moisture content steadily increased over time and the percent solids steadily decreased over time, the process still achieved sufficient results.

Wildwood 26th Avenue

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 41 and 98 days after dredging was completed. The dewatering process used at Wildwood 26th Avenue performed well in comparison to those at the six other sites. The percent moisture content steadily decreased over time and had the fourth lowest value (95.5) in Round 4 after 98 days. Percent solids steadily increased over time and had the third highest average (55.3) in Round 4 after 98 days. The dredged material could have been stockpiled and trucked any time after Round 1 because of the significantly higher percent solids and lower percent moisture than at Manasquan. The Geotubes® dewatered significantly faster than those at the other sites that received a complete dosage of polymer, which indicates a proper polymer dosage was utilized.

Wildwood Department of Public Works (DPW)

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 24 and 72 days after dredging was completed. The dewatering process at Wildwood DPW performed well when compared to those at the six other sites. The percent moisture content steadily decreased over time and had the third lowest value (82.1) in Round 4 after 72 days. Percent solids steadily increased over time, having the fourth highest average (55.1) in Round 4 after 72 days. The dredged material could have been stockpiled and trucked any time after Round 1 because of the significantly higher percent solids and lower percent moisture than observed at Manasquan. The Geotubes® dewatered significantly faster than those at the other sites that received a proper dosage of polymer, which indicates a proper polymer dosage was utilized.

Patcong

The dredged material was effectively dewatered and could be stockpiled and transported via truck between 14 and 58 days after dredging was completed. The dewatering process at Patcong performed well and achieved similar results when compared to the dewatering process at Manasquan. Even though the percent moisture content steadily increased over time and the percent solids remained nearly the same over time, the Geotubes® still achieved sufficient results.

Atterberg Limits and Modified Proctor Test

Absecon

The dewatering process used at Absecon performed well according to the results of the Atterberg Limits analysis. Absecon achieved the sixth lowest average (51.2) among the sites. The Absecon sediment had the highest average Maximum Dry Density (102.0) and the lowest average Optimum Moisture (19.0) when compared to that seen at the two other sites (Manasquan and West Creek).

West Creek

The dewatering process used at West Creek did not perform well according to the results from the Atterberg Limits analysis, showing the largest average (73.5) among the sites. The sediment had the lowest average Maximum Dry Density (84.0) and the highest average Optimum Moisture (31) when compared to that seen at the two other sites (Absecon and Manasquan).

Manasquan

The dewatering process used at Manasquan performed well according to the results from the Atterberg Limits analysis, achieving the seventh-lowest average (67.5) among the sites. The sediment had the second-highest average Maximum Dry Density (90.0) and the second-lowest average Optimum Moisture (25.0) when compared to that seen at the two other sites (Absecon and West Creek).

Keansburg (No Polymer)

The no-polymer dewatering process used at Keansburg performed well according to the results from the Atterberg Limits analysis, achieving the third-lowest average (23.0) among the sites. The sediment was not analyzed for average Maximum Dry Density and average Optimum Moisture (Modified Proctor Test).

Keansburg (Partial Polymer)

The partial-polymer dewatering process used at Keansburg performed well according to the results from the Atterberg Limits analysis, achieving the fifth-lowest average (27) among the sites. The sediment was not analyzed for average Maximum Dry Density and average Optimum Moisture (Modified Proctor Test).

Keansburg (Polymer)

The full-polymer dewatering process used at Keansburg performed well according to the results from the Atterberg Limits analysis, achieving the fourth-lowest average (26.3) among the sites. The sediment were not analyzed for average Maximum Dry Density and average Optimum Moisture (Modified Proctor Test).

Wildwood 26th Avenue

The dewatering process used at Wildwood 26th Avenue performed well according to the results from the Atterberg Limits analysis, achieving the third-lowest average (23.0) among the sites. The sediment were not analyzed for average Maximum Dry Density and average Optimum Moisture (Modified Proctor Test).

Wildwood DPW

The dewatering process used at Wildwood DPW performed well according to the results from the Atterberg Limits analysis, achieving the lowest average (19.0) among the sites. The sediment were not analyzed for average Maximum Dry Density and average Optimum Moisture (Modified Proctor Test).

Patcong

The dewatering process used at Patcong performed well according to the results from the Atterberg Limits analysis, achieving the second-lowest average (21.7) among the sites. The sediment were not analyzed for average Maximum Dry Density and average Optimum Moisture (Modified Proctor Test).

Process Performance

Among the initial three sites, Manasquan achieved the best results for percent solids and percent moisture (percent solids: 36.2 [when sampled 29 days post dredging] and 39.9 [when sampled 75 days post dredging], percent moisture: 150.9 [when sampled 29 days post dredging] and 156.5 [when sampled 75 days post dredging]) when compared against the other project sites (Absecon and West Creek). When analyzing the data for percent solids and percent moisture across all seven sites, Keansburg, Wildwood DPW, and Wildwood 26th Avenue achieved better results than Manasquan.

With the Manasquan results as a benchmark, Keansburg achieved better results in less time. Within 14 days, Keansburg achieved a percent solids of 61.1 and a percent moisture of 65.7. When sampled 14 days after dredging, Keansburg had a grain size distribution of 38.4% fines, 54.6% sand, and 7% gravel. Over the course of dredging, Keansburg maintained an average polymer feed rate of 1.06 pounds per dry ton.

Compared to Manasquan, Wildwood DPW achieved better results in less time. Within 24 days, Wildwood DPW achieved a percent solids of 45 and a percent moisture of 129.6. When sampled 24 days after dredging, Wildwood DPW had a grain size distribution of 84% fines, 15.9% sand, and 0.1% gravel. Over the course of dredging, Wildwood DPW maintained an average polymer feed rate of 16.33 pounds per dry ton.

Wildwood 26th Avenue also achieved better results in less time. Within 41 days, Wildwood 26th Avenue achieved a percent solids of 45 and a percent moisture of 131.2. When sampled 41 days after dredging, Wildwood 26th Avenue had a grain size distribution of 75.4% fines and 24.6% sand. Over the course of dredging, Wildwood 26th Avenue maintained an average polymer feed rate of 24.62 pounds per dry ton.

"Time to Transport Ready"

When analyzing the grain size data for the Patcong, Keansburg, Wildwood DPW, and Wildwood 26th Avenue Geotubes®, Keansburg had the coarsest distribution. Wildwood DPW had the finest distribution, which is consistent with the use of a sand separator. When analyzing the in-situ grain size data for Absecon, Manasquan, and West Creek from within the project channels, Manasquan had the coarsest distribution. West Creek had the finest distribution.

The dewatering times varied for all the sites, and although the sampling rounds varied in frequency and number, approximations may be made for future projects with similar characteristics. These approximations will help forecast the duration required for dredged material to sufficiently dewater and hauled away by truck (also known as "time to transport ready"). Note that these results were not statistically significant due to wide variability in testing data; more testing is necessary to achieve statistical significance to calculate a predictive model.

Table 3 provides a summary of grain size distributions, percent solids, percent moisture, and time to transport ready for all sites.

CONCLUSION

Across the seven sites included in the sediment sampling program, the efficacy and effectiveness of the dewatering processes varied greatly. Statistical significance was not achieved considering the sample sizes, nonuniform durations, and changes in polymer across sites. Nevertheless, the results indicate that percent moisture, percent solids, and grain size distribution are all good indicators of dewatering progress and are recommended for monitoring and processing in similar programs. These three analyses will provide comparative properties over time at an individual site as well as across multiple sites. From the data collected so far, it appears that a percent solids greater than 40% and a percent moisture less than 160% will be suitable for efficient handling and transport of dredged material.

CITATION

Abrahamsen, I., Douglas, W.S., Heeren, J. "Analysis of the Use of Geotubes® in NJDOT Maintenance Dredging Projects – New Jersey Coastline," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

DATA AVAILABILITY

All data generated or used during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

Table 3. Summary of results obtained from various dewatering processes.

Site	Round	Grain Size Distribution (g%, s%, f%)	Average % Solids	95% Confidence Interval	Average % Moisture	95% Confidence Interval	Time to Transport Ready
Keansburg (Polymer)	1	7, 55, 38	52.8	--	106.1	--	Between 14 and 35 days
	2	0, 56, 44	43.8		162		
	3	2, 44, 54	49.2		87.4		
	4	13, 49, 38	45.7		125.7		
Keansburg (Partial Polymer)	1	7, 55, 38	47.7	--	116	--	Between 14 and 35 days
	2	0, 56, 44	52.1		95.6		
	3	2, 44, 54	55.7		81.3		
	4	13, 49, 38	56.2		79.7		
Keansburg (No Polymer)	1	7, 55, 38	61.1	--	65.7	--	Between 14 and 35 days
	2	0, 56, 44	60.7		67.7		
	3	2, 44, 54	54		87.4		
	4	13, 49, 38	58.4		72.7		
Manasquan	1	0, 17, 83 (in situ)	36.2	30.8-41.6	150.9	123.7-178.1	Between 29 and 75 days
	2		39.9	27.2-52.7	156.5	99.4 -213.6	
West Creek	1	0, 1, 99 (in situ)	29.3	25.7-32.9	207.4	179.1-235.7	N/A
	2		35.6	32.8-38.4	185.1	172.6-197.6	
Absecon	1	0, 8, 92 (in situ)	45.4	35.4-55.4	122.4	66.5-178.3	134 days
Patcong	1	0, 10, 90	39	28.7-49.4	155.2	86.6-223.8	Between 14 and 58 days
	2	0, 28, 72	49	33.5-64.5	111	32.4-189.6	
	3	0, 6, 94	38.4	33.7-43.1	170.5	139.7-201.3	
	4	0, 13, 87	39.1	34.9-43.3	161.6	136.2-187.0	
Wildwood 26th Ave	1	0, 25, 75	45	39.8-50.2	131.2	97.9-164.5	Between 41 and 98 days
	2	0, 21, 79	50.8	36.3-65.3	124.7	65.0-183.4	
	3	0, 21, 79	51.2	43.7-58.7	95.4	70.4-120.4	
	4	0, 21, 79	55.3	42.5-68.1	95.5	67.0-124.0	
Wildwood DPW	1	0, 16, 84	45	44.1-45.9	129.6	113.8-145.4	Between 24 and 72 days
	2	0, 35, 65	47.6	41.9-53.3	116.7	75.8-157.6	
	3	0, 21, 79	50.9	41.5-60.3	90.1	59.3-120.9	
	4	0, 16, 84	55.1	43.6-66.6	82.1	40.1-124.1	

ACKNOWLEDGEMENTS

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STRATFORD TIDAL FLATS DREDGING AND RESTORATION

M. Gravelding[1], B. Bonsted[2], R. White[3], E. Dievendorf[4], C. Donolo[5], J. Intrieri[6], Z. Dillon[7], S. Hill[8]

EXTENDED ABSTRACT

The Stratford remediation project is an active remediation effort at the former Stratford Army Engine Plant in Stratford, Connecticut. The project involves multiple phases, including sediment remediation and upland demolition, remediation and redevelopment. This presentation focuses specifically on dredging and restoring the tidal flats in the Housatonic River adjacent to the former plant.

The Army sold the upland site and environmental cleanup management to developer Point Stratford Renewal (PSR) in April 2024. As part of the sale, PSR became responsible for managing the tidal flat remediation, with the Army maintaining liability. PSR selected ENTACT to perform the tidal flats remediation and ENTACT retained Arcadis for engineering services, including finalizing the remedial design and providing engineering support and oversight during construction. The scope of work includes mechanical dredging within a sheet pile enclosure, beneficial use of select dredged material, and tidal flat restoration.

Arcadis signed the final design in early 2025 and ENTACT mobilized for construction shortly thereafter. Construction is ongoing at the time of this abstract with dredging complete and backfilling in progress. The design included dredging a total of 160,000 cubic yards (122,000 cubic meters) to address polychlorinated biphenyls (PCBs), mercury, and eight metals (arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc) as the primary constituents of concern. Dredging was not required beyond a maximum 4-foot (1.2-meter) removal depth. The design also specified backfilling to within 1 foot (0.3 meter) of the pre-construction grade except in areas with dredge cuts less than 1-foot (0.3 meter), which did not require backfill.

Structural offsets were incorporated near shorelines and structures. Design offsets ranged from 5 to 15 feet (1.5 to 4.6 meters). The dredge cut in these areas was designed to slope down at 3:1 (horizontal:vertical) from the offset limit to the design cut grade. Pre-construction samples were not collected in the offset areas as additional action could not be implemented. Instead, the design included placing a 0.5-foot (0.2 meter) sand cover over these areas. The design offsets were maintained throughout the project as the dredge prism was revised.

[1] Engineer of Record, Arcadis, Syracuse, NY, USA, mark.gravelding@arcadis.com.
[2] Project Director, ENTACT, Saratoga Springs, NY, USA, bbonsted@entact.com.
[3] Regulatory and CQC Manager, ENTACT, Broomall, PA, USA, rwhite@entact.com.
[4] Principal Engineer, Arcadis, 110 W Fayette Street Suite 300, Syracuse, NY 13202, USA, T: 315-671-9235, Email: eric.dievendorf@arcadis.com. (corresponding author).
[5] Project Manager, ENTACT, Gibsonia, PA, USA, cdonolo@entact.com.
[6] Construction Manager, ENTACT, Broomall, PA, USA, jintrieri@entact.com.
[7] Construction Oversight, Arcadis, Sandy Hook, CT, USA, zachary.dillon@arcadis.com.
[8] Project Manager, Arcadis, Syracuse, NY, USA, sarah.hill@arcadis.com

ENTACT installed a sheet pile enclosure for tidal control. This also served as the primary water quality control measure. As water was allowed to pass across the enclosure, turbidity curtains and oil booms were deployed as secondary controls. Continuous water quality monitors were deployed at, upstream of, and downstream of the work area. This approach generally worked well; however, challenges arose due to algae growth on the monitors, boating traffic, and ice. Additionally, ice accumulation in the work area led to temporary project shutdowns.

Sediment cleanup goals for the site were more restrictive than upland cleanup goals. As such, dredged material was pre-characterized for beneficial use for site redevelopment. Material with less than 1 part per million PCBs was designated for reuse as upland fill to raise the site above the floodplain elevation for future redevelopment. Approximately 135,000 cubic yards (103,000 cubic meters) of material was reused in uplands – 85% of the total designed dredge material. This saved approximately 18,000 truck trips through local streets for material disposal and backfill import.

Pre-construction sampling was required to confirm dredge limits in two areas. The team collected over 300 samples at over 50 locations as part of the pre-construction sampling effort. Based on the data from these samples, three additional dredge management units (DMUs) were created, expanding dredging by approximately 5,000 cubic yards (3,800 cubic meters). This also resulted in dredging footprint expansion outside the sheet pile containment but within the secondary resuspension controls. The expanded dredge area also infringed on an existing oyster bed. Removal and restoration requirements in this area were determined in coordination with the Connecticut Department of Agriculture.

Confirmation samples were collected after dredging was complete for a given DMU (1 to 2 acres; 4,000 to 8,000 square meters) over a 50-foot by 50-foot (15-meter by 15-meter) grid. The team collected a total of over 800 samples at over 750 locations. Samples initially were screened for PCBs and copper followed by mercury and the remaining metals analyses. The design dredge prisms were adjusted for re-dredging based on the sampling data. In many locations, based on the PCB and copper screening, the team determined it was more efficient to dredge to the 4-foot (1.2-meter) limit rather than performing iterative sampling and re-dredging. This approach limited re-dredging based on confirmation samples to less than 10% of the project area.

The design required approximately 95,000 cubic yards (73,000 cubic meters) of two types of sand backfill from virgin sources. This quantity meant that multiple fill sources were required. To simplify this material search, the two sand materials required in the design (one for backfill, one for offset cover) were combined to only meet one gradation instead of two. Even with this adjustment, several local sources were slightly high on fines content compared to the design requirements.

In addition to backfill, the design included marsh restoration along the western site boundary over 2.1 acres (8,6000 square meters) through installation of 41,300 *Spartina alterniflora* plugs and waterfowl exclusion measures. During construction, it was found that the survey provided for use in the design was not accurate and the final grading of the marsh restoration area was revised.

The project will require post-construction wetland inspections and bathymetric surveys to confirm remedy effectiveness and determine maintenance measures, if any.

Lessons learned from the tidal flat portion of the Stratford remediation project include:

- Project structure: Privatizing the project allowed for accelerated project completion.

- Open design process: Combining the engineering and construction teams to finalize the design allowed for tighter design parameters for known approaches and built-in flexibility for the “known unknowns.”
- Collaborative construction process: ENTACT and Arcadis worked as a unified team, operating like one firm to proactively address challenges during construction.
- Environmental controls and monitoring: Multiple combined controls and real-time water quality monitoring were effective and allowed flexibility during implementation.
- Stakeholder commitment: ENTACT and PSR built and maintained close relationships with project stakeholders. This allowed streamlined coordination and accelerated decision-making during design and construction.

Keywords: Beneficial use, contaminated sediment, design/build, redevelopment, Spartina marsh.

CITATION

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REMEDIATION AND RESTORATION OF AN INDIGENOUS SHORELINE

M. Bodman[1], R. Thomas[2], K. Ritchot[3], A. Corp[4], D. Ormerod[5], T. Kamila-Lindell[6], and M. Carey[7]

ABSTRACT

Esquimalt Harbour is a large working harbour located on southern Vancouver Island, British Columbia, with a long history of impacts from shipbuilding, mills, canneries, and naval activities. The harbour lies within the traditional territories of the Esquimalt Nation and the Songhees Nation, who live along the shores of Plumper Bay. Plumper Bay was historically used for log boom storage and had a plywood mill leading to metals, polychlorinated biphenyl, and wood waste contamination. Additionally, a diesel spill, which occurred in 2016, caused local beaches closures and seafood consumption closure. Despite previous remedial efforts in the adjacent uplands and in offshore sediment, the shoreline areas have remaining contamination not previously addressed. The Department of National Defence (DND), through the Federal Contaminated Sites Action Plan, has engaged Public Services and Procurement Canada (PSPC) to deliver a project that seeks to address remaining shoreline contamination and nearshore wood waste, allowing beaches to be reopened and providing suitable habitats for target species through appropriate substrates. Through DND's engagement with the Esquimalt Nation and Songhees Nation, the Plumper Bay Revitalization Project was initiated, and workshops were held with the First Nations' marine teams to understand future shoreline uses, desired target species for habitat restoration, and areas of cultural significance for incorporation into the conceptual design. Additional project enhancements aim to restore traditional functionality to the shoreline by laying shoreline slopes back, addressing invasive vegetation, completing riparian plantings, placing boulders in intertidal areas, constructing a bioretention area, and incorporating trails to the newly restored beaches to increase community access. The team has undertaken sustained and meaningful coordination with representatives of both the Esquimalt Nation and Songhees Nation, working closely with their communities to support a shared understanding of the project and consider feedback on an ongoing basis. Engagement with the First Nations has led to numerous project

[1] MARPAC Environment Officer CFB Esquimalt, Department of National Defence, PO Box 17000 Station Forces, Victoria, British Columbia, V9A 7N2, Canada, 250-363-4824 D199, Michael.bodman@forces.gc.ca.
[2] Senior Environmental Specialist, Environmental Services, Contaminated Sites, Vancouver Island Group, Public Services and Procurement Canada, 401-1230 Government Street, Victoria, British Columbia V8W 3X4, Canada, 250-418-5731, Robert.thomas2@pwgsc-tpsgc.gc.ca.
[3] Environmental Specialists-Ops, Environment Services, Pacific Region, Public Services and Procurement Canada, 401-1230 Government Street, Victoria, British Columbia V8W 3X4, Canada, 250-363-7861, Kristen.ritchot@pwgsc-tpsgc.gc.ca.
[4] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.
[5] Principal Engineer. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2721, Email: dormerod@anchorqea.com.
[6] Senior Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2734, Email: tkamila@anchorqea.com
[7] Managing Scientist, Anchor QEA, Inc., 12596 W. Bayaud Avenue, Suite 201, Lakewood, CO, USA, T: 303-984-6250, Email: mcarey@anchorqea.com

changes, including an increased focus on long-term project resiliency. The project has currently completed its first of two construction seasons.

Keywords: Dredging, remediation, contaminated sediment, risk management, Plumper Bay.

INTRODUCTION

Plumper Bay is located in Esquimalt Harbour at the south end of Vancouver Island as shown in Figure 1. Esquimalt Harbour is governed by the Canada Marine Act and Transport Canada's Natural and Man-Made Harbour Navigation and Use Regulations, which are administered by DND.

Figure 1. Vicinity map.

Plumper Bay is formed by the Fibremax Headland to the north, which is part of the Esquimalt Nation Reserve, and Ashe Head to the south, which is part of the Songhees Nation Reserve. To the southwest of Plumper Bay are the Inskip Islands, which are separated from Ashe Head by Paddy Passage. The Esquimalt Nation and Songhees Nation reside along the coastline of Plumper Bay with upland property owned by the Nations and/or Indigenous Services Canada. Plumper Bay, below the property boundary, is owned by DND, but is currently leased to the First Nations. While there are currently few active industrial operations, the area has been the site of historical industrial activities dating back to the early 1900s.

The remedial actions planned during the Plumper Bay Revitalization Project (PBRP) include removal of remaining contaminated nearshore soils and sediments, removal of nearshore wood waste that may have associated remnants from a 2016 diesel spill, removal of debris, and development of nearshore habitat.

The PBRP work site has been delineated into five work areas as shown in Figure 2. These work areas were developed based on available data collected during field investigations, similar remediation elements required, and in coordination with the Esquimalt Nation and Songhees Nation.

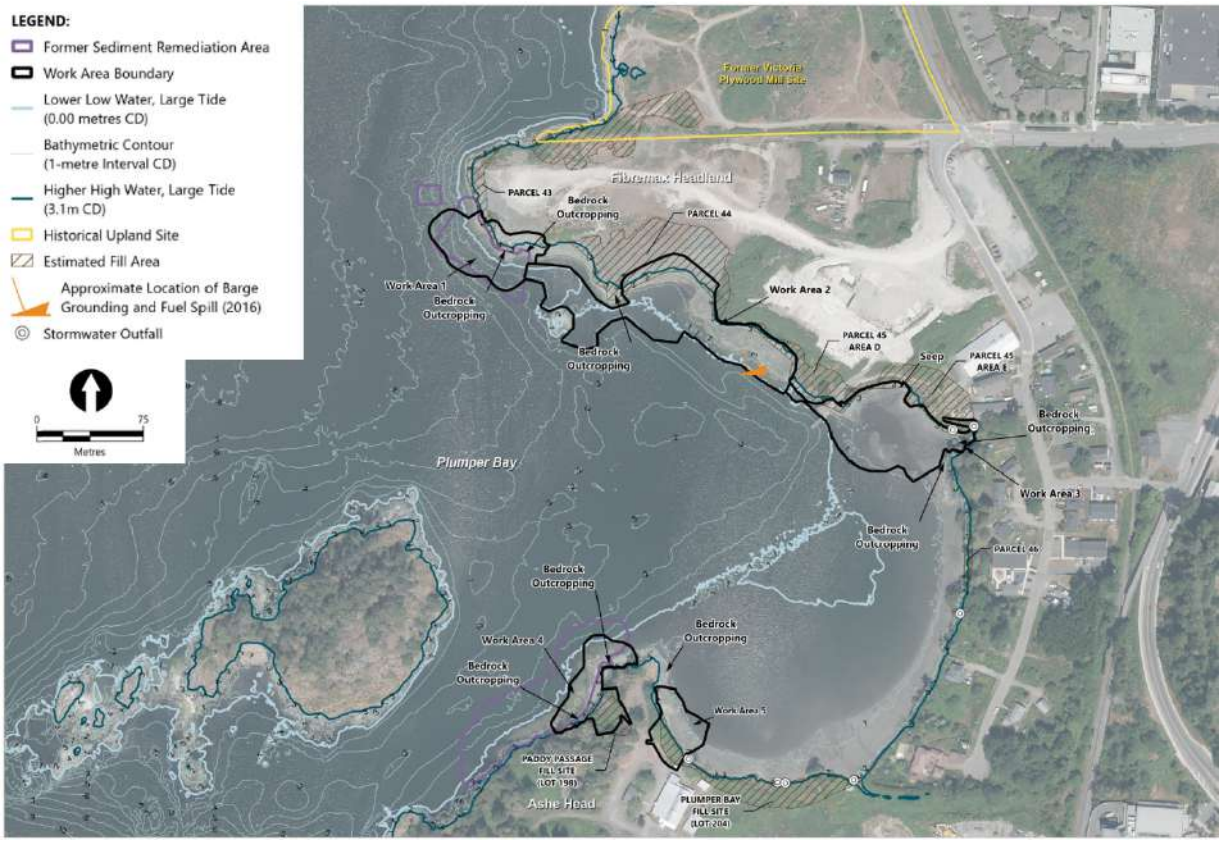

Figure 2. Plumper Bay existing conditions and work areas.

Project Goals and Remedial Action Objectives

The primary goal of the PBRP is to develop and implement a risk management and remediation strategy that effectively reduces the human health and ecological risks associated with historically contaminated sediments and nearshore soils in Plumper Bay. PBRP objectives and project goals include the following:

- Remediation of historically known contaminated sediments and shoreline soils in portions of Plumper Bay
- Reduction in the environmental liability associated with Plumper Bay contaminated sediments
- Minimization of health risks associated with beach use and seafood affected by historical contaminants
- Reduction in ecological risks associated with contaminated sediments and wood waste
- Minimization of recontamination potential through shoreline source control
- Enhancement of habitat in Plumper Bay
- Post-remedial restoration will prioritize Esquimalt Nation and Songhees Nation goals for future use by maximizing beach access and ecological function.

SITE BACKGROUND AND PREVIOUS REMEDIAL ACTIONS

Within Plumper Bay, hydrodynamic modelling conducted by Anchor QEA suggests that net current velocities (tidally averaged) are very low and there is a net clockwise circulation pattern in Plumper Bay (Anchor QEA 2016). A mean sedimentation rate of 1.0 centimetres/year and a conservative range of 0.5 to 1.5 centimetres/year was estimated for Plumper Bay based on geochronology (Anchor QEA 2020a).

The sediment in Plumper Bay can generally be characterized as soft silt at the seabed surface (i.e., mudline) overlying a stiffer silt with varying amounts of sand, clay, and shell fragments. General subsurface conditions of the beach and marine foreshore areas consist of unconsolidated sediments (typically less than 0.5 to 2 m thick) overlying clay (typically Victoria Clay less than 0.5 m thick) or bedrock (Golder 2020; SLR 2016). Shallow mudflats are prevalent along the northern shoreline of Plumper Bay, at thicknesses greater than 2 metres in places, based on jet probe results (WSP 2024). Bedrock is typically present at irregular shallow depths throughout the harbour, and in some cases, it occurs as outcroppings (islands), which is evident in the frequent exposed bedrock in the upper intertidal areas of Plumper Bay.

Areas of fill have been identified along the majority of the shoreline around Plumper Bay and Thetis Cove. Fill materials include various debris and available fill materials at the time of historical fill, such as boiler ash, hog fuel, sand, gravel, clay, blast rock, metal debris, vehicles, and appliances (Dillon Consulting 1999). These upland areas include a surficial fill unit with varying amounts of sand and gravel content below. Areas near the shoreline are generally similar with angular riprap beneath the surficial soils underlain by a layer of silt (Golder 2022a). Upland areas of Ashe Head are generally composed of a surficial silty clay/silt underlain by gravel and finally marine sediments with sand, silt, and clay containing fragments of shells and anthropogenic debris (e.g., wood, glass; Golder 2022b).

Historically, a number of industries have operated within north Esquimalt Harbour and reportedly discharged waste onto the seafloor. These industries included a saw and grist mill, a plywood mill (including log booming operations), a carpenter shop, an automotive wrecking yard, a blacksmith shop, a slaughterhouse, a flour mill, drydocks, shipyards, and the EGD (Golder 2006). In-water operations also included log booming, which began in the 1940s and remained active until 1997. Log booms were located in and around Plumper Bay, Thetis Cove, and the Inskip Islands (Thurber 2005).

In-water and upland areas surrounding Plumper Bay were also used historically by the First Nations for hunting, fishing, and ceremonial purposes (Thurber 2005). In the 1950s, residential homes, small docks, and jetties were built in the town of View Royal, located north of Thetis Cove (Golder 2006).

The Esquimalt Nation and Songhees Nation currently reside along the shoreline of Plumper Bay, as shown in Figure 1. The Esquimalt Nation and Songhees Nation use the shorelines along Plumper Bay for recreational purposes and have indicated a desire to return to more traditional use of these areas. Access paths to the shoreline are currently used by community members, but access to the water is limited.

2016 Diesel Spill

On 8 May 2016, a barge operated by Vancouver Pile Driving broke loose of its mooring, grounded, and by way of ruptured fuel tanks, spilled approximately 30,000 litres of diesel fuel into Plumper Bay (SLR 2020). It was reported that approximately 36,000 litres of wastewater were recovered from Plumper Bay, although during response efforts, containment booms were placed around the barge and at the opening of the bay. The remainder of diesel accumulation was removed from the shoreline using low-flow flushing with mixing/agitation of sediments, high-pressure washing of riprap, and manual removal (Golder 2021).

Seafood consumption within Esquimalt Harbour was subsequently closed by Fisheries and Oceans Canada (DFO) on 10 May 2016. A public health notice to avoid use of the shoreline and water in Plumper Bay was also issued by the First Nations Health Authority.

Following an investigation performed by Keystone Environmental (Keystone 2017), it was recommended that monitored natural attenuation would fulfill remediation goals from the spill. The sediment chemistry data collected by Keystone Environmental showed decreasing diesel-related contaminant concentrations over time; however, observations of shoreline sheens remained along the Work Area 2 and Work Area 3 intertidal areas.

Following the 2016 diesel spill and subsequent cleanup, an environmental site assessment of Plumper Bay was completed by SLR on behalf of DND. The investigation included the collection of sediment, porewater, and tissue samples analyzed for diesel-related parameters. Overall, polycyclic aromatic hydrocarbons (PAH) concentrations were detected above applicable standards, but they were reported to be more closely related to historical contamination than to the diesel spill. Concentrations of PAHs in porewater were consistent with creosote contamination, and piezometers had been installed near the Esquimalt Nation dock, which was in proximity to the diesel spill. Tissue samples also contained concentrations of PAHs greater than applicable guidelines more likely related to historical contamination rather than to the diesel spill. The tissue samples that exceeded guidelines were collected from the central eastern and southern portions of Plumper Bay.

A Beach Use Human Health Risk Assessment (HHRA) was completed for Plumper Bay to examine risks from legacy sources and diesel spill contamination. Visible evidence of diesel contamination was observed in the northeastern section of Plumper Bay, but it was concluded that diesel-related petroleum hydrocarbon risks met acceptable risk levels for high- and moderate-exposure scenarios (SLR 2020). Risks from associated legacy contaminants exceeded negligible risk levels under the high-exposure scenario. Once background levels of arsenic in soil and food were taken into account, risks from legacy contaminants met negligible risk levels under the moderate-exposure scenario.

The HHRA was updated in 2022, focusing on two areas identified as West Bay and East Bay (SLR 2022). Although visual evidence of residual diesel contamination has been observed in the northeastern section of Plumper Bay again in 2022, the HHRA concluded that risks were considered acceptable for humans using the beach in the West Bay (i.e., Work Areas 1 and 2) and East Bay (i.e., Work Areas 3 and 4) areas. This conclusion was based on the contaminant of potential concern screening assessment (SLR 2022) that compared the 95% upper confidence limit contaminant concentrations to soil standards for residential/parkland land use.

Plumper Bay and Ashe Head Remediation Project

The previously completed Plumper Bay and Ashe Head Remediation Projects included the removal of contaminated sediments and backfilling with clean material in 2018. Overall, a total of 12,700 m^3 of contaminated sediment was removed from the Plumper Bay and Ashe Head areas. The Plumper Bay Remediation Project focused on the removal of phenanthrene, lead, and copper, while contaminants removed by the Ashe Head Remediation Project included PCBs and copper (Golder and M&N 2017a, 2017b). After removal, clean granular backfill was placed with the intent of serving as a residuals management cover (RMC) for residual sediment contamination that remained after dredging at the base of the dredge footprint. Backfill was placed to also restore pre-construction elevations.

Confirmatory sampling indicated that all post-dredge samples collected within the subtidal dredge footprint met remediation criteria for all analyzed parameters with no exceedances of 6x the Canadian Council of Ministers of the Environment Probable Effects Level (PEL; federal screening criteria) (Anchor QEA 2018). However, performance monitoring in the 3 years following remediation identified remaining shoreline sediment and porewater contamination in excess of 6x PEL (Anchor QEA 2020b, 2020c, 2021a, 2021b). Results of this monitoring concluded that residual contamination existed within the shoreline areas of Ashe Head for PCBs, copper, and zinc, potentially due to anthropogenic debris eroding along the shoreline (Figure 3). The Plumper Bay shoreline had PEL exceedances of arsenic, copper, lead, and zinc, which were associated with poor fill quality in the adjacent upland and upper intertidal areas (Figure 4).

As discussed above, elevated sediment and surface water concentrations were identified during performance monitoring that were not addressed during the Plumper Bay and Ashe Head Remediation Projects. The “wedge” of remaining contamination was predominantly limited to shoreline areas that were too much in the intertidal zone to be addressed during upland work and too far towards the uplands to be addressed as part of in-water work. Additionally, other remnant contamination (i.e., diesel, wood waste) and area improvements were identified during project evaluations and discussions with the Esquimalt Nation and Songhees Nation for the five different work areas to support and enhance use of the area by the Esquimalt Nation and Songhees Nation community members. Construction in Work Areas 1 through 3 was completed during the first season of construction in 2025. Work Areas 4 and 5 will be completed during the second season of construction in 2026.

Work Area 1 – Fibremax Headland

Work Area 1 is located on the southwestern edge of the Fibremax Headland on the northern shore of Plumper Bay. The majority of the upland area was previously remediated, with the exception of the shoreline wedge located beneath the existing riprap slope and industrial slag on bedrock and riprap in the foreshore. The adjacent subtidal area had been remediated as part of the Plumper Bay Remediation Project, leaving predominantly the shoreline and intertidal areas requiring additional remediation as part of the

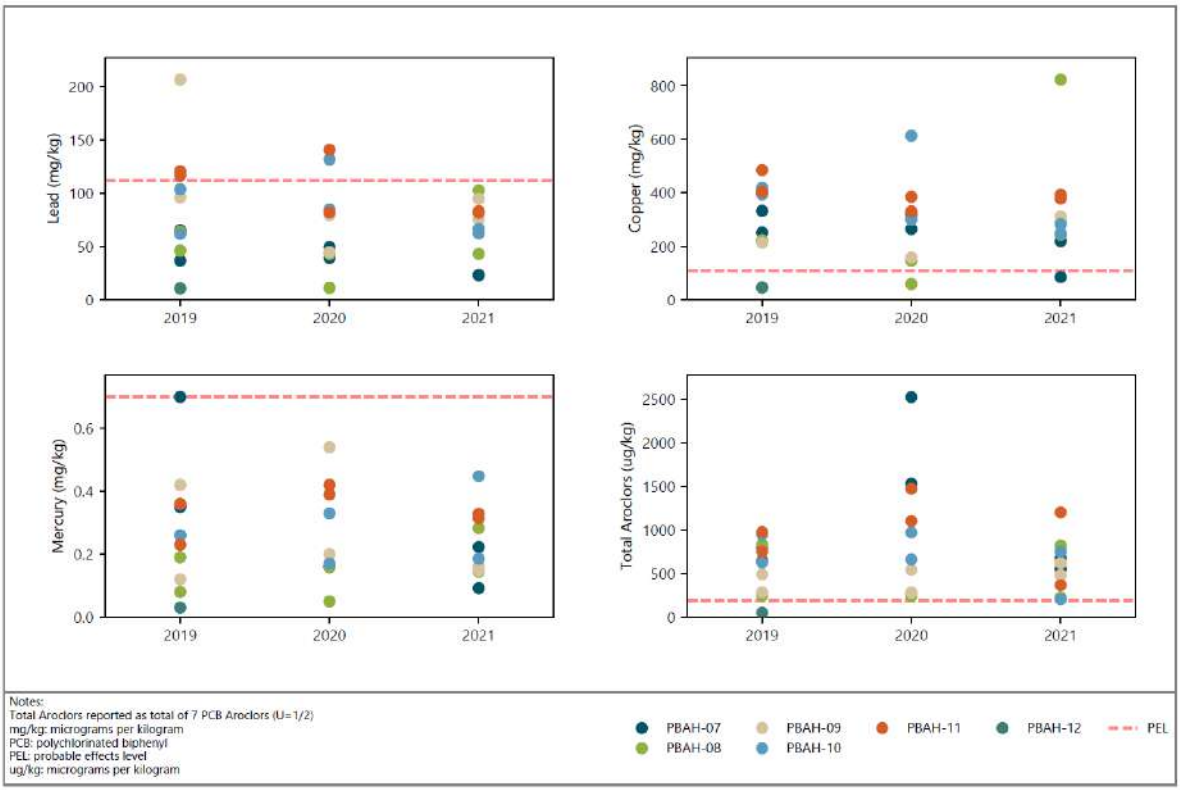

Figure 3. Ashe Head performance monitoring sediment concentration comparison.

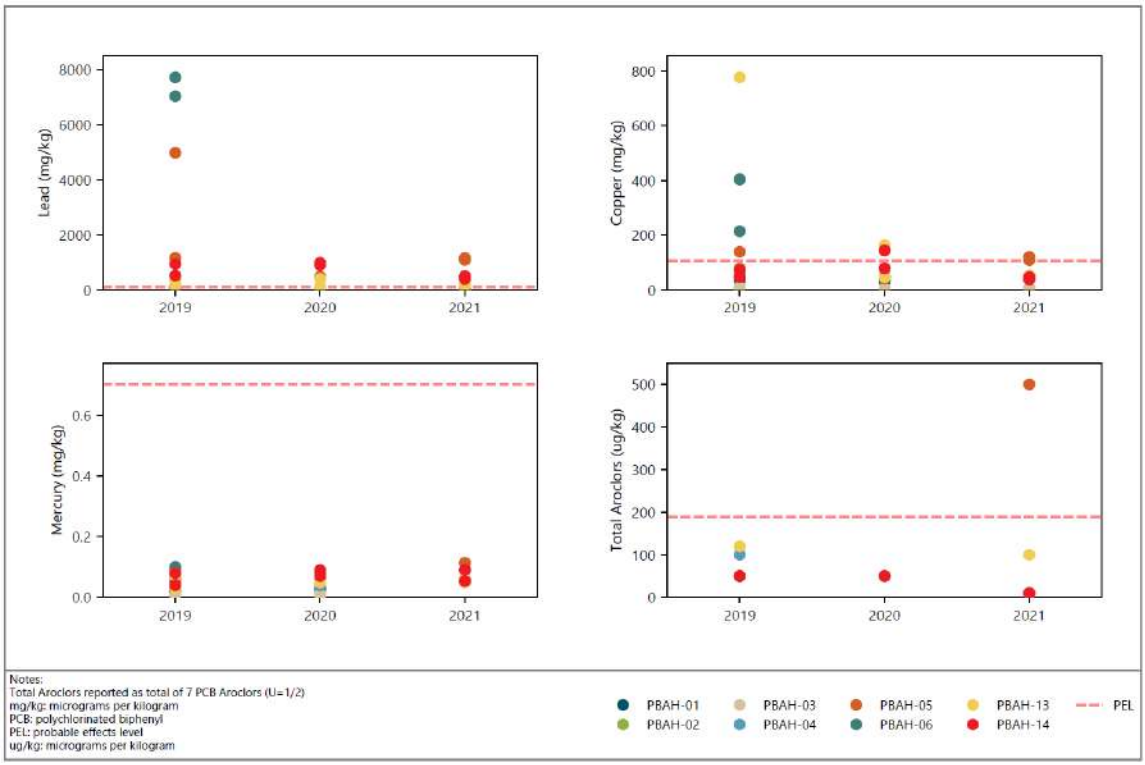

Figure 4. Plumper Bay performance monitoring sediment concentration comparison.

PROJECT APPROACH

PBRP, but portions of the previously-remediated sediment had also become recontaminated with metals presumed to be coming from the shoreline slag source. Remediation of sediment contamination in Work Area 1 was generally driven by metals concentrations, including lead (maximum exceedance 99x PEL) and copper (maximum exceedance 10x PEL). Additional exceedances were identified in sediments for PAHs (maximum exceedance 8x PEL) and PCBs (maximum exceedance 5x PEL). Cleanup efforts in Work Area 1 focused on reducing risks from contamination and re-establishing the existing shoreline and upland areas, at the request of the Esquimalt Nation who did not want to lose any of the upland area for future redevelopment.

Key objectives completed in Work Area 1 included the following:

- Reopening the beach, which had been closed to swimming and recreation due to health concerns related to polluted sediment
- Removing residual pollution from the upper intertidal zone to improve long-term shoreline conditions and prevent further impacts to ecological receptors (Figure 5)

Figure 5. Work Area 1 "wedge" before (left) and after (right) construction.

These actions have improved shoreline conditions and support healthier marine habitat. Although much of the upper shoreline remains armoured with riprap, the intertidal beach area below the riprap is once again accessible for community use, with slag and other contaminants removed or isolated under shotcrete

Work Area 2 – Esquimalt Habitat Beach

Work Area 2 is located to the south of the Fibremax Headland, midway along the northern shoreline of Plumper Bay. The majority of the upland area was previously remediated, with the exception of the shoreline wedge located beneath the existing riprap slope in the embayment portion of the work area. The intertidal shoreline areas had not been remediated prior to the PBRP and included sediment contaminant concentrations up to 28x PEL (2-methylnaphthalene). PAHs and dioxins/furans were the only analytes to exceed 6x PEL, with a maximum dioxins/furans exceedance of 11x PEL. Metals exceedances were also identified, however, at concentrations below 6x PEL. Additionally, this area included large deposits of wood waste, as it is understood to be the location of a conveyor belt that fed the Former Victoria Plywood Mill. Pre-construction characterization was unable to find the bottom of the fine wood waste deposits on

the beach using a 2-m probe. Sheen was also observed in the sediment within this work area during low tide and was assumed to be associated with the 2016 diesel spill that occurred in this area.

The sediment contaminant concentrations, remnant diesel sheens, and wood waste, affected sediment quality, limited habitat, and reduced Nation members' access to the intertidal areas. Cleanup and restoration work in this area focused on improving environmental conditions, beach habitats, and creating better access for First Nations' community use.

Key objectives completed in Work Area 2 included the following:

- Removing residual pollution from the upper intertidal zone
- Removing remaining diesel pollution found along the shoreline
- Removing or isolating wood waste to improve natural shoreline and shallow subtidal conditions
- Improving habitat, including expanding forage fish habitat and restoring clam habitat in intertidal areas
- Providing green shoreline alternative to the existing riprap by laying the slope back in the wedge area and establishing riparian plantings above the high-water elevation
- Increasing First Nations' access, including the construction of a new community access trail and bench viewing area (Figure 6)

Figure 6. Work Area 3 before (left) and after (right) construction.

These efforts have improved shoreline health, supported more diverse habitat, and created new opportunities for cultural and community use of this area.

Work Area 3 – Esquimalt Beach

Work Area 3 is located in the northeast corner of Plumper Bay. The shoreline areas were previously documented to contain sediment contaminant concentrations up to 29x PEL for 2 methylnaphthalene. Similar to Work Area 2, only PAHs and dioxins/furans exceeded 6x PEL. Two PCB Aroclor exceedances were also identified, both of which were below 3x PEL. Metals exceedances were identified for chromium, copper, lead, mercury, and zinc, with the maximum exceedance of 5x PEL for mercury. Additionally, this area included significant deposits of wood waste and minor observations of sheen during low tide. These materials affected sediment quality, and limited quality habitat. Cleanup and restoration activities in Work Area 3 focused on improving environmental conditions while supporting Esquimalt Nation use of the beach (Figure 7). Key objectives completed in Work Area 3 included the following:

- Removing sheen-impacted and contaminated intertidal sediment to improve water and shoreline quality
- Improving habitat, including expanding forage fish habitat and restoring clam habitat in intertidal areas
- Enhancing Esquimalt Nation access, including completing a new access trail and cultural use opportunities
- Rerouting existing stormwater known to contain chemical exceedances of water quality guidelines through a bioretention treatment area to reduce future inputs of pollution to the beach
- Routing an additional stormwater seep/outfall through a pipe under the new beach backfill material to reduce the potential for contaminants from the stormwater to impact future clamming potential in the new beach
- Fixing the approach to an existing Esquimalt Nation wharf, by fixing the bulkhead, backfilling an area of erosion, and repaving the access road

Figure 7. Work Area 3 before (left) and after (right) construction.

These actions have supported healthier intertidal habitat and accessible shoreline access for the Esquimalt Nation.

Work Area 4 – Ashe Head

Work Area 4 is located to the west of Ashe Head along the northern portion of Paddy Passage and east of the Inskip Islands. A portion of the upland area was previously remediated removing landfill deposits placed in a former intertidal embayment. However, this removal stopped at a wedge of soil that was left in place to keep the former excavation dry. A portion of this shoreline wedge along the western edge of the former remediation area and to the north of the fill area was not excavated due to the presence of two Garry Oak trees that were protected in place. It is assumed that the existing fill material located within this northern portion of the work area continues to contribute to recontamination of sediment within the Work Area, as erosion and refuse are visually evident coming out of the bank. Similar to Work Area 1, the subtidal areas were previously remediated as part of the AHRP, leaving predominantly the remaining shoreline and intertidal areas as locations that require additional remediation. It is also noted that a portion of the former subtidal remediation area has become recontaminated due to the remaining shoreline sediment. Sediment concentrations in Work Area 4 are generally driven by the presence of PCBs, with exceedances up to 32x PEL. Copper was the only analyte other than PCBs to exceed 6x PEL with a maximum exceedance of 8x PEL. Exceedances less than 6x PEL were identified for arsenic, lead, mercury, and zinc.

The remaining contamination in shoreline and intertidal areas are affecting sediment quality and limiting quality habitat. Cleanup and restoration activities in Work Area 4 will focus on improving environmental

conditions while also supporting and enhancing Songhees Nation use of the beach. Key objectives to be addressed in Work Area 4 during the second season of construction include the following:

- Removing residual pollution from the upper intertidal and adjacent upland areas
- Improving habitat, including providing a range of material sizes in intertidal areas to promote a healthy benthic community, including substrate expected to be suitable for oysters
- Creating a pocket beach for Nation members with numerous boulders to mimic adjacent bedrock outcrops and establish an embayment for the pocket beach
- Enhancing Songhees Nation access, including completing a new access trail and cultural use opportunities
- Providing green shoreline alternative to the existing riprap by laying the slope back in the wedge area and establishing riparian plantings above the high-water elevation
- Completing upland riparian plantings adjacent to the access trail removing existing invasive vegetation

These actions will improve shoreline conditions, support healthier marine habitat and accessible shoreline access for the Songhees Nation as shown in Figure 8.

Figure 8. Existing landfill deposits eroding onto the beach (left) and anticipated future (right) conditions at Work Area 4.

Work Area 5 – Songhees Beach

Work Area 5 is located to the east of Ashe Head in the southwest corner of Plumper Bay. Work in the shoreline and intertidal areas consists of debris removal and cleanup, public access improvements, and habitat enhancement. Sediment chemical concentrations in Work Area 5 have been documented to be contaminated with anthropogenic debris which are the primary drivers for remedial action in this area. Cleanup and restoration activities in Work Area 5 will focus on improving environmental conditions while also supporting and enhancing Songhees Nation use of the beach. Key objectives to be addressed in Work Area 5 during the second season of construction include the following:

- Removing debris from the beach and shoreline areas, including removal of the existing deteriorated boat ramp, large rubble, angular rock, and concrete/asphalt debris from the beach surface and garbage from the nearby shoreline slopes to the extent practicable without disturbing slopes
- Providing green shoreline alternative to the existing eroding beach scarp by laying the slope back, removing invasive vegetation that dominates the shoreline riparian area and establishing riparian plantings above the high-water elevation

- Improving habitat, including expanding clam habitat in intertidal areas and improving beach material by importing sand to replace the existing fine-grained sediment
- Enhancing Songhees Nation access, including completing a new access trail and cultural use opportunities

These actions will improve shoreline conditions and support healthier marine habitat (Figure 9).

Figure 9. Existing (left) and anticipated future (right) conditions at Work Area 5.

FIRST NATIONS ENGAGEMENT AND FEEDBACK

Various engagement activities and feedback opportunities were conducted and shared between the project team and Esquimalt Nation and Songhees Nation community members. Engagement activities were conducted both with and without the non-First Nations project team members to encourage honest project feedback and discussions.

Engagement Activities

Engagement activities were sequenced between different stages of project design to bring thoughtful, practicable design materials to the engagement activities to focus feedback. Engagement activities included a community beach use survey, beach substrate feedback, various Chief and Council meetings, technical briefings, First Nations Working Group workshops and an associated shoreline walk as well as community open house events.

Beach use surveys were utilized to understand current and future cultural, recreational, and community shoreline use. Chief and Council meetings provided opportunities for project team members to provide updates on project direction and key decisions. Technical briefings were utilized to discuss environmental findings, sediment conditions, and habitat restoration approaches. During technical briefings, various questions were posed to compile input including if Chief and Council felt the design was on the right path for remediation, if there were preferences or questions around restoration and site improvement options proposed for specific areas, and overall questions surrounding the potential impacts of the project on future development within or adjacent to the project area. Briefing notes were also utilized to communicate proposed project activities and seek feedback on specific elements of these activities. Briefing notes were developed for the proposed site access and staging areas, proposed changes to shorelines and associated beach elevation changes, timing of the construction activities, and to provide overall updates on project progress and inquire about preference between multiple project approach options when available.

First Nations technical workshops and associated shoreline walks allowed time for place-based conversations and conversations between members of the Esquimalt Nation and Songhees Nation and the project team and the identification of priority areas for access and habitat improvements based on Traditional Use, as well as learn the history of the areas from community members who had lived there their entire lives. Community open house events were held with members of the Esquimalt Nation and Songhees Nation to provide project updates, answer questions, and gather broader community feedback. There was additional hands-on involvement from the First Nations community with community members participating in planting of trees, shrubs, and groundcover within Work Area 2. Additionally, project support was provided by Salish Seas Industrial Services, a company jointly owned by Esquimalt Nation and Songhees Nation, who contributed to completing key portions of the construction work.

Engagement Results and Feedback

Based on the feedback from various engagement activities, the overall project design was revised to increase focus on long-term project resiliency and restore the traditional functionality of the shoreline. Additionally, communication pathways and key staff were identified as part of the development of a Construction Communications Plan to ensure effective communication continued during project implementation and did not stop after the design phase.

Various changes were made to the design of the PBRP based on feedback received during engagement events. This included enhancements in the project such as restoring the traditional functionality to the shoreline by laying shoreline slopes back, addressing invasive vegetation, completing riparian plantings with plant preferences provided by the Nations, placing boulders in intertidal areas, constructing a bioretention area, and incorporating trails to the newly restored beaches to increase community access. In Work Areas 2, 3, 4, and 5, to improve shoreline access for public users, access trails are or will be built to provide access for Nation members. The locations of the trails have been coordinated with the Esquimalt Nation and Songhees Nation through conversations and meetings.

Additionally, project outreach and engagement with the Esquimalt Nation and Songhees Nation identified the desire to restore spawning substrate for forage fish (Pacific sand lance, surf smelt herring), and provide suitable substrates for clams (littleneck clams and manila clams). This guided backfill material choices and gradations for final fill materials.

To support effective project communication during construction, a Construction Communications Plan was developed to provide a communication framework for parties and key stakeholders involved in construction during the PBRP. The plan details the path of communication, how often that communication should occur, major records of communication, and general communication objectives. This included identifying points of contact at the Esquimalt Nation and Songhees Nation and identifying the types of updates these Key Nation Contacts would be responsible for communicating to Chief and Council and the Esquimalt Nation and Songhees Nation communities.

Throughout construction, environmental and archaeological protection measures were in place to ensure that wildlife, habitat, and cultural resources were safeguarded. Monitoring was carried out continuously to prevent impacts and support management of construction. Key protection activities included:

- Wildlife salvage and relocation, including the recovery and relocation of Dungeness crabs, red rock crabs, juvenile sculpin, and other marine species from active work areas
- Bird nesting surveys ensuring construction avoided disturbance to active nests

- Archaeological oversight during all upland and intertidal excavation, including documenting cultural resources encountered during excavation and shoreline work
- On-site environmental monitoring to guide construction methods, and confirm compliance with requirements

These measures ensured that construction was conducted responsibly for both the natural environment and the cultural significance of the Plumper Bay shoreline.

CONCLUSION AND NEXT STEPS

Engagement activities that were conducted throughout the project process provided opportunities for the project to be revised based on feedback from Esquimalt Nation and Songhees Nation to better align the final project design with community desires and interests for site use and access. The project has currently completed its first of two construction seasons and addressed Work Areas 1, 2, and 3. Cleanup, shoreline restoration, and community access improvements in these areas are now in place to support healthier habitat and enhanced community use options. During the second season of construction, the project will build off the work and engagement completed to date to ensure the remainder of the construction is completed successfully and the areas addressed are ready for Esquimalt Nation and Songhees Nation use.

To evaluate the effectiveness of the remedy and level of potential recontamination at the site, performance monitoring will be conducted annually for 3 years through the collection and analysis of various media in the remedial action area, including surface sediment grabs, porewater samples, and surface water samples. Monitoring will provide localized feedback regarding characterization of sediment and water chemistry conditions of the remedial action area. Additionally, long-term monitoring will be performed to document conditions after site closure and performance monitoring is completed. Long-term monitoring will include surface sediment grabs every 10 years, to be performed in perpetuity unless conditions change to the point where DND no longer requires it. Dungeness crab and clam tissue monitoring may also be performed as a contingency measure if surface sediment concentrations show repeated increases over time or if there is a concern regarding risks to human health and ecological receptors. Updates from the performance monitoring and long-term monitoring will be communicated to the Esquimalt Nation and Songhees Nation communities to ensure they remain up to date on the environmental health of the project area to support their potential future use of the area for traditional use.

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DATA AVAILABILITY

All data, generated during the study are proprietary or confidential. These data may be provided upon request with restrictions on republication and use.

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We would like to acknowledge Esquimalt Nation and Songhees Nation for their continued involvement in the development of the Plumper Bay Revitalization Project.

LESSONS LEARNED FROM G JETTY/JETTY 11 REMEDIATION PROJECT

M. Bodman[1], M. Gerard[2], R. Thomas[3], A. Corp[4], M. Woltman[5] and D. Ormerod[6]

EXTENDED ABSTRACT

Esquimalt Harbour is a large working harbour located on the southern tip of Vancouver Island, British Columbia, with a long history of environmental impacts related to shipbuilding, mills, canneries, and naval activities. Public Services and Procurement Canada (PSPC), in coordination with the Department of National Defence (DND), designed and implemented a sediment remediation project between 2021 and 2023 under and adjacent to G Jetty and Jetty 11. Both jetties are active naval jetties within the Royal Canadian Navy's Pacific Fleet home port. Development and historical activities in the Colwood area near the current G jetty and Jetty 11 structure began in the 1920s and has likely contributed to sediment contamination within and adjacent to the project area. Historical sources of contamination in the Colwood area that may have impacted sediment quality include the following:

- On-land storage and transmission of fuels to ships berthed at F Jetty
- Major leaks from pipelines, including a discharge from F Jetty into the harbour (1988 to 1990)
- Transmission of oily water from F Jetty and subsequent on-land storage and treatment of wastewater
- Ship fueling activities at the jetties, which may have impacted the marine environment
- Sand blasting activities at nearby remedial areas and disposal of sand blast residues both on land and to the marine environment
- Typical vessel cleaning and berthing activities at the jetties, including vessel cleaning and material jettisoned into the harbour
- Resuspension and transport of contaminated sediments from nearby remedial areas into the remedial planning areas from either propeller wash impacts (i.e., propwash), storm events, or tidal circulation
- Other unidentified upland and harbour uses that may have resulted in contaminants being discharged to the marine environment

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[1] MARPAC Environment Officer CFB Esquimalt, Department of National Defence, PO Box 17000 Station Forces, Victoria, British Columbia, V9A 7N2, Canada, 250-363-4824 D199, Michael.bodman@forces.gc.ca.
[2] Environmental Specialist, Environmental Services, Contaminated Sites, Public Services and Procurement Canada, 800 Burrard St, Unit 219, Vancouver, BC V6Z 0B9, Canada, T: 604-389-8935, Email: michelle.gerard@pwgsc-tpsgc.gc.ca.
[3] Senior Environmental Specialist, Environmental Services, Contaminated Sites, Vancouver Island Group, Public Services and Procurement Canada, 401-1230 Government Street, Victoria, British Columbia V8W 3X4, Canada, T: 250-418-5731, Email: Robert.thomas2@pwgsc-tpsgc.gc.ca.
[4] Principal Scientist. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2715, Email: acorp@anchorqea.com.
[5] Principle Engineer, Anchor QEA, 1201 3rd Avenue, Suite 2600, Seattle, WA, USA, T: 206-903-3327, Email: mwoltman@anchorqea.com
[6] Principal Engineer. Anchor QEA, Inc., 20 Bellwether Way, Suite 101, Bellingham, Washington 98225, USA, T: 360-715-2721, Email: dormerod@anchorqea.com.

The extent of sediment contamination in comparison to the established active remediation threshold within the project area was used to define the remedial planning area boundaries. Contamination was typically isolated in a few hotspot areas and generally decreased with distance from the most contaminated hotspot samples. Data gaps sampling in 2019 further refined these remedial planning areas by providing supplemental results to refine the horizontal and vertical extent of surface and subsurface sediment contamination within the remedial areas.

The primary sediment remediation methods were dredging and material processing (removal of approximately 8,600 cubic metres of contaminated sediment); off-site disposal of contaminated materials at an upland disposal facility; backfilling; and structural modifications, such as removing and reinstating floats, jetty fenders, ladders, and structure cross-bracing to access contaminated sediment under the structures or allow cover material to be placed where sediment was unable to be removed.

Key challenges of this project included processing 100% of the dredged sediment and debris to screen for and segregate unexploded explosive ordnance (UXO) prior to transporting sediments to the offloading facility for disposal and coordinating remediation activities with evolving operational requirements at the two jetties. Completing this 100% screening resulted in increased processing times compared to direct transport of dredged material to a disposal facility. Further, completing remediation within an active naval harbour around aging infrastructure required evolving project communications, flexibility and proactive coordination between the contractor and DND. This included understanding the naval fleet diving unit training schedule and underwater workshops being conducted in the water surrounding the project area. Additional challenges included placing backfill material in underpier areas and managing dredging and material processing production rates to meet project schedule restrictions.

Uncertainties and lessons learned during implementation generally involved unidentified data gaps, schedule pressures, equipment selection, communication, and unexpected site conditions. The use of historical bathymetric survey information instead of recent bathymetric data led to an increased dredge prism volume to meet design requirements, as well as various project redesigns. This reinforced the need to maintain recency for design surveys and to build in contingency budget to address unforeseen circumstances due to data gaps. Additionally, the discovery of a previously unknown marine railway structure required adaptive management of project schedules to accommodate additional work, including the higher than expected levels of debris. Equipment selection provided a positive element to the work, with the contractor effectively employing a truck-mounted conveyor/slinger to reach underpier areas for material placement and use of an additional floating barge to facilitate stabilization of hazardous waste-level materials and segregation of suspected UXO and archaeological materials. Conducting critical evaluations of the project equipment before commencing construction to practically select specialized equipment (i.e., truck-mounted slinger for underpier areas) facilitated successful project implementation. The annual funding cycle and other schedule pressures, including cashflow restrictions and variations in tender schedule, were successfully addressed through open and frequent communication throughout the duration of the project. Updates on schedule changes and potential delays helped mitigate schedule pressures throughout implementation. There were some difficulties exchanging information among the construction team including multiple contractors in a timely manner. As a result of these difficulties, a lesson learned and implemented during the project was to have additional meetings requiring all subcontractors presence to facilitate coordination.

Overall, the implementation of the G Jetty/Jetty 11 remediation project highlighted that a complete and recent site understanding is required for effective design, critical analysis of required equipment can make

or break the success of project implementation, flexibility presents an advantage for work on complex project sites, and communication is key for all elements of the project and for all involved in the project.

Keywords: Dredging, contaminated sediment, working harbour, dredged material processing, material disposal.

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DREDGED SEDIMENT BENEFICIAL USE INNOVATIONS: FROM ROUTINE DISPOSAL TO NATURE INSPIRED INFRASTRUCTURE ENABLED BY 3D PRINTING

A. J. Kennedy[1], B. C. Suedel[1], M. L. Ballentine[1], A. D. McQueen[1], E. S. Godsey[2], V. Morrow[2], P. Lee[3]

EXTENDED ABSTRACT

Dredged sediment represents an underutilized material resource that may support natural-inspired infrastructure through modified additive manufacturing. For example, the US Army Corps of Engineers Districts and Divisions are seeking innovative methods to beneficially use more fine-grained dredged sediment, an objective that is broadly applicable to other agencies and industry. This presentation summarizes a metamorphosis of thinking from simply evaluating the physical, chemical and biological compatibility of dredged sediment for placement in open water under Section 103 or 404 permits (Kennedy et al. 2023) to beneficially using it for natural infrastructure (Kennedy et al. 2025a; Tritinger et al. 2024). The authors research and development concept addresses three mission objectives through a culmination of Engineering With Nature® and Regional Sediment Management; specifically: (1) increasing beneficial use of locally sourced dredged sediment through research and development innovation such as additive manufacturing; (2) building nature-inspired infrastructure and restoring aquatic ecosystems for aquaculture, recreation and other resources of economic importance; and (3) improving coastal resilience including storm energy dissipation and sediment retention. Managers of ports and harbors containing fine-grained sediments (silts and clays) do not have as clear beneficial use applications as for sands used for beach nourishment. Additionally, regions with predominately fine-grained sediments would benefit from presence of hard substrate for coastal storm damage reduction, cost reduction of transporting rock (e.g., rip rap), and development with economically important industries such as oyster fisheries. Dredged sediment is a locally available feedstock for building novel infrastructure that is natural and thus more biocompatible than cement if only an innovative method for processing it was available.

Recent advancements in additive manufacturing technologies, including 3D printing, allow for materials beyond polymers (e.g., clays, ceramics, cement) to be shaped into complex, organically inspired geometries. Adaption of 3D printing as a technology enabler is an exciting opportunity to innovate beneficial use of sediment alternatives that could change public perceptions from thinking of dredged material as a waste product (regardless of absence or presence of industrial contaminants) to a valuable construction material that accelerates aquatic ecosystem restoration. Dredged sediment as a feedstock for 3D printing may be sourced from a barge during or after operations or conveniently from Confined Disposal Facilities (CDFs) which often include relatively clean sediment. This study, which is in collaboration with USACE Mobile District, demonstrates 3D printing methods to extrude and solidify dredged sediment from the Blakeley Island CDF (Mobile, AL) into different complex structures with applications ranging from aquaculture, storm energy dissipation, sediment retention, nutrient sequestration and phytoremediation. The

[1] Engineer Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd, Vicksburg, MS 39056, USA, T: 601-415-3344, Email: Alan.J.Kennedy@usace.army.mil.
[2] US Army Corps of Engineers, Mobile District, 106 St. Joseph Street, Mobile, AL, 36602, USA
[3] College of Charleston, Hollings Marine Laboratory, College of Charleston, 331 Fort Johnson Rd., Charleston SC 29412, USA

research and development spans from considering sediment material properties from various ports and harbors relative to the printability of the material, what types of structures would be beneficial to ecosystems, what the resiliency of the printed material may be and ultimately how to scale up the technology to have real mission impact (McQueen et al. 2026).

The data generated through strong collaborations with College of Charleston and the Mobile Bay National Estuary Program provide evidence that 3D printed dredged sediment is attractive infrastructure for a wide range of species. Three case studies are discussed. First, most dredged sediment is relatively uncontaminated and can be directly printed, solidified and used. However, when sediment is contaminated by industry activity, the authors have demonstrated that amended 3D printed sediment structures inserted into water and sediments can reduce the bioaccumulation of both conventional contaminants and nutrients to emerging contaminants such as harmful algal bloom toxins to per- and polyfluoroalkyl substances (PFAS) (Kennedy et al. 2025b; Krupa et al. 2025). Second, the authors discuss the perception that dredging operations with suspended sediments may have impacts on coral while our 3D printed dredged sediment makes an attractive substrate for coral colonization. Third, the authors demonstrate that dredged sediment may be 3D printed at larger scales to support oyster aquaculture in Mobile Bay and that initial tested oyster domes are resilient in the intertidal zone for at least months of environmental challenges (Figure 1). Scale up considerations include tech transitions to industry with capability to 3D print cement at larger scales, providing a business model to include dredged sediment in their structures. As these methods progress toward standard industrial scales through technology transfer, there may be opportunities to restore CDF capacity.

Figure 1. 3D printed sediment from the Blakeley Island Confined Disposal Facility in the form of oyster domes with (left dome) and without oyster shells. The right image shows a deployed dome in Mobile Bay.

Keywords: Dredging, dredged material, sediment, coastal resilience, natural infrastructure, additive manufacturing, nature-based solutions.

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AIR BUBBLE CURTAIN PILOT STUDY

J. Bistrovich[1], N. Gensky[2], J. Bruce[3] and P. Thodi[4]

EXTENDED ABSTRACT

Air Bubble Curtain (ABC) systems are increasingly evaluated as supplemental in-water environmental controls during remediation to manage suspended sediment, non-aqueous phase liquid (NAPL), sheen, and associated dissolved phase contaminants. Arcadis of New York, Inc. (Arcadis), in collaboration with C-CORE (St. John's, Newfoundland and Labrador, Canada), conducted a comprehensive bench scale laboratory and computational fluid dynamics (CFD) study to evaluate the effectiveness of ABC technology for application at sediment remediation (i.e., dredging) sites.

The study was planned and adapted based on testing observations, material and equipment availability, and evolving understanding of system behavior. The primary objectives were to:

1) Assess the effectiveness of ABCs for controlling turbidity, NAPL, sheen, and dissolved phase constituents under stationary and flowing conditions;
2) Generate data to support development and validation of CFD models capable of predicting ABC performance at larger scales; and
3) Evaluate monitoring techniques applicable to bench and field scale ABC deployment.

Phase 1 testing evaluated ABC effectiveness under stationary conditions for turbidity and NAPL containment. Turbidity tests were conducted in stationary water conditions in laboratory tanks using manufactured silt selected to approximate site sediment characteristics and were monitored using real time turbidity probes and visual observations. Multiple ABC configurations, air flow rates, spacing, and geometries were evaluated to assess and optimize performance while identifying bench scale complications such as sidewall induced localized currents.

NAPL testing included both a substitute NAPL mixture intended to represent light and neutral NAPL phases and actual MGP NAPL. The physical properties of the NAPL materials were characterized prior to testing. NAPL behavior was evaluated using qualitative methods (visual observations, Tyvek®, and polyethylene media) and limited water sampling for petroleum hydrocarbons and polycyclic aromatic hydrocarbons.

Phase 2 testing evaluated NAPL behavior under simulated flowing conditions using a large outdoor modular tank configured as a temporary flume. Based on Phase 1 results and preliminary CFD modeling, the recirculating flow test configuration generated a nominal current velocity of approximately 0.1 m/s. ABCs were configured perpendicular to flow with increased spacing between curtains to better represent

[1] Senior Environmental Engineer, Arcadis of New York, Inc., 110 W Fayette Street, Suite 300, Syracuse, New York, 13202, USA, T:315-671-9697, email: joe.bistrovich@arcadis.com.
[2] Technical Expert, Arcadis U.S., Inc., 225 W Wacker Drive, Suite 2015, Chicago, Illinois. 60606, USA, T: 312-575-3757, nancy.gensky@arcadis.com.
[3] Senior Project Engineer, C-Core, Capt. Robert A. Bartlett Building, 1 Morrissey Road, St. John's, Newfoundland, Canada, A1B 3X5, T: 709-864-4319, email: jonathon.bruce@c-core.ca.
[4] Senior R&D Project Engineer, C-Core, Capt. Robert A. Bartlett Building, 1 Morrissey Road, St. John's, Newfoundland, Canada, A1B 3X5, T: 709-864-7403, email: prem.thodi@c-core.ca.

field conditions and reduce tank effects. NAPL release systems and monitoring approaches were refined accordingly.

CFD models were developed following Phase 1 to simulate turbidity and NAPL transport observed in bench scale testing, interpret tank scale effects, and guide Phase 2 test design. Additional CFD simulations evaluated larger tanks and flowing conditions to further refine testing methods. A field scale CFD model was subsequently developed using a two-dimensional approach to evaluate ABC effectiveness under representative water depths, current velocities, ABC spacing, and air flow rates.

Bench-scale testing demonstrated that ABCs consistently generated vertical upward currents that lifted suspended sediment and lighter NAPL components toward the water surface. Turbidity was transported upward by the ABCs; however, in confined bench-scale tanks, turbidity migrated throughout the tank over time, indicating limited containment under stationary conditions. Increased spacing between ABCs, reduced air flow rates, and modified geometries improved performance by reducing localized currents, although tank sidewall effects remained influential.

NAPL testing highlighted distinct behavior between dense and lighter NAPL components. Approximately 90–95% of MGP NAPL behaved as dense phase material and remained primarily on the tank bottom, while approximately 5–10% separated into lighter phase blebs that migrated into the water column and accumulated at the surface. ABCs were substantially more effective in managing the lighter NAPL fraction, promoting upward transport and surface accumulation that facilitated containment between ABCs and potential recovery using surface controls.

CFD modeling effectively reproduced observed turbidity and NAPL behavior, confirming that tank geometry significantly influenced bench-scale results. Modeling indicated that turbidity containment diminishes over time even in larger tanks, whereas NAPL—particularly lighter phase components—was more amenable to control. Field-scale CFD simulations showed that dense MGP NAPL primarily migrates along the bed with ambient currents and is minimally influenced by ABCs, particularly as velocity increases. In contrast, ABCs accelerated the upward migration of lighter phase NAPL and sheen, reducing the horizontal distance to surface expression by approximately 40% under modeled conditions.

Phase 2 flowing tests validated CFD predictions and Phase 1 observations. Lighter phase NAPL blebs were lifted to the water surface and partially retained between ABCs under simulated current conditions, while dense NAPL remained largely confined to the bottom. Performance decreased with increasing current velocity; however, ABCs consistently enhanced surface expression of lighter NAPL, supporting their use as a supplemental control in combination with surface recovery methods.

The bench-scale testing and CFD modeling demonstrate that ABC technology is more effective for controlling lighter phase NAPL and associated sheen than for long-term turbidity containment. ABCs do not provide sustained containment of suspended sediment under confined or flowing conditions but effectively redirect turbidity upward. For NAPL-impacted environments, ABCs are most beneficial in lifting lighter NAPL blebs to the water surface, where containment or recovery using skimmers, pads, or booms is feasible. Monitoring approaches based on visual observations and qualitative media sampling were demonstrated to be effective, while dissolved-phase water sampling was of limited utility. Overall, ABCs represent a viable supplemental environmental control when integrated with additional field controls and applied with consideration of site-specific hydraulic conditions.

Keywords: Air bubble curtains, sediment dredging, environmental controls, CFD modeling, MGP NAPL behavior

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RE-THINKING DREDGE AND DISPOSE: LOW-CARBON IN SITU TREATMENT AND BENEFICIAL USE OF CONTAMINATED SEDIMENTS

L.M. Orr[1], W. Azhar[2], and M. Russell[3]

EXTENDED ABSTRACT

Traditional dredge and dispose remedial approaches for contaminated sediments in rivers and ports are increasingly constrained by limited disposal options, rising lifecycle costs, and pressure to reduce emissions and other implementation impacts from energy-intensive projects. There is no presumptive remedy for contaminated sediment sites, and in situ treatment technologies integrated with beneficial use (BU) of dredged sediments can offer low-carbon remedial alternatives for active rivers and ports.

Existing research demonstrates the advantages of BU over off-site disposal by reframing waste as a resource. Case studies compiled by CEDA (2019) show that BU can substitute for virgin raw materials, restore habitats, and enhance coastal resiliency with many projects delivering combined economic, social, and environmental benefits. The BU literature review by Hedblom et al. (2020) similarly highlights that using dredged sediment as a resource can reduce demand for limited landfill space, lower the overall environmental footprint, provide necessary fill for infrastructure improvements, and provide material for beach nourishment.

This presentation seeks to build upon existing work by providing quantitative and qualitative measures for evaluating the carbon costs of remedial alternatives by presenting a case study of a hypothetical contaminated sediments site where carbon emissions from a dredge and off-site disposal remedy are compared to the emissions from an integrated in situ treatment and BU remedy. The primary objectives of the study are to:

1. Create an emissions comparison of a dredge and off-site disposal remedy versus in situ treatment with onsite BU
2. Discuss example site-specific considerations that may apply to real-world applications
3. Discuss other factors that influence the application and efficacy of greener remedial technologies

The hypothetical site is assumed to be an active navigable river with contaminated sediment. All site parameters (e.g., volume of contaminated sediments and physical and chemical properties) are held constant with only the remedial technologies varying, so a unitized carbon cost can be developed for each option. The simplified remedial alternatives are:

1. Targeted environmental dredging and off-site disposal of full volume of contaminated sediments

[1] Sediment Remediation Technical Director, Parsons, Portland, OR 97202, USA, T: +1 206-288-6142, Email: louisa.orr@parsons.com.
[2] Sediment Practice Lead, Parsons, 999 18th St Suite N 1555, Denver, CO 80202, USA, T: +1 303-837-4098, Email: wardah.azhar@parsons.com.
[3] Associate Engineer, Parsons, 301 Plainfield Rd # 350, Syracuse, NY 13212, USA. T: +1 315-518-8227, Email: michael.russell@parsons.com

2. In situ solidification/stabilization (ISS) of full volume of contaminated sediments and onsite BU of ISS swell material

The standardized emissions comparison was developed using U.S. Environmental Protection Agency's (USEPA's) Spreadsheets for Environmental Footprint Analysis (SEFA, USEPA 2026). Preliminary SEFA assessments indicate that Alternative 2 can significantly reduce remedy-related emissions compared to Alternative 1. The primary drivers of these reductions are the diminished need to haul waste materials off site and onsite BU of swell, which reduces reliance on imported fill material. The comparison shows that ISS grout amendments play a key role in potential emissions reduction. Use of supplementary cementitious materials such as fly ash or blast slag furnace can minimize net emissions, whereas higher Portland cement dosages are associated with a substantially greater carbon footprint.

The unitized emissions comparison created for this exercise is purposefully generalized to be broadly applicable. To translate this evaluation into real world sediment cleanup sites, site-specific factors must be integrated to replace the simplifications and assumptions used in the hypothetical model. Alternatives 1 and 2 respond differently to key site-specific constraints, and a qualitative comparison of some example considerations that may come into play follows.

For Alternative 1, the feasibility and cost of the remedy are strongly influenced by whether dredged sediments must be managed as Subtitle C hazardous waste or can be disposed under Subtitle D non-hazardous criteria; this regulatory distinction drives disposal facility availability, transport logistics, and overall project cost. In contrast, Alternative 2 alleviates disposal challenges but may need to address elevated contaminant concentrations or specific hazardous constituents through additional chemical sequestration (e.g., via application of reactive amendments), which can increase design and implementation complexity and costs (both energy-related and financial). The presence of hazardous material may also limit the range of BU options unless sufficient risk-reduction can be demonstrated for the intended end use or end state.

Subsurface debris also represents critical design and constructability constraints for both alternatives. For Alternative 1, debris primarily influences dredging productivity and equipment selection, with debris typically removed and managed as part of the off-site waste stream. In Alternative 2, the same subsurface debris not only affects construction means and methods and production rates but can also directly influence the quality and uniformity of the treated material, which is critical to achieve risk-reduction targets.

Because Alternative 2 entails leaving treated material in place or onsite, specific consideration must be given to site-specific physical and chemical conditions of the site as they directly govern the required level of solidification or stabilization to achieve acceptable risk. For example, sediments with highly mobile contaminants may necessitate more robust in situ treatment or more restrictive BU applications to ensure long-term containment and protect exposure pathways. Additionally, the suitability of treated sediment for BU should be evaluated within established BU frameworks, such as the USEPA's methodology for assessing beneficial uses of industrial non-hazardous secondary materials (USEPA, 2016) together with any applicable state, regional, or local regulatory requirements to assess risk-based acceptability for specific applications (Goetz et al, 2023).

Looking forward, many factors will shape how broadly and effectively greener remedial technologies are applied at contaminated sediment sites. Scale is a key consideration; global or regional savings may not always translate into measurable local emission benefits at a given site. To support more holistic decision-making, the presentation will complement quantitative emissions evaluations with sustainability

measures checklists developed for project managers. In parallel, evolving regulatory drivers are creating additional incentives and guidance for BU. Notably, the U.S. Army Corps of Engineers (USACE) has set a goal of increasing beneficial use of dredged material to 70% by 2030 (USACE, 2023), signaling a strong policy push toward full life-cycle considerations that centralize low-waste sediment management and reinforce the need to align greener remedial technologies with BU-oriented project planning.

In practice, integrated green and gray design and technologies can help transition contaminated-sediment practice from an offsite disposal-oriented paradigm toward one that treats sediments as a managed resource, delivering long-term economic, environmental, and social value.

Keywords: Sustainability, alternatives comparison, green remediation, lifecycle assessment, emissions.

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FROM DREDGED SEDIMENT TO CONSTRUCTION MATERIAL: A PROVEN MASS STABILIZATION APPROACH

Chris Neilson[1]

EXTENDED ABSTRACT

The United States dredges more than 200 million cubic yards of material annually from federally constructed and maintained navigation channels. According to the U.S. Army Corps of Engineers, only approximately 10 to 15 percent of this material requires special handling, while the remaining material is potentially available for beneficial use. However, only approximately 30 to 35 percent of available dredged material is currently used beneficially (USACE 2026). With the Corps' stated goal of increasing beneficial use of dredged material to at least 70 percent by 2030, and with WRDA 2024 establishing maximization of beneficial use as a national objective, dredging projects increasingly require practical methods to convert soft, wet, or marginal material into usable construction resources (USACE 2023; WRDA 2024).

This abstract presents ex-situ mass stabilization as a treatment method for converting soft dredged sediment into engineered fill. The objective is to summarize the method, describe key equipment and quality-control considerations, and present results from a completed harbor redevelopment project in Helsinki, Finland, where approximately 123,000 m³ of dredged sediment was stabilized and reused in civil construction applications.

Ex-situ mass stabilization uses mechanical mixing to blend dredged sediments with dry binders such as cement, lime, fly ash, flue-gas desulfurization gypsum, or other approved by-product binders. The binder reacts with pore water and soil particles to improve shear strength, reduce permeability, and produce a more stable material suitable for controlled reuse. For high-moisture sediment, this process can be performed in lined basins to contain the material, control leaching risk, and allow the treated mass to cure before excavation, placement, or direct incorporation into earthwork structures.

The case example is the Jätkäsaari harbor redevelopment project in Helsinki. After port operations moved to another location, former harbor basins were dredged to support redevelopment of the area into a new urban district. The dredged material consisted primarily of soft marine clay and mud, with water contents reported across phases from approximately 26 to 159 percent and pre-stabilization undrained shear strength generally below 10 kPa. The material was also mildly contaminated, with trace metals and organic compounds above lower guideline values, which limited open-water disposal options and made beneficial reuse through treatment attractive.

The work was performed in three main phases between 2010 and 2014. Dredged sediment was placed into lined stabilization basins constructed with rock embankments and an asphalt bottom. An excavator-mounted power-mixing head was used to mix sediment in approximately 5 m by 5 m cells to depths of about 2.5 to 3 m. Dry binder was pneumatically conveyed from a pressure feeder to the mixing head and

[1] Director, Project Sales, ALLU USA, 7134 Cockrill Bend Blvd, Nashville, TN 37209, USA, T: 1 702-672-7003, Email: chrisn@allu.net

blended into the sediment at controlled dosages. Production rates reported for the project were approximately 80 to 100 m³ per hour under site conditions.

Binder design evolved during the program. Phase I used cement at approximately 60 kg/m³ and achieved typical in-situ shear strengths of about 20 to 80 kPa, with average values in the 40 to 60 kPa range. Phase II treated a larger volume using cement dosages of approximately 40 to 80 kg/m³ and cement-fly ash combinations, including mixes such as 40 kg/m³ cement with 150 to 250 kg/m³ fly ash. Phase III used additional combined binders, including cement or lime-cement with fly ash, flue-gas desulfurization gypsum, and oil-shale ash. These binder combinations produced laboratory and field strengths reported up to approximately 250 kPa, while reducing reliance on cement compared with cement-only treatment.

Quality assurance and quality control were central to the project. Field verification included column penetrometer and vane soundings, test pits, laboratory specimens tested at multiple curing ages, settlement monitoring, and lysimeter monitoring. The stabilized material met or exceeded the project's target shear strength range of approximately 40 to 60 kPa across phases. Environmental testing also indicated that leaching remained within permit limits. Reported permeability values for selected combined-binder mixes were approximately 1×10^{-9} to 8×10^{-9} m/s, below the stated permit ceiling of 1×10^{-8} m/s. These results demonstrate that stabilization can provide not only strength improvement but also low-permeability behavior relevant to containment and reuse applications.

The treated material was reused in multiple civil works applications, including neighborhood landscaping, park construction, flood barrier construction, and noise barrier construction. Overall, approximately 123,000 m³ of dredged sediment was converted from a disposal liability into a construction material. The reuse reduced the need for imported aggregate, reduced landfill demand, and reduced haul distances associated with off-site disposal.

The Jätkäsaari case illustrates several transferable lessons for North American dredging and beneficial-use projects. First, treatment areas should be located as close as practical to the dredging and reuse sites to reduce handling and transport. Second, binder selection should be based on laboratory treatability testing, with consideration of locally available by-product binders where approved by regulators. Third, precise binder dosing and documented mixing parameters are important for both engineering performance and regulatory acceptance. Fourth, early coordination among owners, engineers, contractors, and regulators is necessary when stabilized sediment will be reused as an engineered material rather than managed as waste.

As beneficial-use targets increase, many dredging projects will encounter sediments that are too wet, too soft, or too variable for direct placement. Ex-situ mass stabilization provides a practical approach for converting those materials into engineered fill when supported by treatability testing, controlled binder dosing, mechanical mixing, and documented QA/QC. The Jätkäsaari project demonstrates that soft dredged sediment can be stabilized at project scale and reused in construction applications while meeting strength, permeability, and environmental performance requirements.

Keywords: mass stabilization, engineered fill, sediment treatment, soft soil, binder dosing, ex-situ mixing, harbor redevelopment, material reuse, QA/QC

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DELIVERING ON EXPEDITED SEDIMENT REMEDIATION WITHIN AN ACTIVE NAVIGATION CHANNEL: LOWER MAUMME RIVER DESIGN

J. Beaver[1], C. Kiehl-Simpson[2], S. Goetz[3], L. Rief[4], C. Pacelli[5], and C. Maass[6]

ABSTRACT

EA Engineering, Science, and Technology, Inc., PBC is supporting the Toledo-Lucas County Port Authority (TLCPA) in completing pre-design investigations, permitting, and remedial design (RD) for two contaminated sites within the Maumee River Area of Concern (AOC) in Toledo, Ohio. This work, conducted on an expedited schedule under the Great Lakes Restoration Initiative, is being implemented in coordination with U.S. EPA Region 5's Great Lakes National Program Office, Ohio EPA, the U.S. Army Corps of Engineers, and the City of Toledo Department of Public Utilities. The project's RD achieves TLCPA's objective of providing remediation while avoiding impacts on terminal operators' use of docking areas and the navigation channel. Approaches were developed to address beneficial use impairments, including degraded benthos and fish populations, dredging restrictions, eutrophication, and habitat loss.

The project area is located along the lower 23 miles of the Maumee River, a section that overlaps the federally maintained navigation channel linking the river to the Western Lake Erie Basin. This region supports commercial shipping of iron ore, coal, and grain while providing important habitat and recreational value. Ohio EPA established sediment remedial goals for polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) thereby addressing co-occurrence of other contaminants detected in the project area. Two locations are included in the RD: the Sway Bridge area along the east bank of the river and the City of Toledo wastewater treatment plant (WWTP) area along the west bank. These areas are influenced by historical and current land uses, including chemical manufacturing, landfilling, and petroleum operations.

RD components include pre-design investigation; dredge prism development; dredged material transport and disposal evaluations; hydraulic and sediment transport modeling; feasibility of dredging in proximity to structures; dredging of approximately 294,000 cubic yards (CY) of contaminated sediment and debris; hydraulic offloading and disposal in the TLCPA confined disposal facility (CDF); post-dredge surveys and

[1] Dredging Engineer, EA Engineering, Science, and Technology, Inc., PBC, 225 Schilling Circle, Suite 400 Hunt Valley, Maryland 20131, USA, T: 410-584-7000, Email: jbeaver@eaest.com.
[2] Project Manager/Senior Engineer, EA Engineering, Science, and Technology, Inc., PBC, 10321 East Grand River Avenue, Brighton, Michigan, 48116, USA, T: 810-206-3048, Email: ckiehlsimpson@eaest.com.
[3] Senior Geologist, EA Engineering, Science, and Technology, Inc., PBC, 10321 East Grand River Avenue, Brighton, Michigan, 48116, USA, T: 810-522-6758, Email: sgoetz@eaest.com.
[4] Senior Engineer, EA Engineering, Science, and Technology, Inc., PBC, 221 Sun Valley Blvd, Suite D, Lincoln, Nebraska 68528, USA, T: 402-817-7624, Email: lrief@eaest.com
[5] Senior Scientist, EA Engineering, Science, and Technology, Inc., PBC, 225 Schilling Circle, Suite 400 Hunt Valley, Maryland 20131, USA, T: 410-527-2413, Email: cpacelli@eaest.com
[6] Staff Engineer, EA Engineering, Science, and Technology, Inc., PBC, 221 Sun Valley Blvd, Suite D, Lincoln, Nebraska 68528, USA, T: 402-817-7665, Email: cmaass@eaest.com

dredge verification sampling; and residuals management by re-dredging or use of amended subaqueous covers. The design approach includes relatively high production rate mechanical dredging with barge transport to the CDF, and modifications at the CDF to improve offloading efficiency while providing debris management within secondary containment. A comprehensive dredge verification and residuals management framework includes re-dredging and amended covers. At the Sway Bridge site, PAH-impacted sediment removal includes backfilling in a challenging area with installation of a permanent sheet pile wall to provide slope stability. Early regulatory coordination for permits and specialized evaluations for historically significant shipwrecks supported development of acceptable mitigation measures. These and other project elements will be detailed in the paper.

Keywords: Environmental dredging, carbon-amended covers, hydraulic offloading with carrier water recirculation, slurry transport, dredged material disposal, Confined Disposal Facility, CDF, contaminated sediment remediation.

INTRODUCTION

The Lower Maumee River (LMR) Sediment Remediation Project is located in Toledo, Ohio, along the Maumee River, a 130-mile waterway that starts near Fort Wayne, Indiana. Portions of the river are designated within the Maumee Area of Concern (AOC) where historical industrial activities have resulted in sediment contamination contributing to multiple Beneficial Use Impairments (BUIs), including impacts to benthos, fish populations, habitat and restrictions on dredging activities {this BUI was removed in 2024} (USACE – Buffalo District 2023). To support removal of these impairments, remedial alternatives were evaluated in the LMR as a part of a Focused Feasibility Study (FFS). Ohio EPA proposed the sediment remedial goals (RGs) for two primary groups of contaminants of concern (COCs) – PAHs and PCBs. The RGs are consistent with probable effect concentrations (PECs) for protection of benthic macroinvertebrates (MacDonald et al 2000). The PEC is a concentration above which adverse effects to the benthic community are likely to be observed. Contaminant levels in the WWTP and Sway Bridge areas exceeded over ten times the PEC. The original remedial design included both areas in the LMR Project area, the Sway Bridge Area and WWTP Area, based on an estimated combined sediment removal volume. Due to funding considerations, the design was divided into separate projects. This paper focuses on the Sway Bridge area, which advanced as a standalone design and is targeting a bidding period in late 2026.

The project is funded through a Great Lakes Restoration Initiative (GLRI) grant, with the Toledo-Lucas County Port Authority (TLCPA) serving as the grantee and project manager. Design development was performed in coordination with EPA Region 5 Great Lakes National Program Office, Ohio EPA, and the City of Toledo. Unlike many contaminated sediment remediation projects that rely on iterative investigation and phased construction, the Lower Maumee River Sway Bridge Project was structured to compress pre-design investigations, design, and permitting into a single year. This delivery approach required early alignment on remedial objectives, proactive regulatory coordination, and the intentional use of navigation-scale dredging practices applied to an environmental remediation project to maintain schedule efficiency. By providing specifications allowing larger-sized equipment for removal operations and relatively high production rate hydraulic offloading of barges at the CDF, this design reduces work duration and therefore reduces impacts to TLCPA's tenants given dredging within active berths and remediation contractor use of the federal navigation channel.

The goals of the project are remediation of sediments impacted with PAHs and PCBs to eventually contribute to removal of several of the AOC's BUIs and subsequent delisting of the AOC. The remedy includes targeted mechanical dredging of 129,000 CY of contaminated sediment and debris, hydraulic

offloading and disposal of sediment and debris in an existing upland Confined Disposal Facility (CDF), and placement of engineered subaqueous covers where contaminants remain after dredging.

OVERVIEW OF PRE-DESIGN INVESTIGATIONS

A PDI was conducted in Fall 2024 by EA to obtain data in support of the Sway Bridge and WWTP Area RD. Activities were planned to refine the extent of contamination and obtain information critical to the RD. PDI activities were scoped to collect data required for dredge prism development and stability analyses, while avoiding redundancy with historical data. PDI activities are summarized in the sections below.

Surveys

Geophysical surveys were conducted to characterize bathymetry, shoreline conditions, utilities, and existing structures using a combination of multibeam sonar, LiDAR, side-scan sonar, and sub-bottom profiling. These data supported dredge prism development, stability analyses, and identification of no-dredge offsets. A baseline assessment of existing structures was performed to support structural engineering capacity analysis and geotechnical global slope stability analyses. A geophysical investigation of steel sheet pile walls employed ultra sonic measurements for approximating embedment depth. A habitat survey was performed of the various habitat zones across the project site to identify regulated areas such as wetlands.

Sediment Quality Investigation and Geotechnical Investigation

EA selected 23 locations for sediment chemistry sampling in the Sway Bridge area and 20 locations in the WWTP area of the LMR to refine lateral and vertical extents of contamination. Some locations were also chosen to fill data gaps based on previous investigations. This chemistry data was used for identifying and developing dredge prisms. Additionally, elutriate toxicity was evaluated to investigate potential water column impacts of sediment disturbance to freshwater invertebrates. Toxicity Identification Evaluation was performed to identify which COCs caused toxicity.

Limited historical data on shoreline structures in the project area and geotechnical data on existing subsurface conditions necessitated field investigations to support the geotechnical and structural analyses. Field investigation activities included rotary borings, Cone Penetration Test (CPT) soundings, and geotechnical lab testing of samples for both upland soils adjacent to the river and sediments deposits within the river. Combined with the geophysical results for wall embedment, this data was used for slope global stability analysis and structural integrity assessment of bulkheads during and after dredging. Approaches to reduce project risks in proximity to utilities and bulkheads evaluated during design include physical offsets from structures for avoiding dredging, temporary shoring with backfilling, and permanent sheet pile walls with and without backfilling.

DESIGN DEVELOPMENT PROCESS

Dredging

The subsections below describe the development of the dredge prism, sediment removal volumes, and anticipated dredging productivity for the Sway Bridge area. These sections summarize the methodology used to define sediment removal limits based on site-specific contamination, stratigraphy, and constructability considerations; outline assumptions related to overdredging and residual dredging; and present production rate estimates and schedule implications. This information provides the basis for evaluating sediment removal quantities, production rates, equipment selection for cost estimating, and overall feasibility of the proposed dredging approach for the RD.

Dredge Prism Definition

Sediment removal within the LMR will be accomplished with mechanical dredging equipment, including a barge mounted crane and excavator equipped with environmental buckets. The development of dredge prisms and extent of removal within the Sway Bridge area was based on area-specific methods. These methods included assessment of the vertical extent of contamination, thickness of overburden, stability considerations, utility crossings, area specific requirements and overall site RGs. Data from studies conducted in 2013, 2021, and 2024 was compiled and analyzed to select sediment removal target depths and identify overburden thickness meeting RGs at each sediment boring location.

Sediment cores lithology were reviewed with analytical results within the Sway Bridge area to assign a target removal elevation for dredge prism development. Based on the data, the following scenarios were applied, listed in order of prioritization for dredging design.

Borings Data Results Scenario	Target Removal Elevation Decision
≥ 4 feet of clean overburden meeting RGs present	No dredge target removal limit was selected, determined to be a depositional area, unlikely to re-expose contamination
RG exceedance is at lowest sampled elevation in boring (i.e., analytical results of discrete sample intervals demonstrate the underlying sample meets RGs)	Apply 2-foot dredge buffer below the bottom elevation of the boring
Elevated PCBs (~0.5 ppm) and/or PAHs (~15 ppm) below RG exceedances	Target removal set at bottom of elevated PCB and/or PAH levels
Lithological indications (i.e. – odor, sheen, NAPL) of contamination are present	Apply a 0.5-foot dredge buffer below the lowest exceedance elevation
No contamination indicators below RG exceedances	Target removal limit set at the bottom of the RG exceedance, no buffer applied

Dredge target removal limits at each boring within the Sway Bridge area were combined to form a three-dimensional surface using AutoCAD Civil 3D. The horizontal extent of dredging was constrained by the shoreline and federal navigation channel, requiring that designated dredging zones did not extend beyond these boundaries. The vertical extent of sediment removal was determined by the removal elevation assignment decision-making described above. However, the sediment removal area near the Toledo CSX Transportation bridge (TCSX-TB) was limited to a depth of 2 feet, even though deeper contamination is present. This was decided to streamline coordination with CSX, thereby reducing risks for implementation. The TCSX-TB is shown in Figure 1 below. This restriction was incorporated into the design to minimize impacts to the bridge while still addressing surface contamination. Contamination extending below two feet from the sediment surface will be managed through subaqueous backfill.

Utility and structure offsets were included in the dredge prism design to protect existing infrastructure. Each offset is an area where dredging activities are prohibited, and they include 3:1 slopes daylighting into the dredge prism.

Overdredge is defined as the acceptable limit of additional sediment removal due to limitations of the equipment used and positioning instrumentation and the precision of the removal verification methods. For this design, a maximum overdredge of 1 foot is included. This is a critical design criteria change from typical environmental dredging projects that was provided to facilitate higher productivity dredging nearer to the limits of dredging. It has been assumed 1 foot of overdredge will occur across 75% of the dredging

Figure 1. Toledo CSX Transportation Bridge.

footprint for quantity estimation. The overdredge allowance reflects the use of larger environmental buckets more typically used for maintenance dredging and the project's emphasis on constructability and construction schedule while maintaining a high degree of environmental protectiveness. Allowing greater overdredge allowance is consistent with navigation dredging practices and reduces the risk of repeated re-dredging events when verification sampling and testing is performed.

Residual dredging is defined as additional dredging required to achieve the RGs based on analysis of samples from post-dredge verification cores. This involves additional dredging beyond the developed dredge prisms based on sampling after primary dredging. For design and volume estimates, this is assumed to amount to 1.5-foot of additional dredging across 25% of all dredging areas, which is generally consistent with available information for environmental dredging projects. Table 1 summarizes the total volumes of the dredge prism, overdredging, residual dredging, and subsequent total volumes.

Table 1. Sediment Removal and Debris Volume Estimates.

Dredging Item	Sway Bridge Volume (CY)	Notes
Primary Dredging Neatline Volume	101,000	Volume of dredge prism, from existing bathymetry to target removal surface; includes debris volume
Overdredge Volume	+15,000	1 foot of overdredge across 75% of footprint; includes debris volume
Subtotal Volume	**116,000**	**Dredge Prism + Overdredge Includes debris volume**
Residual Dredging Volume	+8,000	1.5 foot of residual dredge across 25% of footprint, includes overdredge and debris volume
Subtotal Volume	**124,000**	**Dredge Prism + Overdredge + Residual Dredge Includes debris volume**
CDF Approach Dredging Volume	+9,000	Dredge to increase draft depth from navigation channel to CDF offloading area to facilitate larger barges
Total Volume	**133,000**	**Dredge Prism + Overdredge + Residual Dredge + CDF Approach Includes debris volume**

Dredging Item	Sway Bridge Volume (CY)	Notes
Debris Volume for Landfill Disposal	-4,000	Assumed 50% of debris requires landfill disposal
Total CDF Disposal Volume	**129,000**	**Total sediment and debris volume to be disposed into the CDF (Assumed 50% of debris will be disposed in the CDF)**

Production Rate

To estimate dredging production rates, assumptions were made for the anticipated equipment and common means and methods the contractor may use to complete the work. It was assumed the bucket size used for dredging would be 6 CY, the work time efficiency would be 75%, and the work time per day would be 12 hours. This is a much larger bucket size than typically used for environmental dredging; however, combined with the 1-foot overdredge, and turbidity controls to maintain compliance with the water quality permit, the design team anticipates a production rate that is higher than average.

Several methods were used to evaluate the range of possible dredge production rates. Methods used included the FFS assumed rate, a table from the EPA Contaminated Sediment Remediation Guidance for Hazardous Waste Sites handbook (EPA 2005), U.S. Army Corps of Engineers (USACE) Technical Guidelines for Environmental Dredging (Palermo et. al. 2008), other dredging projects research, and a project-specific production rate estimate. Ultimately, a dredge production rate of 1,300 CY/day was selected to represent the higher-than-average rate considered feasible for primary dredging operations across the Site. The selected production rate of 1,300 CY/day reflects a balance between environmental dredging constraints near structures and navigation-scale production rates achievable in open areas. These rates are higher than those typically assumed for environmentally focused dredging projects and were intentionally selected to support the project's goal for an environmentally protective, expedited schedule.

The daily dredge production rate was used to determine the time required to remove all sediment designated for dredging. It was assumed 2 dredge crews would work concurrently, for 24 workdays per month, and that each dredge season lasted 7 months. Based on these assumptions, all sediment can be dredged in a 2-month period assuming a continuous operation. However, additional steps are required for the dredging process (i.e. – sheet pile installation, dredge verification, residuals management, backfilling, etc.), and these steps will add to the construction schedule. Therefore, a year of work is assumed to be required to complete all site work activities.

Shipwrecks and Debris

Significant debris is expected to be encountered during site dredging activities, primarily associated with historical shipwrecks. Debris embedded in sediment designated for dredging will be removed. Various types and sizes of debris are expected to be encountered, in addition to the shipwrecks, such as broken concrete, wood, rock, metal objects and coiled wire/cables, and miscellaneous trash. It has been estimated that debris occupies 6% of the volume within the defined dredge prisms based on project experience adjusted for site-specific considerations.

Six shipwrecks intersecting dredge prisms will be removed as debris using conventional mechanical methods including orange peel grapple and conventional dredge bucket, pending the State Historical Preservation Office (SHPO) concurrence. The shipwrecks are partially buried in contaminated sediment and remnants of hulls are visible above the river bottom as identified in the PDI. The removal will require a hydraulic grapple capable of high-pressure closure for extracting pieces of each shipwreck from the

riverbed. If there is significant sediment deposited on top of a shipwreck, the RA Contractor may be required to remove sediment with mechanically and/or hydraulically to gain access to the shipwreck. EPA and SHPO are in the process of identifying appropriate mitigation actions for historically significant shipwrecks within a Memorandum of Agreement.

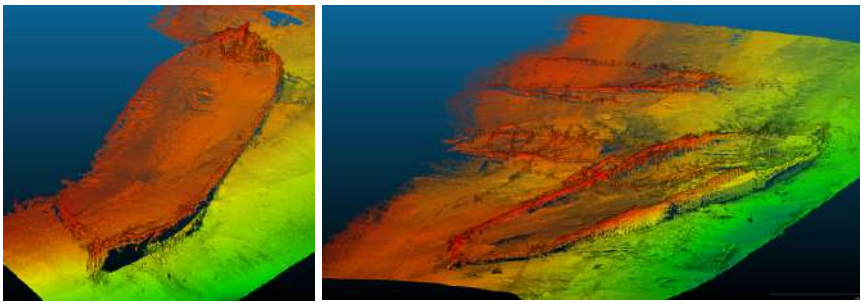

Figure 2. Sonar Survey Images of Shipwrecks.

Debris which is small enough for removal with the dredging buckets utilized in the dredging area will be removed along with the sediment and placed in the scow barge. Large debris which is too large for the dredging bucket being used will be removed by a dedicated debris removal crew with a larger conventional bucket or grapple, i.e., the expectation is that the same grapple used for the removal of shipwrecks would be used for large debris encountered during dredging.

Transport, Offloading, and CDF Disposal

A mass balance and capacity evaluation was conducted to estimate dredged material volumes, define offloading requirements, and confirm the adequacy of the TLCPA CDF to support the Sway Bridge remediation. Using geotechnical data from prior investigations, estimated sediment bulking, solids content from testing, and hydraulic offloading parameters, the analysis quantified in situ, dredged, transported, and offloaded sediment and water volumes and weights. The evaluation confirmed that the CDF has sufficient capacity to accommodate the projected sediment and debris volumes while maintaining required freeboard, provided that water recirculation is implemented to manage excess slurry water generated during hydraulic offloading. Offloading operations, debris handling, and water management strategies have been developed to support continuous dredging operations, protect CDF dikes stability, and ensure compliance with water quality and operational constraints.

Mass Balance

A mass balance calculation was performed to estimate the total volume of slurry (sediment and water mixture) for transportation and disposal in the CDF. The estimate predicts the mass and volume throughout the entire dredging process, including in situ, dredged, and offloaded volumes.

The mechanically dredged volume was estimated using an assumed volume bulking factor based on experience in previous sediment dredging projects. The volume bulking factor is a ratio comparing the in-situ volume of sediment to the dredged sediment volume. A volume bulking factor of 1.4 was selected for the sediment dredged in the project area; this means that the sediment undergoes a 40% increase in total volume as it is dredged from in situ conditions and placed in the scow barge. This is largely due to the incorporation of water and density change of materials as they are dredged. Based on the analysis, the total volume requiring transport in the scow barge is 165,000 CY.

The offloading volume was estimated to determine both the total volume to be disposed in the CDF, and whether the recirculation of water reduces water level elevation in the CDF cell to avoid or limit using the weir to discharge water. The primary assumption associated with this estimate is the high solids pump used for hydraulic offloading is capable of handling 30% solids by mass. This assumption determined the amount of water which must be added to the dredged sediment within the scow barge, as well as the total slurry offload volume of 419,000 CY.

Offloading Area

All material removed within the dredge prisms will be transported via barge to the southwest corner of the CDF, where it will be offloaded either hydraulically (sediment) or mechanically (debris). All sediment dredged from the Lower Maumee River is designed to be hydraulically offloaded into the TLCPA CDF Cell (Cell). Hydraulic offloading requires the use of a long-reach excavator or crane equipped with a high solids pump and a temporary pipeline to transport the sediment and water slurry into the Cell. High solids pumps are designed to pump slurries with increased concentrations of solid material when compared to a typical hydraulic dredge slurry. The offloading system was designed to maintain continuous dredging operations by minimizing barge turnaround times and accommodating large daily sediment volumes, consistent with navigation dredging logistics rather than intermittent environmental dredging campaigns.

Two offloading crews have been assumed to be operating simultaneously to remove sediment from the scow barges. Both crews will work throughout the night to offload the scow barges, until they are empty and prepared for dredging activities on the following day.

Debris larger than 2 feet (or larger than the offloading pump intake) will be mechanically offloaded with an excavator and stockpiled at the selected Debris Management Area of the TLCPA CDF. All debris disposed of onsite shall be placed in the shallow west end of the Cell. Tires and other debris unsuitable for disposal within the CDF will be washed to remove grossly adhered sediment to provide weight reduction, and stockpiled separately for disposal at a Resource Conservation and Recovery Act Subtitle D landfill.

CDF Capacity

The capacity of the Cell was evaluated to confirm adequate storage of sediment dredged from the Sway Bridge area while maintaining 2 feet of freeboard. The Cell capacity analysis used surface data from a 2024 as built site model within AutoCAD Civil 3D to develop an incremental storage volume table at selected elevations. This evaluation occurred at 1-foot intervals from an elevation of 582 feet (lowest elevation within the Cell) to an elevation of 604 feet (elevation of surrounding perimeter berm). The maximum fill capacity was determined at an elevation of 602 feet (2 feet of required freeboard), which is 458,000 CY of material.

The estimated volume of solid material generated by the Sway Bridge remediation and disposed of in the Cell is 129,000 CY, which includes sediment, 50% of estimated debris (4,000 CY) being disposed in the Cell versus offsite landfill, and CDF access dredging (9,000 CY). In addition, up to 78,000 CY of dredged material may be placed in the Cell by others prior to construction. Including these volumes, the total estimated Cell filling is approximately 207,000 CY, resulting in a final fill elevation of about 595.6 feet. Figure 2 demonstrates the fill elevations associated with the various volumes described above.

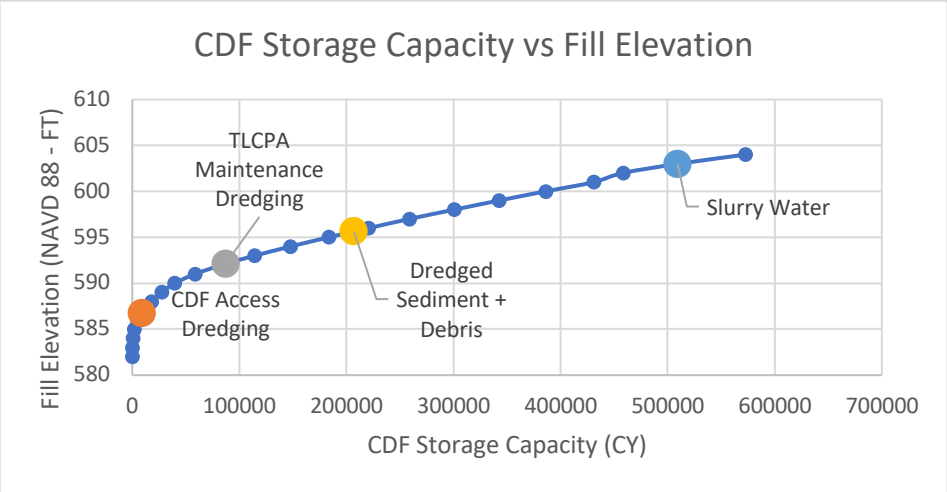

Figure 3. CDF Cell Storage Capacity and Fill Elevation Relationship.

The total volume of offloaded sediment and water (including access dredging and material placement by others) is greater than the Cell capacity by approximately 51,000 CY. Therefore, the capacity analysis was a factor for deciding the requirement for recirculation water from the Cell into the scow barge. Typically, water is decanted through outlet structures installed with a weir to regulate water level within the CDF. However, water produced by hydraulic offloading would remain turbid for extended periods due to the significant fine-grained fraction of the sediment and sediment is anticipated to contain elevated concentrations of COCs. These elevated concentrations of COCs would require water treatment prior to discharge to comply with water quality requirements for effluent discharges unless sufficient time is available for settling of solids. Therefore, it was determined that recirculation of water will be necessary to maintain 2 feet of freeboard, and to comply with the design's requirement for a maximum allowable average ponded depth. The ponded water elevation will be monitored using staff gauges. Water recirculation will also assist with minimizing ponded water depth in the Cell, thereby reducing risk of damaging waves that could erode the Cell banks during storms. Water retained in the Cell will either infiltrate or evaporate.

Under extreme circumstances that may compromise the stability of the perimeter berm, such as a severe storm, the Contractor may be directed by the Owner to rapidly lower the water level within the Cell by discharging water through the outlet structure weir to the LMR. The TLCPA CDF cell layout in proximity to the Lower Maumee River is demonstrated in Figure 3. Note this figure was taken by Ramboll Engineering and was provided to EA by Ohio EPA (Blair 2025) within interior dikes used for the project.

Dredge Verification

A post-dredge verification sampling and analysis effort will be performed to confirm the final dredge surface has reached the design target removal limits and sediment exceeding the site-specific RGs has been appropriately addressed. To support verification that sediment removal met target elevations and to enable efficient testing for residual contamination, the dredge prism was divided into dredge management units (DMUs). DMUs were generally developed from upstream to downstream in each sediment removal area. The bathymetric survey of dredged areas will be compared to the design dredge prism to determine where the target removal limits were reached.

Figure 4. TLCPA CDF Cell in use.

Verification sampling will be performed in each DMU to determine if additional dredging and/or a residuals cover is necessary. DMU verification sample locations will be collocated with previous boring locations for comparison with past sampling results where available. A default re-dredging decision occurs if NAPL is present in the sediment core near the dredged elevation or PCBs and/or PAHs exceed the specified RGs.

The second round of sampling only occurs after re-dredging to remove NAPL or sediment exceeding the RGs. If the second round of sampling results exhibit contaminant concentrations above the RGs, a dredge residuals cover will be applied to the DMU. Within the NAPL area that is determined by the Owner based on the Contractor's additional core locations, a minimum 3-inch layer of bulk organoclay will be applied.

Stability and Integrity of Structures

Several existing structures located adjacent to the Sway Bridge dredging footprint require protection during sediment removal, including multiple sheet pile and concrete walls, bridge piers, utilities, and waterfront infrastructure. The remedial design incorporated a combination of dredge offsets, permanent protection systems, targeted subaqueous backfill, and deflection monitoring to manage structural risk.

Structural protection measures includes high-precision monitoring of walls and bridge piers using optical survey targets to detect potential movement during dredging, with conservative movement thresholds to allow early response if excessive movement occurs. No-dredge offsets were incorporated in the design adjacent to utilities, bridges, walls, and revetments based on geotechnical analyses to maintain stability. Where offsets alone were insufficient where deeper dredging was required, the design included installation of permanent sheet pile to achieve minimum global slope stability safety factors. In select areas, subaqueous aggregate backfill will be placed following dredging to restore stable slopes and mitigate potential impacts to adjacent structures. Together, these measures allow sediment removal to proceed while protecting critical infrastructure in a constrained, industrial river corridor.

Subaqueous Residual Covers

Cover design was evaluated for vessel-induced propeller scour and river hydraulics to ensure long-term stability and protectiveness. These analyses supported selection of a coarse aggregate cover, with activated carbon amendments used where verification identifies residual contamination.

Propeller Scour

The LMR experiences frequent vessel activity in and around the project area, including the docking of ships under their own power and/or tug-assisted. Berthing ships crossing subaqueous cover areas are of concern due to their potential to induce scour in sediment given an overall objective for covers to remain in place without providing a scour protection layer, which is incompatible with current and future uses of the site. Scour from ship and/or tug propellers, if not adequately designed for, can disrupt subaqueous cover materials and the final dredge surface, potentially exposing contaminated sediment.

Two docks (Seneca Petroleum/Toledo Shipyard and Cenovus) are directly adjacent to areas where cover placement will occur. These two docks were included in the analysis due to the potential for ship activity to scour the final subaqueous cover surface adjacent to the berthing area. Figure 5 demonstrates the typical size of berthing ships seen in these docks in the LMR, this figure was also taken by Ramboll Engineering and was provided to EA by Ohio EPA (Blair 2025).

Figure 5. Berthing Ships at Docks near Otter Creek Confluence.

The analysis used methods set forth in the document "Guidance for In-Situ Subaqueous Capping of Contaminated Sediments" (Maynord 1998). The methods estimate the velocity of water discharged from each vessel/tug propeller, the resulting velocity distribution throughout the water column, and the stable particle size under the calculated velocity conditions.

The calculated velocity distribution was used to determine the maximum water velocity at the final subaqueous cover surface elevation. The maximum velocity at the subaqueous cover surface was then used to determine the depth of scour resulting from 3 minutes of continuous ship operation, assuming the ship remains stationary. The depth of scour estimate uses empirical equations outlined in the document "Propeller-Wash Induced Erosion and Method for its Prediction" (Hamill 2007). The methods outlined in the documents produced by Maynord and Hamill were applied to two potential subaqueous cover gradations to evaluate scour depth over time. The results of the analysis are provided in Table 2.

Table 2. Propeller Scour Analysis Results.

Dock	Max Bottom Velocity (feet/second)	Scour After 3 minutes in Fine Aggregate (D50 = 0.024 inches) (inches)	Scour After 3 minutes in Coarse Aggregate (D50 = 0.24 inches) (inches)
Seneca/Toledo Shipyard	2.26	0.05	0.02
Cenovus	3.46	0.15	0.06

The analysis indicated both cover materials will experience minimal scour depth from ship activity, but the coarse aggregate gradation is better suited for berthing areas.

Hydraulic Modeling

Hydraulic analysis of the LMR Sway Bridge Project area was performed to analyze how river dynamics affect the stability and longevity of the RD, how the RD might affect surrounding infrastructure, and to fulfill Federal Emergency Management Agency (FEMA) regulatory requirements. This involves simulating flow scenarios to predict water surface elevations (WSEs) and potential areas of erosion and deposition through sediment transport modeling. This analysis was completed through the development of a 2-Dimensional existing and proposed conditions hydraulic model using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software (Version 6.6).

The sediment transport model is built upon the hydraulic model developed for existing and proposed conditions. Sediment gradation of the LMR riverbed was estimated by averaging gradations from geotechnical borings from past sampling events. The flow rate vs. sediment load (tons of sediment per day) rating curve was estimated using USGS gage records (04193500 Maumee River at Waterville Ohio). Also, the suspended sediment particle size was estimated using USGS gage records and adjusted via model calibration.

The proposed conditions model identified increased scour potential in residuals cover and subaqueous backfill placement areas when compared to the existing conditions. To assess material stability in these areas, two cover material gradations were evaluated in the model, including a primarily sand gradation with a D50 = 0.024 inches (Ohio Department of Transportation Fine Aggregate 703.03, aka fine aggregate), and a small to medium gravel gradation with a D50 = 0.24 inches (Ohio Department of Transportation asphaltic concrete base course, aka coarse aggregate). Based on these sediment transport modeling results, coarse aggregate was selected for all subaqueous cover and backfill applications due to its resistance to scour under modeled flow conditions. The cover gradation is designed as a well-graded distribution of particles for high internal friction to resist erosion even if localized erosion events occur.

The Sway Bridge area (river upstream of the CSX bridge) is located within a FEMA Special Flood Hazard Area Floodway, and therefore a no-rise analysis has been completed. A steady state 1D existing and proposed model was developed to model for no-rise. The 1D comparison between the existing and proposed models indicated no WSE increase, with localized WSE lowering of up to 0.03 feet at cross sections within the FEMA floodway. No WSE increases will occur because the project results in a net removal of sediment and does not raise the bathymetric surface above existing grades within the project area.

PAC Amendment Selection

Subaqueous cover materials will be amended with activated carbon in areas with residual contamination based on verification sampling results compared to RGs. Previous projects were reviewed to establish a baseline for the percentage of activated carbon by dry weight used in subaqueous covers to provide protectiveness after dredging. The decision for subaqueous covers, and specifically the activated carbon amended covers approach, is based on the preference to increase protectiveness for managing dredge residuals covers when elevated total PCBs and total PAHs remain after one additional re-dredging event to address the contamination. This evaluation considered the target dosage of activated carbon based on site-specific contaminant concentrations, and is summarized in Table 3.

Table 3. Subaqueous Cover Activated Carbon Amendment Dosage.

Concentration Designation	Dredge Verification Results or Known Contamination Levels Based on Previous Investigations		Activated Carbon Dosage by Weight
	PAH	PCB	
Low	RG ≤ PAH ≤ 2x RG	RG < PCB ≤ 1000 ppb	0%
Medium	2x RG < PAH ≤ 5x RG	1000 ppb < PCB ≤ 3x RG	2.5%
High	> 5x RG	> 3x RG	5%

In offset areas where dredging cannot occur, a mitigation cover approach was evaluated to avoid no-action areas if elevated PAHs/PCBs are present. This evaluation included a settlement analysis using geotechnical data from pre-design investigations to estimate consolidation parameters. This analysis predicted more than 1 inch of settlement, which is a common maximum allowable threshold used for settlement sensitive structures. This magnitude of consolidation could cause potential loads on the utilities and induce tension at landfall connections or down-drag forces on the utility. To avoid these risks given severe consequences from a pipeline rupture and other utilities risks, mitigation covers were ruled out within all utility offsets.

PERMITTING ACTIVITIES

Achieving the accelerated project schedule necessitated permitting and regulatory coordination to occur concurrently with design development. Early engagement with U.S. EPA Region 5, the Great Lakes National Program Office, Ohio EPA, USACE, and local stakeholders allowed anticipated permitting requirements to be identified and addressed in advance of final design, reducing the potential for late-stage revisions or delays.

Lower Maumee Regulatory Landscape

The project required coordinated federal, state, and local approvals/consultations, with key drivers related to in-water work, threatened/endangered species, and cultural resources. Note the list below is not an exhaustive list, but rather a list of relevant permits to achieve the accelerated project schedule:

- USACE Section 404/10 and Section 401 Water Quality Certificate (USACE and Ohio EPA)
- Consultation with U.S. Fish and Wildlife Service, Section 7 of the Endangered Species Act.
- Ohio SHPO and Tribal Historic Preservation Office Section 106 Consultation
- Ohio Department of Natural Resources (ODNR) In-Stream Work Waiver
- ODNR Mussel Survey Plan
- Flood Hazard Area Development Permit

Site conditions in the Sway Bridge area are highly industrial with limited natural shoreline and no wetlands. Key constraints were the FEMA floodway area, endangered species present in the area (such as native endangered mussels), and the six shipwrecks intersecting the dredge prism.

Permitting Strategy and Challenges Overcome with an Accelerated Schedule

The development of a permitting strategy for Sway Bridge considered the permitting landscape, regulatory needs and preferences that were determined pre-design, along with consideration of the level of coordination with the agencies that would be needed to carry the project from pre-design through start of construction. The strategy included primary components that allowed for effective progression through design, permitting, and into pre-construction coordination phases on an accelerated schedule, as discussed below.

- *Early initiation and proactive research* – Initiated agency/stakeholder coordination during pre-design to confirm permit leads, submittal expectations, and key data needs early enough to avoid rework.
  - Identified specific permit leads to engage and understand the regulatory framework.
  - Early initiation and proactive research to anticipate outcomes of reviews.
  - Scheduled design analysis milestones for the Project Management Team (PMT) provided technical materials to facilitate discussions with agencies.
  - Used early discussions to anticipate likely agency comments and prepare supporting technical memos/figures in parallel with design.
- *Building a Collaborative PMT* – A collaborative Project Management Team (PMT) as shown on **Error! Reference source not found.** was formed at the start of the project built on the FFS team structure.
  - Identify relevant stakeholders to meet on a biweekly basis and discuss pertinent items to successfully permit the project, developing the Permitting Working Group (PWG).
  - Provide information prior to submittals to allow regulatory agencies to voice any concerns or questions ahead of time during PWG biweekly meetings.

Figure 6. Structure of the Sway Bridge/LMR PMT.

Permitting Challenges

Permitting for the Sway Bridge presented a series of complex challenges, largely driven by the need to complete design and regulatory approvals on an exceptionally accelerated schedule. An early hurdle was securing an in-stream work waiver (so that dredging would not need to occur outside of time-of-year restrictions for fish) from the ODNR, which required clear demonstration that construction activities would avoid or minimize impacts to fish during restricted periods. Concurrent, close coordination with ODNR was necessary to assess and address potential impacts to native mussel populations. This effort involved developing a detailed mussel survey plan, rapidly advancing it through agency review, and ensuring that survey execution would align with both seasonal constraints and the compressed project timeline.

In parallel, cultural resource considerations added another layer of complexity. Phase I and Phase II cultural resource surveys had to be planned, executed, and documented within a tight timeframe, with findings requiring immediate coordination with EPA and the SHPO. The presence of documented shipwrecks within the dredge area necessitated careful consultation to determine appropriate treatment measures. This led to the development of proposed mitigation strategies in collaboration with the EPA, which will ultimately form the basis of a Memorandum of Agreement with SHPO. Balancing these environmental and cultural requirements while maintaining schedule commitments required continuous agency engagement, rapid technical analysis, and tightly coordinated decision-making.

CONSTRUCTION CONSIDERATIONS AND KEY SCHEDULE ASSUMPTIONS

A sample construction schedule was developed to establish the one-year constructability of this project. The sample schedule includes permitting after completion of the 100% Remedial Design and initial surveys/ mobilization. The following assumptions were made when forming the sample construction schedule:

- Dredging, verification sampling, and residual dredging/covering will occur simultaneously during a portion of the dredging season.
- Organoclay cover is an optional bid item that will only be procured if NAPL is detected during confirmation sampling. A shipment of bulk organoclay can be delivered within one week, as confirmed in discussions with suppliers. This short lead time would facilitate a rapid response to activate the optional bid item and cover any exposed NAPL.
- Shipwreck removal will be completed by the RA Contractor's dedicated debris removal crew. Use of a dedicated debris removal crew is assumed to allow shipwreck removal to occur in advance of, and concurrently with dredging to reduce the project schedule.
- Permanent sheet piling will be installed prior to dredging along the riprap revetment in the Sway Bridge area between the Norfolk Southern Railroad bridge and the Ironville Dock.
- The dredging season is 7 months long, from approximately late-March to late-October. This is highly dependent upon ice conditions in the LMR, which vary on a yearly basis.
- It is assumed no fish closure period will be required. This is only accomplished with a waiver. Environmental protections such as turbidity curtains will limit exposure during fish passage. Dredging activities will work around a potential fish closure period by allowing passage throughout all construction. The potential Ohio fish window is 15 March – 30 June.

CONCLUSIONS

The Lower Maumee River Sway Bridge Sediment Remediation Project demonstrates that contaminated sediment remediation within an active federal navigation channel can be successfully delivered on an accelerated timeline when remedial design, permitting, and construction approaches are intentionally aligned with navigation dredging practices; additional that environmental dredging operations can be designed to utilize similar large-size equipment used for maintenance dredging. Key conclusions and lessons learned from this project include:

- *Early alignment on remedial objectives and constructability enables expedited delivery:* Establishing dredging tolerances, and residuals management frameworks early in design allowed investigation, engineering, and permitting activities to proceed in parallel rather than sequentially.
- *Navigation-scale dredging practices can be successfully adapted for contaminated sediment remediation:* Application of mechanical dredging, higher production rates, overdredge allowances, and continuous offloading operations cycling scow barges.

- *Data-driven dredge prism development is necessary in complex riverine environments:* Use of area-specific analysis of lithology and analytical data with added buffers for assigning dredge elevations provides appropriate conservatism in the design for primary dredging.
- *Achievable above-average dredging production rates are expected based on strategic design decisions, efficient proximity and offloading at TLCPA CDF, and use of larger-sized dredging equipment in an environmentally protective manner:* Factors such as use of an increased overdredging allowance, efficiency of transportation and disposal operations, and designing separate operations for shipwrecks removal and dredging and including this in cost estimating, is expected to facilitate an above-average production rate for the project while reduces the risk of excessive re-dredging and construction schedule upsets.
- *Integration of structural protection measures is essential when dredging adjacent to infrastructure:* Incorporating no-dredge offsets, monitoring, permanent sheet pile installation, and selectively backfilling dredged areas allows sediment removal to proceed safely near bridges, utilities, and waterfront structures.
- *Hydraulic offloading with recirculation is expected to allow for high production offloading without continual addition of water volume to the TLCPA cell, thereby controlling water level elevation in the CDF:* High-solids pumping, debris segregation, and water recirculation strategies enabled efficient sediment management while maintaining CDF capacity and freeboard requirements without reliance on off-site disposal or water treatment discharges.
- *Early and proactive regulatory coordination supports aggressive schedules:* Engagement with federal, state, and local agencies throughout design development allowed permitting requirements, cultural resource considerations, and mitigation measures to be addressed without delaying construction readiness.

Overall, the Sway Bridge Project illustrates that expedited contaminated sediment remediation PDI/RD/construction is achievable in highly constrained, industrial waterways when design decisions prioritize constructability, operational efficiency, and regulatory coordination. The approaches applied in this project provide a transferable approach for future Great Lakes remediation efforts occurring within active navigation channels.

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DATA AVAILABILITY

Some or all data, models, or code generated or used during the study are available in a repository or online in accordance with data retention policies of GLNPO. (Provide full citations that include URLs or DOIs required to access the information.)

ACKNOWLEDGEMENTS

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CITATION

Beaver, J., Kiehl-Simpson, C., Goetz, S., Rief, L., Pacelli, C., and Maass, C. “Delivering on Expedited Sediment Remediation Within an Active Navigation Channel: Lower Maumme River Design,” *Proceedings of the Western Dredging Association Dredging Summit & Exposition ‘26, Montreal, Quebec, CA*, July 20-23, 2026.

EMERGENCY RESPONSE DREDGING CASE STUDY: RAPID COASTAL RESILIENCE AT INDIAN RIVER INLET NORTH BEACH, DELAWARE

T.W. Merritts[1], L.E. Folkert[2] and J.L. French[3]

EXTENDED ABSTRACT

The Indian River Inlet in southern Delaware provides a safe navigation channel for commercial, recreational, and U.S. Coast Guard vessel use to connect Indian River Bay to the Atlantic Ocean. Delaware Route 1 connects two barrier islands, acts as a major roadway for daily traffic, and serves as a primary evacuation route for coastal towns during storm events. The berm and dune system to the north of the inlet (North Shore Beach) was breached twice in calendar year 2024, resulting in closures of Delaware Route 1 travel lanes. Following the breach in August 2024, the State of Delaware declared the project an emergency action, necessitating rapid response action. Anchor QEA provided coastal engineering support to Delaware Department of Natural Resources and Environmental Protection (DNREC) to expeditiously improve the integrity of North Shore Beach by restoring the dune system and renourishing the beach with sand borrowed from the Indian River Inlet Flood Shoal.

The objective of the emergency action project was to rapidly restore the protective dune and beach profiles to reduce storm risk to State Route 1 while navigating environmental timing restrictions, regulatory requirements, sediment suitability considerations, interagency coordination, and contractor procurement under an accelerated delivery schedule.

DNREC Division of Watershed Stewardship, Shoreline and Waterway Management Section was the Project Owner. DNREC engaged Anchor QEA to provide project planning and engineering support and contracted directly with Dredgit to perform the dredging and beach repair operations. DNREC personnel participated in all phases of project planning, stakeholder coordination, and implementation monitoring. DNREC's project manager was Joanna L. French, PE.

The Delaware Department of Natural Resources and Environmental Control (DNREC) initiated sand hauling to reestablish minimal protective dune elevations while simultaneously advancing design and permitting for a larger-scale dredging project. Anchor QEA supported expedited borrow area evaluation, engineering design, and regulatory coordination. The beach and dune template was based on the post-Hurricane Sandy (2013) U.S. Army Corps of Engineers (USACE) design for North Shore Beach, allowing the team to rely on an established and previously authorized profile.

[1] Principal Engineer, Anchor QEA, Inc., 755 Business Center Drive, Suite 220, Horsham, Pennsylvania 19002, USA, T: 814-932-6732, Email: tmerritts@anchorqea.com.
[2] Senior Engineer, Anchor QEA, Inc., 100 Light Street, Suite 1220, Baltimore, Maryland, 21202, USA, T: 248-595-9814, Email: lfolkert@anchorqea.com.
[3] Engineer Program Manager, Delaware Department of Natural Resources and Environmental Control, Division of Watershed Stewardship, Shoreline and Waterway Management Section, 285 Beiser Boulevard, Suite 102, Dover, Delaware, 19904, USA, T: 302-608-5500, Email: Joanna.French@delaware.gov.

Three borrow areas were assessed for sediment compatibility and feasibility. The previously dredged Indian River Inlet Flood Shoal was ultimately selected as the borrow source.

Regulatory coordination, design development, and contractor procurement were conducted concurrently. The accelerated schedule required flexibility during contractor coordination, to adapt construction means, methods, and associated costs in real time as permit conditions and design details were finalized. Due to the emergency nature of the project, DNREC negotiated scheduling and pricing directly with a large pool of dredging contractors. Based on schedule and pricing considerations, Dredgit Corporation (Dredgit) was selected to perform hydraulic dredging and beachfill placement operations for the Project. This integrated delivery approach enabled the award of a $15 million emergency dredging contract within a few months of the emergency declaration. The project involved close collaboration with USACE, with the State leading initial emergency restoration in advance of subsequent federally contracted nourishment activities.

In addition to the hydraulic dredging and beachfill placement operations, work performed by Dredgit included preparation of the staging area; installing and maintaining signage, barriers, and pedestrian ramps; maintaining munitions and explosives of concern (MEC) screens and inspections as required by the contract specifications; and restoration of the staging area following completion of dredging and beachfill operations. Subcontractors procured by Dredgit to assist with project implementation included Dredge America for lease and operation of the dredge and TetraTech for MEC technician services. Dredgit utilized an 18-inch (45.7 cm) cutter suction dredge (Ellicott Series 1270 Dragon Dredge) for hydraulic dredging operations. Multiple GPS-equipped dozers and excavators were utilized for pipeline management and beachfill grading. Plitko Engineering served as the Contractor’s third-party surveyor.

Dredgit initiated project mobilization operations November 18, 2024, and performed mobilization and equipment setup activities through December 2, 2024. This work included installing temporary security fencing, installing construction matting, and fusing approximately 5,000 linear feet (1,524 m) of 20-inch (50.8 cm) diameter HDPE pipeline. Final project permits were received on November 23, 2024. Permits and approvals obtained for the project are summarized below:

Dredging operations began on December 2, 2024. During dredging operations, the pipeline was anchored to the bottom surface across the inlet using 500-pound (227 kg) and 1,000-pound (454 kg) anchoring to prevent the pipeline from drifting during tidal swings. A support vessel was utilized to reposition pipeline anchors during dredging operations. Beachfill material was pumped through MEC-compliant discharge screens as required by the contract specifications. A Y-valve was utilized so that pumping operations could continue while one of the two screening units could be serviced. GPS-equipped dozers were utilized to spread and grade beach material.

Dredging operations were performed 24-hours per day, 7-days per week from December 2, 2024 through February 17, 2025. Over the 78-day dredging period, approximately 478,000 cubic yards (365,457 cubic meters) were dredged from the flood shoal and transported to the beach placement area for dune restoration and berm renourishment. Factoring in a 3-day down period for pipeline repairs, daily production averaged 6,400 cubic yards (4,893 cubic meters) over the active dredging period. Dune restoration and beach berm renourishment was performed over a 3,500-linear foot (1,067 m) stretch of the North Shore Beach, reestablishing a protective dune profile for State Route 1. Construction began in November 2024 and final restoration and demobilization activities were completed in March 2025, prior to seasonal environmental restrictions. The accelerated design, permitting, and procurement framework successfully compressed traditional project delivery timelines while maintaining regulatory compliance.

The project highlights the importance of interagency collaboration under emergency authority, including coordination among DNREC, USACE, Delaware Department of Transportation, and state regulatory entities to align design, permitting, and procurement timelines. Maintaining flexibility between the design team, agencies, and dredging contractor during execution were critical to the success of the project.

Keywords: Beach, replenishment, dune breach, dune repair, time-critical, interagency coordination.

CITATION

Merritts, T.W., Folkert, L.E., and French, J.L. "Emergency Response Dredging Case Study: Rapid Coastal Resilience at Indian River Inlet North Beach, Delaware," *Proceedings of the Western Dredging Association Dredging Summit & Exposition '26, Montreal, Quebec, CA*, July 20-23, 2026.

COMPRESSED TWO-PHASED BYPASS APPROACH TO AN URBAN WATERWAY CLEANUP

J.A. Zimdars[1], D.J. MacDougall[2], T.J. Olean[3]

ABSTRACT

A compressed two-phased approach to sediment/soil cleanup for an inland waterway was implemented to expedite agency approval, while also contributing to elements of successful remediation under a challenging timeframe resulting in: 1) streamlining remedial design approval, 2) timely provision of the waterway permits from the state, 3) insights gained for planning flood risk mitigation procedures, and 4) optimizing best practices for the creek bypass system. Coal tar releases from a former Manufactured Gas Plant (MGP) site in Antigo, Wisconsin impacted the adjacent Spring Brook creek. The upland site, nearby businesses, homes, a park, and brook are within the 100-year floodplain. This required special flood risk planning for dredge permitting in Wisconsin (State and US Army Corps of Engineers). A key concern was the large watershed, which during frequent storms can cause the creek to swell to more than 10 times the normal flow rate. While the upland remedy involving *In-situ Solidification/Stabilization* (ISS) was approved by the Wisconsin Department of Natural Resources (WDNR), the creek remediation had yet to be approved. The steady flowing creek had not allowed conventional drilling techniques and deep soil investigation. Only the shallow sediment had been sampled. To fully delineate the MGP impacts in soil up to 31 feet below creek bottom, an expedited approach was needed to finalize the design and implement the remedy in a single construction season with the upland remedy. Ramboll conceptualized a design to implement ISS of the deeper impacted soil in addition to dredging the upper 2 feet of sediment. This involved two creek flow bypass events during remedy implementation: Phase 1 for investigation to determine the limits for ISS and Phase 2 for remediation and restoration. Information gathered during Phase 1 was used to finalize the required approvals and for planning the critical Phase 2 remediation and restoration. This approach benefited the project as follows: 1.) cost efficiencies of bypass pumping equipment with a single remedial contractor mobilization. 2) delineated and established remedial boundaries during Phase 1 for final expedited agency approval. 3) performed detailed survey and mapping during Phase 1 of the dewatered conditions. 4) afforded “lessons learned” from Phase 1 to Phase 2 that included bypass system refinements. 5) improved storm preparedness from experience during Phase 1 activities. 6) provided for contractor assessment of the dewatered creek conditions for planning and performing the ISS within the creek, and 7) more efficient restoration means and methods were implemented to match the previously natural creek bed.

Keywords: ISS, flood plain, stream restoration, MGP, sediment excavation

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[1] Senior Managing Engineer, Ramboll Americas, 234 W. Florida Street, 5th Floor, Milwaukee, Wisconsin 53204, USA, T 262-719-4507, Email julie.zimdars@ramboll.com.
[2] Regional Manager, Geo-Solutions Inc., 63 Putnam Street, Suite 202, Saratoga Springs, New York 12866, USA, T 518-365-3189, dmacdougall@geo-solutions.com.
[3] Project Officer, Ramboll Americas, 15 Broad Street Suite 501, Boston, Massachusetts 02109, USA, T 508-395-6960, Email tim.olean@ramboll.com.

INTRODUCTION

Implementation of City Gas Company's former MGP site remediation in Antigo, Wisconsin included addressing both an upland 1.6-acre area and downgradient urban waterway ("Spring Brook") that included shallow sediment and underlying soil and groundwater impacts associated with historical manufactured gas plant operations (Figure 1). Spring Brook traverses the southern portion of the site and serves as both a downgradient migration pathway and direct environmental receptor. Historical investigations identified benzene, ethylbenzene, toluene and xylenes (BETX), polycyclic aromatic hydrocarbons (PAHs), coal tar sheen and non-aqueous phase liquid (NAPL) impacts extending toward the brook corridor.

Figure 1. Upland and Spring Brook.

The original remedial approach proposed removal of the known approximately 2-feet of shallow sediment impacts within Spring Brook and backfill with like material. During final remedial design approvals, shortly before final bid release, WDNR requested additional evaluation regarding the vertical extent of impacts beneath the brook channel and expanded restoration expectations. The steady flowing creek had not allowed conventional drilling techniques and deep soil investigation (Figure 2). These requests introduced significant schedule pressure because the overall project mobilization was already planned for Spring 2025 and the project team needed to preserve seasonal windows for in-water work, and the broader site remediation activities.

BROOK AND SURROUNDING VICINITY

Spring Brook is a relatively small urban, cool water trout stream with a large rural watershed, characterized by flashy hydrologic response during storm events. The brook corridor provided limited access for construction activities and included significant environmental and restoration considerations. In addition to addressing contaminated sediments and source materials, the project team was required to minimize impacts to the surrounding park environment and restore the brook following remediation.

Figure 2. Photo of Spring Brook.

The upland site and much of the surrounding area (nearby businesses, homes, a park) are located within the 100-year floodplain which required a Flood Risk Mitigation Procedures Plan be developed in order to obtain the dam and dredging permit needed for the work from both the WDNR and Army Corps of Engineers (Figure 3).

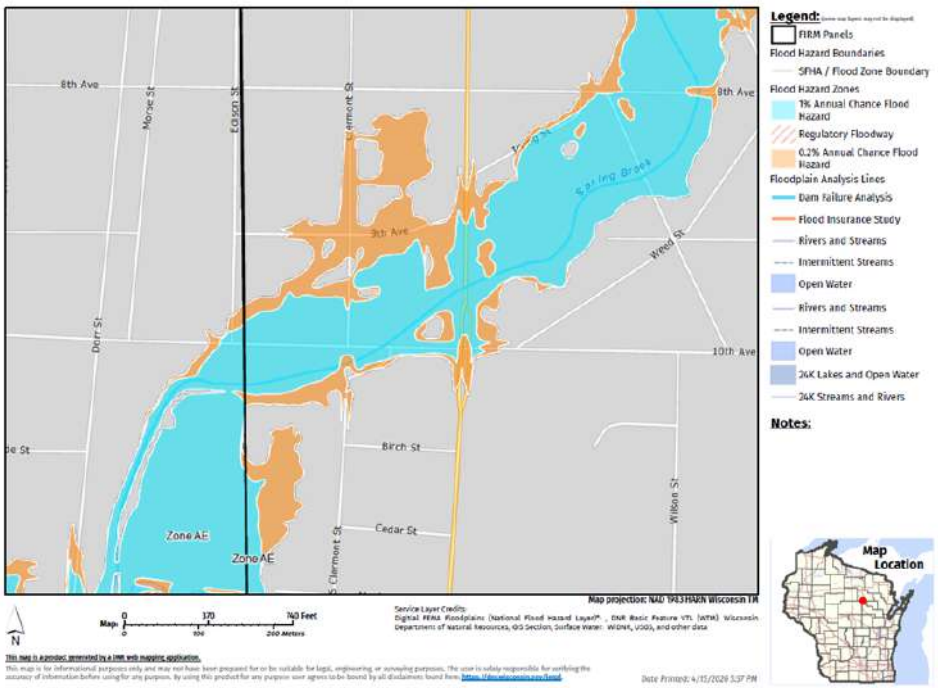


Figure 3. Flood plain area.

For this mitigation plan, 3 “stages of action” were described based on the storm event that was predicted, progressing to the point where all cofferdams and equipment were required to be removed and flow to resume as normal in the brook (Figure 4). A site-specific weather prediction tool, combining reputable weather forecasts with these stages of actions, was developed to be a straightforward tool for the field leads to implement with minimal interpretation.

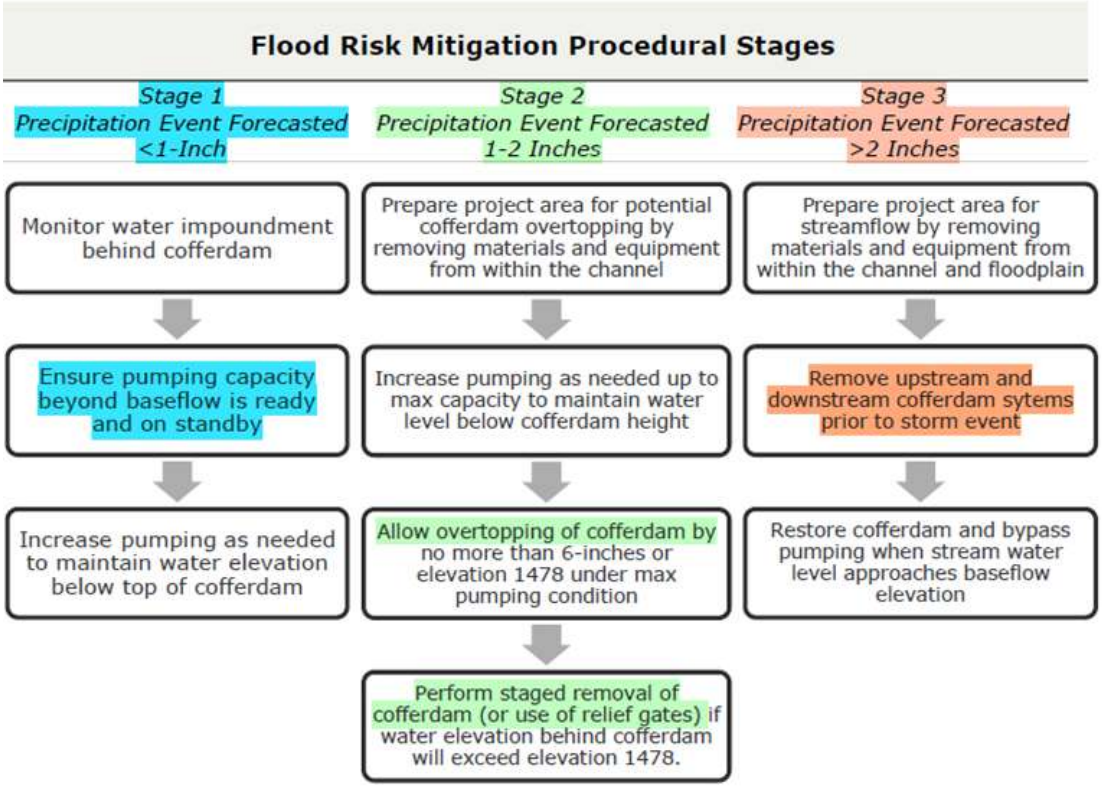


Figure 4. Storm event stages of action.

INITIAL REMEDY AND CONCEPTUAL REVISED REMEDY

The original remedial design for Spring Brook focused primarily on shallow sediment impacts and anticipated a relatively straight-forward sediment excavation and restoration effort (Ramboll, 2024a). However, WDNR review comments identified concerns regarding the potential vertical extent of impacts beneath the brook and requested additional characterization prior to final approval of the brook remedy.

Rather than requiring a complete redesign of the overall remediation program, WDNR requested that the brook portion of the remedy be amended based on additional subsurface characterization. Ramboll developed a phased adaptive strategy consisting of rapid in-channel investigation and brook remedial redesign that would be worked into the overall remedial construction schedule (Ramboll, 2024b).

ISS had been approved by WDNR as the selected remedy for impacted upland soils. Extending ISS beneath the brook was agreed upon with WDNR as the remedial strategy that would provide continuation of the overall remedial strategy.

PHASE 1 BYPASS AND INVESTIGATION PROGRAM

Bypass Configuration

The primary objective of the Phase 1 investigation effort was to determine the vertical extent of coal tar sheen and NAPL impacts beneath Spring Brook and generate sufficient pre-design investigation (PDI) data to support an expedited remedial redesign. The work area was generally limited to approximately 20 feet in width and required construction activities to occur within a confined and hydraulically active stream corridor. In order to accomplish this, approximately 300 linear feet of Spring Brook needed to be temporarily bypassed and dewatered to allow direct access to the brook channel with the Geoprobe rig (refer to Figure 5 for bypass configuration).

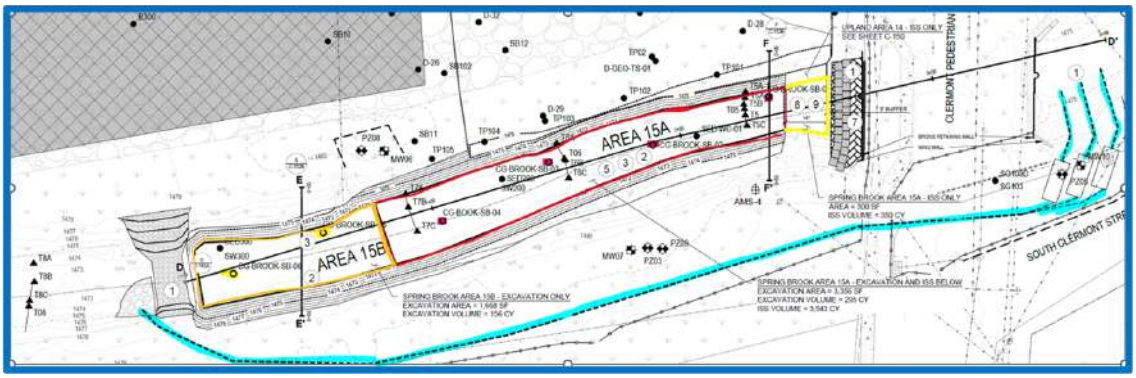


Figure 5. Bypass configuration.

The bypass system utilized three diesel centrifugal pumps with a combined capacity of approximately 40 cubic feet per second and included an 18-inch discharge pipeline, an upstream intake sump and cofferdam, and a downstream isolation cofferdam (Figure 6). The sizing of the pumps was known to be approximately three times the base flow and was predicted to handle an annual 24-hour storm event.

Figure 6. Photo of Phase 1 bypass pumps.

In-stream dewatering utilized a series of submersible pumps serving either of two purposes:

1. Intercept surface water or groundwater springs intruding into the work area before contacting any impacted work areas. The non-impacted water could be pumped directly back to the brook

at the outfall discharge zone and did not require treatment at GSI's on-site water treatment plant (WTP), reducing the volume load at the plant.

2. Collect and remove impacted contact water from the work area and pump it to the WTP for treatment and eventual discharge at the outfall.

During Phase 1, a significant storm event resulted in flooding within portions of the work area. The event effectively stress-tested Ramboll's flood prediction model and emergency response approach and identified limitations associated with cofferdam performance (leaks), bypass manifold configuration (sump scouring, cavitation and priming failure), and outfall energy dissipation. These observations and conditions directly informed improvements implemented during Phase 2 remedial construction, as discussed below.

Investigation Program Results

Six borings were advanced within the dewatered brook channel at approximately 50-foot spacing using a Geoprobe drill rig operating directly on the exposed sand and gravel streambed (Figure 7). Borings were advanced to depths extending at least five feet below the deepest known upland NAPL impacts, or up to ~31 feet below creek bottom. NAPL or coal tar source material was encountered in four of the six borings and generally correlated with the known upland plume geometry.

Figure 7. Photo of Geoprobe rig in dewatered brook.

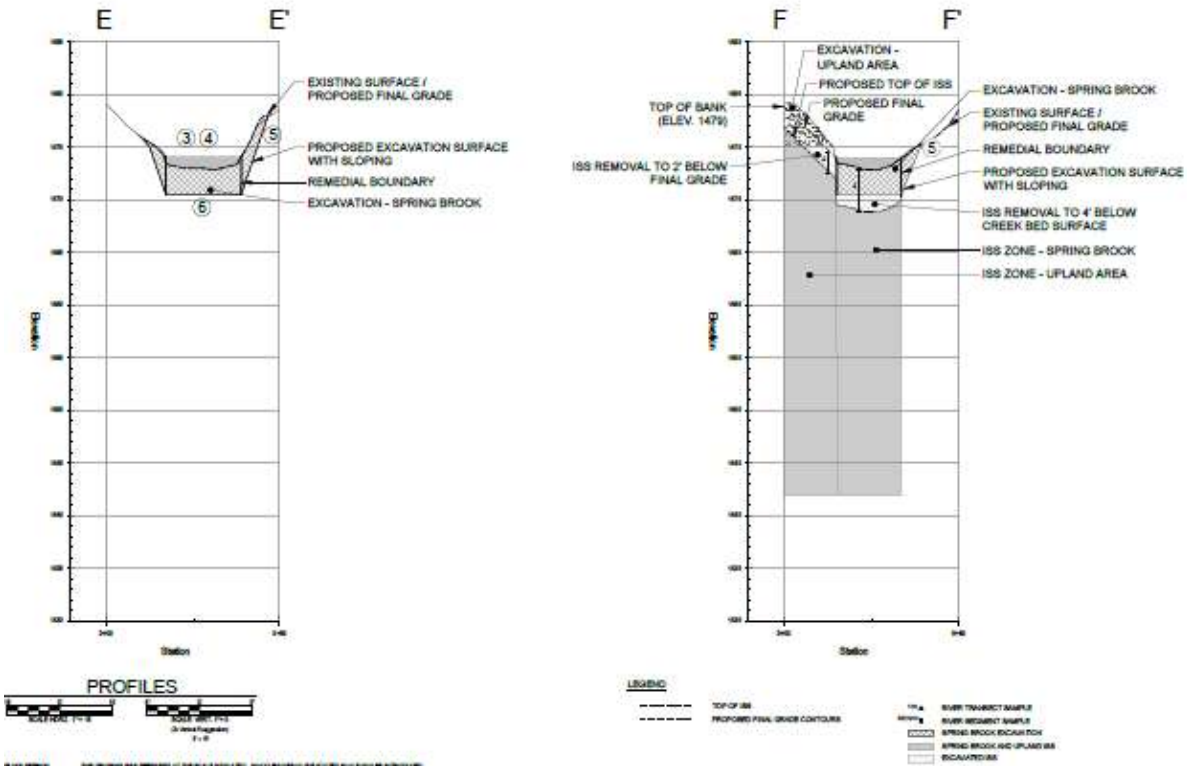
REVISED REMEDY DESIGN

Following completion of the Phase 1 investigation program, Ramboll rapidly developed and submitted a revised remedial design for Spring Brook (Ramboll, 2025). The revised design was submitted to WDNR within approximately two to three weeks following completion of the investigation program, and the review and approval process was completed within approximately six weeks, including permit modifications.

The revised remedial design divided Spring Brook into two treatment areas based on the Phase 1 investigation findings. Area 15A represented the upstream 200-foot portion of the brook where deeper

NAPL and source material impacts were confirmed. Area 15B represented the downstream 100-ft portion where impacts were generally limited to shallow sediments (refer to Figure 5 for the plan view of Areas 15A and 15B).

Area 15A required sediment excavation of the top 2 feet of streambed to be followed by deep ISS extending approximately two feet below the deepest observed source material. Area 15B required a 2-foot sediment excavation only and did not require deeper ISS treatment (Figure 8). The targeted approach minimized unnecessary treatment while addressing the confirmed deeper impacts beneath the brook.



AREA 15B **AREA 15A**

Figure 8. Areas 15A and 15B remediation cross-section view.

PHASE 2 BYPASS IMPROVEMENTS

Lessons learned during the Phase 1 bypass directly improved Phase 2 bypass construction and water management performance through refinements to flood response planning, cofferdam stability, pump manifold configuration, and outfall energy dissipation.

Initial Phase 2 work required re-installation of the temporary bypass pumps, cofferdams, and in-stream dewatering systems. Based on the observations from Phase 1, GSI made several informed improvements to the brook bypass.

1. The cofferdams in Phase 1 were intended for short-term duration, allowing for practical but less durable choices for liner material. During Phase 2, the cofferdams were installed with a

thicker reinforced 20-mil[4] liner and larger streambed aprons. More time was also allocated to identify areas of channeling or seepage and seal the leaks thoroughly.

2. The upstream pump intake sump was improved with additional scour protection (i.e., stone and masonry armoring) to address areas that were affected by Phase 1 operation. The improved sump shape and depth reduced pump cavitation during higher flow rates.
3. The pump manifold which connected all three pumps to the 18-inch discharge line was fitted with an 18-inch gate valve to control back pressure and eliminate problems with priming the pumps.
4. The 18-inch outfall energy dissipator was doubled in size with one additional 20-foot section and additional pipe cutouts. The rip-rap apron was similarly extended in the discharge zone to provide better protection during high flow events.

Figure 9. Photo of Phase 2 bypass improvements.

After the Phase 2 bypass system was operational and the work area in the brook was dewatered, GSI's equipment gained access to the brook. The work area within the brook was generally limited to an approximately 20-foot width, bank-to-bank. Additionally, the slope and height of the banks prevented GSI from operating the drill rig from an upland position. An access ramp was cut into an upstream section of the north bank, and the drill rig was able to enter the dewatered brook and operate on a stable work platform of short (20-foot) crane mats.

BROOK REMEDIATION, ISS PERFORMANCE AND CONSTRUCTABILITY

Dredging and ISS Constructability in Brook

As previously stated, Area 15A required a preliminary 2-foot excavation cut and removal of surficial creek bed sediment prior to ISS. Initially, this task was planned to be a discrete excavation pass along the full

[4] 1 mil = 0.001 inch or 0.0254 mm.

length of Area 15A. However, during the Phase 1 investigation work it was observed that water intrusion from groundwater and springs was significantly aggravated by sediment removal that created a wet, somewhat unstable working conditions within portions of the brook channel. Maintaining safe and stable access for heavy equipment and ISS operations required careful sequencing of smaller excavation and ISS work in sequential segments, and diligent water management (Figure 10).

Figure 10. Photo of ISS operations within dewatered brook.

Actual ISS production required approximately eight working days, and a total of 62 columns using a 10-foot diameter auger (refer to column layout Figure 11). ISS operations were performed using a single-axis auger system using a Casagrande B300 drill rig operating within the dewatered brook channel. The work area was generally limited to approximately 20 feet in width and required continuous use of short crane mats to support the drill rig and associated construction equipment. Despite these constraints, ISS production generally progressed efficiently once operations were underway. The targeted treatment footprint and prior lessons learned from Phase 1 allowed the project team to maintain production and complete the ISS work within the planned schedule.

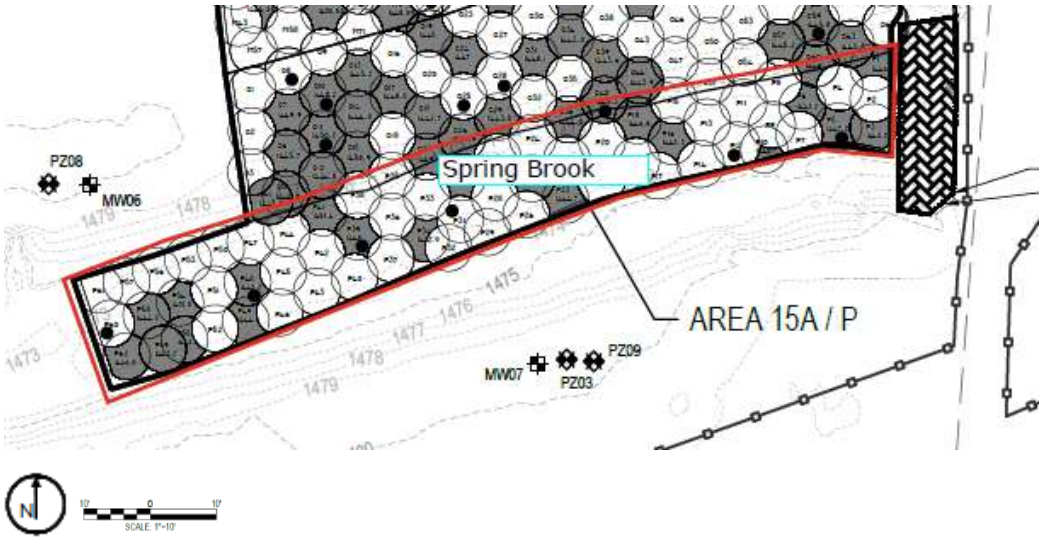


Figure 11. Brook column layout.

ISS Performance in Brook

The brook specific mix design was increased to 9% reagent from the 8% reagent (by wet weight) upland mix (Ramboll, 2026). The mix maintained the 3:1 ratio of granular ground blast furnace slag to Portland cement (Type 1L) at the same water to reagent ratio of 0.75:1 as the upland mix. The strength and permeability average performance results compared to the required specifications are listed in Table 1.

Table 1. Brook ISS performance results.

Test	Method	Required	Brook Results
Unconfined Compressive Strength (Pounds per Square Inch)	ASTM 2166	>50	>450 (average)
Permeability (Centimeters per Second)	ASTM 5084	$<1 \times 10^{-6}$	1.5×10^{-7} (geomean)

Approximately 800 CY of sediment excavation (400 CY more than planned) and 4,000 cubic yards (CY) of deeper soil ISS under the brook was conducted to a depth of 31 feet (refer to cross-section in Figure 12).

The project demonstrated that deep ISS can be successfully implemented within a dewatered stream channel environment when supported by phased investigation, adaptive design, robust water management, and careful sequencing.

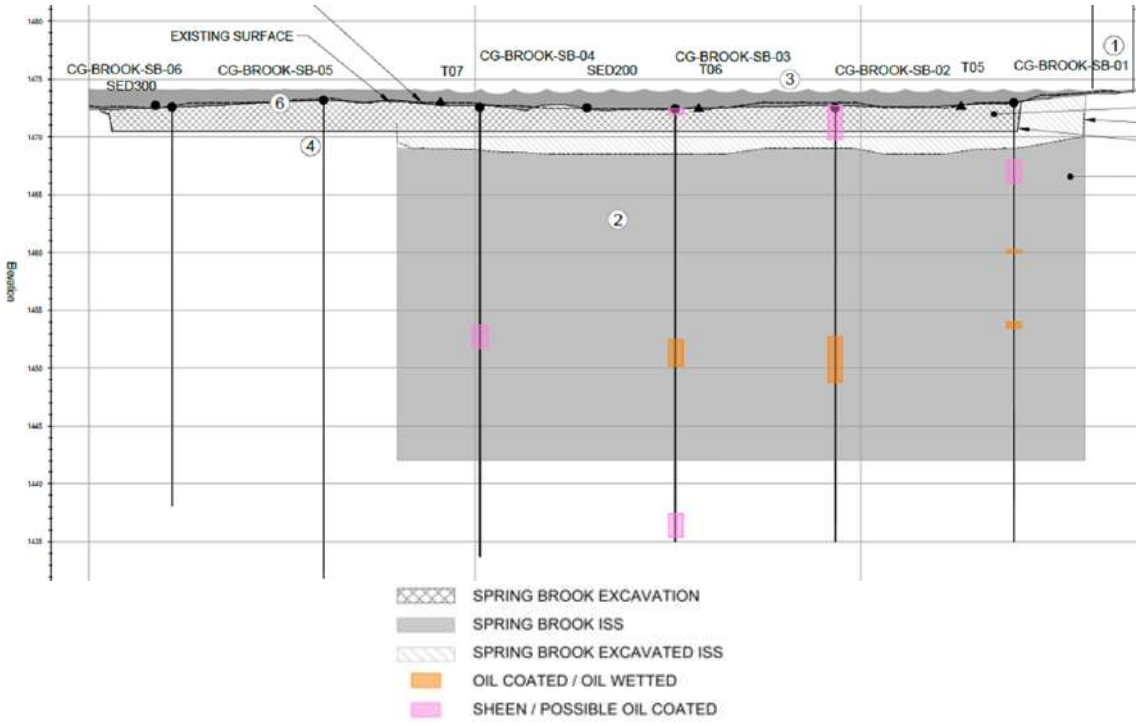


Figure 12. Longitudinal cross-section.

STREAM RESTORATION

Following completion of ISS and necessary removal of solidified material ("final trimming"), the brook corridor was restored to its approximate original and natural conditions in accordance with the revised remedial design and regulatory requirements. Restoration activities included reconstruction of the channel alignment, placement of clean materials, grading and stabilization of stream banks, and restoration of streambed materials intended to support long-term hydraulic and environmental function (Figure 13).

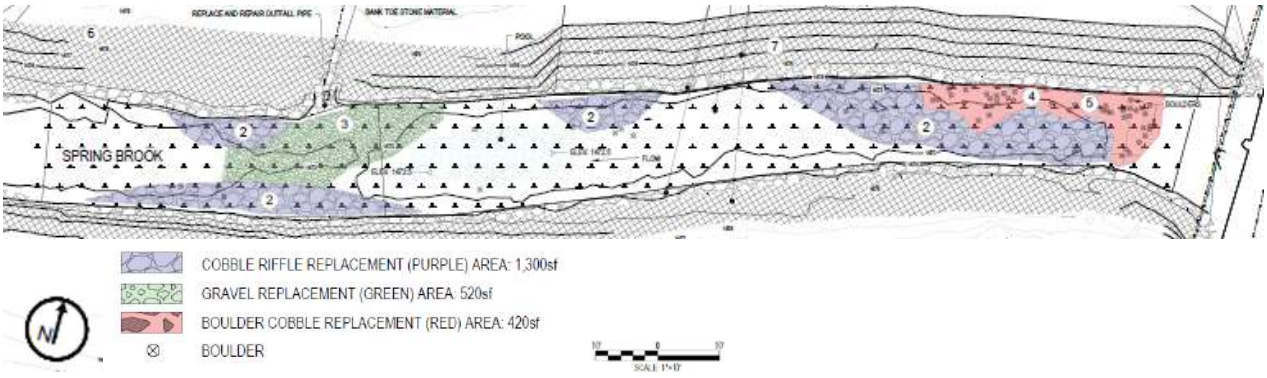


Figure 13. Brook restoration plan.

The requirements of the streambed and bank restoration included:

1. Rounded stone materials were to be used in the creek bed to closely match the natural environment (with the exception of the toe stone).

2. The sizing of all stone materials needed to be mapped during the pre-remedial dewatered state such that the same sizing and placement could be replicated (Figure 14).
3. The topography of the creek bed needed to be surveyed during the dewatered state to fill the creek back to its existing condition.
4. The creek bed morphology needed to be mapped prior to remediation such that the "riffle-run-pool" sequence could be replicated as part of the restoration.
5. Creek bank woody-species plantings were required to be re-planted on the banks where no ISS was to occur. The larger species provide shade to the creek, restoring the natural creek habitat (Figure 15).
6. The creek bed fill material covering the ISS material was required to be 4 feet in thickness (prior to finalization of the brook design, the cover was to be 2 feet thick)

To satisfy these requirements, the restoration activities represented a substantial portion of the overall brook work requiring bypass. The expanded restoration requirements influenced final remaining ISS elevations, construction sequencing, and final stabilization activities. The brook remediation and restoration effort ultimately required approximately seven total weeks to complete, for which 3 weeks were required for the restoration including ISS removal to subgrade elevations, and installation of the clean cover gravel and stone restoration surfaces.

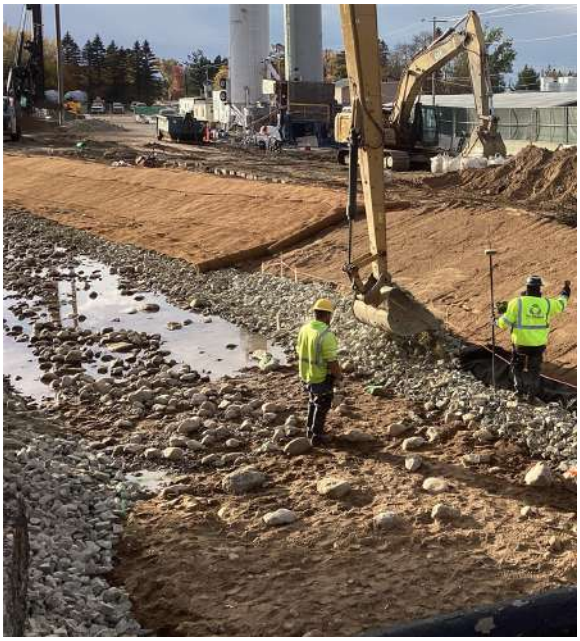


Figure 14. Photo of the stone materials placement.

CONCLUSIONS

Lessons Learned

Several important lessons learned emerged from the project. First, targeted phased investigation programs can provide critical data rapidly enough to preserve aggressive construction schedules. Second, temporary bypass and dewatering systems should be viewed as enabling infrastructure that may evolve and improve throughout project execution. Third, constructability considerations within confined stream environments should be integrated directly into remedial design development.

The project also demonstrated the importance of incorporating operational flexibility into water management planning. Lessons learned during the Phase 1 storm and dam overtopping event directly improved Phase 2 implementation and reduced hydrologic risk during later construction activities.

Construction Outcomes

The adaptive two-phase approach successfully allowed the project team to maintain the overall remediation schedule while addressing late-stage regulatory concerns regarding deep impacts beneath Spring Brook. The approach allowed targeted investigation, expedited design refinement, permit modification, and final remedial construction without requiring a complete redesign of the broader remediation program.

The Phase 1 investigation program provided critical data needed to refine the remedial design while also generating operational lessons that improved Phase 2 implementation. The final remedial approach successfully addressed deep impacts within Area 15A while avoiding unnecessary treatment in Area 15B. The ISS program was implemented within a confined and hydraulically sensitive stream corridor requiring close coordination between drilling operations, excavation sequencing, and water management. The confined geometry of the brook and somewhat unstable subgrade conditions created constructability challenges that required continuous adjustment during operations.

Figure 15. Photo of brook restoration with plantings.

The Spring Brook remediation project demonstrates how phased investigation and adaptive remediation strategies can successfully address deep MGP impacts beneath active stream corridors while maintaining aggressive remediation schedules. The project evolved from an initially limited sediment excavation approach into a comprehensive integrated remediation and restoration effort involving temporary stream bypass, in-channel investigation, deep ISS implementation, and final stream restoration.

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DATA AVAILABILTY

Data generated or used during the work/study are available from the corresponding author by request.