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# Dredged sediments as a natural resource

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**Abstract**. The periodic removal of sediments is necessary to ensure the functionality of ports, to facilitate navigation, for construction, expansion and environmental cleanup processes. The management and fate of the resultant tons of dredged material is a costly issue that must be addressed. Many technologies for the disposal of dredged sediments take no consideration of sediment' reclamation. However, in line with the principles of the circular economy sediment should be treated as a new resource for sustainable reuse rather than as a waste.

The aim and the scope of this paper is to examine the possibilities of sediment' management in the context of the circular economy by presenting sustainable, economically and environmentally friendly "green" management options of dredged sediments. Case studies of alternative and beneficial uses of sediments include the development and restoration of coastlines and landscapes, the construction of water barriers and flood works, sediment use in agriculture, in the production of bricks and ceramics, as well as for road construction.

**Keywords:** beneficial uses, dredged sediments, bricks, cement, circular economy

## 1. Introduction

For a sustainable future on our planet, societies and cultures must operate within the framework of sustainable development and circular economy. Climate change mitigation is included in the broader concept of circular economy, and is essential for achieving an environmentally and socially competitive, resilient and sustainable economy.

Dredging of sediments is necessary to ensure the functionality of harbors and facilitate navigation in waterways, channels, rivers etc. and the management of dredged material is an important issue (Katsiri et al. 2009). Sediments are a natural material. However, dredged sediment' physicochemical characteristics, origin, pollution load, and subsequent application are key factors in determining their management. Both *in situ* and *ex situ* sediment remediation technologies can be applied to restrict, separate, destroy, and convert sediment pollutants into less toxic forms, or to achieve pollutant stabilisation. Several hundred million cubic meters of sediments are dredged from US ports and waterways every year of which 75% is discharged into inland waters and 20% is discharged into the ocean. The remaining 5%, unsuitable for disposal in open water, is placed in upland containment facilities (Western Dredging Association, 2020) since it has no other purpose.

A new economic model of growth is a prerequisite for the continuous development of our society and natural resources' adequacy, stability and durability. This model should restrict waste production, and also reduce the need for new primary resources with high economic and environmental costs. In line with the United Nations' 17 Sustainable Development Goals aimed at raising standards of living through the sustainable use of resources, dredged sediments from ports, and waterbodies including waterways, rivers and lakes, should be reused, recycled and treated as a resource rather than handled as a waste for disposal.

Dredged sediments can be reclaimed and utilized while simultaneously protecting the environment rather than being disposed of as waste with the resultant loss of valuable natural resources. Sediments can be used either as raw materials or after proper processes in a multitude of applications such as the development and restoration of coastlines and landscapes, in agriculture, forestry, horticulture, aquaculture, as cement additives for road construction, bricks and ceramics, water barriers in flood works, etc. Case studies of beneficial uses of sediments are presented and assessed in this paper in order to examine options, viability, scope and preference in applied projects.

## 2. *In situ* and *ex situ* technologies

Sediment treatment refers to the use of physical, chemical or biological technologies to reduce the concentration of

pollutants in sediment in order to achieve environmental cleanup goals. Remediation techniques act mainly by separating, destroying or transforming pollutants from sediment into less toxic forms, or even solidified contaminants to reduce release through environmental pathways. Sediment remediation is usually the most costly part of a project, and processes to achieve sediment decontamination can be *in situ* and *ex situ*. The former relates to the on-site treatment or containment of sediment while the latter refers to remediation techniques on dredged sediment after removal from its location (in other installations), and the techniques employed are based on the chemical and physical properties of the pollutants (Reis et al. 2007) and their concentrations.
*In situ* technologies include on-site containment and on-site treatment for example natural attenuation, capping, containment barriers, solidification and stabilization. Such methods have the advantage of being relatively cheap management options. *Ex situ* remediation technologies for dredged materials include a) biological treatments based on biodegradation, biological oxidation of the biodegradable, by some microorganisms, organic substances, such as bioslurry, composting, phytoremediation, b) physical/chemical treatments such as sediment washing, oxidation, solvent extraction, reduction, chelation, solidification/ stabilisation (Gomes et al. 2013), c) thermal treatments for the removal, destruction or immobilization of both organic and inorganic contaminants present in sediment. In thermal desorption processes including vapor extraction methods, temperatures between 550 °C–650 °C are employed, while thermal destruction treatments such vitrification, incineration, plasma thermal destruction, pyrolysis and combined processes of thermal destruction and immobilization require higher temperatures of between 600 °C and 2,000 °C (US Army Corps of Engineers, 2015; European Commission, 2009).

## 3. Sediment - a natural resource

### *3.1. Beneficial uses of dredged material*

Beneficial use of dredged material embraces the idea of reuse/recycling in such way so as to profit to society and environment. The assessment of the level of contamination in dredging material is a key step in determining its suitability for beneficial uses. In general, the more contaminated the material, the greater the restrictions on reuse. Highly contaminated materials are usually not suitable for reuse unless the potential risk of biomagnification is low (USEPA & USACE, 2007).

Beneficial uses are categorized in accordance with five final applications and the purpose they fulfill. These *'five R's"* are '*Raw Material: substitution for virgin manufactured soil or building materials, such as tiles or aggregates. Remediation: clean-up of contaminated sites, brownfields or closure of landfills and mines. Reclamation: creating new, or expanding existing, land mainly for human/commercial development activities. Restoration: creation of habitat to support aquatic organisms and wetlands to improve natural value. Resiliency: shoreline nourishment and (dyke) reinforcement for defence against floods and extreme climatic events*" (Central Sediment Organization, 2019).

Sediment reuse near its source is convenient and offers saving in costs and $CO_2$ emissions associated with the transport of large quantities of bulky sediment (European Union, 2019). Options exploiting and applying dredged sediments, in line with principles of circular economy include restoration and development of habitats, beach nourishment, parks and recreational facilities, agriculture, forestry, horticulture and aquaculture, mine and landfill reclamation as well as numerous industrial and construction activities (USEPA & USACE, 2007)

### *3.2 Utilization/ recycling of sediments. Case studies*

Globally, management projects for alternative sediment use are implemented based on factors including origin of dredged sediments (sea, lake or river basin), sediment granulometry, physicochemical characteristics (eg organic matter, chloride content) and chemical contamination. Case studies published on the Central Dredging Association (CEDA) website can be classified into the pre-referred *'5 R's functions'* (CEDA, 2019) (Figure 1).

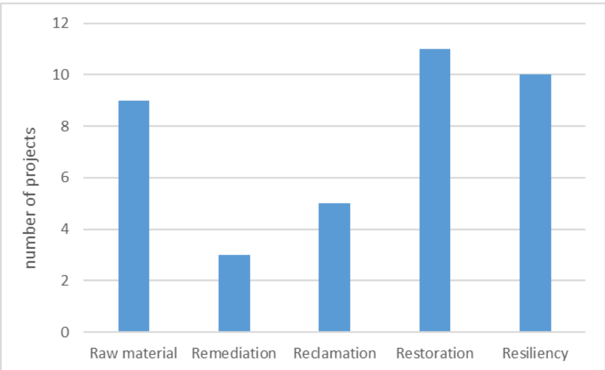


**Figure 1.** Classification of beneficial uses of dredged sediments' case studies published on CEDA website into the *5 R's functions*

Viable applications of dregded materials' reuse that have been implemented in the field include:

Habitat restoration: Land-based confined disposal facility converted into a nesting area for aquatic birds and animals by creating islets and dikes to encourage bird breeding and laying nests through the application of 350.000 $m^3$ dredged sediment from the navigation channel the river Guadalquivir, Spain (CEDA, n.d.).

Construction projects: Sediments from the Port of Dunkirk, France, used in the construction of 700 m of a new road in the port of Dunkirk, and for the building of the concrete blocks containing contaminated sediments on the 'Digue des Huttes' in Dunkirk (September 2013) for use as wave breakers at the port (Herman et al., 2014).

Brownfield restoration: River sediments removed during bridge construction placed on a restored brownfield site at the Tees Barrage, Stockton-on-Tees, UK, for natural dewatering, prior to seeding with reed canarygrass (*Phalaris arundinacea*) for phytostabilisation, soil formation and perennial energy crop production (CEDA, n.d.; Lord, 2015).

Agricultural soil: Dredged silt material from River Ems, Ihrhove, Germany used as agricultural soil following characterisation as non-contaminated as part of a Federal Agency on Waterways and Shipping (GDWS) initiative to lift the river coast and create pastureland (CEDA, n.d.).

Manufacture of ceramic products: - Silty-clayey sediment from Hamburg Port used in the manufacture of ceramic products (e.g. bricks) and light weight aggregates following treatment in the **ME**chanical **T**reatment and Dewatering of **HA**rbour-sediments METHA plant. Approximately 7 million bricks were produced during 4 years of operation (1996-2000) substituting up to 70% natural clay with the METHA material. For more than 10 years (2004-2016) significant amount of METHA material was (> 65000 t) used for light weight aggregates production (Detzner et al. 2004; CEDA, n.d.).

Construction materials: Approximately 4,000 $m^3$ of contaminated sediments dredged from the Sandvika River seabed in the Oslo fjord, was used in the construction of a new quay wall following stabilization with binders (CEDA, n.d.).

Urban construction and infrastructure: Sediment stabilised with innovative binders through GEOWALL ® pressing device transformed into bricks. after acquiring mechanical chemical and physical properties (Ekkelenkamp, 2021).

E*x situ* green infrastructure and living architecture. Dredged material from the Toledo Harbour in Lake Erie Ohio, USA removed for navigational reasons and for the mitigation of cyanobacteria proliferation incidents used in an experimental project for vegetation growth and establishment of green roof growth media (Bhairappanavar et al. 2018).

Coast-line elevation. Approximately 60,000 $m^3$ of dredged material from the Toledo Harbour in Lake Erie Ohio, USA in the same dredging operation as above, placed in cells at a 14-acre facility over two dredging cycles (2016 and 2017) with an average initial consolidation resulting in an average fill depth of approximately 1.2 m raised elevation of near-shore agricultural fields of port Toledo, Ohio. Significant volunteer wetland plant growth was observed, which accelerated dewatering/consolidation of the material and introduced organic matter to the sediment (CEDA, n.d.).

## Conclusion

Dredged sediments in the context of circular economy should not be treated as a waste but as a natural material that must be utilized, reused and recycled. Decontamination of sediments is not necessary for all uses, making these projects more attractive and viable. However, despite the alternative uses of dredged sediment available, that have associated enviromental benefits and financial rewards, as evident from their limited implementation, these projects, although possible, are not common practice. The implementation of sediment reuse projects, while requiring careful interdisciplinary planning, is a significant step towards achieving a sustainable future.

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