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Life cycle assessment for dredged sediment placement strategies

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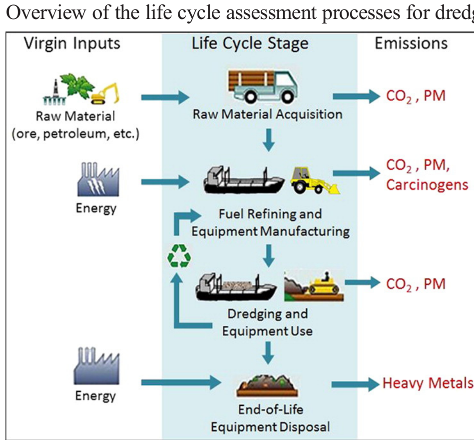
HIGHLIGHTS

- LCA is used to address stakeholder concerns about dredged material disposal.
- Upland placement has the greatest environmental impacts due largely to fuel use.
- Open water placement of uncontaminated sediments generates the least impacts.
- The design and materials for beneficial use sites control the overall impact.
- Longer disposal distance increase impacts for upland more than water placement.

GRAPHICAL ABSTRACT

Overview of the life cycle assessment processes for dredging and sediment placement.



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ABSTRACT

Dredging to maintain navigable waterways is important for supporting trade and economic sustainability. Dredged sediments are removed from the waterways and then must be managed in a way that meets regulatory standards and properly balances management costs and risks. Selection of a best management alternative often results in stakeholder conflict regarding tradeoffs between local environmental impacts associated with less expensive alternatives (e.g., open water placement), more expensive measures that require sediment disposal in constructed facilities far away (e.g., landfills), or beneficial uses that may be perceived as risky (e.g., beach nourishment or island creation). Current sediment-placement decisions often focus on local and immediate environmental effects from the sediment itself, ignoring a variety of distributed and long-term effects from transportation and placement activities. These extended effects have implications for climate change, resource consumption, and environmental and human health, which may be meaningful topics for many stakeholders not currently considered. Life-Cycle Assessment (LCA) provides a systematic and quantitative method for accounting for this wider range of impacts and benefits across all sediment management project stages and time horizons. This paper applies a cradle-to-use LCA to dredged-sediment placement through a comparative analysis of potential upland, open water, and containment-island placement alternatives in the Long Island Sound region of NY/CT. Results suggest that, in cases dealing with uncontaminated sediments, upland placement may be the most environmentally burdensome alternative, per ton-kilometer of placed material, due to the emissions associated with diesel fuel combustion and electricity production and consumption required for the extra handling and

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transportation. These results can be traded-off with the ecosystem impacts of the sediments themselves in a decision-making framework.

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1. Introduction

The dredging process is a key to the United States' economic sustainability. Dredging and related activities maintain the navigability of about 12,000 miles of commercial inland waterways, which facilitates the movement of over 2 billion tons of foreign and domestic commercial commodities each year (U.S. Army Corps of Engineers, 2012). Recent US Army Corps of Engineers (USACE) dredging investments are substantial, totaling around $1.3 billion per year (about one-quarter of the Corps' annual civil works budget) to remove over 200 million cubic yards of material that had or would have encroached upon the nation's waterway system, reducing navigational viability (U.S. Army Corps of Engineers, 2011, 2012).

After a dredge removes these sediments from the navigation channel, they must be placed elsewhere. Placement typically occurs in variety of open or enclosed (confined) aquatic, upland, or nearshore environments. The placement alternatives can be simply for permanent relocation of the dredged material, such as in a landfill or open ocean site, or can be for beneficial reuse, such as beach nourishment or habitat creation. USACE collaborates with other federal and local state environmental agencies to develop dredged material management plans that meet federal and commercial navigation needs as well as local, national, and international environmental sustainability commitments. Dredged material from waterways near cities and industrial sites is sometimes contaminated with chemicals and heavy metals which, while typically inert in undisturbed sediment, can be mobilized in the environment during dredging and placement. Consequently, dredged material placement alternatives may be evaluated in terms of cost, availability, and expected direct health and ecosystem impacts of the sediment. But these metrics often overlook indirect or distributed impacts, resulting in a selection of risk management strategies that are based on incomplete information. In 2009, President Obama issued an executive order instructing "Federal agencies [to]…measure, report, and reduce their greenhouse gas emissions from direct and indirect activities…and prevent pollution," (Executive Order No., 13514). The United States is also a signatory to the London Convention on the Prevention of Marine Pollution, which stipulates that alternatives for marine placement should consider the long-term impacts of the placement activities and that chosen alternatives should avoid simply relocating the pollution to another system (International Maritime Organization, 1972). Together, these commitments require that risk analysis for dredged placement decisions consider not just the local ecosystem impacts but also the other long-term and distributed impacts of different placement alternatives.

Environmental life-cycle assessment (LCA) is a cradle-to-grave method for systematically tracking the energy, resource, and environmental implications (flows) for a product or service. LCA impact assessment methods provide a means to quantify and compare the relative environmental impacts and benefits of those flows for alternative courses of action. LCA is internationally recognized as a tool for measuring the extended environmental and human health impacts associated with a product or process and is established in the International Standardization Organization's 14000 series standards for environmental management and sustainability (International Organization for Standardization, 2009).

Even though LCA has been widely applied to commercial product development (Rebitzer et al., 2004), its application to sediment management has been limited. Sparrevik et al. (2011) apply LCA to evaluate the full environmental footprints of four management alternatives to cap contaminated sediments in Grenland Fjord, Norway. The results of the LCA showed that the preferred alternative depends on the scope of the study, as local effects differed significantly from full life-cycle effects (Sparrevik and Linkov, 2011). This paper is the first to address the life cycle impacts associated with placement of dredged materials. A case study of placement alternatives for material dredged from the Long Island Sound uses LCA to capture the relevant environmental impacts from extracting raw materials from the earth, producing and using the equipment and fuel needed to construct the placement sites and handle and transport the dredged material, and eventually disposing of the equipment and resources used in the process. Some fraction of each of these activities contributes to ecosystem, human health, and resource consumption impacts that are relevant to the dredging decision makers and stakeholders but have not previously been considered in the placement of dredged material. LCA is particularly applicable for dredged material placement scenarios where life-cycle activities can vary significantly among alternatives, where controversy over placement locations exists, or where full environmental impact evaluations are required. All three of these conditions exist in the case of the open water, upland, and containment island placement options around Long Island Sound.

2. Materials and methods

The controversy over dredged material placement in the Long Island Sound is presented here along with the system boundary, process data, and impact assessment methods used to model the placement alternatives common in the region.

2.1. Case study description: dredged material placement in the Long Island Sound region

Long Island Sound (LIS) is a 1300 square mile body of water between mainland Connecticut and Rhode Island and Long Island, New York, and one of the most significant coastal regions in the nation (Fig. 1). It contains dozens of coastal ports, harbors, and shipping routes and supports approximately $9.4 billion in annual navigation dependent economic output, providing 55,720 jobs (U.S. Army Corps of Engineers, 2010). The sound accumulates sediments drained from a watershed area of 16,000 mile^2 (Connecticut Department of Energy and Environmental Protection, 2013), and over one million cubic yards of sediment are dredged from LIS harbors and waterways each year to maintain navigation facilities for commercial deep-draft shipping terminals, marinas, yacht clubs, and fisheries, and ports and facilities for the US Coast Guard and US Navy (U.S. Army Corps of Engineers, 2009b).

Environmental concerns are important to many stakeholders in the LIS region. The past few decades have seen high levels of pathogens, toxic substances, and hypoxia in the Sound, resulting in closures of shellfish harvesting areas, issuance of fish consumption advisories, beach closures, degradation of tidal wetlands, and overall loss of abundance and diversity of plant and animal populations (Long Island Sound Study, 2003). In 2005, the governors of New York and Connecticut, reacting to the US Environmental Protection Agency's (EPA) designation of two open water placement sites for dredged material in LIS, requested that EPA and USACE develop a regional Dredged Materials Management Plan that would also evaluate upland (e.g., daily cover at landfills, concrete plant additive) and beneficial use (e.g., beach nourishment, wetlands and habitat restoration) placement alternatives not involving relocating the dredged sediments within the sound. Some of the alternatives considered would require significant additional