Beneficial Use of Contaminated Sediments

A White Paper Prepared for:

Sediment Management Work Group

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This paper represents a review of available literature on the topic of beneficial use of sediment. As it is a distillation of the work of a broad range of those interested in the topic, it may include views that are not necessarily endorsed by members of the Sediment Management Work Group.

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Executive Summary

Beneficially using the significant volume of sediment dredged from waterways worldwide as a resource can offer environmental and societal advantages over managing the sediment as a waste requiring disposal. Examples of these advantages include:

- Reduces the need for limited landfill space for disposal
- Reduces the overall environmental footprint (e.g., lowers energy use, fuel use for long transport routes and treatments, etc.)
- Supports the demand for fill for shoreline and coastal infrastructure (e.g., bank stabilization, shoreline erosion control, etc.) to address pressing needs
- Avoids local or widespread erosion, accumulation, and subsidence challenges; supports ecosystem restoration

In consideration of the above, the objective of this white paper is to present the findings of a literature review on beneficial use of sediments, with explicit focus on contaminated sediments, in North America and Europe, undertaken to identify the current state of the practice for this important topic. The full bibliography contains more than 170 references from professional and scientific literature, regulatory agencies, and professional working groups. An annotated bibliography provides summaries of key references, organized into five categories:

- Regulatory guidelines
- Examples of beneficial use
- Barriers to use
- Remediation decision-making frameworks and strategies
- Techniques and technologies

Findings from a review of North American and European regulatory programs are included in tabular form. A detailed spreadsheet is provided that includes information such as whether regulatory programs allow beneficial uses of sediment in upland applications only or if they also may consider in-water uses (such as habitat or coastal restoration). These additional details demonstrate that some regulatory programs consider procedures by which beneficial uses of contaminated sediment may be acceptable. The United States Army Corps of Engineers' (USACE) regional efforts to promote and include beneficial use of sediment in its projects are cited as examples of progress in beneficially using dredged sediments. The USACE is responsible for maintaining public waterways for navigation and protecting coastlines. This creates a synergy because dredged materials can be used effectively for coastal/shore protection purposes. The USACE has evolved and grown its expertise in managing sediments in environmentally appropriate ways; where sediment beneficial use has been linked to regional transportation and navigation, the concept has taken hold. The USACE has helped form and lead numerous sediment management planning efforts, and standing regional teams now exist for all coastal areas of the United States as well as some inland waterways.

The regulatory program review specifically searched for instances where contaminated sediments had been considered for beneficial use. There are no programs for beneficially using contaminated sediments per se, but there are examples of regulatory flexibility to consider specific cases of beneficial use of contaminated sediments when it can be done in an environmentally appropriate manner. States open to considering contaminated sediments for beneficial use typically have a pre-existing cleanup program that incorporates risk-management principles. Regulatory flexibility also exists in other countries, including The Netherlands, where contaminated sediment may be used within the same water body provided it does not worsen its quality and does not exceed specified thresholds. Some European countries direct that contaminated sediments above specific risk thresholds be used only in confined settings or for specific upland purposes, and in some cases, pre-treatment is also required.

Dredging sediment and moving it somewhere else is expensive, and costs accumulate across all stages: in determining a suitable place for relocation, and in the removal, transportation, placement, and long-term storage of vast volumes of sediment. If the sediment is contaminated, then each stage also incurs the costs of making sure the entire process does not just export the contaminant exposure problem from one setting to another.

The need for more sensible options than disposal to manage sediment that must be dredged to maintain navigation is another incentive for putting contaminated sediments to beneficial use. For example, in New York/New Jersey Harbor, sediment with impacts exceeding open-ocean disposal criteria have been stabilized and used for upland fill, geotechnical-amended fill, landfill capping, and mine/quarry reclamation. The Montezuma Wetland Restoration project in the San Francisco Bay estuary in California is another example of regulatory flexibility and regional coordination in the beneficial use of sediment. A consortium of governmental and non-governmental entities recognized an opportunity to beneficially use dredged sediment for habitat restoration work. This regional group is working to restore more than 2,300 acres of regional salt marsh. Minnesota and Wisconsin, bordering the Great Lakes and the upper Mississippi River, have guidance on managing dredged sediment that provides paths for sediment to be used for in-water habitat restoration projects if sediment quality criteria are met. If the criteria are exceeded, then upland beneficial uses may still be considered. If upland soil criteria are exceeded, then sediment in the two states' guidance calls for the sediment to be treated prior to beneficial use or disposed of as waste.

European literature contains numerous discussions of beneficially using sediment for fill, to make bricks or tiles, as a component of cement, or as geotechnical fill. The primary driver for evaluating such beneficial uses is a desire to sustainably manage sediment rather than dispose of it in landfills. Other beneficial uses for dredged sediment in Belgium, and the Netherlands include using it as a soil amendment, to restore agricultural soils, or for reclamation. Regulatory criteria for these types of beneficial uses of sediment focuses on protecting water quality and crop health. Criteria applied to upland soil uses are generally only slightly less conservative than for sediments proposed for use in wetland or shore zone restorations.

Europe is developing adaptation and sustainability strategies within the Green Deal and its fiscal policy. The strategies will work in concert with the six principles governing the Green Deal: 1) climate adaptation, 2) climate mitigation, 3) circular use of natural resources, 4) zero pollution, 5) healthy water ecosystems, and 6) biodiversity. European Union (EU) goals of developing a more circular economy and undertaking critical climate adaptation measures are consistent with beneficial use of sediment. Circular economy and climate adaptation concepts are driving interest, inquiry, and potentially innovation in beneficial use. Various sites in Europe demonstrate how a region can focus on using sediment for ecosystem restoration and regional socio-economic development, for example the Solent Region in England, the Eems-Dollard estuary in The Netherlands and the Hamburg Region in Germany.

Internationally, the 1992 Rio Declaration on Environmental Development (United Nations 1992), principle 15, calls for the use of the scientific method to explore potentially beneficial, cost-effective uses while developing the scientific knowledge necessary to prevent unacceptable environmental degradation. While relatively old, this declaration still holds relevance. This declaration allowed nations from around the world to declare that environmental protection and the development process are inseparable, and that the scientific method, applied within an adaptive management and inclusive decision-making framework, is the engine that allows society to turn uncertainty about impacts into environmental progress. The beneficial use of contaminated sediment is one promising opportunity to apply these principles by working with nature to enhance the flow of ecological services.

The literature emphasizes the importance of piloting, pre-planning and regional coordination to the success of environmentally appropriate beneficial use projects. Pre-approved uses and programs to match dredged sediment with projects needing sediment are becoming more common in North America and Europe. Public trust or acceptance is an impediment to both implementing uses of contaminated sediment in the environment and creating products using contaminated sediment as a raw material. This aversion might be overcome by educational campaigns and the inclusion of adaptive management principles.

Recent publications regarding contaminated sediment remediation present new decision frameworks that evaluate broader stakeholder and environmental concerns than did prior evaluation frameworks. These newer frameworks typically incorporate the practices of green and sustainable remediation, including considering sediment a resource rather than a waste. Stakeholder value assessment, sustainability linkage evaluation, life-cycle assessment, and multi-criteria decision analysis are among the newer frameworks. Sustainability, sustainability principles and green and sustainable remediation were frequently referenced in the literature. For our review and analysis, we refer to the United Nations (UN) and Central Dredging Association (CEDA) sustainability definitions and the US Environmental Protection Agency (EPA) regarding green and sustainable remediation concepts (see ***Section 3 Terms and Definitions*** for further discussion).

Technologies are also being evaluated from an end-use perspective with new technologies developed to reduce exposure to sediment contaminants. These include direct stabilization, such as incorporating contaminated sediment into concrete, as well as incorporating biochar into contaminated sediment with and without subsequent biochar removal. Monitoring and adaptive management are important risk management tools that also can complement technologies. Risk assessment tools and methods (e.g., weight-of-evidence guidance) continue to evolve and improve as well.

The white paper concludes with 14 key observations from the literature review:

- Sediment is increasingly seen as a resource, not a waste material.
- Treatment or pre-treatment is commonly used to facilitate/expand potential options for beneficial use.
- Beneficial use of contaminated sediments is more common in upland settings while rarer in aquatic settings.
- End use of contaminated sediment affects both risk and risk acceptability.
- Regional sediment management/planning efforts have been helpful to facilitating programmatic approaches to beneficial use.
- There have been a number of advances in beneficial-use techniques and applications.
- Beneficial use aligns with sustainability principles as defined below.
- Sustainability evaluations are increasingly widely adopted.
- Computing project lifecycle costs, including indirect benefits and costs, facilitates beneficial use options.
- Educating and communicating with stakeholders about sediment contamination can reduce the stigma of beneficial use.
- Stakeholders may draw valid, but contradictory conclusions about the acceptability or added value of a beneficial use, because each stakeholder will evaluate project economics and benefits through their unique perspective.

- Regulatory program flexibility to allow for risk-based decisions and adaptive management is a foundational necessity for beneficial use of contaminated sediments to be considered.
- Environmental risk assessment improvements can better evaluate potential risk exposure from sediment in specific settings.
- Sediment management has become a sustainability issue, therefore sediment management options are now being evaluated for consistency with sustainability principles which should create opportunities rather than barriers.

1. Introduction

Beneficially using the significant volume of sediment dredged from waterways worldwide as a resource can offer environmental and societal advantages over managing the sediment as a waste requiring disposal. Examples of these advantages include:

- Reduces the need for limited landfill space for disposal
- Reduces the overall environmental footprint (e.g., lowers energy use, fuel use for long transport routes and treatments, etc.)
- Supports the demand for fill for shoreline and coastal infrastructure (e.g., bank stabilization, shoreline erosion control, etc.) to address pressing needs
- Avoids local or widespread erosion, accumulation, and subsidence challenges; supports ecosystem restoration

In consideration of the above, the objective of this white paper is to present the findings of a literature review on beneficial use of sediments in North America and Europe, undertaken to identify the current state of the practice for this important topic, with explicit focus on contaminated sediments.

Assessment and management of sediment is performed for many purposes. Free-flowing United States commerce relies heavily on well-maintained navigation infrastructure, often requiring the removal and relocation of sediment accumulated in navigational channels (EBP 2021). In some cases, leaving contaminated sediment in place can pose risks to aquatic life and/or humans who consume fish or shellfish that take up (i.e., bioaccumulate) sediment contaminants. Two generations ago, the concept of beneficial use of dredged material was already well developed (USACE 1987). A generation ago, it was evident that decisions regarding how to address contaminated sediments could involve very costly options and that selecting from among the options could be highly controversial (NRC 2001). The tensions surrounding the issue have not abated, and global prioritization of sustainability, responsible use of natural resources, and climate-change resiliency have highlighted the need to thoroughly consider the full environmental footprint associated with implementing different contaminated sediment remediation alternatives (Sparrevik et al. 2011). These alternatives include monitored natural recovery (MNR), capping, *in situ* treatment, and removal (dredging). This white paper focuses on beneficial use of dredged sediment, with explicit focus on contaminated sediments.

When dredging decisions are made, people focus on the problem in front of them, whether it be removing sediment for navigational safety or to protect environmental and human health from exposure to potentially harmful contamination. However, dredging sediment and moving it somewhere else is expensive, and costs accumulate across all stages: in determining a suitable place for relocation, and in the removal, transportation, placement, and long-term storage of vast volumes of sediment. If the sediment is contaminated, then each stage also incurs the costs of making sure the entire process does not just export the contaminant exposure problem from one setting to another. In addition to the financial costs, other potential impacts and risks that must be considered when making sediment management decisions include worker safety and residents' quality of life due to the noise, lights, and traffic of a sediment dredging operation on-site and along the transport route. Other options for transporting sediment, such as barge and truck traffic or pipeline access and crossings, also can impact the local community.

Concerted advocacy since the 1990s has resulted in many countries recognizing that dredged sediment is a resource, resulting in an increasing allowance of, and in some cases demand for, sediment to be used for a myriad of helpful (i.e., non-waste) purposes (CEDA 2019a; USACE 2021b, PIANC 2022). Most regulatory entities across North America and Europe evaluate dredged material as if it were a waste material; however, some programs have evolved to consider the beneficial uses of dredged sediment, when it can be done in an environmentally appropriate manner (e.g., USACE 2021a; EPA 2021a). Regulatory and permitting entities tend to be cautious about allowing contaminated sediments to be used beneficially, even when the risk of exposure to sediment contaminants is low (Welch et al. 2016). As such, contaminated sediment is often removed and transported to containment and/or treatment facilities, thereby expending considerable energy and resources to dispose of the sediment as a waste, as well as creating environmental and human health risks related to sediment dredging operations and transportation safety. Considering that sediment can be a resource, the next question is: Can entities identify beneficial uses for contaminated sediment that provide reasonable and advantageous socio-economic benefits and result in less exposure to contamination than if the sediment is left in the open environment?

This white paper presents the findings of a review of available literature[1] regarding beneficial use of sediments in North America and Europe, including examples exploring, encouraging, or undertaking the beneficial use of contaminated sediments. Included are background information (Section 2), terms and definitions (Section 3), descriptions of the research approach (Section 4), and a guide to using the attached tables (Table 1 and Table 2) related to applicable regulatory programs (Section 5). Sections 6 (Literature Overview) and 7 (Key Observations) discuss analysis of the literature and the state of the practice related to management techniques/technologies, roadblocks, and opportunities in advancing beneficial use of contaminated sediment. Section 8 presents the bibliography of reviewed literature, Section 9 includes regulatory program tables (Table 1, Comparison of Regulatory and Other Programs – North America; Table 2, Comparison of Regulatory and Other Programs – Europe, and Section 10 presents an overview of Adaptive Management (Attachment 1), an annotated bibliography (Attachment 2) and beneficial use project examples (Attachment 3).

2. Background

Contaminated sediment management in the United States represents significant liability to the U.S. Department of Defense (DOD), private industry, ports, and governments. Current estimates of sediment contamination liability at DOD facilities alone approach $2 billion (SERDP and ESTCP 2021). Private U.S. industries spend $100s of millions each year managing contaminated sediments in the nation's waterways and face multi-billion-dollar costs to clean up legacy contaminated sediment in the United States (EPA 2021b, EPA 2021d), . Additionally, the USACE—tasked with maintaining federal navigation channels, ports, and harbors to facilitate efficient maritime transportation through its dredging program—spends $10s to $100s of millions annually to manage nearly 200 million cubic yards of sediment, which includes approximately 1% to 5% requiring special management due to contaminants (Moore 2022). Additionally, available landfill space is decreasing. These factors necessitate evaluating other options that are more socio-economically and environmentally sustainable over time.

The concept that sediment is a resource that can be used for construction, beach nourishment (i.e., replenishing eroded shorelines), land reclamation, wetland habitat restoration, or as a raw material is well

[1] The literature resources reviewed for this white paper were limited to those available in the English language.

recognized, as evidenced by the levees and land reclamation projects undertaken in the coastal areas of northwestern Europe for centuries (Hoeksema 2007; Hamm et al. 2002). More recently, USACE developed the concept of beneficial uses for sediment removed from channels in building flood control levees and restoring floodplain wetland habitats and backwater islands (USACE 1987; Gailani et al. 2019).

Scientists and engineers have raised serious concerns that existing infrastructure on shorelines and coastal areas will need to be significantly altered as climate change causes higher water elevations, increased intensity weather and storm events causing more erosion (Kopp et al. 2019 and Ulibarri et al. 2020). Beneficial use of sediments, both clean and contaminated, will become increasingly important in controlling the effects of climate change on land use as impacts become more severe, especially in coastal areas; Bardos et al. (2020) highlight the coastal zone risks from the increasing magnitude and frequency of coastal storms. Adapting the built environment in coastal and port areas will likely require material to raise land elevations, create offshore berms and habitats to attenuate storm-related effects, or reinforce waterfront facilities (Ulibarri et al. 2020; Temmerman et al. 2013).

A growing number of regulatory programs recognize that some contaminated sediment may be of sufficient quality to be used beneficially. Regulations remain conservative about allowing the use of these sediments for such purposes, despite significant strides in the science of understanding ecological and human health risk, bioavailability, and mobility of potential contaminants, as well as the technologies available to manage or treat risk concerns. In fact, the willingness to consider beneficial uses for such sediments is not simply based on the need or demand for such uses. It is based on the knowledge that sediment risk assessments are often, if not generally, intentionally conservative (i.e., overly protective), and technologies exist to physically and chemically stabilize and isolate sediment contaminants, and monitor their performance to minimize the risk of future exposure.

Finally, beneficial use of sediment may be seen as a potentially expensive option, particularly if the sediment is contaminated. However, a more holistic risk-based and multi-criteria cost-benefit approach would focus on maximizing the valuable uses of contaminated sediment rather than simply managing it as a waste. This sort of approach could involve public-private partnerships and cost sharing to support infrastructure projects that deliver cost-effective solutions benefiting both the environment and society, while recognizing that the beneficial use must be environmentally appropriate.

3. Terms and Definitions

This section identifies how some key terms are used by the authors for the purposes of this paper.

Beneficial use/reuse – Beneficial use or reuse is the use of a material that might normally be considered a waste as a resource (PIANC 2009; CEDA 2019a). Examples include placing material for some productive purpose, such as using dredged sediment in beach nourishment or for habitat creation or restoration. The Great Lakes Commission (GLC), a binational commission of the United States and Canada, and the Great Lakes National Program Office of the EPA note that "…sediments have been beneficially used in landscaping, topsoil creation, road construction, land creation or reclamation (e.g., strip mines, brownfields), and in the manufacture of aggregates for marketable products such as ceramics or asphalt" (GLC 2001). The GLC points out that the benefits of reuse may be derived from the material itself or the design and location of the material's placement.

Reuse versus use – In the literature, the terminology "sediment beneficial *reuse*" is commonplace. However, the authors have chosen the term "use" over "reuse" because in most cases sediment removed from its depositional environment likely never has been previously "used" for another purpose. From the perspective of the dispensation of a volume of removed sediment, the authors have elected to refer to the "use" of a material as a resource (I.e., an *intentional* use designed to benefit the environment and society). In the literature search effort, it was important to search using both terms.

Sediment – This term refers to accumulated particles settled out of a state of suspension. More generally, sediment is a collection of grains or fragments of solid material that have been transported and deposited by wind, water, or ice, as well as material that has been chemically precipitated from solution or secreted by organisms. Sediment accumulates in layers and may be graded (i.e., sorted) due to differential settling among particles. Consequently, sediment layers or deposits have grain-sized gradations that generally represent the depositional environment (i.e., conditions) under which they were deposited and often include organic matter intermixed with mineral clastic fragments or precipitates. Sediment includes fine (clay and silt) and coarse (sand and gravel) particles. Sediment generally refers to particles in aquatic settings, as opposed to soil, which is related to terrestrial settings.

Contamination or contaminated – Such terms refer to an accumulation of metals or non-native chemicals in the natural environment in concentrations and forms likely to result in adverse effects on biota or humans. The effects of exposure to contaminants are due to chemical interactions with biological systems that produce injury and harm to plants and/or animals. The concentration, form (e.g., molecular, valence state, dissolved vs. total), and pathway (e.g., in solution, adhering to soil particles, in dust, in air vapor, etc.) by which contaminants may be encountered by an organism dictate the contaminant's "bioavailability" and determines its toxicity. Organism responses to chemicals vary based on chemical-specific modes of action and species-specific sensitivity, and risk profiles for different contaminants vary accordingly. Contaminant distribution and exposure potential in the environment also vary based on chemical fate properties (e.g., hydrolysis, biodegradation, volatilization), including the tendency to bioaccumulate and be transferred within the food chain.

Sustainability and Sustainability Principles – The literature reviewed regarding beneficial uses of sediments, makes frequent reference to "sustainability" or "sustainability principles." The authors adopt the definitions as set forth in UN 2015a and Laboyrie et al., 2018. Sustainability involves balancing uses of resources, investments, and societal acceptance to achieve current and future goals or needs without compromising future generations' needs. The United Nations passed resolution A/RES/70/1 "United Nations Transforming our world: The 2030 agenda for sustainable development" which discusses sustainability as an approach to inform social, environmental, and economic development. The agenda identified 17 sustainable development goals which encompass broad interests, values and objectives, water infrastructure projects touch on many of the sustainable development goals and therefore the development goals can be used to guide or weigh decisions affecting such development projects.

The book "Dredging for Sustainable Infrastructure" published by the Central Dredging Association (CEDA) and International Association of Dredging Companies (IADC) (Laboyrie et al. 2018) notes that sustainable projects or infrastructure should efficiently invest the resources needed to support desired social, environmental, and economic services (three pillars of sustainable projects) for the benefit of current and future generations. Balancing the present with future performance gives weight to design choices that result in efficient uses of resources, and which consider long-range performance needs such as may be realized through designs that work with natural processes and which best harmonize with ecosystem characteristics. Beneficial uses of sediments as a resource often aid the framing or development of a sustainable project plan. They also cite seven principles of sustainable dredging outlined by the World Organization of Dredging Associations (WODA) in its 2013 communication to members, which are paraphrased as follows:

1. Systematically consider social, environmental, and economic objectives in planning dredging projects.
2. Work with natural processes, consider site-specific characteristics of ecosystems, and understand the carbon footprint in developing the project objectives and design.
3. Engage a broad range of stakeholders actively and collaboratively beginning early in planning.
4. Use scientifically based criteria, performance guidelines, and environmental safeguards.
5. Consider dredged material management options that reflect a holistic and systematic understanding of the ecosystem and natural processes, and prioritize beneficial uses, such as shoreline nourishment, habitat enhancement and restoration.
6. Consider dredging a key solution for remediation or restoration of historically contaminated aquatic sites.
7. Analysis of monitoring and assessment information before, during and after project implementation provides a basis for effective and sustainable project management.

Green and Sustainable Remediation (GSR) – U.S. EPA released a primer in 2008 on incorporating "green remediation" into contaminated site cleanups. This document defines green remediation as "the practice of considering all environmental effects of remedy implementation and incorporating options to maximize net environmental benefit of cleanup actions" and goes on to identify examples of both short- and long-term environmental impacts that may affect environmental media throughout the cleanup process. The primer discusses how green remediation is part of the incorporation of sustainability principles, defined above, as a means to increase the environmental component of the "environmental, economic, and social benefits". In the following years, several states released their own fact sheets, primers, or frameworks on the combined term "Green and Sustainable Remediation", which extends EPA's definition of green remediation to include methods and technologies that incorporate all three pillars of sustainable principles into the site remediation process. See: https://www.epa.gov/remedytech/green-remediation-incorporating-sustainable-environmental-practices-remediation

Waste – Waste comprises discarded materials such as garbage, refuse, sludges, and byproducts from processing facilities in solid, semisolid, liquid, or contained gaseous forms. Such materials can result from industrial, commercial, mining, and agricultural operations, as well as other anthropogenic activities. Wastes that are reactive, flammable, corrosive, radioactive, or acutely toxic are classified as hazardous substances[2]

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[2] Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) section 101(14), as amended, defines "hazardous substance" by referencing other environmental statutes, including:

- Clean Water Act (CWA) sections 311 and 307(a)
- Clean Air Act (CAA) section 112
- Resource Conservation and Recovery Act (RCRA) section 3001
- TSCA section 7

CERCLA section 102(a) also gives EPA authority to designate additional hazardous substances not listed under the statutory provisions cited above. There are currently about 800 CERCLA hazardous substances. In addition, there are approximately 1,500 known radionuclides, approximately 760 of which are listed individually (https://www.epa.gov/epcra/cercla-hazardous-substances-defined).

and regulated in most jurisdictions. Waste can also include animal waste, earthen fill, sewage sludge, solid or dissolved material in domestic sewage, or other common constituents in water resources, such as silt or dissolved or suspended solids in industrial wastewater effluents or discharges. Waste is typically managed by treatment, destruction (e.g., incineration), or placement in landfills or other managed containment facilities.

Risk – In the general sense, risk is the probability of an undesirable outcome. The term, as used in this paper, refers to environmental (human and ecological) risk (taken to include human and ecological risks), which describes the possibility of a contaminant having an adverse effect on a living organism, population, or community.

Treatment – This term refers to treating a material or mixture to alter its physical and chemical character. Treatment usually requires inputs of energy, reagents, or admixtures, as well as physical processing, to alter the material to have desirable characteristics. Treating contaminated sediments to immobilize a chemical contaminant may involve exposing the sediment to high temperatures or a chemical oxidant or mixing the sediments with an adsorbent or a solidifying agent to render the contaminant inert or immobile.

Management – Sediment management refers to the set of decisions and actions undertaken to address a project-specific, regional, or societal need regarding disposition of sediment. Environmental regulations in the United States, Europe, and elsewhere require that the possibility of harm be assessed, and that acceptable uses limiting the possibility of harm are found, if contaminated sediments are to be used beneficially. Contaminated sediment risk management decisions may include evaluating and employing strategies that break risk exposure pathways and allow sediment to be utilized as a resource rather than a waste. The alternative is to dispose of contaminated sediments as waste, a process typically requiring significant inputs of energy, and resources to remove, transport, and dispose of the sediment in some form of containment repository. Disposal of contaminated sediments as a waste generates more waste. Adaptive management is a structured process involving continuous integrated planning and assessment to reduce uncertainty for ongoing management decisions as earlier decisions are being implemented (Attachment 1). Adaptive management is especially useful on large, complex sediment remediation sites requiring ongoing, multi-phase, interrelated sediment management decisions over multiple years.

4. Research Approach

The research approach involved two teams: a technical leadership team consisting of Eric Dott, Eric Hedblom, Luca Sittoni, and John Toll, and a research team consisting of experienced researchers and editors. The research team performed coordinated Internet searches to develop a bibliography of beneficial contaminated sediment use papers, publications, and policies that were discussed with the technical leadership team during weekly team meetings to identify potential areas for further research.

Beneficial use of contaminated sediment has been an important topic since the 1990s. Accordingly, the research team identified more than 170 references for inclusion in the bibliography (Section 8). The bibliography presents the resources identified through existing information known to the technical leadership team, integrated with internet searches of professional and scientific literature and regulatory and related non-governmental organizations charged with aquatic resource management. The research process relied on the foundation provided by the recent work of the PIANC Working Group 214 (PIANC 2018), the SedNet Working Group (SedNet 2021), the Western Dredging Association (WEDA 2021), and the Central Dredging Association (CEDA 2019a, b). The technical leadership team members are heavily involved with these groups, both in person and through professional relations.

The annotated bibliography (Attachment 2) includes summaries of more than 50 references judged to be the most relevant by the authors, organized into the following categories:

- Regulatory Guidelines
- Examples of Beneficial Use (“What Works”)
- Barriers to Use (“What Doesn’t Work”)
- Remediation Decision-Making Frameworks and Strategies (includes subsections Traditional Strategies [pre-2010], Case Studies/Guidance Documents of Management Strategies [post-2010], Proposed Green and Sustainable Remediation/Life Cycle Assessment Frameworks)
- Techniques and Technologies

The annotated bibliography categories are intended as an aid to the reader in determining which papers, publications and websites are most appropriate for their specific needs or interests.

Findings from a review of North American and EU/UK regulatory programs are presented in the attached tables (Table 1. Comparison of Regulatory and Other Programs – North America; Table 2. Comparison of Regulatory and Other Programs – Europe).

5. Regulatory Programs

Contaminated sediment management is not consistent among the various regulatory programs charged with making and enforcing sediment management policy in North America, the EU, and the UK. As such, this paper includes a review of applicable regulatory programs presented in the attached tables. Table 1 identifies programs in US states and Canadian provinces, as well as regional and binational US and Canadian programs; Table 2 identifies programs in the EU and the UK. Each table specifies whether the research found publicly available information indicating that each identified program permits beneficial use of sediments. Researcher notes are included in the tables and comprise references, Internet links and notes regarding the sediment management approach or framework being employed by a given jurisdiction, as applicable. Regarding the many instances for which the research revealed little or no information, this is noted as well.

While there is a considerable amount of information provided in the tables, these should not be considered a complete compendium of all programs and practices that may exist for all relevant jurisdictions. The authors suggest that the tables provide an indication of the general state-of-affairs with respect to sediment beneficial use adoption in jurisdictions with publicly available information. The paucity of noted cases wherein beneficial use of contaminated sediment has been implemented is marked.

A detailed spreadsheet is also provided as a companion to this paper; it includes the Table 1 and 2 information as well as whether programs allow beneficial uses of sediment in upland applications only, or if they also may consider in-water uses (such as habitat or coastal restoration). These additional details indicate that some programs (e.g., in The Netherlands, State of New Jersey, and State of California) appear willing to consider processes by which contaminated sediment may be managed to control potential risks or risk pathways.

6. Literature Overview Regarding Contaminated Sediment Beneficial Use

As noted in Section 4, the literature review resulted in the annotated bibliography presented in Attachment 2 and organized into five pertinent categories:

- Regulatory Guidelines
- Examples of Beneficial Use (aka "What Works")
- Barriers to Use (aka "What Doesn't Work")
- Remediation Decision-Making Frameworks and Strategies
- Techniques and Technologies

This section summarizes the key findings within those categories.

Regulatory Guidelines

The regulatory information discussed here is broadly organized geographically covering North America (Table 1) and EU/UK (Table 2). The literature reviewed pertaining to regulatory programs and policies includes well-developed guidelines and resources for managing dredged sediment. However, where found, the regulatory program literature focuses on methods, procedures, and criteria for beneficially using *uncontaminated* dredged sediments.

Tables 1 and 2 (Column 3, "Recognizes beneficial uses of (clean) sediment") show that nearly all the jurisdictions with information available share a common starting point—that *uncontaminated* sediment may be beneficially used. Publications annotated in Attachment 2 under this category focus on how sediment may be characterized for beneficial use (NDT 2003; AINA 2008; Commonwealth of Australia 2009; USACE 2020; DHV B.V. 2013; USACE et al. 2018). Most of the work focuses on habitat-restoration uses for what would be characterized as clean sediments except when used for an upland purpose, where soil screening criteria may apply.

A representative example in the United States comes from the Minnesota Pollution Control Agency's guidance document, "Managing Dredge Materials in the State of Minnesota (USA)" (MPCA 2014) (Table 1 and Attachment 2).

North America

Since the 1990s, initiatives to promote and expand beneficial use of sediment have gained traction by offering clean sediment as a resource (Ulibarri et al. 2020; Milligan and Holmes 2017; USACE 2015; CEDA 2010; NDT 2003). While most US coastal and Great Lakes states recognize beneficial uses, nearly all states consider sediment removed from a water body to be a waste, so they have had to develop waste management policies to allow for beneficial uses (Table 1).

Review of the Atlantic and Pacific coastal Canadian province regulatory programs identified almost no references to beneficial use of sediment (Table 1). Ontario, on the Great Lakes, is an exception, providing information on beneficial use of sediment and outlining its contaminated sediment management programs on its website (OMOE 2011). Ontario has developed risk-based criteria for evaluating sediment quality and considers contaminated sediment sites and risks on a case-by-case basis, such as at a site in Thunder Bay, Ontario, where contaminated sediment was beneficially used as fill to improve upland port land and dock structures (Ancheta 1998 and Attachment 2). Ontario is a member of the Great Lakes Dredging Team, a regional effort to coordinate dredging approaches and sediment management across the Great Lakes states and provinces (GLDT 2016). As shown in Table 1, most US coastal states and have either established beneficial use policies or developed full programs with guidance and standards or criteria.

The literature references the fact that open water or open ocean disposal of sediments is becoming less acceptable (OSPAR Commission 2021; Douglas et al. 2003). In North American jurisdictions with marine coastal waters, restrictions and bans on open ocean disposal of either clean or contaminated dredged sediments have spurred identification of beneficial uses for these sediments in New York/New Jersey Harbor, San Francisco Bay, Los Angeles, and San Diego-area jurisdictions since the 1990s (Maher et al. 2020; CRWQCB 2012; Moffatt & Nichol et al. 2009; POLB 2021). Minnesota and Wisconsin ban open water disposal (MPCA 2014; WDNR 2015), making management of sediments in this region a challenge (GLC 2001).

USACE: A leader in beneficial use

Some authors note the United States and Japan have made significant progress in beneficially using dredged sediments (Stern et al. 2019; Maher et al. 2017; Watabe and Noguchi 2011; Kitazume and Satoh 2005). Ausden et al. (2018) and Bell et al. (2021) highlight the USACE's regional efforts to promote and include beneficial use of sediment in its projects as an example. The authors assert the need to implement such efforts at a regional level and to involve key parties affected by project planning as well as experts in the field of sediment management.

Wijdeveld (2019) compares EU environmental programs to those in the U.S. and notes that the "polluter pays" principle in the U.S. and the shared responsibility viewpoint of the EU are two different lenses through which to view sediment and its use as a resource. Ausden et al. (2018) note that progress in the U.S. typically occurs where leadership has advocated for beneficial use, and that the USACE has often provided that leadership. The USACE is responsible for maintaining public waterways and navigation as well as coastal protection—two tasks that can be mutually beneficial because dredged materials (primarily clean maintenance dredged sediment to date) can be used effectively for coastal/shore protection purposes.

The USACE began beneficially using clean maintenance dredged sediments, mainly as a cost-saving strategy, in the 1940s. The practice was largely focused on beneficially using (clean) maintenance dredged sediments (Bell et al. 2021). With increased awareness of the need to manage contaminated sediments and water quality, the USACE has adapted and grown its expertise in managing sediments in environmentally appropriate ways. The public works nature of navigation dredging, as implemented by the USACE, allows projects to proceed with beneficial use of contaminated sediments (Ausden et al. 2018; Bell et al. 2021; Wijdeveld 2019). Where planning for sediment beneficial use has been undertaken as a regional effort linked to transportation and navigation, the concept has taken hold. The USACE has played a central role in helping form and lead numerous sediment management planning efforts, and standing regional teams now exist for all coastal areas of the US as well as some waterways (Lukens 2000; USACE 2020; Schrader 2019; Parson and Swafford 2012; POLB 2021) (Attachment 3).

Key guidance in EPA planning manual

The EPA also has a key role in supporting beneficial use of maintenance (clean) dredged materials, especially in support of environmental restoration opportunities (EPA and USACE 2007a) which is largely accomplished through the USACE and the National Dredge Team (NDT 2003). The EPA and USACE (2007b) planning manual identifies that "...assessing the level of contamination in dredged material is a key step in determining its suitability for beneficial uses. In general, the more contaminated the material, the greater the constraints on reuse." This guidance manual goes on to say "...highly contaminated material is not usually suitable for reuse unless its potential risk for biomagnification is low. The important issue is not so much whether the material is contaminated but whether the level and type of contamination are consistent with the intended use (EPA and USACE 2007b)."

Recently the EPA developed a dredged material beneficial use decision tool for evaluating and comparing dredged material management planning, decisions, and stakeholder engagement (EPA 2020).

Emerging regulatory flexibility

The literature and regulatory review specifically searched for instances where contaminated sediments had been considered for beneficial use. There are no programs for beneficially using contaminated sediments *per se;* however, there are some examples of regulatory flexibility being used to consider specific cases of beneficial use of sediments that were anthropogenically contaminated. U. S. states open to considering contaminated sediments for beneficial use are typically those with a pre-existing cleanup program and policies that include an approach to decision-making based on risk management and effects-based evaluations. Instances include California, New Jersey, New York, Maryland, Delaware, Connecticut, and Minnesota (Table 1, Column 6, "Considers uses of contaminated sediments"). Regulatory flexibility also exists in the Netherlands, where the "stand still" principle exists (Table 2). It affirms that sediment can be used within the same water body if it does not worsen its quality and does not exceed certain threshold values. Other countries reviewed in Europe, where some regulatory flexibility appears to exist, are noted in Table 2 (Column 3, "Considers Beneficial Use of Contaminated Sediment"). However, some countries direct that contaminated sediments above specific risk thresholds be used only in confined settings or for specific upland purposes, and in some cases, pre-treatment is also required (Table 2).

Another relevant factor is the magnitude of need for finding non-disposal options for sediment that must be dredged to maintain navigation. Most of the extant examples are in large, urban ports with long histories of industrial activity and an ongoing need to maintain navigation channels. For example, in New York/New Jersey Harbor, sediment with impacts exceeding open-ocean disposal acceptance criteria have been stabilized (i.e., treated) and used for upland fill, geotechnical-amended fill, landfill capping, and mine/quarry reclamation (Maher et al. 2020). A description of beneficial use activities in New York/New Jersey Harbor is included in Attachment 3. Another such example is the Middle Harbor project of the Port of Long Beach, California, where more than 4 million cubic yards of fill were needed for a $1.5 billion container terminal modernization and expansion project (POLB 2021) (Attachments 2 and 3). This 10-year, three-phased project filled unused slips with 2.2 million cubic yards of sediment and upland fill, a sizable portion of which was contaminated sediment dredged from part of the project area. An additional 2 million cubic yards of imported fill and sediment was solicited from within the Los Angeles and Long Beach region (POLB 2009. Powers 2017; Tomley 2016). This project developed a protocol and state-approved program for acceptance and selection of sources of clean and contaminated sediment for beneficial use, as well as fill soil from brownfield sites near the project location (POLB 2009). The result of these efforts was the creation of a 300 – plus-acre cargo terminal and expanded boat slip area (POLB 2021). Attachment 3 further describes this project.

The Montezuma Wetland Restoration project in the San Francisco Bay estuary in California also provides an example of regulatory flexibility and regional coordination in the beneficial use of sediment. The estuary is the largest on the Pacific Coast of North America and includes an important harbor requiring more than 1.2 million cubic yards of annual maintenance dredging (DMMO 2021). The Bay Area also faces major concerns over loss of critical salt marsh habitat and major subsidence of former marsh lands and upland areas (as much as 10 to 15 feet below sea level), as well as pressure to reduce open water dredged sediment disposal. A consortium of governmental and non-governmental entities recognized an opportunity to beneficially use dredged sediment for habitat restoration. This regional group is working to restore more than 2,300 acres of regional salt marsh. A description of the San Francisco Bay estuary Montezuma Wetland Restoration project is included in Attachment 3.

Minnesota, located on Lake Superior and the upper Mississippi River, has guidance on managing dredged sediment (MPCA 2014) that includes a flexible, risk-based approach using ecological effects-based sediment criteria (MPCA 2007) and soil risk-based criteria to guide how the material may be handled. Although Minnesota statutes define dredged sediment as a waste, this guidance provides potential paths for sediment to be accepted for beneficial use in water for habitat restoration projects if the conservative quality criteria are met. If the criteria are exceeded, then risk-based criteria may be applied for use in an upland setting. If upland soil criteria are exceeded, the sediment would need to be treated or disposed of as a waste.

Europe

A similar picture emerges in literature regarding European practices (OSPAR Commission 2021; Sapota 2011) (Table 2). Open ocean disposal with no beneficial use is viewed increasingly negatively in the EU, and multi-country conventions such as the London (1972), OSPAR (1992), Barcelona (1976), and Helsinki (HELCOM) (1992) conventions generally require that ocean disposal be conducted with care toward preventing adverse environmental impacts.

European countries such as The Netherlands, Belgium, France, and Italy have established programs to beneficially use dredged sediments (Dede et al. 2018; Wijdeveld 2019; Grandchamp et al. 2014; Sapota 2011; D.L. 152/2006; D.M. 172/2016; D.M. 173/2016; D.L. 152/2006). The Netherlands have adopted a flexible evaluation of beneficial uses with respect to a select list of contaminants and certain upland uses. Its program takes toxicity and bioavailability into account and considers the local setting and land use as part of the evaluation process for upland beneficial uses of sediment (Wijdeveld 2019; Grandchamp et al. 2014). Beneficial use of sediment in-water for purposes such as beach nourishment, coastal defenses, dikes, or habitat restoration projects is typically subject to the most conservative acceptance criteria (i.e., non-contaminated maintenance sediments). Across the other European countries reviewed, only sediment with low (or no) contaminant concentrations are considered for these types of habitat restoration or in-water uses (Grandchamp et al. 2014; Sapota 2011; Wijdeveld 2019).

European literature contains multiple discussions of beneficially using sediment as a raw material, to make bricks or tiles as a component of cement or as geotechnical fill (once the sediment has been stabilized). Attachment 2 provides specific examples regarding use as a raw material. The primary driver for evaluating such beneficial uses is a desire to sustainably manage sediment rather than dispose of it in landfills (Dede et al. 2018; Lemiere et al. 2012). Other beneficial uses for dredged sediment in The Netherlands include using it as a soil amendment, to restore agricultural soils, for reclamation, such as is presented in CEDA (2019b) case study “R2A_1995_NL”. Life cycle analysis evaluations considering agricultural land treatment compared to treatment and disposal options are discussed in Pasciucco (2021) and Dede et al. (2018). Regulatory criteria for these types of uses focus on protecting crop health and water quality. Criteria applied to upland soil uses are only slightly less conservative than for sediments proposed for use in wetland or shore zone restorations (Dede et al. 2018).

The EU is developing a taxonomy focused on adaptation and sustainability strategies within the Green Deal (EU 2019) and its fiscal policy (EU 2020). The EU taxonomy will work in concert with the six sustainability-based principles that govern the Green Deal: 1) climate adaptation, 2) climate mitigation, 3) circular use of natural resources, 4) zero pollution, 5) healthy water ecosystems, and 6) biodiversity (EU 2019, UN 2015a). Beneficial sediment use touches on all these themes, while contaminated sediment use focuses mostly on the third, fourth, and fifth principles. Some key EU commitments, such as a fully circular economy and zero carbon dioxide emissions by 2050, stem directly from this longer-term perspective (EU 2019, UN 2015b).

European goals of developing a more circular economy (EU 2019; EU 2020; Mazur-Wierzbicka 2021) and undertaking urgently needed climate adaptation measures (UN 2015b) are linked to beneficial uses of sediment (Bardos et al. 2020; Ausden et al. 2018). Indeed, there is an increasing number of articles discussing these considerations with respect to natural resource management and environmental planning (Apitz et al. 2017, Noren et al. 2020, Cappucci et al. 2019, and Pasciucco et al. 2021). These two important concepts appear to be driving interest, inquiry, and potentially innovation.

Regional efforts are important

Literature on United Kingdom projects and programs notes that promoting and planning for beneficial use of sediment is important, requires pre-planning and consultation, and benefits from a regional viewpoint. The Solent region of England is an example of how a region within the UK has focused on beneficially using sediment for coastal restoration projects (Bardos et al. 2020; Ausden et al. 2018). In the Solent coastal area, dredged sediment is being beneficially used to fortify shore areas where erosion or subsidence has diminished tidal marsh area. ABPmer (2018) describe recent beneficial use projects in the Solent area, including placement to a) enhance tidal marshes, b) create island marshland, c) use offshore placement to supply longshore transport to slow erosion of an existing marsh, and d) discharge dredged material onto a marsh area to aid restoration. The ABPmer (2018) report also describes proposed approaches for continuing and expanding beneficial uses of dredged material to support coastal beach and tidal marsh restoration efforts.

Another regional program worth noting is the Eems-Dollard 2050 program developed in The Netherlands. This program stems from the need to improve the water quality and ecology of the Eems-Dollard Estuary, suffering from excess turbidity levels. Different strategies are being tested and evaluated to beneficially use dredged sediment from the Eems-Dollard beneficially for applications such as dike strengthening or improvement of agricultural land, for counteracting subsidence as well as to improve the fertility of the soil. A parallel program, *Verbetering Landbouwgronden door Ophoging met slib uit de Eems-Dollard* (VLOED), is currently ongoing to evaluate technical but also socio-economic and legal feasibility to implement those solutions and regional scale (ED2050 2022). In this example, sediment issues requiring management include salt and organic content and require regulatory flexibility similarly to chemical contamination.

Dede et al. (2018) and Grandchamp et al. (2014) describe a continuing effort in Europe to plan for and coordinate sediment management and water quality initiatives at the regional watershed level. Watersheds often extend across countries. In this case, multiple countries are now working together to implement the EU Waste and Water directives. The authors point out, however, that much work is still needed to develop consistent criteria for sediment screening because criteria and procedures vary across the EU. A common set of guidelines or procedures among multiple countries is likely still a long way off unless agreement can be reached on ways to evaluate projects and make choices—for example, through shared policies as is recommended by Dede et al. (2018), Grandchamp et al. (2014), and Wijdeveld (2019).

International Forum

Both North America and Europe have programs that could permit beneficial uses of sediments, including environmentally appropriate beneficial use of contaminated sediments. "Environmentally appropriate beneficial use" of raw materials that have been polluted by the byproducts of human activities is a central issue addressed in the 1992 Rio Declaration on Environmental Development (United Nations 1992), which has over 175 national signatories. The Rio Declaration is comprised of 27 principles intended to guide countries in future sustainable development. Some address environmentally appropriate beneficial use. For example, principle 4 asserts that environmental protection cannot be considered in isolation from the development process. Other principles in the Rio Declaration address equally important matters, e.g., protecting the interests of future generations, importance of inclusive processes, and managing transboundary issues.

Perhaps the most often cited, and most misunderstood of the Rio Declaration's principles is principle 15, which has come to be known as the "precautionary principle." The precautionary principle states that "lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." Ironically, the precautionary principle commonly is misinterpreted as a call for risk aversion, which can have the effect of postponing cost-effective measures to prevent environmental degradation. In fact, the precautionary principle is closely connected to adaptive management. Adaptive management techniques allow people to experiment with beneficial use ideas, despite the lack of full scientific certainty (Attachment 1). Adaptive management experiments are scientifically monitored to develop the evidence needed to identify, adopt, and scale-up measures that will yield important environmental benefits, while appropriately managing associated risks. Clark (1980) uses the term "soft-fail" to describe "resilient" environmental management alternatives that will yield important environmental benefits while appropriately managing associated risks, without being paralyzed by the need for "full scientific certainty," which is unattainable. Clark was part of the group of researchers at the University of British Columbia that literally wrote the book on adaptive management of renewable resource systems (Walters 1986). The precautionary principle recognizes the importance of "*robustness to the unknowns on which actual coping performance is contingent.*" It calls for the use of the scientific method to explore potentially beneficial, cost-effective uses while developing the scientific knowledge necessary to prevent unacceptable environmental degradation.

In summary, the Rio Declaration allowed nations from around the world to declare that environmental protection and the development process are inseparable, and that the scientific method, applied within an adaptive management and inclusive decision-making framework, is the engine that allows society to turn uncertainty about impacts into environmental progress. The beneficial use of contaminated sediment is one promising opportunity to apply these principles, by working with nature to enhance the flow of ecological services.

Examples of Beneficial Use ("What Works")

The 12 publications annotated (Attachment 2) for this category include numerous examples of beneficial use of sediment and presentations on useful pilot projects and approaches. One document, *Sustainable Management of the Beneficial Use of Sediments: A Case-Studies Review* (CEDA 2019b), presents 38 case studies, 20 of which involved beneficially using contaminated sediments. Several publications discuss supporting or complementary techniques or ideas relevant to contaminated sediment beneficial use such as in roadbeds, berms, geotechnical applications as fill, cover material (CEDA 2019b; Balkaya 2019). Examples of beneficial use of contaminated sediment often involve using sediment as a raw material (e.g., construction material for dikes, bricks, etc.) or as upland fill or cover (Amar et al. 2021; CEDA 2019b). The literature review identified numerous instances in Europe and North America wherein contaminated sediments have been successfully stabilized (usually with a pozzolanic binder) and used for upland fill or cover (Maher et al. 2020; De Gisi et al. 2020; HLA 2000; Kinsella et al. 2013; Silitonga 2017).

The literature identifies how pre-planning and regional coordination have been necessary; these efforts are commonly cited as essential to the successful acceptance and permitting of beneficial use projects. Pre-approved uses and programs to match dredged sediment with projects needing sediment are becoming more common in North America and Europe (Ausden et al. 2018; SFBJV et al. 2021).

In the New York and New Jersey harbor area, Douglas et al. (2003) note that an important aspect of the successful efforts to beneficially use Portland cement-stabilized contaminated dredged sediment from the harbor for upland geotechnical fill was the creation of a program patterned after the concept of a "beneficial use determination" for solid waste. Under this program the State of New Jersey allows use of contaminated dredged material based on the nature of the resulting stabilized material and the environmental controls at, and intended use of, the placement site. An evaluation is performed to confirm that the proposed use will protect human health and the environment. Based on that finding, the state then issues an "Acceptable Use Determination." The Determination is issued for the processing and placement sites and the steps of the processing (Douglas et al. 2003) (Attachments 2 and 3).

The Middle Harbor project literature notes that including the plan to beneficially use clean and contaminated sediments in the filling for this large project from the very earliest stages of planning and environmental review, helped with acceptance and in developing the approach with relevant regulators and stakeholders (POLB 2005, 2021; Tomley 2016). In addition, the Port of Long Beach developed an environmental protocol for regulator concurrence and to guide how the project would evaluate and accept materials for the Slip 1 and East Basin fill (POLB 2009) (Attachments 2 and 3).

Barriers to Beneficial Use ("What Doesn't Work")

A common theme among beneficial use projects is that they are usually restricted to minimally contaminated sediment, which some publications refer to as sediment with ambient levels of anthropogenic constituents (SFB RWQCB 2000). Sediments with elevated concentrations of anthropogenic chemicals or compounds or non-native materials (i.e., micro-plastics or solid waste debris) typically are not considered for beneficial use, even if it would reduce or eliminate existing risk exposure pathways. The screening criteria used by most jurisdictions are conservative. Among programs that have upper and lower criteria, the upper criteria are typically selected as protective, with a margin of safety applied to provide high confidence of protectiveness, assuming contamination resides in a setting where long-term exposure is expected to occur (ITRC 2005).

In the authors' cumulative experience, permitting and licensing procedures are multifaceted, complex, frequently unclear, and require extensive consultation. These activities may require coordination with local and regional authorities, as well as national entities and tribal governments in some cases. Public consultations are also required by most jurisdictions. Each proposed beneficial use is handled uniquely; consequently, there is little chance of streamlining the process. This is particularly true for contaminated sediments. Public trust or acceptance is an impediment to both implementing uses of contaminated sediments in the environment and creating products using contaminated sediment as a raw material. Cappuyns et al. (2015) note that bricks created using sediment that had been classified as contaminated were considered suspect by consumers with respect to their quality and safety. This aversion could be overcome through educational campaigns that explain the benefits of reducing waste and producing products that greatly lessen the potential for significant exposure to contaminants. Such efforts might be analogous to campaigns explaining the environmental benefits of gray water use in applications that result in relatively low exposure to gray water contaminants (WWG 2021).

Remediation Decision-Making Frameworks and Strategies

The research team assembled a body of literature on processes for evaluating remediation strategies for contaminated sediments and guidance from USACE regarding determining the suitability of dredged material for beneficial uses. Included is EPA guidance for evaluating beneficial uses of industrial non-hazardous secondary materials (EPA 2016b), as well as a companion collection of resources and tools supporting beneficial use evaluations (EPA 2016a). Maher et al. (2013) provide an engineering manual on processing and beneficially using fine-grained dredged sediment, with case examples specific to the marine and coastal estuaries of New Jersey and New York.

Programs where guidance on beneficial use decision frameworks are presented all include the concept that acceptance criteria should be developed and that monitoring of performance both during implementation (construction) and post-construction is necessary to assure effectiveness and protectiveness. Examples include: EPA and USACE guidance (2007b), the Solent coast of eastern England (ABPmer 2018; Ausden et al. 2018); the Port of Long Beach and Los Angeles (POLB 2005 and 2009); the San Francisco Bay estuary restoration effort (aka Montezuma wetland restoration) (CRWQCB 2012, CSWRCB 2018.), the port of New Jersey/New York (Douglas et al. 2003 and Maher et al. 2020), the port of New Haven, Connecticut (Tipping Point 2021). The concept of adaptive management fits well in this context and is recommended by the National Research Council for managing water resources projects (NRC 2004) and in guidance from the US Army Corps of Engineers (Fischenich et al. 2019).

Proposed Green and Sustainable Remediation/Life Cycle Assessment Frameworks

Simply managing sediment as a waste has significant negative tradeoffs. This approach is costly in terms of energy used, landfill space occupied, and emissions produced, and imposes other, less measurable impacts such as social costs (Apitz et al. 2018). Milligan and Holmes (2017), and Laboyrie et al. (2018) and CEDA (2019a) note that there are important opportunities to use contaminated sediment to benefit infrastructure improvements, such as those needed to implement climate change adaptation. Indeed, there are increasing calls to accelerate these efforts as climate change forces a need to adapt waterfronts, estuaries, coastlines, watersheds, and waterways (Bardos et al. 2020; Temmerman et al. 2013). An emerging category of publications regarding contaminated sediment remediation presents new decision frameworks that evaluate broader stakeholder and environmental concerns than did pre-existing evaluation frameworks. These new frameworks typically incorporate the principles of green and sustainable remediation and discuss considering sediment as a resource, while accounting for environmental, social, and economic factors when evaluating sediment uses other than simple disposal (Apitz et al. 2018; Bardos et al. 2020). Sediment life cycle assessments (LCAs) are a specific type of these sustainability-focused decision frameworks that allocate decision-making criteria for both the short- and long-term environmental impacts of contaminated sediment remediation alternatives (see **Section 3 Terms and Definitions** for discussion of green and sustainable remediation, sustainability and sustainability principles**)**.

Apitz et al. (2017) outlines an effort to identify multiple stakeholder values related to sustainable elements of the large Portland Harbor Superfund site, laying out a stakeholder value assessment (SVA) tool that evaluates stakeholder value-associated costs and benefits of remedial alternatives. The SVA tool could be useful for scoring beneficial uses higher than traditional disposal or remediation measures, thereby identifying the benefits of managing contaminated sediments in a sustainable yet responsible manner.

Bardos et al. (2020) discuss "sustainability linkages" for managing contaminated sediments at coastal brownfields sites and propose a framework to evaluate such linkages. Barjoveanu et al. (2018) present an LCA on stabilization/solidification treatment processes for contaminated marine sediments in southern Italy, where such scenarios were concluded to be beneficial. Lemiere et al. (2012) also discuss LCA in beneficial use evaluations in making the case for material recovery from waterways in Belgium and Northern France.

Labianca et al. (2020) present the use of a multi-criteria decision analysis approach for selecting best sediment remediation options. The authors discuss how involving stakeholders in the analysis can aid in developing their buy-in of final selected approaches. This idea might have relevance for beneficial use evaluations of dredged sediment, either as a separate step or as part of remedy selection.

Noren et al. (2020) and Pasciucco et al. (2021), both focusing on procedures in Europe, use sustainability-focused evaluations to develop information on using contaminated sediments in beneficial ways. Noren et al. (2020) use an integrated assessment method; interestingly, they discuss an evaluation of value potentially derived by extracting metal contaminants (to reduce contamination) and offsetting the costs of management of the remaining sediment. This concept of extracting metals from sediment is identified as a potential benefit—especially with increasing price of metals and cost of landfill disposal— providing an opportunity for a circular economy. Pasciucco et al. (2021) conclude that beneficial uses compare favorably to placing contaminated sediment in a landfill.

Reddy and Kumar (2018) and Sparrevik et al. (2011) review sustainability evaluations that consider multiple sediment management options including assessing beneficial sediment uses versus remediation/disposal options. Both references touch on evaluating primary and secondary impacts. Sparrevik et al. (2011) develop an LCA to compare methods of addressing polychlorinated biphenyl (PCB) contamination in sediments in Norwegian fjords; they advocate that LCA better evaluates the long-term benefits of beneficial use against the short-term higher resource and financial costs.

Techniques and Technologies

Based on the literature review, several techniques or technologies have been used successfully to manage concerns of contaminant risk in support of beneficial use of contaminated sediment. These include:

- Various applications of cement stabilization
- Physical separation such as placement within an upland structure or changing the location to one where risks are managed (i.e., beneath, or as part of, a cap or cover or within a wharf or embankment)

- The use of amendments to chemically bind contaminants such as the use of activated carbon or biochar (amendments)

The following paragraphs highlight representative literature on these three techniques and technologies.

Cement Solidification/Stabilization

Cement stabilization, a well-known waste treatment method, has been used for decades to treat contaminated dredged material (sediment) in the New York/New Jersey harbor. More than 30 million cubic yards of the contaminated sediment have been stabilized/solidified using Portland Cement to create upland geotechnical fill. This key finding from the literature review is highlighted with annotated bibliography information providing further highlights for Douglas et al. (2003) and Maher et al. (2020). See Attachment 3 for more details on the methods used and the state regulatory program that have been developed to support these efforts. Stabilization is also the focus of Amar et al. (2021), who evaluated incorporating contaminated sediments into cement or concrete, finding that with appropriate treatment sediment-based concrete performs like control concrete.

In Todaro et al. (2019) both cement stabilization and the addition of amendments are investigated. In this article sediments were treated with activated carbon or biochar and evaluated for how these sediments then perform in stabilization/solidification processes. The authors find that neither pre-treatment adversely affects the stabilized sediment end-product, and both pre-treatments help reduce the bioavailability of contaminants.

CEDA (2019a) presents a case study of a project in Oslo (Norway) Harbor, from which tributyl tin (TBT), metals, and PAH-contaminated sediment was dredged, stabilized with a mixture of 50% ground granular blast furnace slag and 50% Portland cement, and subsequently used in constructing a new quay wall along the harbor shoreline on which a pedestrian parkway was then constructed.

Physical Separation Techniques

The Montezuma Wetland Restoration project in the San Francisco Bay area is an example of contaminated dredged sediment being used by physically separating it from the overlying wetland restoration. In this large-scale tidal marsh restoration effort, moderately contaminated dredged sediment is physically separated from the overlying wetland restoration by first placing it at depth ("foundation" sand) and then covering it with cleaner ("cover") sediment, essentially capping the contaminated sediment (CRWQCB 2012; SFB RWQCB 1992; SFB RWQCB 2000). The regulatory program for acceptance of contaminated sediments in this project is presented in CRWQCB (2012). To address the issue of subsidence across the estuary, the "foundation" sediments provide the benefit to the restoration project of filling the basal volume required to raise the overall elevation of the restoration project area back to near current sea level, so that once the final clean sediments are placed the restored area can once again function as a tidal marsh in connection with the adjacent San Francisco Bay estuary. This example is discussed in further detail in Attachment 3. Table 1 calls attention to this project as a rare instance where contaminated sediment is used beneficially for an in-water purpose. It is also a model for how sediment resources may be used as part of future efforts to subsidence.

At the Port of Long Beach for its Middle Harbor redevelopment project 4.8 million cubic yards of sediment and soil fill were needed to develop its state-of-the-art cargo terminal expansion starting in the early 2000s and spanning a ten-year development period (POLB 2021). Paralleling the approach developed in the Montezuma Wetland Restoration work in San Francisco Bay, the early Middle Harbor plan development envisioned beneficially using contaminated dredged sediment from nearby areas of the harbor that both needed remediating, but also needed to be removed for the necessary deepening and widening of the West

Basin Slip as part of this project (POLB 2021; Tomley 2016). The first dredging targeted the West Basin Slip contaminated sediment removal so that 400,000 cubic yards of PCB-contaminated sediment could be placed in the lowest portions (below the waterline) where they would later be covered by cleaner sediments and soils resulting in these and other contaminated (but non-hazardous) sediment and soil fill being "sequestered in the Slip 1 fill site..." (Tomley 2016). This example is discussed further in Attachment 3 and Table 1.

Use of contaminated sediments at Mosgoen Harbor, Norway, involved placement of polynuclear aromatic hydrocarbon (PAH)-contaminated sediment from decades of aluminum smelting operations into wharf structures, resulting in expansion of the harbor infrastructure (BRE Group 2019). Some of the sediment was also solidified after placement into steel sheet pile cells of the new wharf structures. Ancheta (1998) presents an early example of using contaminated sediment beneficially while also addressing contamination risks. The sediment remediation project on the northwestern shore of Lake Superior in Thunder Bay, Ontario, Canada, involved treating PAH-contaminated sediment dredged from a former paper mill waste deposit before placement with soil into a new harbor dock fill area. The contaminated sediment was physically isolated, thereby reducing exposure risk while providing fill to construct the new dock and pier feature.

Holm et al. (2014) discusses a Swedish study of successful beneficial use wherein metals- and organics-contaminated sediments were treated with the stabilization/solidification method (S/S) and subsequently used as fill material to expand the port area from which they were dredged. The authors argued the environmental merits of both expanding sea transport as well as using the sediment in place of other limited natural resources. An example of combining cement stabilization with physical separation is in Kinsella et al. (2013), who report on beneficially using dioxin-contaminated sediment dredged from a harbor, stabilized, and incorporated into a permanent capping system for a former landfill in Bellingham, Washington.

Use of Sediment Amendments for Binding Contaminants

Bianco et al. (2020) review literature on remediating polycyclic aromatic hydrocarbon (PAH)-contaminated sediments using biochar and its impact on beneficial use options. The authors conclude that biochar is effective at adsorbing PAHs in bulk sediments, and that further research should examine how to separate biochar from bulk sediments once PAH adsorption to the biochar has occurred. They suggest this amendment holds promise as a pre-beneficial use treatment.

De Gisi et al. (2020) performed pilot studies of amending contaminated sediment (PAH, PCB and metals) using lime, organoclay and activated carbon amendments. The study found that for their specific site in Italy, the various pre-treatment amendment options were necessary prior to stabilization and solidification with cement to help the stabilized sediments to pass a 28-day leaching test.

Todaro et al. (2019) explore pre-treating contaminated sediment with biochar or activated carbon before solidification/stabilization, concluding that this treatment "...does reduce the bioavailability of the contaminants through a sustainable treatment method."

Kupryianchyk et al. (2015) evaluate the use of activated carbon amendments with contaminated sediments and find that this treatment technology could be used *in situ* or *ex situ* with medium economic costs. This conclusion could be helpful in facilitating the acceptance of contaminated sediments for proposed beneficial uses.

CEDA (2019a) provides a position paper that includes evaluation and discussion of techniques and technologies for beneficially using contaminated sediment. For additional information on examples of beneficially using contaminated sediment we found that the CEDA (2019a, b) work is still relevant. It presents 38 detailed case studies involving beneficial sediment uses, including identification of techniques and technologies that have proven effective. Of the 38 case studies, 20 involve beneficial use of contaminated sediment. Both CEDA (2019a, b) and PIANC (2009) surveyed literature parallel to the literature reviewed for this paper.

7. Key Observations from Literature Review

Based on the literature review, the authors offer the following conclusions and observations on factors that help enable beneficial use of contaminated sediment:

1. **Sediment is increasingly seen as a resource, not a waste material.** Literature indicates a rapidly growing interest in evaluating how to use sediment as a resource rather than as a waste. This is particularly true among researchers and organizations publishing in Europe (Laboyrie et al., 2018, CEDA 2019a, PIANC 2009).
2. **Treatment or pre-treatment is commonly used to facilitate/expand potential options for beneficial use**. Some treatment or pre-treatment is often needed to reduce the bioavailability, mobility, and/or concentrations of contamination, thereby addressing the primary concerns of regulators and gaining acceptance for beneficial use. There is a well-established program of solidification/stabilization using pozzolanic compounds (i.e., Portland cement) to immobilize contamination.
3. **Beneficial use of contaminated sediments is more common in upland settings while rarer in aquatic settings**. The literature includes numerous examples wherein contaminated sediment was beneficially used in an upland setting or as a raw material; such examples often included some type of treatment or pre-treatment. Examples include as a raw material for making bricks or tiles, as upland fill, or, if concentrations are sufficiently low, as an agricultural soil amendment. The literature search identified only two instances of contaminated sediments being used beneficially in an aquatic setting. One is the Montezuma Wetlands Restoration Project (CRWQCB 2012), a summary of which is included in Attachment 3. There, moderately contaminated sediments were placed beneath other, cleaner dredged sediment, in effect capping the contaminated sediment. Another in The Netherlands is a program that allows mildly contaminated sediments to be used within the same water body if it is shown that its quality does not decrease as a result of the use. Mildly contaminated sediments were used to fill old gravel pits to regenerate past biodiversity by decreasing water depth. It is more common to beneficially use contaminated sediments in non-aquatic applications.
4. **End use of contaminated sediment affects both risk and risk acceptability**. Sediment is characterized as contaminated if it contains hazardous substances that make the sediment unsuitable for a particular use. The final disposition of the sediment, including any treatment or processing to reduce contaminant bioavailability, or placing it such that exposure pathways are reduced or eliminated, is important in determining the human health and/or ecological risks of beneficial use. For example, sediment contaminants might pose risk as substrate[1] but not as brownfield reconstruction fill. The notion that end-use affects risk acceptability is harder to convey. The idea is that a risk that is unacceptable if there's no concomitant benefit might be acceptable if benefits are created. People can distinguish their preferences among remedial alternatives that have the same residual risk by comparing the benefits associated with the alternatives. Appropriately determining beneficial use can mean putting contaminated sediment that is considered unfit for one purpose to good use for another purpose (CEDA 2019b).

5. **Regional sediment management/planning efforts have been helpful to facilitating programmatic approaches to beneficial use.** Numerous regional efforts have promoted beneficial use of clean and contaminated sediments. Examples include efforts headed by the USACE (2020) and the Pacific Northwest Regional Sediment Evaluation Team (RSET 2018), in North America; the Association of Inland Navigation Authorities (AINA 2008) in England and Wales; the Solent region tidal marsh restoration efforts (Ausden et al. 2018) on the English coast; and the Eems-Dollard 2050 Program in The Netherlands (ED2050 2022). Ausden et al. (2018) points out that beneficial use proposals require long planning horizons to accommodate the necessary pre-planning and consultations. They suggest that developing sources and needs inventories can be very helpful, to optimize the link between supply and demand. Such an effort of matchmaking is presently occurring in the San Francisco Bay area of California via SediMatch, a Bay Area GIS-based project matching tool hosted by the San Francisco Estuary Institute (SFBJV et al. 2021).
6. **There have been a number of advances in beneficial use techniques and applications.** Most of the literature proposing more environmentally sustainable decision-making frameworks has been published since 2017. The concluding remarks for most of these papers call for more research into beneficial use techniques to 1) improve the versatility of beneficial use options and 2) reduce the environmental impact of using contaminated sediment as a resource. A recent influx of beneficial use method development studies suggests a response to this call and shows that current research focuses on addressing key feasibility concerns associated with the beneficial use of contaminated sediment. As beneficial use opportunities expand, the price that parties are willing to pay for hauling and landfill space should decline. That in turn should diminish the suitable landfill space. What other economic alternatives are out there, and which sediment can be used for these alternatives? Coordination between different organizations (private and public agencies) is necessary to increase demand.
7. **Beneficial use aligns with sustainability principles.** Awareness is growing that disposing of materials that have potential value or uses, is counter to sustainability principles. Beneficial use of contaminated sediment reduces the need to extract native material for which the contaminated sediment can substitute. Extracting native material has a net environmental and economic impact, whereas extracting contaminated sediment has a net environmental and economic benefit. Using contaminated sediment can improve ecosystem quality and reduce carbon footprint by filling local demand for materials. These direct benefits of using contaminated sediment align with the United Nations' Sustainable Development Goals, EU Regulation 2020/852 Framework to Facilitate Sustainable Investment, EU Circular Economy Development Priority (Mazur-Wierzbicka 2021), EU Taxonomy for Environmentally Sustainable Economic Activities, and the Paris Climate Agreement. (Laboyrie et al., 2018, 2019a, b), and PIANC (2018) examine what factors should be considered when weighing how to manage contaminated sediments.
8. **Sustainability evaluations are becoming widely adopted.** Innovation in sustainability evaluations (Bardos et al. 2020; Noren et al. 2020; Sparrevik et al. 2011) drives alternatives and project selection, particularly in the European and international (International Financing Institutions) arenas. International demand and commitment for sustainable solutions further enhances demand for beneficial use of both clean and contaminated sediment, connecting quantity and quality.
9. **Computing project life cycle costs, including indirect benefits and costs, facilitates beneficial use options.** Many of the decision-making framework publications identified in the literature review convey the message that the long-term economic and environmental costs associated with sediment management options are not computed in traditional cost-benefit analyses. Acknowledging secondary and tertiary impacts of sediment management alternatives often resulted in the final

decision of these frameworks selecting a scenario that involved beneficial use of a contaminated sediment in some capacity. These papers strongly advise including beneficial use scenarios early-on in the sediment management process when environmental and economic value enhancement via beneficial use is highest.

10. **Addressing broad concerns about sediment contamination can reduce the stigma of beneficial use.** People's attitudes toward sediment contamination depend on more than just potential for risk from exposure to contaminants (Slovic et al. 1979; Fischoff et al. 1984; Hattis and Kennedy 1986; NAE 1986; Luhmann 1991). Effective communication and end-use co-creation, designed to 1) understand and incorporate stakeholders' perspectives and 2) demonstrate why beneficial use alternatives make sense from stakeholders' perspectives, will help make beneficial use alternatives more acceptable (Cappuyns et al. 2015).
11. **Stakeholders may draw valid, but contradictory conclusions about the acceptability and added value of a beneficial use, because each stakeholder will evaluate project economics and benefits through their unique perspective.** A use can be considered beneficial even if some stakeholders find that the good results or helpful effects do not justify the cost; this is the art of political compromise (Susskind et al. 2000). In part, identifying economical beneficial use alternatives is about finding synergies that allow competing stakeholders to agree on an alternative that is mutually beneficial. This can include providing opportunities for stakeholders to be involved in the co-creation process of determining the best beneficial use and in the project itself, thereby increasing its value (Moons et al. 2021; Costello et. al. 2009).
12. **Regulatory program flexibility to allow for risk-based decisions and adaptive management is a foundational necessity for beneficial use of contaminated sediments to be entertained (Clark 1980).** People strive to isolate hazardous materials regardless of whether they pose risk. In at least some jurisdictions, sediment management rules and guidance can be interpreted as risk-based, but they leave room for regulators to rely on hazard assessment results to make risk management decisions. Hazard-based criteria have the advantage for regulators of being black and white. Hazard is a function of the chemical properties of the hazardous substance. It is easy to define hazard thresholds. Because hazard assessment is devoid of environmental realism, it is easy to avoid interpreting the strength, relevance and reliability of hazard thresholds. Rather, they are treated as meaningful irrespective of context, simply because they have been promulgated. The simplicity of a hazard assessment might appeal to regulators because it insulates them from criticism about leaving their fingerprints on the black box of environmental realism that separates hazard and risk. Where flexibility has allowed projects to proceed, the precautionary principle (UN 1992) and an adaptive management approach (Attachment 1) is commonly involved to support the effort. When proposed as an environmentally appropriate undertaking, a beneficial use project can then be monitored and, if necessary, adjustments made to assure effectiveness and protectiveness.
13. **Environmental risk assessment can and must improve to better evaluate potential risk exposure from sediment in specific settings**. Environmental hazard assessment can help identify potential for harmful effects, but favorable evaluation of a beneficial use requires realistic assessment of risks posed by hazardous substances in a particular sediment, in a particular setting. Environmental risk assessment includes three essential elements not found in environmental hazard assessment: i) it evaluates actual potential for exposure in a particular setting, ii) it provides a framework for weighing risk and benefits, and iii) it assesses risks to valued assessment endpoints (Barnthouse 2008; Dale et al. 2008; Dearfield et al. 2005; Kapustka 2008; Suter 2008; Toll 2020). Unfortunately, most regulatory guidance only defines environmental hazard assessment procedures. Responsible parties are left to scope and conduct site-specific environmental risk assessments on a case-by-case

basis, sometimes over the objections of regulatory project managers concerned over the challenges of communicating risk assessment results to affected communities. The site-specificity and complexity of environmental risk assessments affects remedy selection decisions by exposing uncertainty that is difficult for communities to process. That causes communities to become less accepting of remedies that, if implemented, would none-the-less be protective of human health and the environment. Community acceptance influences state acceptance, so both National Contingency Plan (40CFR300.430(e)(9)) modifying criteria (community and state acceptance) are detrimentally affected by failure to convince stakeholders to agree that beneficial uses would protect human health and the environment. This is a shortcoming of current environmental risk assessment practices. Overcoming it would allow for more favorable evaluations of beneficial use alternatives. Perhaps in some cases, a better portrayal of benefits will be enough to win community and state support for a beneficial use alternative, but better environmental risk assessment practices will also be part of winning acceptance. In framing a beneficial use proposal, the inclusion of a description of the benefits as well as the adaptive management measures as part of the project definition may help raise its acceptability by illustrating the project's benefits, implementation, and adaptation strategies.

14. **Sediment management has become an issue, therefore approaching management options through a sustainability evaluation creates opportunities rather than barriers.** Sediment management decisions have historically prioritized sediment disposal due in large part to its short-term appeal regarding immediate financial costs, concerns about chemical exposure, and lack of precedent or need for more creative, sustainable alternatives. Decision-making frameworks and LCA analyses now offer improved methods to more accurately capture the financial, social, and environmental impacts of sediment management options, whose effects on these impacts extend far beyond the short-term. When the evaluation of sediment management alternatives appropriately accounts for long-term costs and benefits, sustainable alternatives including beneficial use are found to be more favorable, which creates incentives for various stakeholders to consider them (Bardos et al. 2020; Sparrevik et al. 2011; Laboyrie et al., 2018, CEDA 2019a, b). Research shows that early involvement and education of stakeholders can be successful in overcoming reservations about beneficially using contaminated sediments (Cappuyns et al. 2015; POLB 2005, 2007, 2021; Tomley 2016). These opportunities are supported by the growing body of recent literature advancing beneficial use technologies in a way that focuses on reducing the financial and environmental impacts (CEDA 2019b; BRE Group 2019; Laboyrie et al., 2018, Maher et. al. 2020; POLB 2021). Developing approaches for managing contaminated sediments will be an ongoing, collaborative effort requiring participation from regulators, researchers, and stakeholders to promote more environmentally and societally advantageous solutions to deal with the significant volume of clean and contaminated sediment produced from maintenance and remediation dredging projects. The literature review identified numerous precedents for incorporating beneficial use of dredged sediment in sustainable and resilient sediment management options that provide more environmental and societal benefits than disposing or treating the sediment as a waste.

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9. Comparison Tables of Regulatory and Other Programs

Table 1	**North America**
Table 2	**Europe**

10. Attachments

Attachment 1 **Adaptive Management Overview**

Attachment 2 **Annotated Bibliography**

Attachment 3 **Beneficial Use Project Examples**

TABLE 1

Comparison of Regulatory and Other Programs - North America

Beneficial Use of Contaminated Sediments -

A White Paper Prepared for: Sediment Management Work Group

State/Province	Regional	Recognizes beneficial uses of clean sediment	Upland uses	In-water uses	Considers uses of contaminated sediments?	Upland uses?	In-water uses?	Criteria		Notes	References/resources	Researcher's Additional Notes
United States Atlantic Coast												
Connecticut	Statewide	Yes	Yes	Yes	Yes	Yes	No	Case-by-case exposure-based. Ref. MacDonald et al., 2002. Manual		Connecticut Dept of Energy & Envir Protection (CT DEEP). Emphasis on salt marsh restoration and beach nourishmnt. Recent news on permitting beneficial use of stabilized contaminated sediment for upland brownfield site use.	Stern EA, Miskewitz R, Maher A, Kovalik A, Kitazume M, Yang D, Ringen A. 2019. Stabilization and beneficial use of contaminated sediments applying mobile pneumatic flow tube mixing for a circular economy. 11th International SedNet Conference, Dobrovnik, Croatia, April 3-5, 2019. O'Donnell J, Vaudrey J, Tobias C, French R, Schenck P, Lin C. 2018. Beneficial use of dredged material for salt marsh restoration and creation in Connecticut. Tipping Point. 2021. Spotlight feature: CT DEEP Beneficial Use Determination (BUD) approval [online]. Tipping Point Resources Group, LLC, New Haven, CT. [Cited November 2021.]	*States commonly reference MacDonald, D.D., Ingersoll, C.G., and Berger, T.A., 2000. Development and evaln. of consensus-based sediment quality guidelines... for approach to risk screening of sediments.* *See technology information regarding TippingPoint Resources Group of CT (2021). https://tprgllc.com/ .*
Delaware	Statewide	Yes	Yes	Yes	Considered case-by-case based on risk management	potentially	unlikely			The State of Delaware Dredging Policy Framework in guidance.	DNREC. 2001. The Delaware statewide dredging policy framework. Delaware Department of Natural Resource and Environmental Control, Dover, DE. (page 48)	
Florida	Statewide	Not found in the information reviewed	--	--	Not found	--	--	effects-based sediment quality assessment guidelines (SQAGs)		Florida Dept of Environmental Protection	MacDonald DD. 1994. Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Volume 2 - Application of the Sediment Quality Assessment Guidelines. Prepared for the Florida Department of Environmental Protection.	
Georgia	Statewide	Not found in the information reviewed	--	--	Not found	--	--			Georgia Dept of Natural Resources- Environmental Protection Division		
Maine	Statewide	Yes	Yes	No	Not found	--	--			Maine Dept of Environmental Protection- allows for dredge material as construction fill. Other beneficial use info not found.		
Massachusetts	Statewide	Yes	Yes- use at landfills is only use mentioned	Yes. Beach nourishment and marsh projects mainly	No- Not mentioned- however, a risk-based approach allows for case-specific projects to be considered	--	--			In general State treats dredged sediment as a waste. May consider concepts presented in USEPA Beneficial Use Planning Manual (USEPA, 2016a or Brandon & Price (USACE), 2007).	EPA. 2016a. Beneficial use compendium: a collection ofresources and tools to supposrt beneficial useevaluations. EPA 530-R-16-009. US Envir. Protection Agency, Washington D.C. Brandon DL, Price RA. 2007. Summary of available guidance and best practices for determining suitability of dredged material for beneficial uses. ERDC/EL TR-07-27. US Army Corps of Engineers.	
Maryland	Statewide	Yes	Yes	Yes	Considered case-by-case based on risk management	yes	potentially	Various criteria outlined in guidance and permit applications. Sediment quality guidelines are risk-based/effects-based criteria.		In 2001 Maryland passed Dredged Material Management Act which defined "beneficial uses" of dredged material. Main program focused on beach nourishment and marsh creation. Maryland Dept. of Nat. Resources is the lead agency.	MDE. 2019. Innovative reuse and beneficial use of dredged material guidance document. Maryland Department of the Environment, Baltimore, MD.	
New Hampshire	Statewide	Not found	--	--	--	--	--	Risk-based screening criteria are used for sediments - see 2005 guidance ref.			DES. 2005. Evaluation of sediment quality guidance document. NHDES-WD-04-9. New Hampshire Department of environmental Services, Concord, NH.	
New Jersey	Statewide	Yes - State of NJ gives preference to Beneficial Reuse over other disposal options (Lukens, 2000) (Maher, 2020).	yes	yes	Considered case-by-case based on risk management. See notes on Maher et al., 2020.	Yes, usually stabilized and used as upland fill in controlled settings	unlikely			Since 1993 the NJ DOT has led efforts for planning and management of dredging that focuses on using dredged sediments in environmentally benefical ways.	The Nature Conservancy, NJDEP. 2021. Beneficial use of dredged material to enhance salt marsh habitat in New Jersey. Project summary and lessons learned. The Nature Conservancy and New Jersey Department of Environmental Protection. Lukens JL. 2020. National Coastal Program dredging policies. An analysis of state, territory, & commonwealth policies related to dredging & dredged material management. Volume I of II. OCRM/CPD Coastal Management Program Policy Series. Technical Document 00-02. National Oceanic and Atmospheric Administration. Maher A, Douglas WS, Jafari F, Pecchioli J. 2013. The processing and beneficial use of fine-grained dredged material: a manual for engineers. Rutgers Center for Advanced Infrastructure and Transportation.	*Maher et al., 2020. Evaluation of long-term performance of stabilized sediment for beneficial use. "These regulations resulted in one strategy that is commonly used in New Jersey, stabilization and beneficial use of the stabilized dredged material (SDM) as a capping or filling material for landfills, industrial sites, and abandoned mines. It has also been used as road base and the construction of road embankments." This reference also notes that since 2000, more than 30,000,000 cubic yards of impacted dredged material has been stabilized and used beneficially at several sites in NJ (Maher et al., 2020) .*
New York	Statewide	Yes, State makes beneficial use determinations under its solid waste rules	yes	no	Considered case-by-case based on risk management	Yes, case-by-case	unlikely			State has established Beneficial Use Determinations- they are limited to upland uses.	Maher A, Miskewitz R, Nazari R, Douglas S. 2020. Evaluation of long-term performance of stabilized sediment for beneficial use. Final report. Center for Advance Infrastructure and Transportation of Rutgers University and New Jersey Department of Transportation, Piscataway, NJ.	*See notes regarding Maher et al., 2020 under NJ.*
North Carolina	Statewide	Not found in the information reviewed	--	--	Not found	--	--			North Carolina Dept of Environmental Quality		
Rhode Island	Statewide	Yes	Only Upland BUs	no	No	--	--				RI DEM. 2003. Rules and regulations for dredging and the management of dredged material. Regulation DEM-OWR-DR-02-03. State of Rhode Island and Providence Plantations Department of Environmental Management.	
South Carolina	Statewide	Not found in the information reviewed	--	--	Not found	--	--			South Carolina Dept of Health and Environmental Control		
Virginia	Statewide	Yes	Yes	Yes	Not found	--	--			Dredged material siting: Fast-track permitting and beneficial use program guidance (VDEQ, 2019). This program focused on tide water localities. VDEQ and USACE have roles for permitting and both support beneficial reuse concepts.	Virginia DEQ. 2019. Dredged material siting: fast-track permitting and beneficial use program. Virginia Department of Environmental Quality. Becker S, Brauer S. 2019. Beneficial use of dredged material: role of state permitting programs and regulations. William & Mary Law School.	
United States Gulf Coast												
Alabama	Statewide & Gulf Coast Ecosystem Restoration Council	Yes - at the State and the Federal level	Yes	Yes	Not found	--	--			Since the 1990s has done projects with ACOE. State has set a priority on beneficially using dredged sediments for its habitat restoration projects.		*Part of the Resources and Ecosystem Sustainability, Tourist Opportunities, and Revived Economies of the **Gulf Coast States Act (RESTORE Act)** and the **Gulf Coast Ecosystem Restoration Council (Council)** which includes the Governors of the Gulf States, Secretaries of US Dept of Ag, the Army, Commerce, Homeland Security, Interior and US EPA. Funds projects for restoration in the Gulf and for beneficial use of dredged sediment in environmentally beneficial ways.*
Florida	Statewide & Gulf Coast Ecosystem Restoration Council	Yes - at the State and the Federal level	Yes	Yes	Not found	--	--	effects-based sediment quality assessment guidelines (SQAGs)		Florida Dept of Environmental Protection FL DEP & US ACOE have a memorandum of agreement to coordinate dredging in coastal zone on a regional reather than a project scale-supporting joint planning to implement shore protection, navigational and beneficial use projects. Since the 1990s has done BU projects with the ACOE.	MacDonald DD. 1994. Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Volume 2 - Application of the Sediment Quality Assessment Guidelines. Prepared for the Florida Department of Environmental Protection.	*Gulf Coast Ecosystem Restoration Council member.*
Louisiana	Statewide & Gulf Coast Ecosystem Restoration Council	Yes- at the State and the Federal level. State places high priority on beneficially using dredged sediment to help off-set on-going losses of coastal wetland area (Lukens, 2000).	Yes	Yes	May be considered on case-specifc basis with management of risks.	--	--			USACE New Orleans Distr. Is a leading district in beneficial use of dredged sediment. One third of sediment dredged in the US is dredged in channels of this district's waters.	Lukens JL. 2020. National Coastal Program dredging policies. An analysis of state, territory, & commonwealth policies related to dredging & dredged material management. Volume I of II. OCRM/CPD Coastal Management Program Policy Series. Technical Document 00-02. National Oceanic and Atmospheric Administration.	*Gulf Coast Ecosystem Restoration Council member.*

State/Province	Regional	Recognizes beneficial uses of clean sediment	Upland uses	In-water uses	Considers uses of contaminated sediments?	Upland uses?	In-water uses?	Criteria	Notes	References/resources	Researcher's Additional Notes
Mississippi	Statewide & Gulf Coast Ecosystem Restoration Council	Yes, Miss. Code requires projects >2,500 cy to beneficially reuse sediments	yes	Potentially, but must address case-by case	May be considered on case-specifc basis with management of risks.	--	--		Master Plan for Beneficial Use of Dredged Material for Coastal Miss.. Permits required.		*Gulf Coast Ecosystem Restoration Council member.*
Texas	Statewide & Gulf Coast Ecosystem Restoration Council	Yes - at the State and the Federal level	Yes	Yes	May be considered on case-specifc basis with management of risks.	--	--	Ecological benchmark values for surface water, sediment and soil (Texas (TCEQ), 2018)	Texas Commission on Environmental Quality. The Texas Water Development Board (TWDB, 2005) encourages sediment reuse to restore topsoil. Texas General Land Office permits projects on State-owned coastal lands.	TCEQ. 2018. Supporting documentation for the TCEQ's ecological benchmark tables. RG-263b. Texas Commission on Environmental Quality, Remediation Division. Alan Plummer Associates. 2005. Dredging vs. new reservoirs. Texas Water Development Board TWDB Contract #2004-483-534. Alan Plummer Associates, Inc.	*Gulf Coast Ecosystem Restoration Council member.*
United States Great Lakes											
Illinois	Statewide	Yes	Yes	Div Water Control of IEPA- case by case	Not found	--	--	Risk-based screening approaches used	Illinois Envir Protection Agency (IEPA). No specific guidance or examples of contaminated sediment criteria or beneficial uses.		
Indiana	Statewide	Yes	Yes		Not found	--	--		Indiana Dept of Environ Mngmnt (IDEM)	IDEM. 2012. Remediation closure guide. WASTE-0046-R1-NPD. Indiana Department of Environmental Management.	
Michigan	Statewide	Yes	Yes		Case-by-case	yes	--		Distinguishes between unregulated and regulated materials.		
Minnesota	Statewide	Three levels of dredged material- may require a State Disposal System (SDS) permit for beneficial use	Yes	Yes, handled case-by-case and based on risk management	Yes - Minnesota Pollution Control Agency (MPCA) has allowed on case-by-case basis while managing risks.	Yes- soil risk screening criteria applied	Yes- sediment quality target criteria applied	Sediment quality targets (SQT)- level I is lowest and relates to threshold effect concentration and level II relates to probable effects concentration.	Minnesota statues start from the premise that sediments removed from a water body are a waste. MPCA Solid Waste program has beneficial use program patterned after Federal model. Mainly focused on secondary manufactured materials (biproducts). Allows for case-specific beneficial use determinations.	MPCA. 2014. Managing dredge materials in the State of Minnesota. Minnesota Pollution Control Agency, Saint Paul, MN. MPCA, 2007. Guidance for use and application of sediment quality targets in Minnesota.	*In order to re-locate/re-use sediment in water, it must be less than relevant Level I SQTs for chemicals of concern. Beneficial use of sediment with impacts must be dealt with case-specifically. Within the MPCA Solid Waste program a case-specific beneficial use determination- is an involved process in which the proposed use and material characteristics must be proved through testing and may require a pilot or bench studies.* *MPCA Brownfield program recognizes off-site soil re-use, but has not settled on contaminated soil beneficial use concepts. Minnesota beneficial use program is similar to Wisconsin both were modeled after EPA solid waste program/guidance.* *Sediment criteria were derived similar to Wisconsin - consensus-based based on MacDonald et al., 2000 approaches (MPCA, 2007).*
Ohio	Statewide	Yes	Yes	Potentially case-by-case	Case-by-case, relies upon the GLDT, 2020 manual (USACE)	yes	none identified	Risk-based screening criteria- sediment quality goals.	OEPA Div of material and waste management.		*Kreitinger et al., 2011. Evaluation of beneficial use suitability for Cleveland harbor dredged material: interim capacity management and long-term planning. ERDC/EL Proj Rpt, Aug., 2011. Prepared for US ACOE, Buffalo Distr. 282 pgs.*
Pennsylvania	Statewide	Dredged material uses	Yes	yes	Not found	--	--				*participant in regional Delaware River Dredged Material Management planning with regional partners and US ACOE.*
Wisconsin	Statewide	Yes, Wisc DNR promotes reuse.	Yes	Yes	Potentially, but on a case-by-case basis	--	--	Consensus-based sediment quality guidelines- WiDNR (2003) RR-088.	Wisc Admin. Code 347.01 and risk-based screening criteria are used to evaluate options. Sediment Quality Guidelines (SQG).	WDNR. 2021. Chapter NR 538. Beneficial use of industrial byproducts [online]. Wisconsin State Legislature (Wisconsin Department of Natural Resources). Updated February 2021. [Cited November 2021. WDNR. 2015. Guidance for the beneficial use of industrial byproducts under Ch. NR 538, Wis. Admin. Code. PUB-WA-1769 (revision of WA-822-98). Wisconsin Department of Natural Resources, Madison, WI. WDNR. 2003. Consensus-based sediment quality guidelines. Recommendations for use & application. Interim guidance RR-088. Wisconsin Department of Natural Resources, Madison, WI.	*Beneficial use in Wisconsin is focused on use of industrial byproducts (Ch. NR 538, Wis. Adm. Code)- Guidance PUB-WAS-1769 (March, 2015). Modeled after EPA Solid Waste program.* *Wisconsin sediment criteria developed similarly to Minnesota, Consensus-based Sediment Quality Guidelines (SQG) per MacDonald et al., 2000.*
United States Pacific Coast											
Alaska	Statewide	Yes, obtain a letter of non-objection from Solid Waste and Contaminated Sites programs.	Yes	Yes, on a case-specific basis and meeting criteria or other ecological risk criteria	May be considered on case-specifc basis and	--	--	Using the NOAA SQuiRT screening values - Threshold Effects Level (TEL) and Probable Effects Level (PEL).	The sediment quality guidelines are to be used as a first tier screening evaluation. A second tier may include toxicity testing, benthic community surveys, bioaccumulation evaluations, and/or fate and transport modeling.	ADEC. 2013a. Dredge material guidance. Alaska Department of Environmental Conservation. ADEC. 2013b. Technical memorandum. Sediment quality guidelines (SQG). Alaska Department of Environmental Conservation.	*NOAA, 2008. Screening Quick Reference Tables, SQuiRT. sediment screening values table. https://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html , accessed Nov. 2021.*
California	Statewide	Yes, Case-specific see CRWQCB (2012) example.	Yes	Yes, limited and must meet Sediment Quality Provisions	Not addressed in searched agency websites. See SFWQCB, 2012.	--	--	--	Calif. Environmental Protection Agency subunit responsible for quality of waterways and water resources is the California State Water Resources Control Board, comprised of nine regional WQ Control Boards.	Calif. Environmental Protection Agency (CEPA). 2021. California State Water Resources Control Board, comprised of nine regional WQ Control Boards.	
California	Coastal Sediment Management Workgroup- California Natural Resources Agency and US Army Corps of Engineers- since 1999	Yes, Sediment management plans by coastal region- include beneficial use of sediment	Yes- main focus is shore zone	Yes	Only noted as an issue	--	--	--	Seeking to re-nourish beaches and reduce/prevent coastal erosion due to loss of historic sediment sources. Most active from 2004 to 2016.	CSMW. 2021. Coastal Sediment Management Workgroup home page [online]. State of California. [Cited November 2021.]	*web page resides in Calif. State Parks and Waterways div. Accessed Nov 2021- noted that funding was depleted in 2019.*
California	**SediMatch** is a **planning tool** to assist partners in identifying potential matches for the beneficial reuse of sediment.	Yes	yes	Yes	Yes- see Montezuma Wetlands Restoration project notes.	Yes	Yes	General screening criteria and testing requirements for beneficial "reuse" are published in (SFBRWQCB, 1992).	San Francisco Bay area GIS-based project matching tool to encourage regional coordination of projects generating sediment and projects needing sediment for beneficial uses.	SFBJV, BCDC, SFEI, SFEP. 2021. SediMatch web tool [online]. San Francisco Bay Joint Venture, San Francisco Bay Conservation and Development Commission, San Francisco Estuary Institute, and San Francisco Estuary Partnership. [Cited November 2021.]	***SediMatch*** *is a collaborative program between wetland habitat restoration, flood control, and dredging communities to discuss mutually beneficial strategies for reuse of dredged sediment at habitat restoration sites. The goals of SediMatch are to (1) create healthy habitats while maximizing beneficial sediment reuse, (2) develop a web tool for matching sediment needs with available sediment, and (3) provide opportunities for collaboration. For more information on the program and its partners, visit the SediMatch project page- https://www.sfei.org/projects/sedimatch-web-tool#sthash.KOsNpB0B.dpbs*
California	San Francisco Bay Regional Water Quality Control Board pertaining to Bay Estuary restoration efforts	Yes. Since 1992, the SFBRWQCB, followed Regional Water Quality Control Board Resolution No. 92-145, Sediment Screening Criteria and Testing Requirements for Wetland Creation and Upland Beneficial Reuse (SFBRWQCB, 1992).	Yes	Yes	Yes- in the narrow instance where moderate impacts are allowed as "foundation sediment" which is then covered by a minimum layer of dredged sediment.	Yes- see note	Yes- foundation sediment beneath cover sediment followed by inundation to create a restored tidal marsh habitat.	Yes, dredged material acceptance criteria- **two categories- Surface** (cover) and **Foundation** (non-cover). Plan also requires dredged material screening which includes an effluent elutriate test.	San Francisco Bay Reg WQ Control Bd- beginning in 2000, guides beneficial reuse of dredged materials. Establishes screening and testing guidelines. 2,300 acre regional salt marsh restoration effort is projecting more than 17 million cubic yards of maintenance dredge sediment will be used for restoration of salt marshlands around the northeastern Bay area. **Foundation sediment** may account for approximately 20% of overall sediment to be placed.	CRWQCB. 2012. Updated waste discharge requirements, water quality certification, and recission of Order No. 00-061 for: Montezuma Wetlands LLC, Montezuma Wetlands Restoration Project, Solano County. California Regional Water Quality Control Board, San Francisco Bay Region.	*metals criteria for "surface (cover)" sediment appear to be generally near common background levels for 10 listed metals. Acceptance concentrations range from 2 to 3 times higher for "foundation (non-cover)" sediment for placement at depth to fill subsided areas prior to final "cover sediment" placement. Total PCBs* ***cover*** *= 22.7 ug/kg,* ***foundation*** *= 180 ug/kg. Total PAHs* ***cover*** *= 3,390 ug/kg,* ***foundation*** *= 44,792 ug/kg. References for the Dredged Material Management Office (DMMO) appear after 2016. See DMMO, 2020. Annual Report- specific to the San Francisco Bay area dredging disposals versus beneficial wetland restoration uses.*
Oregon	Statewide	Yes	Yes	Yes- case-by-case, based on chemical screening	Yes	Yes- construction fill if below screening criteria.	No- likely excluded by sediment quality screening criteria	effects-based sediment quality criteria	Oregon Dept of Environmental Quality	ODEQ. 2021. Rule 340-093-0270. Standing beneficial use determinations [online]. Oregon Department of Environmental Quality. [Cited November 2021.]	
Washington	Statewide	Yes, Wash state sediment management standards and Model Toxics Control Act (MTCA)- evaluate sediment quality	yes	yes- Sed Mngmnt stds (SMS) regulate in-water placement.	Potentially, on case-by-case	yes	no- noted as a limitation due to risk criteria restrictions.	Sediment screening levels based on risks to benthos and /or bioaccumulative risk.	Washington State Department of Ecology. State looks to USACE for reference in its guidance development. See RSET (2018) sed evaluation framework developed by Pacific NW regional sediment management team.	Ecology. 2013. Sediment management standards. Chapter 173-204 WAC. Toxics Cleanup Program, Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/documents/1309055.pdf Ecology. 2019. Sediment cleanup user's manual. Guidance for implementing the cleanup provisions of the sediment management standards, Chapter 173-204 WAC. Second revision December 2019. Pub. No. 12-09-057. Toxics Cleanup Program, Washington State Department of Ecology, Olympia, WA. https://apps.ecology.wa.gov/publications/documents/1209057.pdf	

TABLE 1
Comparison of Regulatory and Other Programs - North America
Beneficial Use of Contaminated Sediments -
A White Paper Prepared for: Sediment Management Work Group

State/Province	Regional	Recognizes beneficial uses of clean sediment	Upland uses	In-water uses	Considers uses of contaminated sediments?	Upland uses?	In-water uses?	Criteria	Notes	References/resources	Researcher's Additional Notes
Regional	Northwest Regional Sediment Evaluation Team	Yes	Yes	Potentially case-by-case	May be considered - case-by-case evaluation- risk-based.	--	--	Tiered sediment evaluation- if greater than screening levels then material unfit for in-water placement unless bioassays support such a use.		RSET. 2018. Sediment evaluation framework for the Pacific Northwest. Regional Sediment Evaluation Team (US Army Corps of Engineers; US Environmental Protection Agency; National Oceanic and Atmospheric Administration; US Fish and Wildlife Service; Oregon Department of Environmental Quality; Idaho Department of Environmental Quality; Washington State Department of Ecology; and Washington State Department of Natural Resources).	
United States Federal											
US Army Corps of Engineers Great Lakes Dredge Team (Manual)	Great Lakes	Yes	Yes	Yes	Yes- Tier III evaluation approach. Case-specific and risk based	Yes	Yes, but case-specific evaluations must show protectiveness		Great Lakes Dredge Team (GLDT) - regional coordination effort led by ACOE with all Great Lakes States.	GLDT, 2020. Environmental Eval and Mngmnt of Dredged material for beneficial use: Regional Manual for the Grt Lks. GLDT, 2016. Gd to policies & projs rela to BU of dredged material in t. Grt Lks. July 2016.	
US Army Corps of Engineers	Regional Sediment Management (RSM) Planning - Federal Coastal Zone areas around the US	Yes	Yes	Yes	May be considered if risks can be managed and consensus can be reached with all parties.	Yes	Yes, but case-specific evaluations must show protectiveness		Regional sediment management (RSM) planning efforts have arisen around the U.S. in coastal zone areas where the ACOE shares jurisdiction with State and local authorities. Effort often includes other NGO stakeholders and a strong focus on restoration or habitat enhancement beneficially using dredged sediment.	Schrader MH. 2019. Implementing regional sediment management (RSM): policy guidance and authorities pertinent to improving the use of dredged sediments. ERDC/TN RSM-19-1. US Army Corps of Engineers, Engineer Research & Development Center.	*Some regional dredge management efforts have also pointed to sustainability and climate adaptation as important drivers for beneficial use of sediment as a resource that can aid projects in coastal areas.*
US Army Corps of Engineers	Dredging Operations Tech Support- Beneficial Uses of Dredged Material	Yes	Yes	Yes	Not addressed directly.	--	--	--	Beneficial use group and website within - Engineer Research and development Center of the ACOE.	USACE, 2021. Discover, learn, and grow beneficial uses of dredged sediment.	*"Over 200 milion cubic yards of material is dredged annually from the bottom of federally-constructed and maintained navigation channels..." "83% is available for BU- currently about 30-35% of this is used beneficially..."*
US Environmental Protection Agency	With ACOE co-chairs National Dredging Team (NDT)	Yes	Yes	Yes	Not addressed by sources researched.	--	--	Risk-basded approaches must assure protectiveness.	NDT a federal interagency group working to ensure US hasrbors, channels, & waterways are dredged in timely and cost-effective ways. Assure environmental protection, restoration and enhancement goals met and seeks to use sediment as a resource used in environmentally beneficial ways.	EPA. 2003. Dredged material management: action agenda for the next decade. Based on a workshop sponsored by the National Dredging Team, January 23-25, 2001, Jacksonville, Florida. EPA 842-B-04-002. US Environmental Protection Agency, Washington, DC.	*Ausden et al. (2018) notes, the US is ahead of most countries exc. Japan and Netherlands in beneficial use of sediments- likely because of the ACE role in coastal zone public works to support shipping and maritime industry- and since about the 1990s they have been active in promoting initiatives to increase beneficial uses of dredged sediment.*
US Environmental Protection Agency with US Army Corps of Engineers	National guidance	Yes	Yes	Yes	Yes- Points out that decisions can be case-specific and risk based, that the end use will affect how contamination may affect decisions.	Yes	Yes, but case-specific evaluations must show protectiveness	Risk-basded approaches must assure protectiveness.	Joint EPA/USACE Planning Manual- notes that there may be applications where it is appropriate to consider beneficially using contaminated sediments- see page 12- "*... In general, the more contaminated the material, the greater the constraints on reuse. Highly contaminated material is not usually suitable for reuse unless its potential risk for biomagnification is low. The important issue is not so much whether the material is contaminated but whether the level and type of contamination are consistent with the intended use.* "	EPA USACE. 2007b. Identifying, planning, and financing beneficial use projects using dredged material: Beneficial use planning manual. US EPA and US ACE, Washington DC. EPA-842-B-001.	
Gulf of Mexico Alliance	Gulf Coast Region	Yes	Yes	Yes	Not addressed directly.	--	--	--	"Wise use of sediment resources from dredging is integral to accomplishing the conservation and restoration initiatives and objectives being recommended under the Gulf of Mexico Alliance. Keeping dredged sediments within the natural system or using it in the construction of restoration projects can improve environmental conditions, provide storm damage..."	Parson LE, Swafford R. 2012. Beneficial Use of Sediments from Dredging Activities in the Gulf of Mexico. J Coast Res 60(1):45-50.	
Canada- Provinces											
British Columbia	Provincial	Not found	--	--	Not found	--	--	Sediment Standards (SedS)	Technical guidance #15- sets concentration limits for protection of aquatic receiving environments.	BC MOE. 2013. Technical guidance 15. Technical guidance on contaminated sites. Version 1. Concentration limits for the protection of aquatic receiving environments. British Columbia Ministry of Environment, Vancouver, BC.	
Newfoundland and Labrador	Provincial	Not found	--	--	Not found	--	--				
New Brunswick	Provincial	Not found	--	--	Not found	--	--				
Nova Scotia	Provincial	Not found	--	--	Not found	--	--				
Ontario	Provincial	Yes	Yes	Yes	Potentially, but on a case-by-case basis	yes	not found	Env Protection Act sediment standards provided in lookup table.	Ontario Ministry of the Environment	OMOE. 2011. Evaluating construction activities impacting on water resources Part III B - handbook for dredging [online]. Ontario Ministry of Environment. Updated January 2011. [Cited November 2021.]	
Quebec	Provincial	Not found	--	--	Not found	--	--				
Yukon	Provincial	Not found	--	--	Not found	--	--				
Canada- Federal											
Government of Canada, Environment and Natural Resources, Pollution and waste management		Not found	--	--	Not found	--	--		Canadian Envir Protection Act of 1999 created disposal at sea provisions. Environment and Climate Change Canada (ECCC) responsible for permitting and monitoring sediment disposals- which must meet 1996 convention on prevention of marine pollution by dumping of wastes and other matter into oceans (by London Convention treaty).		

TABLE 2

Comparison of Regulatory and Other Programs - Europe

Beneficial Use of Contaminated Sediments -

A White Paper Prepared for: Sediment Management Work Group

Country	Geographic Region	Other Jurisdiction	Regional	Recognizes beneficial uses of clean sediment	Upland uses	In-water uses	Considers uses of contaminated sediments?	Upland uses?	In-water uses?	Criteria	Notes	References/resources	Researcher's Additional Notes
Europe, United Kingdom & Republic of Ireland													
United Kingdom-England, Northern Ireland, Wales and Scotland	United Kingdom (UK)	London Convention. OSPAR.	--	Yes	Yes	Yes	Yes, generally limited to upland uses	Yes	No	Ecological toxicity-based criteria	The Environment Agency (in England), Dept for Environment, Food and Rural Affairs (Defra) Nat Resources Wales Scottish Environment Protection Agency (SEPA)	Ausden M, Dixon M, Lock L, Miles R, Richardson N, Scott C. 2018. Precipitating a SEA change in the Beneficial Use of Dredged Sediment (SEABUDS). RSPB technical report. Royal Society for the Protection of Birds. 50 pp.	*Britain's harbor and transportation dredging is largely private, whereas, Ausden notes, the US is ahead of most countries exc. Japan and Netherlands in BU of sediments- likely bc of the ACE role in coastal zone public works to support shipping and maritime industry- and since about the 1990s initiatives to increase BU of dredged sediment.*
Republic of Ireland	EU	London Convention. OSPAR.	--	Yes	Yes	Yes	Not addressed in references reviewed.	--	--	Two levels - based on OSPAR, 2008 - Lower level action limit 1 and upper level action limit 2. List of 8 heavy metals, PAHs, PCBs, tri- and di-buytltin, γ - Hexachlorcyclohexane, and total extractable hydrocarbon (Harrington and Smith, 2013).	"To date only a relatively small number of dredging projects in Ireland have encountered contaminated dredge material. The DM contamination encountered has been associated with current and historical industrial activities, mining activities and wastewater inputs (Clenaghan et al., 2005). The primary contaminants found in DM in Ireland include heavy metals (e.g. mercury), organo-metal complexes (e.g. tributyl tin – TBT) and various organic congeners (e.g. Polychlorinated Biphenyls – PCBs and Polycyclic Aromatic Hydrocarbons – PAH's). TBT contamination from marine paint.."	Sheehan C, Harrington J. 2012. Management of dredge material in the Republic of Ireland - a review. Waste Management 32(5):1031-1044. https://doi.org/10.1016/j.wasman.2011.11.014 Harrington J, Smith G. 2013. Guidance on the beneficial use of dredge material in Ireland. Cork Institute of Technology, School of Building & Civil Engineering, Cork, Ireland. https://www.epa.ie/publications/research/small--scale-studies/Beneficial-Use-of-Dredging-Material.pdf	
European Union	EU	--	EU	In concept, yes	Yes	unlikely	Generally, NO. Case-by-case depending on the country-highly variable. In most instances this option would be rejected.	--	--	Limit values level 1 and level 2. If greater than level 2 the material is handled as a waste.	In the EU, dredged material is adressed across - **EU Waste**, **EU Water** (which is subdivided into marine, inland water and groundwater), **EU Marine Strategy** Framework directives- All dredged sediment is classified as waste. There are many different criteria some varying from country to country. EU directives generally limit allowable contaminant levels. Some countries have exemptions for land applications. Environmental restrictions and handling sediment as waste narrow the management options.	Wijdeveld AJ. 2019. Scientific progress in sediment and water quality assessment: implementation of practical case studies. PhD. Geochemistry, University of Utrecht, The Netherlands. Https://doi.org/10.4233/uuid:6127d95f-4fe1-4417-949c-5158ddb1fb3 Grandchamp F, Van Paassen L, Sutton G, Harrington J, Belhadj E, Mcheik A, Masson E, Van Dessel J, Lemiere B, Brakni S. 2014. CEAMaS project: civil engineering applications for marine sediments. I2SM 2014 - International Symposium on Sediment Management, Ferrara, Italy. https://www.researchgate.net/publication/282298388_CEAMaS_project_Civil_Engineering_Applications_for_Marine_Sediments Jimenez SP. 2016. CEAMaS, end of project first impressions [online]. EkoConception. Updated February 2, 2016. [Cited November 2021.] https://www.ekoconception.eu/en/first-impressions-on-ceama	*The northwestern EU contries combined dredge more than 200 million cubic meters of marine sediments.* *EU is trying to promote a more "circular economy" by finding sustainable uses for materials and to avoid simply disposing of materials. In addition there is a demand for raw construction materials (aggregate, fill, matrices for construction products like bricks or cement). In 2014 there was a call to use sedimets as a resource and to find opportunities to minimize managing it by disposal (Grandchamp et al., 2014). The CEAMas project developed a multi-cirteria decision analysis system. Web page reports end of study in 2016. Jimenez, S.P. et al. (2016) provides a summary of findings from CEAMas project.*
Belgium	EU	Helsinki, Oslo, and London Conventions. OSPAR.	Some coordination with Netherlands and France	Yes	Yes	Yes	Yes, but generally focused on sequestration/treatment then to upland use.	Yes	May be considered on a case-by-case basis	Sediment quality criteria- ecological risk-based.	Very similar to the Dutch policies. OVAM document (in Dutch) regarding inland water ways and sediment management.	https://www.ovam.be/sites/default/files/atoms/files/WEB_OK%20COM_Onderzoek%20van%20waterbodem%20en%20oevers_CVGP210216.pdf	
Denmark	EU	Helsinki, Oslo, London Conventions. OSPAR.	--	Yes			Not addressed in references reviewed.	--	--	--			
Finland	Baltic Sea	London, Helsinki, Oslo Conventions. OSPAR and HELCOM.	--	Yes, if passing the risk criteria.	Yes	Yes	Only if contamination can first be treated/removed	Yes	No	National criteria developed for screening what may be disposed at sea. Ecotox based values. If any substance is greater than limit value 2 of the tabulated contaminants of concern the dredged material is a waste and restricted from use in the ocen or on land.	Finland recognizes the 2013 IMO London Protocol and London Convention guidelines for assessing and managing dredged material including for disposal in the open ocean.	HELCOM, 2015. Guidelines for management of dredged material at sea. Baltic Marine Environment Protection Commission. HELCOM 36-2015 adopted 4 March 2015. Sapota. 2011. Environmental policy and legislation on dredged material in the Baltic Sea region. Sustainable Management of Contaminated Sediments.	
France	EU	London, Helsinki, Oslo Conventions. OSPAR.	Some coordination with Netherlands and Belgium	Yes	Yes	Yes	Yes, but generally focused on sequestration/treatment & used in upland.	Yes	May be considered on a case-by-case basis	Sediment quality criteria- ecological risk-based.			
Germany	Baltic Sea	London, Helsinki, Oslo Conventions. OSPAR and HELCOM	--	Yes	Yes	Yes	Not found in references reviewed.	--	--	Limit values level 1 and level 2. If greater than level 2 the material is handled as a waste.		Sapota G. 2011. Environmental policy and legislation on dredged material in the Baltic Sea region. Sustainable Management of Contaminated Sediments.	
Italy	EU Mediterranean	Oslo, London, Paris, and Barcelona Conventions. OSPAR.	--	Yes	Yes	Yes	Yes- Legislative and minsterial decrees discuss management of dredged sediments from known contaminated sites or for maintenance dredging (low or no impacts) management including beneficial uses. Categories established based on criteria and/or toxicity testing - different use cases considered in-water or upland. Literature discusses agricultural upland uses, stabilization and solidification with use for upland fill, and use in manufactured materials- i.e. bricks, concrete.	--	--	Sediment quality criteria and soil criteria- risk-based. Also considers toxicity testing.	There are three components of Italian regulations that relate to sediments, dredged sediment, and permissible management uses or dispensation of sediment: a) D.L. 152/2006, which is the more general Environmental Law (this includes use of sediment on land, with specific reference to Art. 184-quater); b) D.M. 172/2016, which is dedicated to dredging activities at contaminated sites ("Siti di Interesse Nazionale (SIN))" – or sites of national interest - SIN (sites) are analogous to CERCLA sites of the USA); c) D.M. 173/2016, which is dedicated to dredge sediment which remain in water, or that originate from a SIN while remaining in water.	**a) D.L. 152/2006**. Decreto Legislativo n. 152: Codice dell'Ambiente. Art. 184-quater. Italian legislation; b) **D.M. 172/2016.** Decreto Ministeriale n. 172: Regolamento recante la disciplina delle modalita' e delle norme tecniche per le operazioni di dragaggio nei siti di interesse nazionale, ai sensi dell'articolo 5-bis, comma 6, della legge 28 gennaio 1994, n. 84. Italian ministerial directive; **c) D.M. 173/2016.** Decreto Ministeriale 15 luglio 2016 , n. 173. Regolamento recante modalita' e criteri tecnici per l'autorizzazione all'immersione in mare dei materiali di escavo di fondali marini. (16G00184). Italian ministerial directive.	***web sites accessed 02/28/2023:*** *a) D.L. 152/2006, https://leap.unep.org/countries/it/national-legislation/legislative-decree-no-152-approving-code-environment; b) D.M. 172/2016, https://leap.unep.org/countries/it/national-legislation/decree-no-172-methods-and-technical-standards-dredging-operations; c) D.M. 173/2016, https://www.gazzettaufficiale.it/eli/id/2016/09/06/16G00184/sg#:~:text=MINISTERO%20DELL%27AMBIENTE%20E%20DELLA%20TUTELA%20DEL%20TERRITORIO%20E,Generale%20n.208%20del%2006-09-2016%20-%20Suppl.%20Ordinario%20n.*
Netherlands	EU	London and Oslo Conventions. OSPAR.	--	Yes	Yes	Yes	Yes, "stand still" principle allows for case-specific sediment/soil criteria	Yes	Yes	General sediment/soil standards are available-however, location specific standards allow for some case-by-case evaluation based on land use, contaminant mobility/toxicity (bioavailability) in applied setting.	The "Stand still principle" is unique to the Netherlands. Under this principle the use of sediment (or soil) as a building material leads to evaluating sediment quality in the context of overall system quality rather than if a portion may exceed a specific criterion. Sediment or soil use is allowed as long as the overall system quality improves or remains the same. Local sediment standards may therefore be applied (Wijdeveld, 2019).	Wijdeveld AJ. 2019. Scientific progress in sediment and water quality assessment: implementation of practical case studies. PhD. Geochemistry, University of Utrecht, The Netherlands.	
Norway	Europe	London and Oslo Conventions. OSPAR.	--	Yes	Yes	Yes	Yes, only if contamination treated or stabilized	Yes	No	Sediment quality criteria- ecological risk-based.		Sparrevik M, Breedveld GD. 2010. From ecological risk assessments to risk governance: evaluation of the Norwegian management system for contaminated sediments. Integr Environ Assess Manage 6(2):240-248.	
Spain	EU Mediterranean	OSPAR, Barcelona, Oslo Conventions	--	Yes	Yes	Yes	Not found in references reviewed.	--	--	Set sediment standards			
Sweden	EU, Baltic Sea	London, Helsinki, Oslo Conventions. OSPAR and HELCOM.	--	Limited recognition of beneficial uses.	Yes	Generally, no	Not found in references reviewed.	--	--	Set sediment standards			

TABLE 2
Comparison of Regulatory and Other Programs - Europe
Beneficial Use of Contaminated Sediments -
A White Paper Prepared for: Sediment Management Work Group

Country	Geographic Region	Other Jurisdiction	Regional	Recognizes beneficial uses of clean sediment	Upland uses	In-water uses	Considers uses of contaminated sediments?	Upland uses?	In-water uses?	Criteria	Notes	References/resources	*Researcher's Additional Notes*
Regional Efforts													
15 Governments of the EU and the EU	Marine Environment of the North-East Atlantic	--	The Oslo and Paris Convention (1992) created the OSPAR Commission in 1998. Referred to as "OSPAR"	Yes	Yes	Yes	Not allowed.	--	--	toxicity based evaluation of chemicals or other factors of concern- on case-by-case basis. Bioassays suggested.	OSPAR is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. Nations using this area for open ocean disposal of dredge materials have agreed to meet sediment quality standards. Since 2014 OSPAR is tracking beneficial uses of dredged sediments. Sees value in reducing ocean dumping by beneficial uses.	OSPAR Commission. 2021. Dredging & dumping [online]. OSPAR Commission. [Cited November 2021.]	Oslo-Paris Conventions (OSPAR) started in 1972 with the Oslo Convention against dumping and was broadened to cover land-based sources of marine pollution and the offshore industry by the Paris Convention of 1974. These two conventions were unified, up-dated and extended by the 1992 OSPAR Convention. The new annex on biodiversity and ecosystems was adopted in 1998 to cover non-polluting human activities that can adversely affect the sea.
International Efforts													
International	Netherlands-based	--	EcoShape Consortium	Yes	Yes	Yes	Potentially, yes- if risks managed.	--	--	--	Foundation carrying out public-private Building with Nature innovation programs focused on developing and knowledge-sharing about Building with Nature. Particular focus in hydraulic engineering with sediment/coastal/aquatic system projects.	Moons S, Baldal E, Kok S, Sittoni L. 2021. Integrated system-based asset management. The business case for scaling-up building with nature in the Netherlands. EcoShape.	focuses on hydrodynamic forces and interactions of natural systems and the use of natural materials within a natural system to implement improvements, restorations, climate adaptation projects.
International	--	--	World Assoc for Waterborne Transport (PIANC)	Yes	Yes	Yes	--	--	--	--	Prepare & share technical information and guidance on practice of beneficial use of sediment- world-wide focus. Partnered with CEDA. In 2019 work group 214 was initiated to "... provide technical information and guidance regarding the state of the practice for use of sediment as a beneficial use product by drawing from existing approaches and best practices worldwide" (PIANC, 2021).	PIANC. 2021. Environmental Commiss. Wkg Grp 214 Beneficial Sediment Use.	Partnered with WEDA of the World Organization of Dredging Associations (WODA).

Attachment 1. Adaptive Management Overview

The concept of adaptive management of natural resources emerged from the Institute of Resource Ecology at the University of British Columbia in the 1970s and '80s (Holling 1973; Walters 1986). More recently, it has been evaluated by the NRC (2004) and championed by the U.S. Army Corps of Engineers' Engineer Research and Development Center (ERDC) (Fischenich et al. 2019). An EPA task force charged by the EPA Administrator with developing recommendations to, among other objectives, identify strategies for restructuring the Superfund cleanup process to expedite cleanups.

One of the task force's recommendations called for the EPA to "broaden the use of adaptive management at Superfund sites" to focus "… limited resources on making informed decisions throughout the remedial process." The Superfund remedial program established an adaptive management workgroup to implement the task force's recommendation (Woolford 2018). The workgroup reviewed existing definitions of adaptive management, and developed the following working definition for application at Superfund sites:

> "*Adaptive management is a formal and systematic site or project management approach centered on rigorous site planning and a firm understanding of site conditions and uncertainties. This technique, rooted in the sound use of science and technology, encourages continuous re-evaluation and management prioritization of site activities to account for new information and changing site conditions. A structured and continuous planning, implementation and assessment process allows EPA, states, and other federal agencies (OFAs), or responsible parties (PRPs [*sic*]) to target management and resource decisions with the goal of incrementally reducing site uncertainties while supporting continued site progress.*"

The EPA's implementation of adaptive management, in the context of its Superfund program, is twofold (EPA 2019):

- Accelerate progress on remedial actions by making greater use of early actions, addressing immediate risks, preventing source migration, and returning portions of sites to use pending more detailed evaluations of other site areas.
- Use data to support early action to update the conceptual site model and reduce the remedial investigation/feasibility study's duration and cost.

ERDC's interest in adaptive management is connected to implementation guidance for Sections 2016 and 2039 of the Water Resources Development Act of 2007, as well as Section 1161 of the Water Resources Development Act of 2016. These sections require that ecosystem restoration projects either include appropriately scoped adaptive management plans or provide sound justification for why adaptive management is not warranted.

ERDC defines adaptive management as "a decision process that promotes action in the face of uncertainties and adjustment as outcomes from management actions and other events are better understood. Careful monitoring of these outcomes advances scientific understanding and helps adjust policies or operations as part of an iterative learning process." It goes on to divide adaptive management into active and passive subdisciplines:

- **Active adaptive management** implements multiple management alternatives in parallel. Each alternative is tested on an experimental unit. Ideally, this process is analogous to experimental design as it is used in agriculture. The units are replicates and the management techniques are defined as part of the experimental design, so experimental measurements can be planned to generate valuable information about the relative performance of the management techniques. What today is called active adaptive management is essentially adaptive management for renewable resource systems, as defined by Walters (1986).
- **Passive adaptive management** "reduces uncertainty by using a single design or operational plan to test hypotheses about system responses to a management action." The modern concept of passive adaptive management harkens back to systems ecology: the science of studying ecosystem responses to perturbation with a focus on emergent properties like resilience and stability.

Thinking about the ties between active adaptive management and agricultural science, as well as those between passive adaptive management and systems ecology, is helpful in evaluating the pros and cons of these two subdisciplines.

Active adaptive management uses more controlled experimentation to answer questions that are, by design, simpler. It uses replicates to study the effect of altering the level of an experimental factor on an output variable. Walters (1986) discusses using this technique to study the effect of timber management practice "treatments" on forest recovery in adjacent watersheds. Passive adaptive management does not provide for comparing the effects of multiple treatments on replicate systems, but it does lend itself to studying complex real-world systems wherein replication is not an option. The key point about passive adaptive management is that it frames testable hypotheses about management actions and designs a monitoring program to get the data needed to evaluate the hypotheses. So, both active and passive adaptive management techniques are founded on the scientific method.

As society moves toward adopting beneficial uses of contaminated sediment, the promise of applying scientific rigor to ensure the safety and effectiveness of proposed uses could be a key to gaining acceptance by communities concerned about the effects of contaminants on public health and the environment.

Annotated Bibliography

REGULATORY GUIDELINES

- **AINA. 2008. Waste management for dredgings operations - a good practice guide for navigation authorities. Association of Inland Navigation Authorities. (AINA 2008)**
  This practice guide was prepared to help navigation and drainage authorities understand and interpret current legislative requirements applicable to dredging activities "in the most practical and economic manner whilst safeguarding the environment." The guide provides a legislative overview--including a definition of various types of waste, environmental permitting considerations, and exemptions to permitting requirements--as well as a summary of use-and-recovery options and dredging-and-treatment methods. The guidance relates only to England and Wales.

- **Commonwealth of Australia. 2009. National assessment guidelines for dredging. Commonwealth of Australia, Department of the Environment, Water, Heritage and the Arts. (Commonwealth of Australia 2009)**

  This document provides a framework for the environmental impact assessment and permitting for ocean disposal of dredged material. The framework includes alternatives evaluation, assessment of loading and disposal sites, assessment of potential environmental impacts, and determination of management and monitoring requirements. Additional topics include components of sampling and analysis plans and reports, sampling methods and sampling program design, and field and laboratory quality assurance and control.

- **USACE. 2020. Environmental evaluation and management of dredged material for beneficial use: a regional beneficial use testing manual for the Great Lakes. Draft final. US Army Corps of Engineers. (USACE 2020)**

  This manual provides technical guidance for evaluating the environmental suitability of dredged material for beneficial placement and reuse in both upland and aquatic settings in the Great Lakes region. The manual includes a background on common dredged material management approach and existing guidance, as well as an overview of the environmental regulations to consider when determining suitability. It also provides examples of beneficial use placement across a range of broad placement-option categories. The manual also explains the concepts of a risk-based approach to evaluating dredged material, as well as considerations for developing a sampling and analysis plan.

- **MDE. 2019. Innovative reuse and beneficial use of dredged material guidance document. Maryland Department of the Environment, Baltimore, MD. (MDE 2019)**

This guidance document describes the policies and procedures for reviewing proposed beneficial use and innovative reuse projects utilizing dredged material as authorized by the State of Maryland and regulations applicable to specific uses. The document was developed to guide scientists, engineers, and other technical professionals in how the Maryland Department of the Environment makes approvals and related determinations to beneficially use or innovatively reuse dredged material.

- **MPCA. 2014. Managing dredge materials in the State of Minnesota. Minnesota Pollution Control Agency, Saint Paul, MN. (MPCA 2014)**

  This guidance document provides assistance to project managers and governmental entities to facilitate proper management of dredged material. It is intended to protect water quality at project sites by (1) providing a consistent and clear regulatory framework for managing dredged materials, (2) promoting consistency in the characterization and risk assessment of these materials, and (3) identifying best management practices at dredged material sites. The relevance of this document to our study is that the 2014 dredged material management guidance is a step toward shifting public opinion in favor of beneficial reuse.

- **DHV B.V. 2013. Beneficial use of dredged material in the North Sea. An assessment framework. Royal HaskoningDHV. (DHV B.V. 2013)**
  This report provides an assessment framework for the beneficial use of dredged material in the North Sea in accordance with the Dutch Soil Quality Decree. The framework was then tested in the Port of Rotterdam and Rotterdam waterways. The framework can be used to stipulate under which conditions dredged material can be relocated while abiding by the legislation and regulations in force.

- **USACE, EPA, WDNR, Ecology. 2018. Dredged material evaluation and disposal procedures. User manual. Dredged Material Management Program: US Army Corps of Engineers, Seattle District, Seattle, WA; US Environmental Protection Agency, Region 10, Seattle, WA; Washington State Department of Natural Resources; and Washington State Department of Ecology, Olympia, WA. (USACE et al. 2018)**
  This manual, prepared by an interagency group overseeing dredged material management in the state of Washington, provides a framework for characterizing dredged material for its suitability for aquatic disposal and characterizing post-dredge surface material to determine compliance with state antidegradation policies. While this manual does not offer potential strategies for beneficial use of sediment, it does outline the requirements and steps for determining suitability for beneficial use.

EXAMPLES OF BENEFICIAL USE (AKA "WHAT WORKS")

- **Balkaya M. 2019. Evaluation of the usage of various capping materials in capping of contaminated sediments. Desalination and Water Treatment 172:54-60. (Balkaya 2019)**

  This study modeled the use of alum sludge, which is a byproduct of the drinking water treatment industry, as a capping material for in situ capping. The effort was coordinated by the Department of Civil Engineering at Istanbul Technical University. The engineering behavior of the alum sludge was compared with that of sand, which is often used in passive in situ capping. The findings showed that alum sludge could be an appropriate material for active (i.e., contaminant removing) capping applications, as it is cost effective and readily available and has low hydraulic conductivity, high shear strength properties, and effective contaminant removal abilities.

- **CEDA. 2019. Sustainable management of the beneficial use of sediments. A case-studies review. Central Dredging Association, Rotterdamseweg, The Netherlands. (CEDA 2019b)**

  See CEDA, 2019 listing below under Evaluating Options and Strategies - *38 case studies are presented and discussed by this paper.*

- **Cervera et al. 2015. Dredged sediments, web-GIS and analysis tools – The CEAMaS case study. (Cervera et al. 2015)**

  This paper describes two European case studies (Cork Harbour, Ireland and Nord Pas du Calais, France) showing how incorporating web-GIS early in the dredging planning stages can increase the rates of sediment beneficial use. The CEAMaS web-GIS platform evaluates beneficial use suitability based on sediment characteristics and facilitates sediment management decisions.

- **De Gisi S, Todaro F, Mesto E, Schingaro E, Notarnicola M. 2020. Recycling contaminated marine sediments as filling materials by pilot scale stabilization/solidification with lime, organoclay and activated carbon. J Cleaner Prod 269:122416. (De Gisi et al. 2020)**

  This study tested a stabilization/solidification (S/S) method as use for filling material using dredged sediment from Southern Italy that was contaminated with PAHs, PCBs, and metals. Without pre-treatment, they found that the post-S/S materials did not pass the 28-day leaching test. The authors calculated that, when applied to the case study location, recycling the marine sediments showed the potential reusing 974 kg per 1000 kg dredged sediment, which would result in avoiding 0.65 m^3/1000 kg in landfill disposal.

- **Douglas, W. S., Baier, L., Gimello, R. J., Lodge, J. 2003. A comprehensive strategy for managing contaminated dredged materials in the Port of New York and New Jersey. J Dredging Engineering. 5. Accessed December 2021 at** https://www.state.nj.us/transportation/frieght/maritime . **(Douglas et al. 2003)**

- This paper gives a detailed history of how the Port of NY/NJ arrived at strategies for managing contaminated dredged material from harbor maintenance spanning from the mid-1990s when open water disposal options became restricted due to evolving Federal environmental regulations including the London Convention of the early 1990s. Key factors driving the development of a dredged material management approach in the area of the NY/NJ harbor system are the extreme importance of sustaining the operations of the harbor navigation to support the regional economy, the opportunity to beneficially use contaminated dredged sediment for upland site filling by solidifying and stabilizing (S/S) it with pozzolanic agents such as Portland cement, numerous New Jersey brownfield sites in need of for geotechnical fill and a State brownfield regulatory program which provided acceptability determinations approving the use of amended dredged sediment to support development of the waterfront in the harbor area. Other uses have also included cover for landfills and for mine/quarry reclamation fill. Additional references cited in this paper as well as in Maher et al. 2020, provide details of long-term post-placement performance. Douglas et al. 2003 and 2005 provide information on regulatory acceptance criteria. This paper and Maher et al. 2017 with Stern et al. 2019 discuss the pneumatic flow tube technology used for most recent S/S processing in the Port of NY/NJ in support of upland placement of contaminated sediments as geotechnical fill.
- **Gailani J, Brutsche KE, Godsey E, Wang P, Hartman MA. 2019. Strategic placement for beneficial use of dredged material. ERDC/CHL SR-19-3. US Army Corps of Engineers. (Gailani et al. 2019)**

  This paper, written by a team from the USACE Research and Development Center, describes ways to support and protect natural and nature-based features (NNBF) through strategic placement of dredged material. In this context, strategic placement is defined as the process of placing sediment at one location with the expectation that hydrodynamic and possibly aerodynamic forces will transport certain classes of that sediment to desired locations. The paper outlines the technical aspects of both current emerging techniques, and provides case studies from North America, England, and the Netherlands.
- **HLA. 2000. The beneficial reuse of dredged material for upland disposal. Prepared for Port of Long Beach. Harding Lawson Associates, Novato, CA. (HLA 2000)**

  This report summarizes the current state of beneficial reuse of dredged material, the available technologies and applications, and examples of projects where dredged sediments have been reused. It describes how confined disposal facilities (CDFs) can be used to dewater material for reuse and why that type of facility is preferable to a contained aquatic disposal (CAD) facility. Beneficial reuses are described for industrial, municipal, and commercial users, and examples for each kind of user are provided. Finally, project examples are provided, including the Claremont Channel in New Jersey and the Port of Oakland, Sonoma Baylands Tidal Marsh, and Moss Landing Harbor in California. Projects outside of the United States are provided as well.

- **Holm G, Lundberg K, Svedberg B, Larsson A. 2014. Beneficial use of dredged contaminated sediments. South Baltic Conference on Dredged Materials in Dike Construction, Rostock, Germany, April 10-12, 2014. pp 129-136. (Holm et al. 2014)**

  This paper discusses a Swedish case study of successful beneficial use wherein metals- and organics-contaminated sediments were treated with the stabilization/solidification method (S/S) and subsequently used as fill material to expand the port area from which they were dredged. The authors argued the environmental merits of both expanding sea transport as well as using the sediment in the place of other limited natural resources. The highest concern was the durability of the bricks through freeze-thaw cycles of Swedish ports, which were addressed during the risk assessments and permitting.

- **Hou D, Al-Tabbaa A, Guthrie P, Hellings J, Gu Q. 2014. Using a hybrid LCA method to evaluate the sustainability of sediment remediation at the London Olympic Park. J Cleaner Prod 83:87-95. (Hou et al. 2014)**

  This paper describes a case study conducted for a petroleum hydrocarbon-contaminated sediment dredging project at the London Olympic Park site. The waterway associated with the site could be used for freight craft and the import and export of material needed for revitalization of the site, but such use would necessitate dredging the riverbeds to an adequate depth. The study did not include a beneficial use option, but it did highlight the importance of assessing tertiary impacts, specifically the ability to use water transport rather than truck transport to significantly reduce environmental emissions. This tertiary impact shifted the preferred alternative from no action to a dredging option, either with landfill disposal or sediment washing.

- **Kinsella S, Pischer D, Gouran B, McRae B. 2013. Beneficial reuse of dredge spoils from Squalicum Harbor. Proceedings of Ports '13: 13th Triennial International Conference, Seattle, WA, August 25-28, 2013. (Kinsella et al. 2013)**

  This is a case study of successful beneficial use in Bellingham, Washington, USA. Dioxin-contaminated sediment was dredged from a harbor, stabilized, and incorporated into a permanent capping system for a former landfill. The Port of Bellingham performed the dredging and use operations and gained approval from the Washington State Department of Ecology to be incorporated into the landfill cover.

- **Maher A, Miskewitz R, Nazari R, Douglas S. 2020. Evaluation of long-term performance of stabilized sediment for beneficial use. Final report. Center for Advance Infrastructure and Transportation of Rutgers University and New Jersey Department of Transportation, Piscataway, NJ. (Maher et al. 2020)**

  This paper provides background on the on-going use of amended dredged material around the ports of New York/New Jersey (NY/NJ), and then discusses the technology of cement solidification/stabilization (S/S) as it has been developed over the past 30 plus years, followed by descriptions of the use of this technology for S/S of contaminated sediments dredged from the NY/NJ Harbor and then used as geotechnical fill on upland brownfields sites. Douglas et al. (2003) provides a more detailed overview of the history of this work in NY/NJ Harbor along with details on the State's program and policy for acceptance of upland beneficial use of S/S contaminated sediment. Further technical information on the technology of pneumatic flow tube mixing, which was developed for efficiently mixing and delivering S/S sediment to upland project sites, is outlined in previous works such as Kitazume and Satoh (2003), Watabe and Noguchi (2011), Maher et al. (2017), and Stern et al. (2019). This paper concludes with reviewing performance of six sample sites, out of more than 30, where amended dredged material (S/S contaminated sediment) geotechnical fill had previously been placed (all are at upland use locations). The authors conclude that stabilized dredged material "...does not break down or fail to maintain its design function."

- **Ozer-Erdogan P, Basar HM, Erden I, Tolun L. 2016. Beneficial use of marine dredged materials as a fine aggregate in ready-mixed concrete: Turkey example. Construction and Building Materials 124:690-704. (Ozer-Erdogan et al. 2016)**

  This is a feasibility study evaluating the suitability of dredged Turkish sediment for use in concrete. The authors note that Turkey lacks any notable beneficial use examples and seek to exemplify the mixing treatments and performance tests performed on Turkish sediments. The study concludes that Turkish dredged material can be used as a partial replacement for silica sand in ready-mix concrete without structural impact to the concrete.

- **Silitonga E. 2017. Stabilization/solidification of polluted marine dredged sediment of port en Bessin France, using hydraulic binders and silica fume. IOP Conf Ser: Mater Sci Eng 23(012031). (Silitonga 2017)**

  This study concluded that dredged sediment is feasible to beneficially use as road material by testing—and enhancing—the physical, mechanical, and chemical characteristics of the sediments with specific binders, and by reducing the bioavailable contamination using Silica Fume dust by-product.

- **Vogt C. 2010. Beneficially using dredged materials to create/restore habitat and restore Brownfields, and team collaborative efforts that have achieved**

success. Examples/case studies. Craig Vogt Inc. (Vogt 2010)
This report presents case studies of the use of dredged material in restoration or creation of habitat and the restoration of brownfields which can be used as models for beneficial use in the Great Lakes. The report also provides examples of stakeholder collaboration related to these projects.

BARRIERS TO USE (AKA "WHAT DOESN'T WORK")

- **Apitz SE, Black K. 2019. Research and support for developing a UK strategy for managing contaminated sediments: an analysis of project findings. Partrac, Glasgow, Scotland. (Apitz and Black 2019)**

  This report summarizes the principal findings of a study to define the extent of contaminated marine sediments in United Kingdom waters and clarify options for dredging and disposal of this material, as well as related liability and legislative issues. Included in the report is an overview of beneficial re-use options for contaminated dredged material (CDM). The study acknowledges that increasing concerns over the placement of CDM and lack of disposal space has led to growing interest in beneficial re-use. However, the study found that there are few options for the beneficial use of highly contaminated material and that re-use is generally restricted to material that has been treated.

- **Ausden M, Dixon M, Lock L, Miles R, Richardson N, Scott C. 2018. Precipitating a SEA change in the Beneficial Use of Dredged Sediment (SEABUDS). RSPB technical report. Royal Society for the Protection of Birds. (Ausden et al. 2018)**

  This report outlines the key drivers and opportunities for using dredged sediments for coastal habitat restoration in the United Kingdom. The report also details issues limiting these efforts, such as a difficult licensing process, lack of communication about beneficial-use opportunities, and added costs associated with delivering beneficial-use projects compared to disposal at sea. Potential solutions to these barriers also are provided.

- **Cappuyns V, Deweirt V, Rousseau S. 2015. Dredged sediments as a resource for brick production: possibilities and barriers from a consumers' perspective. Waste Management 38:372-380.(Cappuyns et al. 2015)**

  This paper discusses the technical and economic feasibility of using dredged sediments in brick production, as well as the Belgian legislation that regulates that process. The authors surveyed Belgian brick consumers to determine influences of consumer behaviors towards providing demand for bricks produced using dredged sediments. When considering bricks made from contaminated sediments, consumers were found to be concerned the most about brick quality (and not overpaying for inferior quality), and the association with contamination. The authors concluded that familiarizing consumers with the option of beneficially used sediment as a component of bricks as well as with information about the brick's performance characteristics are the primary solutions towards making beneficially used sediment bricks a successful product. The authors of this paper are from the Centre for Economics and Corporate Sustainability (CEDON) in Belgium.

- **Majone M, Verdini R, Aulenta F, Rossetti S, Tandoi V, Kalogerakis N, Agathos S, Puig S, Zanaroli G, Fava F. 2015. In situ groundwater and sediment bioremediation: barriers and perspectives at European contaminated sites. New Biotech 32(1):133-146. (Majone et al. 2015)**

  This paper explores the prospects for improving the economic viability of *in situ* remediation. Lack of public trust was identified as a significant barrier even if *in situ* remediation technology becomes economical. While the paper does not specifically address beneficial use, the take-home message—that public trust is a significant factor in sediment remediation—is salient.

- **Ulibarri N, Goodrich KA, Wagle P, Brand M, Matthew R, Stein ED, Sanders BF. 2020. Barriers and opportunities for beneficial reuse of sediment to support coastal resilience. Ocean & Coast Management 195:105287. (Ulibarri et al. 2020)**

  This research gathered information from 22 individuals who are experts in sediment management in Southern California to identify the existing barriers to beneficial use, such as economics, policies and regulations, climate change, and extreme weather events. The general consensus was that although the current approaches are successful in dealing with excess sediment, they are insufficiently flexible to deal with issues related to societal and environmental changes. This paper also includes brief descriptions of efforts that have taken place in the Tijuana River Valley: a pilot project involving the placement of 45,000 cubic yards of sediment in the coastal nearshore, and the restoration of the Nelson Sloan Quarry with beneficially used sediment.

Remediation Decision-Making Frameworks and Strategies

Traditional Strategies (pre-2010)

- **Ancheta C. 1998. Remediation strategies and options for contaminated sediment. National Conference on Management and Treatment of Contaminated Sediments, Cincinnati, OH, May 13-14, 1997. (Ancheta 1998)**

  This paper provides an overview of the process to evaluate strategies to remediate contaminated sediment sites, including brief descriptions of remedial technologies and a case study involving the remediation of creosote-contaminated sediment at Thunder Bay in Lake Superior, Ontario, Canada. Relevant to contaminated sediment beneficial use, the example included using some dredged material as fill to create new industrial land. A consortium of three private sector and two public sector groups selected a remediation strategy involving a combination of technologies to address the remediation needs for different levels of contamination, based on the severity of biological toxicity. Monitored natural recovery was implemented for the least-contaminated sediment, capping was used to isolate moderately contaminated sediment from the water column, and the most highly contaminated sediment was dredged. The dredged material was treated to industrial use criteria and placed, in combination with clean fill, behind a constructed containment berm, creating new industrial lands.

- **Brandon DL, Price RA. 2007. Summary of available guidance and best practices for determining suitability of dredged material for beneficial uses. ERDC/EL TR-07-27. US Army Corps of Engineers. (Brandon and Price 2007)**

  This report compiles current guidance and best practices in the evaluation of dredged material for beneficial uses in the United States. It describes the technological advances in equipment, treatment, and handling which have opened the door to new options for beneficial use. The report identifies 10 beneficial use categories: habitat development; beach nourishment; aquaculture; parks and recreation; agriculture, forest, and horticulture; strip-mine reclamation and solid-waste management; shoreline stabilization and erosion control; construction and industrial use; material transfer; and multiple purpose.

- **EPA, USACE. 2007. Identifying, planning, and financing beneficial use projects using dredged material. Beneficial use planning manual. US Environmental Protection Agency and US Army Corps of Engineers, Washington, DC. (EPA and USACE 2007)**

  This planning manual describes the range of opportunities, identifies potential project partners, and outlines planning, financing, and stakeholder engagement options toward the beneficial use of dredged material. The manual is written for a wide audience, including dredging organizations, permitting authorities, environmental resource agencies, port authorities, and other organizations that can use or encourage the use of dredged material for beneficial purposes.

- **USACE, EPA, BCDC, SFBRWQCB. 2001. Long-term management strategy for the placement of dredged material in the San Francisco Bay region. Management plan 2001. (USACE et al. 2001)**

  The USACE, U.S. Environmental Protection Agency, San Francisco Bay Conversation and Development Commission, and San Francisco Bay Regional Water Quality Control Board prepared this management plan to reduce disposal of dredge spoils into the San Francisco Bay by identifying alternative and beneficial use strategies. The plan identifies beneficial use of dredged material as a "cornerstone" of implementing the long-term management strategy. It outlines steps involved with obtaining authorization to take dredged material to beneficial use sites, as well as the steps and potential hurdles involved with implementation of use projects.

Case Studies / Guidance Documents of Management Strategies (post-2010)

- **CEDA. 2019. Sustainable management of the beneficial use of sediments. A case-studies review. Central Dredging Association, Rotterdamseweg, The Netherlands. (CEDA 2019b)**

  This case study review commissioned by the CEDA Environmental Commission summarizes recent advances and ongoing initiatives, programs, and best management practices on the beneficial use of sediments. The 38 case studies included projects involving both contaminated as well as clean sediments across 11 countries since 1987. The review focuses on the technical aspects of these case studies to demonstrate feasibility. The paper does not address legislative or economic aspects in detail.

- **EPA. 2016. Methodology for evaluating beneficial uses of industrial non-hazardous secondary materials. EPA 530-R-16-011. US Environmental Protection Agency, Washington, DC. (EPA 2016b)**
  This document describes the EPA's methodology for evaluating the potential beneficial use of industrial non-hazardous secondary materials. This methodology can be used to determine whether the potential for adverse impacts to human health and the environment from a proposed beneficial use is comparable to or lower than from an analogous product, or at or below relevant health-based and regulatory benchmarks.

- **EPA. 2016. Beneficial use compendium: a collection of resources and tools to support beneficial use evaluations. EPA 530-R-16-009. US Environmental Protection Agency, Washington, DC. (EPA 2016a)**
  A companion to *Methodology for Evaluating Beneficial Uses of Industrial Non-Hazardous Secondary Materials* (above), this document provides a more detailed discussion of some specific considerations that may arise in the evaluation process, as well as a list of existing resources and tools that can assist with these evaluations. The compendium is organized into sections that mirror the phases and steps of the beneficial use methodology.

- **Grandchamp F, Van Paassen L, Sutton G, Harrington J, Belhadj E, Mcheik A, Masson E, Van Dessel J, Lemiere B, Brakni S. 2014. CEAMaS project: civil engineering applications for marine sediments. I2SM 2014 - International Symposium on Sediment Management, Ferrara, Italy. (Grandchamp et al. 2014)**

  The CEMaS project and this paper promote the beneficial use of marine sediments in civil engineering applications in a sustainable, economical and socially acceptable manner. The paper advocates for international cooperation to exchange knowledge and methodology to set recommendations for integrated regulation regarding the re-use of dredged sediments.

- **Harrington J, Smith G. 2013. Guidance on the beneficial use of dredge material in Ireland. Cork Institute of Technology, School of Building & Civil Engineering, Cork, Ireland. (Harrington and Smith 2013)**

  This paper provides guidance on the beneficial use of dredge material in Ireland. The paper summarizes strategies and best practices in European countries with an extensive history of dredging and re-use. Beneficial use options are presented in three categories -- engineering uses, environmental enhancement, and agricultural & product uses. Examples are provided under each category and are compared to current practices in Ireland. Another table presents differences approaches to dredge material management, including innovative approaches. Another section provides different, lesser-used approaches, including innovative practices. The paper also describes relevant Irish and EU legislation and directives and provides a process diagram for determining what type of authorization may be required for beneficial-use approaches in the three categories described above.

- **HELCOM. 2020. HELCOM guidelines for management of dredged material at sea and HELCOM reporting format for management of dredged material at sea. (HELCOM 2020)**

  This guidance document, adopted by the Baltic Marine Environmental Protection Commission (Helsinki Commission – HELCOM), was developed in accordance with the 2013 IMO London Protocol and London Convention Specific Guidelines for Assessment of Dredged Material. The document outlines five potential beneficial use options, applicable depending on the physical and chemical characteristics of the material. The five beneficial use options are: (1) sustainable placement by retaining sediment within the natural sediment system, (2) habitat restoration and development, (3) beach nourishment, (4) shoreline stabilization and protection, and (5) engineering uses (e.g., as a capping material or for land reclamation).

- **Lemiere B, Michel P, Abriak N-E, Haouche L, Laboudigue A, Alary C, Badreddine R, Hazebrouck B, Meersman J. 2012. The GeDSeT project: constitution of a decision support tool (DST) for the management and material recovery of waterways sediments in Belgium and Northern France. WASCON 2012 - towards effective, durable and sustainable production and use of alternative materials in construction, Gothenburg, Sweden, May 2012. (Lemiere et al. 2012)**

  This paper presents a decision support tool that allows stakeholders to compare the positive and negative impacts of various sediment management decisions based on their priorities. The relevance to contaminated sediment beneficial use relates to the goal of weighing management options in terms of sustainability goals. The tool applies a life cycle analysis approach and compares sediment disposal to sediment beneficial use options. The authors clearly state that this tool is not designed for finding the best outcome by sustainability metrics but rather to allow stakeholders to collaborate easily. This study reiterates the common theme that using decision making tools early in the planning stages maximizes the available options for remediation and beneficial use for dredged sediment.

- **Maher A, Douglas WS, Jafari F, Pecchioli J. 2013. The processing and beneficial use of fine-grained dredged material: a manual for engineers. Rutgers Center for Advanced Infrastructure and Transportation. (Maher et al. 2013)**

  This manual provides information and guidance for engineers and dredging contractors on implementation of emerging and innovative dredged material management techniques in the state of New Jersey. Topics include the geochemical and geotechnical characteristics of dredged sediment specific to coastal and estuarine waterways of New Jersey and New York, placement and transportation methods, processing and stabilization systems, decontamination methods, and quality control/ assurance protocols. Example projects, including the Jersey Gardens Mall and Bayonne Golf Course, are reviewed in detail.

- **Welch M, Mogren ET, Beeney L. 2016. A literature review of the beneficial use of dredged material and sediment management plans and strategies. Portland State University. (Welch et al. 2016)**

  This report, undertaken to help inform development of the Lower Columbia River Regional Sediment Management Plans, summarizes key findings from the body of literature prior to 2016 addressing beneficial use of sediment. The report identifies seven distinct types of beneficial uses (beach nourishment; habitat restoration, creation, and development; structural and shore protection; recreation; agriculture, forestry, horticulture, and aquaculture; strip-mine reclamation and solid-waste management; and construction / industrial development). It also provides a review and lessons learned from sediment management plans across the United States and how they might inform management of sediment for navigation purposes in Washington and Oregon.

Proposed Green & Sustainable Remediation / Life Cycle Assessment Frameworks

- **Apitz SE, Fitzpatrick AG, McNally A, Harrison D, Coughlin C, Edwards DA. 2017. Stakeholder value-linked sustainability assessment: evaluating remedial alternatives for the Portland Harbor Superfund site, Portland, Oregon, USA. Integr Environ Assess Manag 14(1):43-62. (Apitz et al. 2017)**

  This paper from the Portland Harbor Sustainability Project (PHSP) describes a Stakeholder Value Assessment (SVA) tool to evaluate the stakeholder value-associated costs and benefits of remedial alternatives. The case study explains how remedial actions proposed for the site impacted the three sustainability pillars (environmental, social, and economic). It illustrates how the benefits of active remediation can be offset by undesirable risks to stakeholder group values, especially among the more extensive remedial alternatives. The case study includes a detailed description of the SVA tool—including how metrics developed from feasibility study (FS) data were used to generate scores for each of the sustainability pillars for all remedial alternatives—and ranked the alternatives based on the overall stakeholder group values-based sustainability score. Beneficial uses may be recognized by such an SVA evaluation as being supportive of sustainability goals.

- **Bardos P, Spencer K, Ward RD, Maco B, Cundy AB. 2020. Integrated and sustainable management of post-industrial coasts. Front Environ Sci 8(86). (Bardos et al. 2020)**

  This paper describes how historical remediation strategies are being undermined by climate change and proposes a "sustainability linkages" approach for coastal brownfield and contaminated sediment management. The framework incorporates "gentle" remediation options (e.g., bioremediation) and beneficial uses, and the paper summarizes several case studies in Europe and the United States that incorporated such tools in ways that improved ecological resources or mitigated climate change effects. The methodology of the proposed framework is analogous to a "source-pathway-receptor" model, and the authors provide an example of its applicability to sustainable use. This work was performed and funded by: the Centre for Aquatic Environments, University of Brighton; r3 Environmental Technology Ltd.; Queen Mary University of London; Estonian University of Life Sciences; Program Advisor for Inter-State Technology and Regulatory Council Sustainable Remediation and Resilience Team, Oakland, CA; and the University of Southampton.

- **Barjoveanu G, De Gisi S, Casale R, Todaro F, Notarnicola M, Teodosiu C. 2018. A life cycle assessment study on the stabilization/solidification treatment processes for contaminated marine sediments. J Cleaner Prod 201:391-402. (Barjoveanu et al. 2018)**

  This study performed the life cycle analysis on the S/S methods described in De Gisi et al. 2020 for a marine case study in Southern Italy. S/S scenarios were developed to pass leachability tests as well as performance assessments as building materials and were evaluated for environmental impact in the LCA against a "no action" scenario. The study concluded that the S/S beneficial use scenarios are environmentally beneficial to the local area.

- **CEDA. 2019. Assessing the benefits of using contaminated sediments. Central Dredging Association. (CEDA 2019a)**

  This position paper, prepared by CEDA's Working Group on the Beneficial Use of Sediments (WGBU), proposes that sediments must be used beneficially because the alternative "no action" approach transfers—and often increases—risk and cost to future generations. Beneficial use case studies, along with an overview of proven treatment techniques and risk-evaluation methods, help demonstrate that contaminated sediments can be a resource for mitigating the effects of climate change and help promote a circular economy. While the paper does not include a detailed overview of country-specific sediment quality standards or disposal regulations, it emphasizes the importance of flexible legislation to help facilitate beneficial use of contaminated sediments.

- **Kupryianchyk D, Rakowska MI, Reible D, Harmsen J, Cornelissen G, van Veggel M, Hale SE, Grotenhuis T, Koelmans AA. 2015. Positioning activated carbon amendment technologies in a novel framework for sediment management. Integr Environ Assess Manag 11(2):221-234. (Kupryianchyk et al. 2015)**

  This paper evaluates many sediment remediation strategies (including beneficial use) by factors of efficiency, risk, applicability, complexity, cost, and both public and regulatory acceptance. The focus of this paper zeros in on how using activated carbon can affect these factors as a means to reduce chemical exposure from beneficially used sediments. The authors conclude incorporating activated carbon in various *in situ* or *ex situ* methods generally have medium to high efficiency, low risks, medium complexity, medium economic costs, and medium public approval (little precedent for regulatory acceptance).

- **Labianca C, De Gisi S, Todaro F, Notarnicola M. 2020. Evaluation of remediation technologies for contaminated marine sediments through multi criteria decision analysis. Environ Eng Manage J 19(10):1897-1903. (Labianca et al. 2020)**

  This study created and applied a multi-criteria decision analysis (MCDA) approach for selecting the best sediment remediation option for varying stakeholder criteria. The authors explain how this method ensures that stakeholders understand how results are calculated and therefore become active participants in the remediation/beneficial use method selection process. The authors of this study represent the Polytechnic University of Bari, Italy.

- **Noren A, Fedje KK, Stromvall A-M, Rauch S, Andersson-Skold Y. 2020. Integrated assessment of management strategies for metal-contaminated dredged sediments - What are the best approaches for ports, marinas and waterways? Sci Tot Environ 716:135510. (Noren et al. 2020)**

  This study from Sweden proposes a stepwise integrated assessment framework for ranking dredged sediment management solutions, and then applies the framework to six case studies. The final section discusses how stakeholder perceptions affect the final decision for a site and how this process can help communicate the best options for stakeholders early in the decision-making process. This is a recurring theme: Stakeholder perceptions drive remedy selection and can shift the balance from disposal to beneficial use. The study identifies winning public support as the key impediment to beneficial use but does not propose a solution.

- **Pasciucco F, Pecorini I, De Gregorio S, Pilato F, Iannelli R. 2021. Recovery strategies of contaminated marine sediments: a life cycle assessment. Sustainability 13(8520). (Pasciucco et al. 2021)**

  This study performed a Life Cycle Assessment (LCA) to score recovery and beneficial use methods for dredged Mediterranean sediments for environmental impact; the methods were compared to a reference scenario of landfilling the sediment. For the majority of sediment contamination scenarios, partial or complete beneficial use had lesser environmental impacts than did landfilling. This research was funded by the Interregional Italy-France Maritime.

- **Reddy K, Kumar G. 2018. Green and sustainable remediation of polluted sites: new concept, assessment tools, and challenges. ce/papers 2(2-3):83-92. (Reddy and Kumar 2018)**

  This paper addresses the common theme of acknowledging the significant secondary environmental impacts (e.g., greenhouse gas emissions, energy and water use, etc.) that sediment remediation can have in the efforts towards reducing the primary impact of chemical risk. The authors promote green and sustainable remediation (GSR), which is a remediation management approach that identifies the remediation method with the best overall environmental outcome. Examples of several US state-specific management tools under the umbrella of GSR are discussed, which incorporate sediment and site beneficial use plans, conservation of raw materials, chemical fate and transport, and human and ecological health. Obstacles to sustainable remediation are identified including lack of financial incentives, lack of regulatory mandate, lack of public awareness, and need for greater academic focus on developing standardized frameworks.

- **Sparrevik M, Saloranta T, Cornelissen G, Eek E, Fet AM, Breedveld GD, Linkov I. 2011. Use of life cycle assessments to evaluate the environmental footprint of contaminated sediment remediation. Environ Sci Technol 45(10):4235-4241. (Sparrevik et al. 2011)**

  This study uses the LCA approach to evaluate the environmental footprint of sediment remediation alternatives in Norwegian fjords contaminated with polychlorinated dibenzo-*p*-dioxins and -furans (PCDD/Fs). The authors break down the revisions to the LCA method necessary for applications to sediment remediation, describe how they applied the method to assess primary and secondary environmental impacts, and present their sensitivity analysis. The paper concludes that LCA is useful for prioritizing remedial options from an environmental perspective by better comparing the short-term resource intensive options to the long-term benefits, and vice versa. This research was performed by the Norwegian Geotechnical Institute, the Norwegian University of Technology, the Norwegian Institute for Water Research, and the U.S. Army Engineer Research and Development Center.

TECHNIQUES AND TECHNOLOGIES

- **Amar M, Benzerzour M, Kleib J, Abriak N-E. 2021. From dredged sediment to supplementary cementitious material: characterization, treatment, and reuse. Intl J Sed Res 36:92-109. (Amar et al. 2021)**

  This paper is a thorough review of the methods that have been tested to incorporate contaminated sediments into cement or concrete as beneficial use. Treatments of the sediments vary depending on the contamination type and concentration, but the authors conclude that, with the appropriate treatment approach, sediment-based concretes performed similarly to control concrete.

- **Bianco F, Race M, Papirio S, Oleszczuk P, Esposito G. 2020. The addition of biochar as a sustainable strategy for the remediation of PAH-contaminated sediments. Chemosphere 263:128274. (Bianco et al. 2020)**

  This paper reviewed the available literature on remediating PAH-contaminated sediments using biochar and the impact that this method would have on available beneficial use options. The effect of biochar on pre-beneficial use treatments such as on the integrity of bricks or concrete from S/S or for coastal rehabilitation are still in the research stages and the recommendation in the literature seems to be to find better ways of removing the biochar after absorbing PAHs and before other beneficial use treatments. The paper concludes that biochar does completely remove PAHs from contaminated sediments.

- **Couvidat J, Benzaazoua M, Chatain V, Bouamrane A, Bouzahzah H. 2016. Feasibility of the reuse of total and processed contaminated marine sediments as fine aggregates in cemented mortars. Construction and Building Materials 112:892-902. (Couvidat et al. 2016)**

  This study considered the technical requirements that are necessary for cemented mortars and how different processing of contaminated sediments will affect their ability to be beneficially used in this way. Sieving sediments to only use the coarse fraction removes the most contaminated fraction of sediment, and additionally improved mechanical strength. Using only the coarse fraction additionally reduced the porosity of the mortar and thus reduced water demand during formulation. The tested sediments were sampled from a French harbor and were contaminated with copper, lead, and zinc and the authors highlighted that this study falls within the sustainability recommendations of the EU.

- **Interreg. 2019. Using sediment as a resource. Sediment recycling strategy. Interreg 2 Seas. (Interreg 2019)**

  The European Union's Interreg 2 Seas Program funded the *Using Sediment as a Resource* project from 2016 through 2020. This resulting report describes four avenues for beneficial use of contaminated sediment: (1) Agriculture – spreading dredged material on adjacent parcels of land, (2) Construction – use in civil engineering and public infrastructure work, (3) Habitat Creation – enhancement, creation, or reinstatement of coastal habitats such as salt marshes, mudflats, and shingle ridges, and (4) Flood Defense – techniques such as controlled flood areas, managed realignments to restore natural wetlands, or dykes.

- **Todaro F, Vitone C, Notarnicola M. 2019. Stabilization and recycling of contaminated marine sediments. E3S Web Conf 92:11004. (Todaro et al. 2019)**

  This study investigated the effect on the S/S output of treating contaminated dredged sediments using active carbon and biochar. The authors conclude that either treatment does not significantly affect the S/S beneficial use of sediments but does reduce the bioavailability of the contaminants through a sustainable treatment method.

- **USACE. 2015. Dredging and dredged material management. EM 1110-2-5025. US Army Corps of Engineers, Washington, DC. (USACE 2015)**
  This manual summarizes the dredging equipment and dredged material placement techniques used by the Corps of Engineers and describes managed and design processes associated with new-work and maintenance dredging related to navigation projects. The manual provides guidance on planning, designing, and managing dredged material for beneficial uses while incorporating ecological concepts and engineering designs.

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Beneficial Use Example – Middle Harbor Contaminated Sediment Beneficial Use Physical Separation Technique

Middle Harbor Redevelopment Project

Ports of Long Beach/Los Angeles, California, Pacific Coast, United States

In the early 2000s, the Port of Long Beach, California (Port), realized a need to accommodate increasing container traffic and ship sizes at its container handling facilities. Through an extensive review, evaluation, and community involvement process, and following the Port's Green Port Policy (POLB. 2005), the Port arrived at a plan to rehabilitate old infrastructure, modernize the marine terminal, and increase its capacity to meet future cargo container throughput volumes and modern cargo vessel sizes.

The $1.5 billion project happened in three phases over 10 years (POLB. 2021). The design involved creating a new shore container handling area overlying what was at the time a 294-acre area of underutilized slips and wharfs and including the deepening and widening of a ship basin adjoining the "water side" of the container handling area to accommodate multiple and larger modern container ships. Two underutilized slips and a low area on an adjoining wharf would be filled to create a larger, more contiguous "land-side" area covering 342 acres. The project required the filling of 48 acres of water, mainly a former slip and former boat basin. In its Green Port Policy (POLB. 2009) the Port had committed to remediate contaminated sediments and to beneficially use dredged sediments where feasible and to supporting regional beneficial use of soil and sediment materials in its redevelopment efforts. Consequently, the need for up to 4.8 million cubic yards of fill to construct the project, offered the opportunity to beneficially use clean sediment, contaminated sediment, and industrial fill soils from within the project footprint. However, the immense size of the project necessitated also seeking fill from external sources (Tomley. 2016 and POLB, 2021).

An added benefit of the plan was that legacy sediment contamination (which the Port had inherited responsibility for) in the West Basin slip area was also removed as part of the deepening and widening of this area. The removed contaminated sediment was placed as part of the initial filling in of the Slip 1 fill area. Types of contamination present included polychlorinated biphenyls (PCB) associated with the West Basin slip area. The most contaminated sediments were placed in the lowest portions of the fill area.

The Slip 1 filling phase of the Middle Harbor project received "…*close to 1 million cubic yards of contaminated third-party material being sequestered in the Slip 1 fill site. This provided a mutually beneficial partnership in which the Port was able to cost-effectively complete the construction of the fill and provide an environmentally sustainable and cost-effective disposal option that otherwise would not have been available, for third parties in the Southern California region*…" (Tomley. 2016).

As part of the planning and implementation process, the Port prepared an Environmental Protocol to guide how the project would evaluate and accept materials for the Slip and boat basin filling (POLB. 2009). The overall redevelopment project resulted in placing approximately 2.2 million cubic yards of material collected from various parts of the Port's Middle Harbor project, and it additionally required 2.6 million cubic yards of material to be imported from outside the project. Consequently, the Port reached out to potential projects in the region seeking proposed import fill (POLB. 2009, Tomley.2016). The protocol was used to communicate how materials would be considered and what would constitute acceptable material, including setting forth minimum chemical criteria. Not accepted were:

- hazardous waste as termed by the U.S. Environmental Protection Agency (EPA) or the State of California,
- material deemed unsuitable for confined aquatic disposal by the EPA, or
- material having land-use restrictions or other long-term operations and maintenance requirements imposed by California Department of Toxic Substances Control (DTSC).

The filling plan also considered whether fill material was coarse-grained (optimal) or fine-grained, and it set targets for constraining the proportion of placed fill that would be fine-grained in nature. The plan also outlined a prioritization scheme for accepting proposed outside fill sources such as schedule and timing, whether the source material had been fully characterized for chemistry and grain size, geographic proximity, and whether the source project had a level of design and permitting completed to assure the material would be available within a window of scheduling certainty to the Middle Harbor project (POLB. 2009).

This project demonstrates how regional coordination and planning, with patience and persistence, are needed to undertake such a large-scale port infrastructure improvement effort. Project partners were many but included the U.S. Army Corps of Engineers and the Los Angeles Contaminated Sediments Task Force. Innovatively, the project considered incorporation of contaminated sediment as part of the materials accepted into the fill cross section in a fashion somewhat parallel to the San Francisco Bay area Montezuma Wetland Restoration project. Because the proposing parties committed to seeking beneficial uses of sediments as part of the early planning effort, this aspect was designed-in from near the beginning, and ultimately helped the project gain acceptance, benefitting not only the Port of Long Beach, but also a wide array of nearby projects. The project was completed in August 2021 (POLB. 2021).

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Beneficial Use Example - Montezuma Wetland Restoration

San Francisco Bay Area, California, USA

The Montezuma wetland restoration project is a large-scale tidal marsh restoration effort beneficially using dredged sediment from throughout the San Francisco Bay area (Bay area), with two categories of sediment quality accepted for use in the restoration work. The San Francisco Bay Regional Water Quality Control Board (SFBRWQCB, 1992) projected that more than 17 million cubic yards of maintenance dredge sediment will be used for the restoration of thousands of acres of significantly subsided and altered salt marshlands around the northeastern Bay area (California Regional Water Quality Control Board (CRWQCB, 2012). The Water Quality Control Board forecasts the restoration effort to span more than two decades.

Sediment sourced from on-going maintenance dredging in the Bay area falls into two categories: surface (cover) and foundation (non-cover) sand. The first category, consisting of sediment having low ("ambient") anthropogenic contamination up to ecological threshold effects-based surface sediment screening criteria levels, may be used for surficial tidal marsh creation, referred to as "surface (cover)." The second category, which comprises an estimated 20% of the dredged material, is expected to have higher anthropogenic constituent levels and may be accepted for deep placement, referred to as "foundation (non-cover) sand." The foundation sand is covered by surface sediment to create the final restoration elevation for a restored tidal marsh area (CRWQCB, 2012 and SFRWQCB, 2000). The acceptance criteria for foundation (non-cover) sand are 2 to 3 times higher than the acceptance criteria for surface sediment (CRWQCB, 2012 and SFBRWQCB, 1992 and 2000). Foundation sand placement is used to raise subsided areas prior to placement of a minimum three-foot thick surface sand layer to establish the final tidal marsh elevation. What is significant in this example is the use of moderately contaminated sediment for a beneficial purpose in the overall restoration design. The foundation sediments are kept below the biologically active zone and elutriate testing is used to confirm that anthropogenic constituents will not be mobilized in leachate after placement (SFBRWQCB, 2000).

Annual maintenance dredging in the San Francisco Bay harbor generated more than 2.6 million cubic yards in 2020, of this total 32% was beneficially used. The US Army Corps of Engineers (USACE) Dredge Material Management Office (DMM)) reports 848,000 cubic yards beneficially have been used, with roughly 66% (560,000 cubic yards) beneficially used for salt marsh habitat restoration in 2020 (DMMO 2021). Similar figures have been reported for five previous years. The efforts in the Bay area are clearly a sizeable, multiyear undertaking and although no specific figures were reported for quantities, it appears to be accepting significant amounts of anthropogenically contaminated sediment for beneficial use as foundation sand placement within tidal marsh restoration areas. The DMMO 2020 annual report on dredging and beneficial use for the Bay area concludes that more can be done to increase the proportion of sediment beneficially used on projects within the Bay area, rather than disposed in open waters of the Bay or in the ocean (DMMO, 2021).

This project is also discussed and compared to other programs in **Table 1 Comparison of Regulatory and Other Programs – North America**.

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Beneficial Use Example - Contaminated Sediment Stabilization/Solidification and Beneficial Use on Upland Sites

New Jersey/New York Harbor, Atlantic Coast, United States

The harbors of New Jersey/New York require as much as 4 to 6 million cubic yards of dredged sediment removed annually to maintain navigation throughout this large busy port area (Douglas et al. 2003). Douglas et al. (2003) points out that this highly urbanized area has an extensive past industrial and urban development history and consequently the dredged materials generated from maintenance dredging have anthropogenic contamination from this legacy. A crisis arose in 1991 with issuance by the US Army Corps of Engineers (USACE) and US Environmental Protection Agency (USEPA) of new acceptance requirements for disposal of dredged materials in ocean disposal areas (USEPA and USACE, 1991). The result of these new requirements meant that as much as 75% of planned maintenance dredging areas failed acceptance for ocean disposal which had been the management approach of choice. Consequently, maintenance dredge management costs jumped from $5-$10 per cubic yard to over $100 per cubic yard (Douglas et al. 2003).

As a result of the restrictions on open water/ocean disposal sites and the sudden increase in costs; harbor, transportation, and shipping stakeholders together with the US Army Corps of Engineers (USACE) sought large-scale options for managing the more contaminated sediments in ways other than disposal into landfills or confined disposal facilities (Maher et al., 2020). Since 2000 New Jersey port entities have solidified and stabilized (with Portland cement or other pozzolanic compounds) and beneficially used more than 30 million cubic yards of impacted sediment from New Jersey/New York harbor dredging (Maher, et al., 2020). In a recent evaluation of long-term performance of stabilized sediment for beneficial use, Maher et al. (2020) state that the tightening of open water disposal acceptance criteria "…*resulted in one strategy that is commonly used in New Jersey, stabilization and beneficial use of the stabilized dredged material (SDM) as a capping or filling material for landfills, industrial sites, and abandoned mines. It has also been used as road base and for the construction of road embankments.*" The stabilized sediment has been used beneficially at multiple upland sites throughout New Jersey, most of which are on the harbor waterfront (Douglas et al., 2003; Maher et al., 2020).

One solidification and stabilization technique described includes use of a pneumatic mixing tube method to introduce the sediment into the cement slurry with the mix then pumped as a slurry either to its final use location or to a staging area (Stern et al. 2019; Kitazume and Satoh. 2005). The resulting soil/fill material is a geotechnically suitable fill for subsequent construction using traditional earth work equipment. Douglas et al. (2003) note that amending contaminated sediment with Portland cement produces three beneficial features- "...binds contaminants to the sediment particles, removes excess water and improves the structural characteristics of the silt and clay particles." Maher et al. (2020) evaluated long-term performance of stabilized dredged sediments from NY/NJ Harbor at a subset of six sites out of more than 20 sites which encompass projects performed over the past 20 years. According to the authors the study sites have all been successfully filled or capped and then redeveloped, or prepared for up-coming redevelopment, for uses as varied as retail and residential to transportation hubs and parking lots. Their review notes that issues were encountered at two of the sites, including one issue attributed to the underlying substrate (a former landfill) preparation resulting in differential settlement and another due to incomplete mixing of the Portland cement with the sediment resulting in more difficulty in handling and placement as geotechnical fill. This review concluded that at all six locations "...the stabilized dredged material had not broken-down or failed to maintain its design function (Maher et al. 2020)."

Douglas et al. (2003) point-out a key element in allowing for the beneficial use of contaminated sediments from the NY/NJ Harbor, was creation of a program patterned after the concept of a "beneficial use determination" for solid waste. They explain that under the program the State of New Jersey permits use of contaminated dredged material based on the nature of the resulting stabilized material and the environmental controls and intended use of the placement site. An evaluation is performed to confirm that the proposed use will be protective of human health and the environment and based on that finding the State then issues an "Acceptable Use Determination." The Determination is issued for the processing and placement sites and the steps of the processing (Douglas et al. 2003). They note that the placement sites frequently also have engineering and institutional control requirements as part of the approval and issuance of the Determination, this program is administered through the New Jersey Office of Dredging and Sediment Technology within the Site Remediation Program (NJDEP SRP - About the Site Remediation Program). Another aspect of the program is a policy that placement sites where pre-existing contamination is present are preferred for placement of stabilized contaminated dredged material. Douglas et al. (2003) and Maher et al. (2020) both note this policy, however reference is also made to use stabilized dredged material for reclamation cover at former quarry or mine sites. No details about receiving reclamation site's pre-placement conditions were provided. Consequently, it is not clear if the policy is flexible to allow acceptance for such reclamation uses. Douglas et al. (2003) point to the potential to use stabilized dredged material for reclamation of large former coal mines in nearby Pennsylvania, as a future opportunity for beneficially using contaminated dredged materials (sediments).

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Beneficial Use Example – St. Louis River/Interlake/Duluth Tar (SLRIDT) Site

Duluth MN/Superior WI, Great Lakes, United States

The remediation and restoration of the St. Louis River/Interlake/Duluth Tar (SLRIDT) site in the St. Louis River estuary approximately four (4) miles upriver from Lake Superior in Great Lakes Area of Concern #1 incorporated beneficial use of contaminated sediment, as well as other dredged sediment and waste materials. The Sediment Operable Unit (SedOU) portion of the SLRIDT site includes two constructed peninsulas, a natural bay and two shipping slips. The site straddles the Wisconsin/Minnesota state line and includes a federal navigation channel, requiring communication and coordination with the U. S. Army Corps of Engineers (USACE), Minnesota Pollution Control Agency (MPCA), Minnesota Department of Natural Resources (MDNR) and Wisconsin Department of Natural Resource (WDNR) to implement the combination dredge/cap remedy.

Many of the key components of the Remedial Design/Response Action Plan (RD/RAP) were developed during a two-day workshop with participation by a Peer Review Team (PRT) of national and international sediment remediation experts and significant engagement with local, state, and federal stakeholders, as well as neighborhood residents (Costello et. al. 2009). Workshop participants expressed their goals and objectives for the site, then after technical presentations of the design-level investigation results the participants formed work groups to help develop remedial alternatives the met their goals. The resulting remediation/restoration options and features developed by the workshop participants were presented at the end of the workshop and formed the basis of the RD/RAP which was subsequently constructed over six years of implementation from 2006-2011.

A pilot capping project completed in a portion of one of the shipping slips using sand from USACE navigation dredging in the Duluth/Superior harbor provided proof of concept (Hedblom et. al. 2004, and Costello et. al. 2003) and constructability. The imported dredged sand cap material was monitored in real-time to ensure polynuclear aromatic hydrocarbons (PAHs) concentrations met cap material specifications for in-water placement. The pilot was successful, and the RD/RAP included 16 cap/cover/armor configurations constructed in 26 locations (Hedblom et. al. 2014).

Riprap and armor cobble material used to protect sand caps in areas with high erosion potential, including a rock dike constructed to convert one of the shipping slips into a contained aquatic disposal (CAD) facility, consisted of waste rock transported by rail from mines in the Iron Range region of northern Minnesota. Crushed dolomite sand, which comprised most of the capping material, was transported by ship to limit the amount of truck traffic in the adjacent residential neighborhood.

A portion of a natural bay containing sediment with the highest PAH concentrations was capped with a surcharge cap to accelerate consolidation to achieve habitat restoration goals based on water depth (Hedblom et. al. 2012). Excess sand used in the surcharge process was removed after two years and used to cap the CAD, which contained approximately 140,000 cubic yards of contaminated dredged sediment and wetland material. The CAD cap included an activated carbon mat (ACM) funded by U.S. Environmental Protection Agency (EPA) Great Lakes National Program Office (GLNPO) through the Great Lakes Legacy Act (GLLA) fund. Organic material from the Tallas Island mitigation project, which dredged uncontaminated sediment to restore a back-channel river connection and create deep off-channel hole to provide fish habitat, was used to cover the sand cap in the CAD.

The top of the rock dike at the end of the former slip was removed after the contaminated sediment was capped to reconnect the CAD to the estuary and convert the former industrially influenced shipping slip into an 11-acre shallow bay adjacent to the river channel, which was identified as a high priority restoration feature by estuary natural resource managers (St. Louis River Citizens Action Committee [SLRCAC] 2002).

An additional beneficial use aspect of this project included the use of organic material (referred to as Environmental Medium in the RD/RAP) dredged from the Tallas Island mitigation project to cover the sand caps, successfully accelerating establishment of vegetated wetlands with native flora and fauna on the top of the remedial sand capped areas (Partch et. al. 2017).

The SLRIDT site is on both the federal National Priority List and the State of Minnesota Permanent List of Priorities and is being monitored for compliance with regulatory and permit requirements in accordance with a Long-Term Monitoring and Maintenance Plan (LTMM) approved by the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR). One element of the monitoring plan is the collection of multiple depths of porewater within the cap layers at designated monitoring locations. The porewater results have consistently shown that the remedial caps are performing as designed.

The SLRIDT site is part of the St. Louis River Superfund Site and is subject to 5-year reviews completed by the MPCA; the fourth 5-year review was completed in 2018.The results of the monitoring and 5-year review inspections show that the PAH-impacted sediments remaining on-site have not impacted the environment or human health in the decade since completion of the SedOU remediation and restoration in 2011.

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