

Dredging of Harbours and Rivers: Review of Practices and Associated Environmental Impacts.

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ABSTRACT

Dredging of harbors and rivers is essential for waterway accessibility and infrastructure enhancement. This review explores key aspects of dredging, including types, applications, environmental concerns, mitigation strategies, and insightful case studies. This paper highlights the importance of dredging in improving water transport and related sectors. It covers diverse dredging types and applications such as Maintenance dredging, Capital dredging, Environmental dredging and Land Reclamation showcasing their adaptability to different project needs. It examines environmental issues linked to dredging and proposes effective mitigation methods. These measures address sediment disturbance, habitat disruption, and water quality degradation. There were two case histories which are The Panama Canal Expansion and The Rhine river dredging in Europe illustrating practical dredging applications. These cases offer insights into both successful practices and challenges encountered during project execution. This paper summarizes key findings and provides sustainable dredging recommendations. These include enhanced planning, monitoring, and the integration of eco-friendly technologies

Keywords: *Dredging, Harbors, Rivers, Waterway accessibility, Panama Canal Expansion.*

1.0 INTRODUCTION

Dredging is undertaken for a variety of reasons including navigation, environmental remediation, flood control, and the emplacement of structures (e.g., foundations, pipelines, and tunnels) (Borland et al., 2022).

This practice, aimed at maintaining navigable channels, expanding ports, and ensuring safe passage for vessels, plays a pivotal role in supporting global trade and transportation. However, the extensive utilization of dredging has not been without controversy. This review delves into the multifaceted world of dredging, exploring the practices, techniques, and equipment involved, while also addressing the environmental impacts that have sparked debates and concerns in recent years (Nyrkov et al., 2015).

Dredging operations, involving the removal of sediments, silt, and debris from the bottom of water bodies, are essential to keep waterways open for shipping, prevent flooding, and enhance accessibility to ports. It is an indispensable tool in the management of water resources, providing a lifeline for coastal communities and economies worldwide. Yet, as the demand for

maritime and inland transportation continues to rise, so do the scale and frequency of dredging activities. Most dredging activities, particularly hydraulic dredging, generate an overspill of fine solid material as a consequence of the dredging activity (Pineda et al., 2016).

The review will delve into the diverse techniques employed in dredging, from hydraulic dredges to mechanical equipment, outlining their respective advantages and limitations (Van Lancker et al., 2010). Moreover, it will explore the regulatory frameworks and guidelines that govern dredging operations, emphasizing the need for sustainable practices that minimize ecological harm.

Environmental impacts resulting from dredging activities are of particular concern presently as a result of heightened environmental awareness. These impacts span a wide spectrum, including habitat disturbance, water quality degradation, and disruption of aquatic ecosystems. Balancing the economic benefits of dredging with its environmental repercussions poses a formidable challenge, necessitating the development of innovative solutions and technologies (Bray and Cohen et al., 2004).

As we embark on this comprehensive exploration of dredging practices and their associated environmental impacts, it is crucial to recognize the complexity of the issue. Finding a harmonious equilibrium between the demands of maritime and inland transportation and the preservation of fragile aquatic ecosystems is a goal that requires collective effort and informed decision-making. This review seeks to shed light on the intricacies of dredging, with the ultimate aim of fostering a deeper understanding of its role in our interconnected world and the imperative need to approach it with environmental sustainability in mind (Wilber and Clarke et al., 2001).

2.0 TYPES AND APPLICATIONS OF DREDGING

Dredging is a versatile and indispensable practice with a wide array of types and applications, each tailored to specific needs and conditions. Whether it's maintaining navigational channels, supporting coastal infrastructure, or environmental restoration, dredging plays a pivotal role in various sectors. Here, we explore some of the key types of dredging and their diverse applications:

1. Maintenance Dredging:

Application: Maintenance dredging is the most common type and is employed to keep existing waterways, ports, and harbors at their designed depths. It ensures the safe passage of vessels and the efficient operation of maritime infrastructure (Wenger et al., 2017).

Techniques: Hydraulic dredging, mechanical dredging, or a combination of both can be used.

2. Capital Dredging:

Application: Capital dredging is carried out to create new harbors, deepen existing channels, or expand port facilities to accommodate larger vessels.

Techniques: Capital dredging often involves extensive excavation and can include various methods like cutter suction dredging and hopper dredging.

3. Environmental Dredging:

Application: Environmental dredging is centered on extracting tainted sediments, pollutants, or debris from aquatic environments with the aim of rejuvenating ecosystems and enhancing the purity of the water (Bernard et al., 2018).

Techniques: Specialized equipment is used to carefully extract and dispose of hazardous materials while minimizing ecological disruption.

4. Land Reclamation:

Application: Land reclamation involves dredging sediments from water bodies to create new land for development, such as ports, airports, and urban expansion.

Techniques: Cutter suction dredges or trailing suction hopper dredges are often used to pump sediments to designated areas for land creation.

5. Navigation Channel Dredging:

Application: Navigation channel dredging focuses on maintaining specific routes for ships, ensuring safe and efficient transit in rivers, canals, and coastal waters.

Techniques: Dredgers are employed to remove accumulated sediments and maintain the desired depth and width of the channel.

6. Beach Nourishment:

Application: Beach nourishment involves adding sand or sediments to eroding shorelines to protect coastal communities, infrastructure, and recreational areas.

Techniques: Trailing suction hopper dredges or hydraulic dredges are used to extract and transport sand to replenish beaches.

7. Mining Dredging:

Application: Mining dredging is the extraction of minerals, ores, or aggregates from the seabed or riverbed to meet industrial or construction demands.

Techniques: Cutter-head dredges and suction dredges are commonly employed for mining operations.

8. Underwater Archaeological Dredging:

Application: This specialized form of dredging is used in archaeological expeditions to recover submerged artifacts and explore underwater historical sites (ZHU et al., 2020).

Techniques: Careful excavation and retrieval methods are employed to preserve historical treasures.

9. Agricultural Dredging:

Application: Agricultural dredging is used to manage irrigation canals and drainage systems, ensuring efficient water distribution and flood control in agricultural areas. (Ells et al., 2008).

Techniques: Maintenance dredging equipment is often used for this purpose.

Dredging is a diverse field with applications ranging from economic development and transportation to environmental remediation and historical preservation. The choice of dredging type and technique depends on the specific goals, environmental considerations, and regulatory requirements of each project. As the requirements of society constantly change, innovative methods for dredging will also evolve, guaranteeing that this crucial procedure stays a flexible and adaptable tool for overseeing our water resources and infrastructure (Martelo et al., 2019).

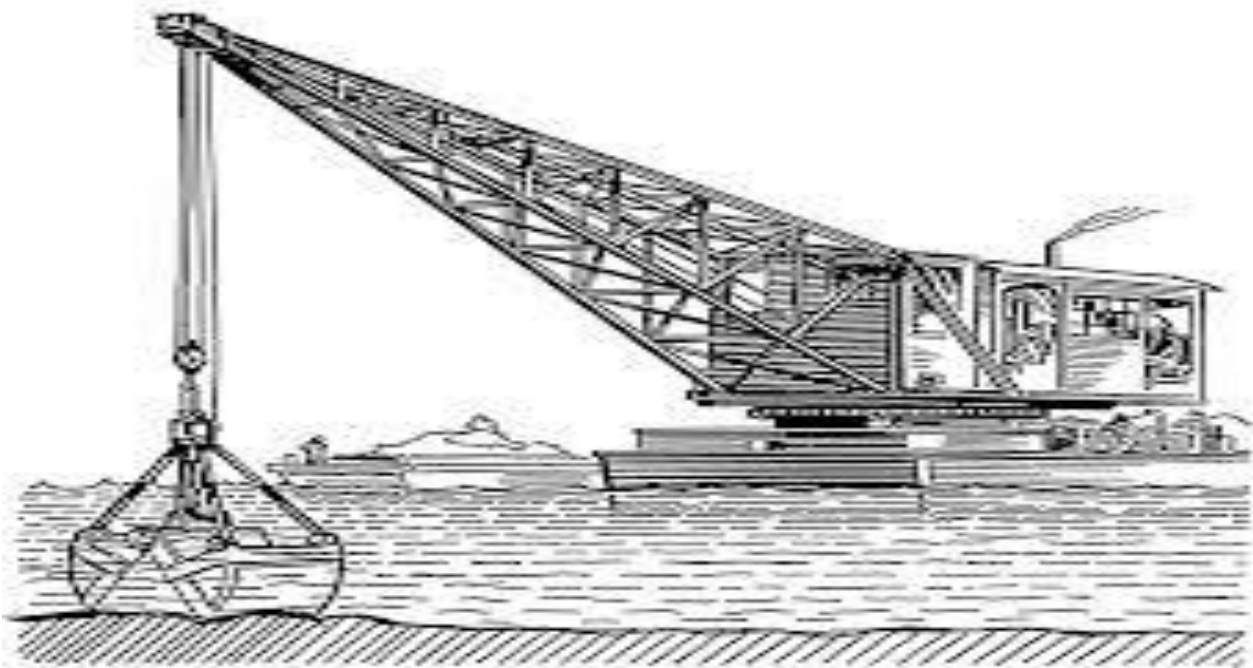


Fig 1: A grab Dredge adopted (from Nicholas et al., 2018)



Fig 2: A hydraulic Dredger adopted (from Oliver et al., 2013)

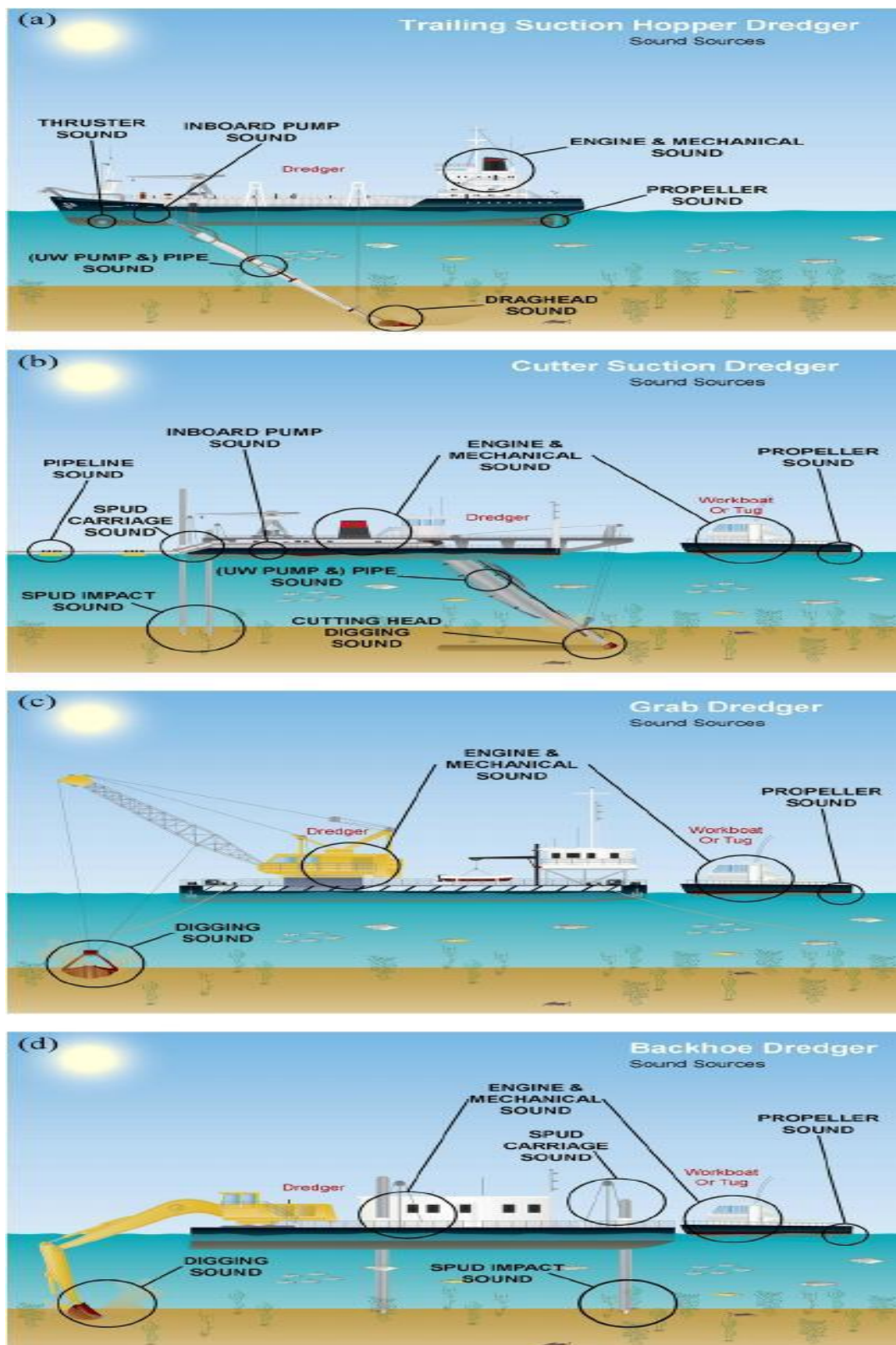


Fig 3: (Color online) Schematic overview of dredge types and potential sources of sound for (a) trailing suction hopper dredge, (b) cutterhead suction dredge, (c) mechanical bucket dredge, and (d) mechanical backhoe or excavator dredge. (Photo credit: Philip Spadaro, Intell Group).

3.0 ENVIRONMENTAL PROBLEMS OF DREDGING AND THEIR MITIGATION

Dredging, while crucial for various purposes, poses significant environmental challenges that require careful consideration and mitigation measures. Here, we explore some of the environmental problems associated with dredging and discuss strategies for mitigating their impacts:

1. Sediment Disruption:

Problem: Dredging disturbs and suspends sediments on the seabed or riverbed, leading to increased turbidity and reduced light penetration in the water column.

Mitigation: To address this issue, sediment curtains, also known as turbidity barriers, can be deployed around the dredging area to contain and settle suspended sediments. Additionally, scheduling dredging during non-spawning seasons for aquatic life can reduce the impact.

2. Habitat Destruction:

Problem: Dredging can harm benthic (bottom-dwelling) ecosystems and the organisms that rely on them by physically removing or altering habitats.

Mitigation: Efforts can be made to identify and protect critical habitats before dredging commences. In some cases, “beneficial reuse” strategies may involve using dredged materials to create new habitats or restore damaged ones.

3. Water Quality Degradation:

Problem: Increased turbidity, along with the release of contaminants from dredged materials, can negatively affect water quality.

Mitigation: Implementing sediment control measures, such as sediment ponds or settling basins, can help remove suspended particles before discharge. Additionally, thorough testing and treatment of dredged materials may be necessary to mitigate contamination risks.

4. Noise Pollution:

Problem: Dredging operations can generate underwater noise, which can disrupt marine life and communication between aquatic species.

Mitigation: Noise-reducing technologies, quieter equipment, and scheduling dredging activities to minimize their impact on sensitive species can help mitigate noise pollution.

5. Invasive Species Spread:

Problem: Dredging can inadvertently transport invasive species from one water body to another, leading to ecological imbalances.

Mitigation: Implementing strict biosecurity measures and cleaning equipment to prevent the spread of invasive species is crucial. This includes decontaminating dredgers and equipment before and after use.

6. Chemical Contamination:

Problem: Dredging can release chemicals, heavy metals, or other contaminants trapped in sediments into the water, posing risks to aquatic life and human health.

Mitigation: Rigorous testing of sediments, proper disposal of contaminated materials, and adherence to environmental regulations are essential to prevent chemical contamination. Remediation of contaminated sediments may also be necessary (Cooper et al., 2008).

7. Erosion and Shoreline Impact:

Problem: Dredging can alter sediment dynamics, leading to increased erosion in some areas and sediment deposition in others.

Mitigation: Implementing shoreline stabilization measures and carefully planning dredging projects to minimize unintended erosion and sediment transport can help mitigate these impacts.

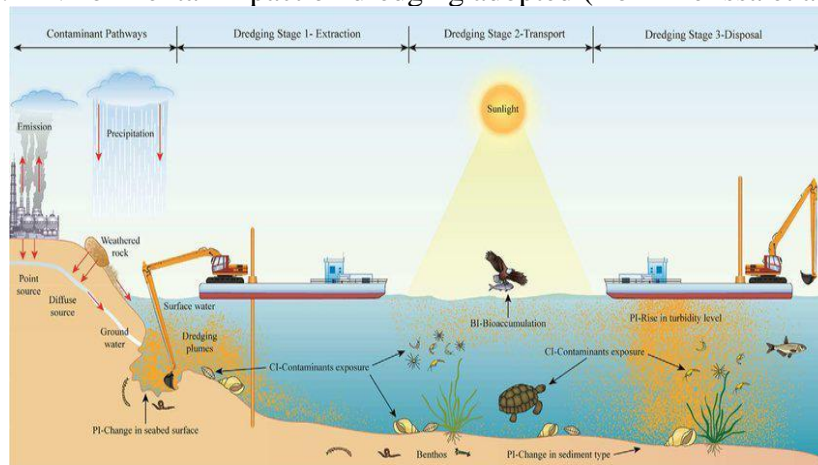
8. Cultural and Historical Heritage:

Problem: Dredging can potentially damage or destroy submerged cultural and historical heritage sites (Ohimain et al., 2004).

Mitigation: Conducting thorough surveys to identify and protect cultural and historical sites in dredging areas is crucial. Dredging plans should be adjusted to avoid impacting such sites whenever possible.

Mitigating the environmental problems associated with dredging requires a comprehensive approach that considers the specific characteristics of each project and its ecological context. Environmental impact assessments, stakeholder engagement, and adherence to relevant regulations are essential components of responsible dredging practices. As technology advances and environmental awareness grows, the progress and acceptance of inventive and eco-friendly dredging methods will increasingly aid in reducing the ecological impact of this crucial process (Peter et al., 2021).

Fig 4: Environmental impact on dredging adopted (from Melissa et al., 2019)



4.0 CASE HISTORIES

4.1: The Panama Canal Expansion

Overview:

The Panama Canal, connecting the Atlantic and Pacific Oceans, is a vital international trade route. As global shipping trends shifted toward larger vessels, the need to expand the Panama Canal became evident to accommodate New Panamax ships, which are significantly larger than the previously accommodated Panamax vessels. The expansion initiative, referred to as the Panama Canal Expansion or the New Panamax Expansion, had the objective of boosting the canal's capacity and improving its operational efficiency (John et al., 2018).

Dredging Practices:

To achieve the expansion, extensive dredging was required. The project involved the removal of millions of cubic meters of sediment, widening and deepening the canal, and the creation of new navigation channels. Dredging operations utilized various types of equipment, including cutter suction dredges and trailing suction hopper dredges, which could efficiently remove and transport sediments.

Environmental Impacts:

The expansion project's dredging activities raised several environmental concerns:

1. **Sediment Suspension:** Dredging resulted in the suspension of sediments, increasing turbidity in the water. This elevated sediment concentration could negatively impact aquatic ecosystems, including coral reefs and marine life.
2. **Habitat Disturbance:** The dredging process disrupted benthic habitats and potentially harmed species living in the affected areas.

Mitigation Measures:

To address these environmental concerns, a series of mitigation measures were put in place:

1. **Sediment Monitoring:** Rigorous sediment monitoring was conducted to assess and manage sediment concentration, ensuring it remained within acceptable limits (Smith and Ebrahim et al., 2002).
2. **Turbidity Barriers:** Turbidity barriers were deployed around dredging areas to contain and settle suspended sediments, reducing their spread into surrounding waters.
3. **Habitat Restoration:** In some cases, habitat restoration efforts were initiated to offset the impacts of dredging on marine ecosystems.
4. **Beneficial Reuse:** A significant portion of the dredged material was repurposed to create new land and mitigate environmental impacts. This approach minimized the need for off-site disposal. (Loginov et al., 2012)

The Panama Canal Expansion project serves as an example of the complexities involved in dredging projects of this magnitude. Balancing the economic benefits of such expansions with

the environmental challenges they pose requires careful planning, technological innovation, and a commitment to mitigating environmental impacts. In the case of the Panama Canal Expansion, these efforts were largely successful in achieving the dual goals of enhancing maritime trade and minimizing ecological disruption (Ertfemeijer et al., 2012).

Fig 4: Panama canal expansion adopted (from Kristjan Olgeirsson et al., 2015)



Fig 5: Panama expansion project adopted (from Moore, Tony et al., 2014)

4.2: The Rhine River Dredging in Europe

Overview:

The Rhine River is one of Europe's major waterways, playing a crucial role in regional transportation and trade. It flows through multiple countries, including Switzerland, Germany, France, and the Netherlands. To maintain its navigability and support commerce, regular dredging operations are essential.

Dredging Practices:

Dredging along the Rhine River involves a combination of practices and techniques to ensure the river's depth and width meet the required standards for safe navigation. These practices include the use of trailing suction hopper dredges and hydraulic dredges to remove accumulated sediments (Manap and Voulvoulis et al., 2016).

Environmental Impacts:

Dredging in the Rhine River has raised several environmental concerns:

1. **Sediment Disruption:** Dredging activities can disturb riverbed sediments, leading to increased turbidity levels in the water. Elevated turbidity can hinder light penetration and affect aquatic ecosystems (Van Bloois et al., 2009).
2. **Habitat Alteration:** The physical removal of sediments can alter benthic habitats and potentially harm species dependent on these areas.
3. **Water Quality:** Increased turbidity can degrade water quality, impacting aquatic life and the availability of oxygen for fish and other organisms.

Mitigation Measures:

Efforts to mitigate the environmental impacts of dredging in the Rhine River include:

1. **Sediment Monitoring:** Regular monitoring of sediment concentration is conducted to assess the environmental impact of dredging activities.
2. **Turbidity Management:** Methods for managing turbidity, such as utilizing sediment curtains and barriers, are applied to confine and settle suspended sediment (Riza et al., 2023).
3. **Eco-Friendly Dredging:** Certain areas have embraced environmentally conscious dredging methods, concentrating on reducing the environmental impact of dredging operations through the use of inventive techniques and equipment (Matt et al., 2016).
4. **Beneficial Reuse:** Like in many dredging projects, efforts are made to reuse dredged materials beneficially, such as for land reclamation or habitat restoration. (Bray et al., 2008).
5. **Environmental Regulations:** Compliance with stringent environmental regulations and guidelines is essential to ensure that dredging operations meet water quality and habitat protection standards (Erfteemeijer and Lewis et al., 2006).

The case of dredging in the Rhine River exemplifies the challenges of balancing the economic benefits of maintaining a vital trade route with the environmental responsibilities of preserving aquatic ecosystems. By implementing advanced monitoring, mitigation, and eco-friendly practices, European authorities strive to ensure that the Rhine River remains navigable while minimizing its impact on the environment and safeguarding its biodiversity.



Fig 6: Rhine river adopted (from Borger et al., 2019).

4.3. Chesapeake Bay Dredging in the USA:

Overview: Chesapeake Bay is the largest estuary in the United States, and maintenance dredging is essential to keep its channels open for shipping.

Dredging Practices: Hydraulic dredging and environmental monitoring are employed to manage sediment removal (Norman et al., 2014).

Environmental Impacts: Dredging in Chesapeake Bay has faced scrutiny due to concerns about sediment transport and its impact on water quality and oyster populations. Measures to mitigate these impacts include sediment management plans, shellfish bed restoration, and strict adherence to sediment quality standards.

4.4. The Port of Rotterdam, Netherlands:

Overview: The Port of Rotterdam is one of the busiest in the world and requires constant maintenance dredging to accommodate large vessels.

Dredging Practices: Cutting-edge dredging methods, such as cutter suction dredges and environmentally sustainable approaches, are utilized to reduce the environmental influence. (York et al., 2015).

Environmental Impacts: Dredging in Rotterdam's sensitive ecosystems has led to innovative solutions such as the "Quiet Dredger" project, which aims to reduce underwater noise pollution, and sustainable disposal practices to protect aquatic habitats.

These case histories illustrate the diverse range of dredging projects worldwide and the associated environmental challenges they face. In each case, a combination of advanced

dredging technologies, strict environmental regulations, and innovative mitigation measures were employed to address environmental concerns while meeting the critical needs of maritime transportation and infrastructure development

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The dredging of harbors and rivers is an essential practice that supports global trade, transportation, and infrastructure development. However, it is not without its environmental challenges. As highlighted in the case histories and discussions, dredging can lead to sediment disruption, habitat destruction, water quality degradation, and other ecological impacts. To strike a balance between economic development and environmental sustainability in dredging projects, a holistic approach is imperative. In conclusion, dredging of harbors and rivers is an essential but complex practice that demands a proactive and environmentally conscious approach. By implementing the recommended strategies and continuously seeking ways to minimize environmental impacts, we can ensure that dredging remains a vital tool for economic development while safeguarding the health and integrity of aquatic ecosystems for generations to come.

5.2: Recommendations:

1. Environmental Impact Assessment (EIA):

Prior to initiating dredging projects, conduct thorough EIAs to assess potential environmental impacts. This should involve comprehensive baseline studies to understand the existing ecological conditions.

2. Technological Innovation:

Invest in research and development to advance dredging technologies that minimize environmental impact. Quieter, more efficient equipment and eco-friendly dredging techniques can significantly reduce disturbance.

3. Sediment Monitoring and Management: Implement sediment monitoring programs to track turbidity and sediment dispersion during dredging. Adjust dredging practices in real-time to mitigate adverse effects.

4. Mitigation Measures:

Deploy mitigation measures such as sediment curtains, turbidity barriers, and habitat restoration to limit the ecological impact of dredging.

5. Beneficial Reuse:

Promote the beneficial reuse of dredged materials wherever possible. This includes land reclamation, habitat creation, or shoreline stabilization, reducing the need for off-site disposal.

6. Regulatory Compliance:

Enforce and adhere to strict environmental regulations and guidelines governing dredging activities. Ensure that projects are in compliance with water quality standards and habitat protection measures.

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