



INTERNATIONAL ASSOCIATION OF DREDGING COMPANIES

SAND AS A RESOURCE:

BEST PRACTICES TO CONDUCT RESPONSIBLE DREDGING PROJECTS



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“Sand, gravel, crushed stone and aggregates (hereinafter sand resources) are the second most exploited natural resource in the world after water, and their use has tripled in the last two decades to reach an estimated 40-50 billion metric tons per year, driven by factors such as urbanisation, population growth economic growth, and climate change.

Sand resources play a strategic role in delivering ecosystem services, vital infrastructure for economic development, securing livelihoods within communities as well as maintaining biodiversity. Sand is the key raw material in concrete, asphalt and glass that built our infrastructure. It is also used for land reclamation as well as flood protection in coastal areas, part of the efforts to protect eroding coasts and address climate change impacts such as sea-level rise and increasingly severe storms. Satisfying a growing sand demand without transgressing planetary boundaries represents an important and insufficiently recognised sustainability frontier.”¹

The above citation is from UNEP’s 2022 paper “Sand and Sustainability: 10 strategic recommendations to avert a crisis”. The recommendations call for actions to set the global sand agenda in addressing environmental needs alongside justice, equity, technical, economic and political considerations.²

In this paper, “Sand as a resource: Best practices to conduct responsible dredging projects”, the International Association of Dredging Companies (IADC) builds on this call from the perspective of the dredging industry. It directly refers to UNEP’s recommendation number 7, “Establish best practices and national standards, and a coherent international framework”.

¹ UNEP, *Sand and Sustainability: 10 strategic recommendations to avert a crisis*, 2022.

² Idem.

EXECUTIVE SUMMARY

The path towards sustainable use of sand is set out in the ten recommendations formulated by UNEP³. Keeping pace on this path requires the combined efforts of authorities, project owners, stakeholders, project designers and industry. When all actors contribute within their field of competence and responsibility, opportunities can be seized to significantly reduce negative impacts on environment and society and to increase positive contributions.

The dredging industry has an important part to play in seizing these opportunities. Operating globally, dredging contractors are working within a wide variety of physical, environmental, social, and legal conditions. Their first-hand experience can serve as a guide to formulating recommendations for responsible use of sand resources.

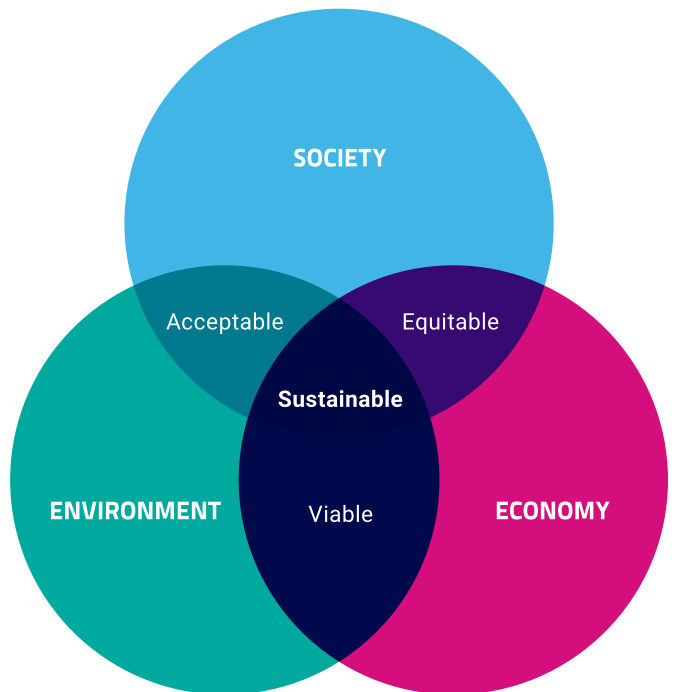
This paper presents best practices for optimal use of scarce sand resources, on both project and operational levels. Every stage of a project presents opportunities to increase the sustainability of sand extraction. Key takeaways are:

- Performing and adhering to an Environmental and Social Impact Assessment are key to finding consensus about conditions and requirements for sand extraction;
- Impact mitigation and nature-inspired design start with monitoring and understanding the physical and ecological processes involved;
- Dredging in or near sensitive sites with high natural or cultural value is only feasible with extensive monitoring, adherence to strict limits and adequate supervision;
- Beneficial use of dredged sediment from capital and maintenance dredging projects is an alternative to sand extraction;
- Stakeholder engagement addresses concerns and unlocks potentials;
- Adaptive management counters risks and uncertainties associated with dredging projects;

- Appropriate procurement processes are able to prioritise project objectives;
- Large marine infrastructure projects entail opportunities to involve the local socio-economic community;
- Incentives for investment in innovation, safety culture and impact mitigation measures encourage improved practices; and
- Transparency about activities, with publicly available monitoring data and warning triggers, helps to maintain focus on impacts and to obtain project acceptance.

Figure 1

The three pillars of sustainability.



³ UNEP, *Sand and Sustainability: 10 strategic recommendations to avert a crisis*, 2022.

1. INTRODUCTION

For hundreds of years, dredging activities have shaped the interface between land and water to support a variety of human activities including navigation, coastal protection, flood risk management, as well as residential, tourist, commercial, agricultural and industrial activities. The use of dredging to achieve these purposes has always been guided by an understanding of the costs and benefits.⁴

The increasing tension between human development and planetary resilience urges us to rethink the way we work and live. The dredging sector is no exception. It uses sand as a building block to create infrastructure projects for social and economic development. At the same time, the increasing quantities extracted and its impacts on environment and society raise concerns.

"Global sand consumption is the sum of the activities of many local players, each having their own motives and drivers. There are no dominant players.⁵ The dredging industry is keen to turn this issue around but cannot do it in isolation. It is the shared responsibility of suppliers, contractors, project designers, project owners and authorities."

The dredging industry has an important part to play in addressing these concerns. Operating globally, dredging contractors are working within a wide variety of physical, environmental, social, and legal conditions. Their first-hand experience can serve as a guide to formulate recommendations for responsible use of sand resources.

The dredging industry has measures at its disposal on both project and operational levels. On a project level, impacts can be reduced before the construction starts, with nature-inclusive designs, alternative materials and by using sand in such a way that it contributes to a more sustainable world. Other impacts can be reduced during the implementation of the project – on an operational level – by adapting working procedures and technology and applying mitigation measures.

The activities of the dredging industry can be split into two types: (1) capital and maintenance dredging of ports and waterways, which account for 80% to 90% of volumes moved by dredging activities⁶; and (2) extraction of sand from marine deposits to be used in land reclamation and coastal protection. Type (2) is the focus of the UNEP report⁷ and of this document. Both types of activities share equipment and methods, create similar impacts and implement similar mitigation measures. They are also linked in that sediment dredged during capital and maintenance dredging projects can be beneficially used as an alternative to sand extraction from a marine resource.

The extraction of sand for use in infrastructure (asphalt, concrete) and process industry (glass, electronics) is the business of the aggregate industry. It is a different sector with its own representation and similar but different equipment and methods. Notwithstanding this, the sectors share a number of concerns.

This document begins by describing the framework within which dredging projects are realised (chapter 2). The societal concerns that are associated with dredging activities are listed in (chapter 3). These concerns are primarily addressed by initiatives on a project level. By reorganising the different stages of projects, negative impacts can be turned into positive contributions to environment and society (chapter 4).

The remaining impacts can be mitigated or reduced on an operational level by adapting working methods and technology (chapter 5). Finally (chapter 6) considers ongoing and future actions.

⁴ CEDA/IADC, *Dredging for Sustainable Infrastructure*, 2018.

⁵ Holm D., Gallagher L. and Franks F. "An invitation to explore responsible sourcing of sand and silicates". Final report from a round table discussion at the OECD 2023 Forum on Responsible Mineral Supply Chains, 27 April 2023, The University of Queensland. Australia.

⁶ IADC unpublished data.

⁷ UNEP, *Sand and Sustainability: 10 strategic recommendations to avert a crisis*, 2022.

2. DREDGING PROJECT FRAMEWORK

Dredging contractors work within an established framework of project development and execution that is derived from the civil construction sector and that has been developed over the course of many decades. In this framework, different parties have roles in different stages:

- Authorities: Government and administration that define the legal boundaries within which the other parties operate (including licenses and permits).
- Stakeholders: Entities that are involved and/or affected by the project but that are not contractually bound to it.
- Project owner: Either a government agency or a private entity that initiates and oversees a project.
- Engineer: Technical consultant employed by the project owner.
- Contractor: private or state-owned company that is contracted by the project owner to realise the project.

A project starts with an idea (a port, an island, a beach) imagined by the future project owner. The idea is based on one or more purposes or functional requirements (coastal protection, industrial or residential development, port development for shipping or tourism, etc.).

The funds required to develop this idea into a construction contract are typically in the order of 1% to 3% of total project costs and are usually not available at this stage. The project owner therefore compiles a conceptual design and a business plan to convince funders. Sometimes contractors assist with

budget estimates and method statements. This is called “Early Contractor Involvement” (ECI, see section 4.8).

Once the necessary funds are secured, the project owner appoints an engineer. The engineer’s task is to make a feasibility study, master plan, field studies, front-end engineering design (FEED), and a project environmental and social impact assessment (ESIA) in order to obtain permits required for construction. The ESIA includes baseline monitoring, evaluation of impacts and alternatives, and stakeholder consultations.

The engineer also prepares tender and contract documents and organises a competition to select a contractor. There are many tender and contract systems, depending on risk and responsibility allocations and the weight that is given to different criteria such as price, contract conditions, risk and environmental management, carbon footprint, innovation, etc.^{8,9}

The tender process usually consists of several stages in which the number of candidates is narrowed down based on capabilities, and technical and financial proposals.

The winner of the competition becomes the dredging contractor. The selected contractor is responsible for executing the project scope in accordance with the contract conditions, permit requirements, local jurisdiction and international regulations.

⁸ D. Kinlan, “50 years of Case Law that Transformed Marine Infrastructure Contracts”, *Terra et Aqua* 166 (Spring 2022), pp. 40-49.

⁹ CEDA, *Effective Contract-Type Selection in the Dredging Industry, A Guidance Paper*, <https://dredging.org/media/ceda/org/documents/resources/cedaonline/2019-12-ecs.pdf>, 2019.

3. SOCIETAL CONCERNS ABOUT SAND CONSUMPTION

Dredging projects are usually part of larger-scale socio-economic development schemes that impact a significant portion of society. It is therefore not surprising that societal concerns about sand consumption have been raised in several recent publications and that the issue has been thoroughly studied by international institutions and working groups:

- Since the publication of the first article about sand consumption in 2014¹⁰, the United Nations Environment Programme (UNEP) has raised awareness about the unsustainability of many current practices. UNEP consolidated expertise from different sectors into the reports: "Sand and Sustainability: Finding new solutions for environmental governance of global sand resources" (2019) and "Sand and Sustainability: 10 strategic recommendations to avert a crisis" (2022).
- The United Nations Environmental Programme Finance Initiative (UNEP FI) published a briefing paper entitled "Harmful Marine Extractives: Understanding the risks & impacts of financing non-renewable extractive industries" (2022).
- The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) reported in its 46th session about "Sand and gravel mining in the marine environment – New insights on a growing environmental problem" (2019).
- The International Council for Exploration of the Sea (ICES) provides a review of marine aggregate extraction activities, impacts and management in member countries in their annual reports and in the cooperative research report "Effects of extraction of marine sediments on the marine environment 2005-2011" (2016).

In the following paragraphs these concerns are thematically summarised.

3.1. ENVIRONMENTAL CONCERNS

When sand is extracted from active riverine and marine ecosystems, the activities can disturb both local and regional systemic functions and underlying chemical, biological, ecological, hydrological, hydrodynamic and morphological processes.

Local effects include the removal of habitats and marine organisms, and the introduction of abnormal stress levels. Suspended sediments may result in smothering benthic species and disturbing fish that rely on visual cues for predation.

Regional effects include changes in current and wave patterns, sediment transport and soil permeability that can lead to coastal and river erosion, salinisation of coastal aquifers and groundwater reserves, shrinking deltas, threats to freshwater, fish stocks, biodiversity, land-use changes and air pollution.

The impact of the activities and therefore the concerns about them vary depending on location, affected ecosystems and stakeholders. Finding consensus about the conditions under which sand extraction can be allowed and about the measures to accompany the activities is always a delicate balance that requires thorough understanding of natural processes and the ecosystem services provided by both the project and environment. These are the prerequisites of an effective Environmental and Social Impact Assessment (ESIA).

3.2. SOCIO-POLITICAL CONCERNS

The degree to which sand mining is regulated exhibits a huge range across the globe. Many countries have strict regulations for sand extraction, and this creates a fair and level economic playing field.

At the other end of the spectrum, reports indicate that sand extraction is undertaken illegally in both riverine and coastal areas in some 70 countries.¹¹ Such illegal markets are often controlled through coercion and violence, with disregard for property rights, liveable wages, safe working conditions and health risks.¹²

Bringing practices in line with regulations will contribute to more environmentally sustainable supply chains but can also disturb the local social balances. Interference in existing informal markets without accompanying social measures may lead to loss of income, disruption of the local economy and displacement of illegal or informal activities to other areas.

¹⁰ Peduzzi P. (2014), "Sand Rarer Than One Thinks", *Environmental Development*, 11, 208-218.

¹¹ Brown O. and Peduzzi P. (2019), *Driven to Extraction: Can Sand Mining be Sustainable?* Hoffmann Centre for Sustainable Resource Economy.

¹² Ibid

3.3. SOCIO-ECONOMIC CONCERNS

The increasing demand for sand is driven by the growth of the global population, welfare and the associated need for housing, transport infrastructure and climate adaptation measures.

In areas where sand is scarce and extraction is unregulated, inequalities and shortcomings in decent work standards may be exacerbated by this growth trajectory. Stark levels of inequality can be found when looking at the distribution of benefits (e.g. jobs, revenues) and environmental, social, and economic impacts resulting from these developments.¹³ Large discrepancies along

the value chain may occur, leaving those dependent on the industry and natural resources impoverished, without improved social and economic advantages.^{14,15}

Environmental effects, such as changing hydrodynamic conditions, may affect a variety of other ecosystem services and thus negatively impact livelihoods that people in affected communities depend upon such as fishermen, sea farers and farmers.^{16,17} These aspects are all part of an effective Environmental and Social Impact Assessment (ESIA).

4. PROJECT LEVEL APPROACHES TO RESPONSIBLE DREDGING

To make optimal use of scarce sand resources, interventions are required before the operational phase. It is during project preparation that the required quantities and qualities of sand are determined and the ecosystem functions are incorporated into the project scope. Decreasing negative impacts and increasing positive contributions can be done with different strategies in every stage of the project.

4.1. QUANTITY OF SAND EXTRACTED

Sand deposits that are accessible and eligible for extraction are considered to be finite, non-renewable resources. Even though sand is formed continuously by weathering and erosion processes of rock and accumulation of inorganic remains of marine organisms, only a fraction is readily accessible.¹⁸

The issue of depleting sand resources is not visible to the same extent in every region. For developed countries that have a large infrastructure budget but limited sand deposits such as Singapore, Florida and Israel, the issue is pressing. It is even more pressing for developing countries where the lack of sand deposits lead to uncontrolled excavation and destruction of crucial ecosystems. This, for example, is the case at Cabo Verde's beaches.¹⁹ These countries are faced with rising aggregate prices, which pushes them towards illegal and environmentally detrimental practices. Transitioning towards reduced sand consumption by promoting alternative materials, construction techniques and infrastructure concepts is a very challenging task.

¹³ Lamb et al. (2019), *Trading sand, undermining lives: Omitted livelihoods in the global trade in sand*.

¹⁴ WWF (2021), *Sand Mafias: Environmental Harm, Corruption and Economic Impacts*.

¹⁵ John (2021), *Sand geographies: Disentangling the material foundations of the built environment*.

¹⁶ WWF (2021), *Sand Mafias: Environmental Harm, Corruption and Economic Impacts*.

¹⁷ Aliu et al. (2022), *Sustaining urbanization while undermining sustainability: the socio-environmental characterization of coastal sand mining in Lagos Nigeria*.

¹⁸ Padmalal D. and Maya K., *Sand Mining*, 2014.

¹⁹ Vieira M.S. and Rocha E.V., "Gender and Environment in the Interior of Santiago Island/Cape Verde: Sand Harvesting From Women Heads of Families", *Frontiers in Sociology* 6:625405, April 2021.

Other countries, such as the Netherlands, Germany and India have seemingly infinite quantities of sand available for centuries to come, despite the large quantities consumed.

For developed countries that can afford the significant costs, international transport from countries with abundant resources can be a solution, but it is not an option for many developing countries. Moreover, countries that are geologically blessed with large sand deposits are more and more inclined to keep this strategic resource for their own future generations.

While the focus of this paper is on the impact of sand extraction, infrastructure projects require other primary materials such as gravel, rock and cement. It is important to note that the availability, sourcing and/or impact of using these materials deserve equal attention. In some cases, a design that uses more sand and less concrete or rock may therefore be a more sustainable option.

The quantity of sand extracted from marine resources can be reduced by using alternative sources. Sediments extracted during capital and maintenance dredging works are used to an increasing extent as an alternative for sand.²⁰ Prerequisite is that the quality of the material – that can be mud, clay, silt sand, or rock – fits its potential use, that a suitable recipient is nearby and that the time schedule of the two projects fit.^{21,22} In an ideal scenario, there are recharge plans in place (with required consent) for vulnerable and suitable sites so that sediments of all types can be used effectively and quickly when they are available.²³ Although other alternative materials are available, such as crushed rock, quarry dust, fly-ash and metal slag, they do not play a significant role as a sand alternative.

FIGURE 2

Closure of the soft sea defence on July 11, 2012. Closing the gap, the landbased equipment spreading sand. Terra et Aqua 131.



FIGURE 3

Horsey Island (Jim Pullen UAV Surveys, April 2017).



²⁰ CEDA, "Sustainable Management of the Beneficial Use of Sediments", *Information paper*, 2019.

²¹ USEPA/USACE, "Identifying, Planning and Financing Beneficial Use Projects Using Dredged Material", *Beneficial Use Planning Manual*, 2007.

²² PIANC, *Dredged Material as a Resource, Options and Constraints*, Technical Report Envicom 104, 2009.

²³ ABPmer, "Horsey Island Coastal Restoration - 10 Years On, Review of UK's first and largest mixed-sediment beneficial use projects", Ref 1400-16-13, March 2016.

Example:

Between 1990 and 2023, dredged sediments were placed onto intertidal habitat to achieve both habitat restoration and coastal protection objectives at Horsey Island on the eastern coast of England. Sand and silt from capital and maintenance dredging at the nearby ports of Harwich and Felixstowe were used to create a mix of habitats including mudflats, marsh and a shingle spit to be used by nesting birds. The project has demonstrated that the environmental benefits can persist over decades.²⁴ Case studies such as this one were collected by the CEDA Working Group on the Beneficial Use of Sediments.²⁵

4.2. LOCAL EFFECTS OF SAND EXTRACTION

When sand is extracted from marine deposits, sediment layers are removed that have different ecosystem functions, such as hosting nutrients and benthic fauna and flora in the top layer. Exposing older geological strata with different composition alters living conditions. The most poignant manifestations of habitat destruction are found in countries lacking sand resources. This deficiency combined with a high demand for aggregates often leads to destruction of vulnerable ecosystems and illegal economies.

Dredging in or near sensitive sites with high natural or cultural value is only feasible with extensive monitoring, adherence to strict limits and adequate supervision. These sites can be protected by defining marine conservation areas, setting up a marine spatial plan and enforcing compliance. This is applicable to areas with living coral reefs, coastal wetlands and other habitats with high biodiversity or endangered species and similarly to sites with historical or cultural importance, including indigenous values.

Habitat and biodiversity losses are best tackled in the conception and design phase of a project. In this early project phase, abundance and biodiversity can be inventoried. With this knowledge, the sand extraction zone with the lowest impact can be selected and mitigation, compensation and restoration measures can be included in the project scope. Loss of substrate or alteration of seabed composition can be transformed into the creation of a habitat that is regionally in decline, rare or specifically targeted for valuable or endangered species.

When an area is approved for sand extraction, authorities monitor dredging activities in order to ensure that extraction remains within the boundaries of the licenced area. In many

countries, the representative on board of the dredger has been replaced by a black box computer system that is installed before the vessel arrives on site. The system transmits the drag head's location and production data in real time without the interference of the crew or computer systems on board.

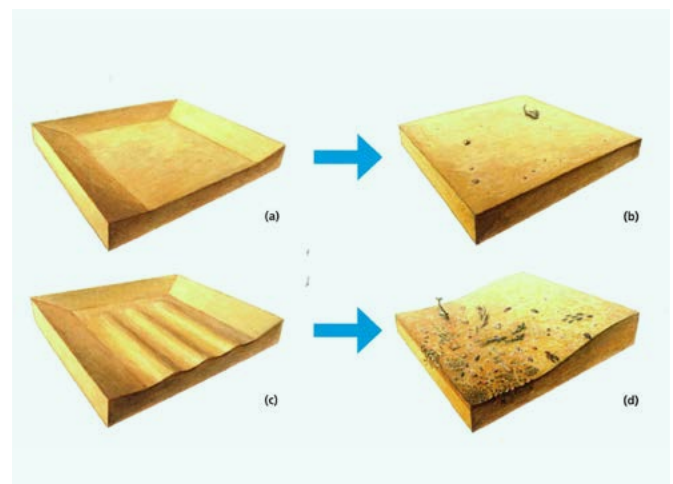
Due care has to be taken that vessels do not inadvertently carry species that are considered invasive exotics at its destination. For this reason, international and local regulations may require cleaning of hull, water intakes and ballast tanks before the start of a voyage. Such regulations also apply to dredging vessels.

Example:

For the extension Maasvlakte 2 of the Port of Rotterdam, 220 million m³ of sand were extracted between 2009 and 2013. The maximum extraction depth was 20m below seabed, which is tenfold the traditional limit. This method reduced the directly impacted surface area from 110 km² to 11 km². Two sandbars mimicking natural sand waves were left behind after extraction to increase habitat heterogeneity.²⁶ This is one of the optimisations researched in OR ELSE (recommendations for Ecosystem-based large-scale sand extraction) a consortium of 21 partners funded by the Dutch Research Council (NWO) programme.

FIGURE 4

Artist's impression of the concept of seabed landscaping in extraction sites: (a) traditional extraction areas with a flat seabed yield poor habitats (b), whereas the Building with Nature landscaped areas (c) encourage biodiversity (d).



²⁴ Idem.

²⁵ <https://dredging.org/resources/ceda-publications-online/beneficial-use-of-sediments-case-studies>.

²⁶ De Jong, M.F., Borsje, B.W., Baptist, M.J., van der Wal J.T., Lindeboom H.J., Hoekstra P., "Ecosystem-based design rules for marine sand extraction sites", *Ecological Engineering* 87 (2016), pp. 271-280.

4.3. REGIONAL EFFECTS OF SAND EXTRACTION

Extraction of sediments results in a local depression of the seabed. This changes local bottom friction and may have an impact on local hydrodynamics. Currents and waves may be less attenuated on their way to the coast when the seabed is deepened. Waves encountering a depression in the seabed at specific angles may refract or reflect in a different direction and hit previously sheltered coastlines.

In rivers and deltas, the tidal flow is in dynamic equilibrium with bottom level, shape and roughness. When sand is extracted from these systems, the equilibrium is disturbed and this may lead to increased tidal amplitude (flood risk) and increased flow (change of habitat conditions). When impermeable layers are removed, salt water may infiltrate into nearby coastal areas.

All these issues can be identified through modelling during the planning and permitting phase of a project. Modelling of coastal zones outside the dredging area is however not a standard requirement for a dredging permit. A marine spatial plan may define exclusion zones for dredging in highly dynamic zones such as reefs, sandbanks, river beds, beaches and beach foreshores.

Example:

Since 2021, the extraction depth limit of 5 metres in the Belgian Continental Shelf was replaced by a limit based on scientific principles. The limit ensures the preservation of the surface sediment characteristics, the structure of the sandbanks, a maximum use of sand from mobile structures and limited impact on hydrodynamic conditions. The implementation of this new reference level led to a reduction of less than 2% of available quantity, while the extraction area was reduced by 25%, excluding the ecologically most valuable areas.²⁷

4.4. REGULATIONS AND DUE DILIGENCE

When societal concerns signal activities that manifest coercion, violence, unsafe working conditions and health risks, this clearly highlights the inability of mainstream producers and regulatory authorities to cope with the rapidly increasing demand for sand. The result may be that communities living on or near accessible sand deposits are deprived of their land and livelihood. Even if the dredging activities are in compliance with legislation, the industry may depend on local contractors and suppliers whose activities are not always easily traceable.

Restricting sand extraction to responsible practices inevitably comes down to regulation and enforcement, which can be carried out in several ways. Next to local, national and regional legislation, financial institutions can be held accountable for the impact of the projects they are funding (e.g., by the IFC performance standards).²⁸ Project owners can reward contractors for their efforts with a competitive advantage. Prequalification criteria can include company-level compliance with requisite minimum environmental and labour standards.

The management of sand resources is necessarily a task of the competent authority. Income from sand concessions can be used for monitoring, assessing the quantity and quality of the resource and drafting a responsible sand resource strategy and marine spatial plan.

Still, the contribution of the dredging industry to a safe and healthy work environment for its employees and its supply chain is essential. Responsible companies promote a safety culture in company-wide programs, organise mandatory courses for their employees, which enable them to recognise signs of modern slavery and conduct due diligence on subcontractors and suppliers. These initiatives are recorded in a register that can be consulted by clients during their due diligence.

Example:

The Safety Culture Ladder (SCL) is a certified assessment method for measuring safety awareness and conscious safe and healthy acting in companies, with an emphasis on safety culture. The higher the safety awareness, the higher the assigned ladder step. Steps range from ignorance about safety to full integration of safety in the business processes. Since 2022, the SCL is mandatory for project owners that have undersigned the Dutch construction governance code.²⁹

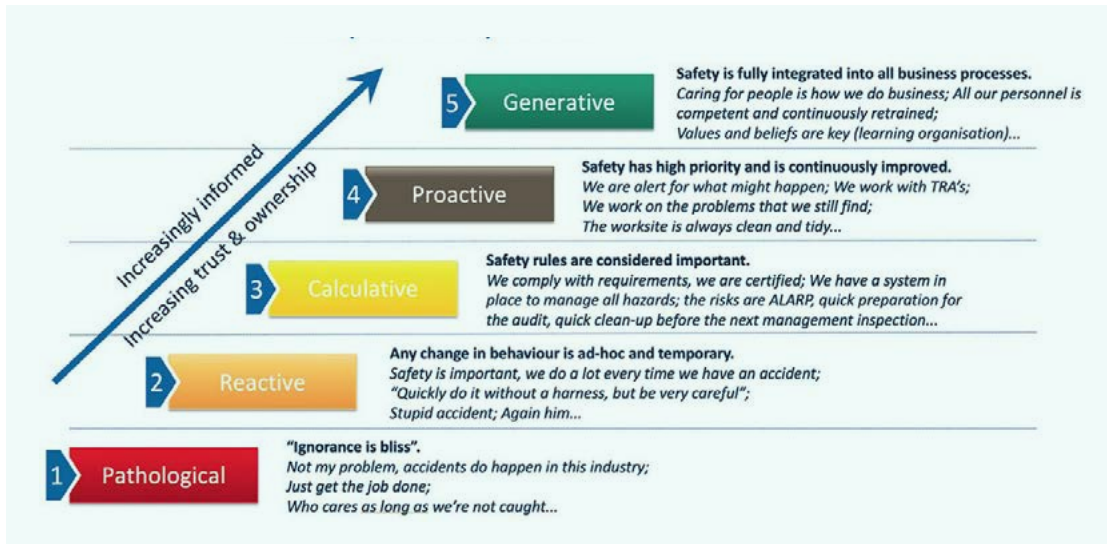
²⁷ Degrendele, K., Roche M., Barette F., Vandereycken H., "The implementation of the new reference level for sand extraction on the Belgian Continental Shelf", in: Vandenreyken, H. (Ed.) A 360° perspective on sea sand: Proceedings study day, 19 November 2021, Zwin Natuur Park. pp. 57-66.

²⁸ International Finance Corporation, *IFC Performance Standards*, 2012.

²⁹ Van de Minkelis, T., Leroy, C., "Building a Proactive Safety Culture within a Marine Contractor Organisation", *Terra et Aqua* 166 (Spring 2022), 30-39.

FIGURE 5

The 5 steps of safety culture.



4.5. STAKEHOLDER ENGAGEMENT

Stakeholders can be defined as "any" group or individual who can actively affect or be affected by the project development.³⁰ As such, stakeholders can be anything from individuals affected by a project through to large-scale NGOs whose organisational goals are related to aspects of the project.

Connecting with all relevant stakeholders and partners as part of any project planning and design is key to unlocking positive potentials. Through systematic and equitable involvement across partners and stakeholders, a comprehensive system perspective can be derived, and local voices equitably heard.

Infrastructure projects operate across the boundaries of physical, ecological, and socio-economic domains. A multitude of interests and backgrounds are involved in the successful development of such projects. Thoughtful management of these interests – as well as combining them in a specific design – contributes to project success.³¹ Effective incorporation of interests can only be achieved by careful engagement of stakeholders. Key for the organiser is to be attentive to the incitement of the public by project opponents with misinformation and covered funding.

There are several ways to engage stakeholders in a project:

- Public consultation as part of an ESIA process helps to identify societal concerns and impacts on local communities.

- Citizen participation in project capital incorporates the stakeholder's agenda into the project objectives.
- Design process based on co-creation where working group sessions of stakeholders decide on focus and phasing of the project within the physical and economic boundaries set by the project team.
- Real-time access to a monitoring platform related to the dredger's activity and environmental parameters.
- Periodic newsletters and grievance procedures.

Example:

Port Philip channel deepening project, Melbourne, Australia, that involved the removal of 23 million m³ of sediment of which 3 million m³ was contaminated, was met with strong and continued opposition. The client and contractor formed an alliance contract to share responsibilities and risks, as well as communication efforts. Stakeholder acceptance of the project was a result of the accurate and transparent public communications, which included public consultations, public hearings, a dedicated website, a 24-hour toll-free telephone number, weekly press conferences, media releases, mailing lists, signage around the Bay and notices to mariners. A vessel tracking system and online video data was used to prove that the operations proceeded in accordance with the environmental management plan.³² These joint efforts led to successful completion of the project.

³⁰ Freeman R.E., *Strategic Management: A stakeholder approach*, 1984.

³¹ Biernaux V., Miller G., "The Responsible Project: A View on Social Licence", *Terra et Aqua* 165 (Winter 2021), pp 6-19.

³² Idem.

4.6. NATURE-INSPIRED DESIGN

An infrastructure project is part of a system. It affects and is affected by the processes operating within that system. The concept of ecosystem services supports this very notion.

Ecosystem services are benefits that humans derive from nature. Ecosystems generate human welfare because they produce goods and services that humans can use directly or indirectly (through the use of other goods or services). Examples of indirect forms of use are "nutrient recycling" and "fish nurseries" which result in 'clean water' and "fish production", respectively.^{33,34}

The more ecosystem processes are taken into account over the full life-cycle of a project and the more natural processes and materials are incorporated into the project, the more

sustainable a project can be. These practices are commonly referred to as Nature Inspired Design (NID) or Nature-based Solutions (NbS). In practical terms, the sustainability of an infrastructure project is increased by:

1. Increasing the overall value of the project by increasing the range of services it provides;
2. Reducing costs associated with the project, where costs include all monetary and non-monetary (e.g., environmental impacts) costs and resources consumed by the activity; and
3. Balancing the distribution of the value and costs among the social, environmental, and economic domains over time.

For more than a decade the dredging industry has invested in nature-based solutions and has developed multiple initiatives such as Engineering with Nature,^{35,36} Building with Nature^{37,38} and Working with Nature.³⁹

FIGURE 6

Encouraging headlines indicate the success of the extensive communication efforts.



³³ Reid W.V. et al., *Millenium Ecosystem Assessment Synthesis Report*, 2005.

³⁴ TEEB, *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*, 2010.

³⁵ Fredette T.J. et al., *Environmental Enhancements and Navigation Infrastructure: A Study of Existing Practices, Innovative Ideas, Impediments, And Research Needs*, ERDC EL TR-11-7, 2011.

³⁶ Whitfield et al., *Engineering with Nature Principles in Action: Islands*, ERDC TR-22-9, 2022.

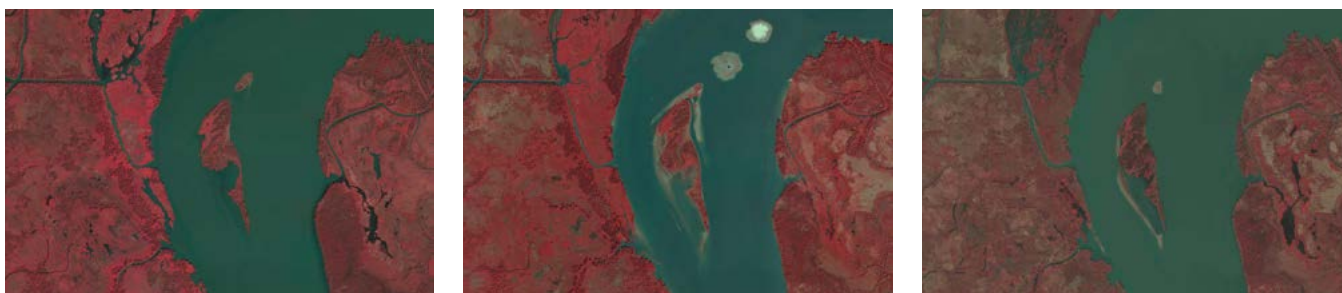
³⁷ De Vriend H.J., van Koningsveld M., *Building with Nature: Thinking, acting and interacting differently*, 2012.

³⁸ Van Eekelen E., Bouw M., *Building with Nature: Creating, Implementing and Upscaling Nature-based Solutions*, 2020.

³⁹ PIANC, *Guide for Applying Working with Nature to Navigation Infrastructure Projects*, ENVICOM WG 176, 2018.

FIGURE 7

Atafalaya River (USA).



Example:

In the Atafalaya River (Louisiana, USA), dredged sediment was placed in the middle of the river, just upstream of a natural shoal, and contributed to the formation of an island. In 10 years' time, a 35 hectare island was created that hosts a rich wildlife habitat with access for recreation and a better aligned navigation channel.⁴⁰

4.7. ADAPTIVE MANAGEMENT

Alternative building methods and concepts add risks and uncertainties on top of difficult-to-predict natural processes, climate change and the effects on environmental and socio-economic receptors. Adaptive management addresses these uncertainties by incorporating flexibility and robustness, and allowing decision-making based on continuous data/information that is acquired during the project.⁴¹

In the early stages of the project, project goals on environmental, social and economic levels are defined. The preferred strategy is then selected and implemented based on an inventory of alternatives.

As the project proceeds, goals are translated into warning indicators that are monitored and evaluated continuously. These indicators are the basis of adjustments in design, construction, maintenance and monitoring.

Example:

During the dredging works at Teluk Rubiah in Lumut, Malaysia, continuous water quality monitoring was combined with hindcast plume modelling to safeguard the nearby sensitive receptors. Based on the forecast, the dredging schedule was adapted, resulting in a zero exceedance of trigger levels and ahead-of-schedule completion of the project. The setup also allowed the contractor to avoid the necessity of 14 km silt screen.⁴²

4.8. EARLY CONTRACTOR INVOLVEMENT

The involvement of contractors and specialist suppliers is from time to time solicited by project owners prior to setting construction phase contracts. Contractors have expertise on construction methods, the availability of equipment and alternative materials, the implications of design for the ease and safety of construction, the resilience and sustainability of the constructed works, and the cost and time required to provide the designed works.⁴³ Early Contractor Involvement (ECI) is a tool to introduce sustainable project approaches such as the beneficial use of sediments.

While ECI has many benefits, prior knowledge and equal treatment of tenderers is a concern that needs to be addressed.

4.9. PROCUREMENT PROCESS

The procurement process is decisive for prioritizing within different objectives and risks associated with infrastructure projects and natural processes.⁴⁴ It can therefore contribute to more sustainable practices.

⁴⁰ Suedel B., Flanagan M., Stevenson J., Corbino J., "Using Strategic Placement of Dredged Material to Create River Island Habitat: an Engineering with Nature Demonstration Project in Coastal Louisiana, USA", *Coastal Sediments Proceedings*, 2015.

⁴¹ CEDA, *Integrating Adaptive Environmental Management into Dredging Projects*, CEDA position paper, 2015.

⁴² Savioli J.C., Magalhaes M., Pedersen C., Van Rijmenant J, Oliver M.A., Fen C.J., Rocha C., "Dredging – how can we manage it to minimise impacts", in: APAC 2013: Proceedings of the 7th International Conference on Asian and Pacific Coasts, 24-26 September 2013, Bali Indonesia.

⁴³ PIANC, *A Framework for Early Contractor Involvement in Infrastructure Projects*, Marcom WG194, 2022.

⁴⁴ CEDA, *Effective Contract-Type Selection in the Dredging Industry, A Guidance Paper*, 2019.

A wide variety of procurement principles are used:

- Prequalification: a first selection of candidates based on setting minimum standards for safety, financial stability, experience and competences.
- Competitive dialogue during tender: meetings are organised between the client and tenderers where concepts and strategies can be checked and adjusted.
- Design and build: the contractors, using their experience and capabilities, can optimise the project design reconciling the project objectives.
- Risk allocation: stakeholder communication, complaint handling and nuisance mitigation can be allocated to the contractor scope.
- Qualitative, non-monetary award criteria: these criteria value proposals that benefit nature and society, and mitigate risks and impacts.

These requirements are demanding and sometimes at odds with the competitive character of the tender process. Strict requirements can lead to exclusion of a number of smaller, local contractors that cannot comply, which can result in the disturbance of the local market. Additional requirements should therefore be accompanied by incentives for local contractors to upgrade their equipment and working methods.

Example:

Most Economically Advantageous Tender (MEAT)⁴⁵ and Best Value Procurement (BVP)⁴⁶ are two tender systems where price is only part of a valuation system that also includes safety initiatives, risk management, stakeholder engagement, innovation, emissions, etc.

4.10. SOCIO-ECONOMIC CONTRIBUTION

Environmental impacts can have consequences that affect other marine users. The livelihood of local fishing communities may be affected by decreased fish stocks caused by prolonged turbidity or deterioration of their fishing grounds. Coastal communities may be deprived of inhabitable land, cultural sites and natural wealth as a result of erosion or salinization. Addressing these impacts is a requirement for project permits in many countries. This is usually done under "Areas of Operations" in an ESIA.

However, prohibiting sand extraction in vulnerable habitats also has an inevitable impact on the livelihood of local communities. Even if some of these activities may be illegal, they provide the means of survival for many communities. Any change in regulations to protect the environment should therefore be accompanied by measures to provide alternative local employment.

These stakeholder impacts can be identified and mitigated with appropriate regulations and ESIA procedures in place. Although in most projects, these regulations and procedures are beyond the contractor's scope and responsibility, contractors can exercise due diligence and apply leverage and assist project owners with that responsibility.

A dredging project is short-lived and requires large deployment of human resources and equipment, often in little-developed areas. Yet it has the potential to contribute significantly to the local economy in the form of:

- Salaries for the local workforce;
- Local expenses (office, housing, transport, catering); and
- Local purchases and subcontracts (fuel, civil construction, fabrication, equipment rental).

Tax revenues (import duties, royalties, withholding tax, corporate tax, personal income tax on salaries). The local content in the project budget can be improved by different incentives:

- Onboarding and awareness training of local workforce with a focus on health and safety, environmental care, diversity, equality and respect.
- Training of local workforce when gaps are identified between required and available skills.
- Selection and training of local suppliers based on labour and human rights, biodiversity, emissions, waste management and business ethics.
- Advertisement of supply opportunities in local media.
- Unbundling of contracts into units that are tailored to the local market.
- Engagement in local community projects.

⁴⁵ Alhola K., Nissinen A., "Environmental Impacts and the Most Economically Advantageous Tender in Public Procurement", *Journal of Public Procurement* 12 (2012) 1, pp. 43-80.

⁴⁶ Storteboom A., Wondimu P., Lohne J., Laedre O., "Best Value Procurement – The Practical Approach in the Netherlands", *Procedia Computer Science* 121 (2017), 398-406.

4.11. INNOVATION AND CONTRIBUTION

Knowledge and best practices to increase sustainability in dredging projects are not written in stone. They develop with changing conditions, with learning by doing, with scientific knowledge and with public focus. Knowledge and best practices require a strategy to develop and to disseminate them to the stakeholders.

Development strategy

Many countries and regions have research and innovation funds to encourage scientific institutions and industry to develop new goods and services with the aim to increase competitive advantage and employment. Research and innovation funds can be a tool for authorities to:

- Stimulate co-operation between local players in order to create sector-specific communities and local supply chains;
- Stimulate the inclusion of small and medium sized enterprises as they seldom have the means to innovate on their own;
- Create programmes where industry, scientific institutions and authorities work together to ensure that the solution is endorsed by everyone;
- Develop performance metrics; and
- Facilitate demonstration projects with tangible results that are accessible to potential clients.

Dissemination strategy

The task of dissemination is shared by industry, sector organisations and scientific institutions. The target is to:

- Inform all workforce about new developments. Innovation is usually in the hands of a small group that is not necessarily linked to the operational division of the company;
- Educate students in order to create a workforce knowledgeable about the potential, the challenges and limits of existing and developing solutions; and
- Inform stakeholders, clients and licensing authorities about the pros and cons of existing and alternative solutions.

There is a wide variety of information channels depending on the target public: newsflashes, reports, courses, seminars, publications, websites, Wikipedia pages and data platforms.

Example:

A maritime consortium is conducting research funded by the Dutch government into methanol as an energy step towards zero-emission shipping (MENENS). The consortium, which includes ship owners, shipyards, suppliers of specialist maritime equipment and knowledge institutions, retrofits six different vessel types to test the viability of methanol fuel systems. The programme builds on earlier feasibility studies like the Green Maritime Methanol Consortium. The dredging industry is keen to be part of this research, because it has specific needs that differentiate them from the rest of the shipping industry, such as a volatile load-curve and operations close to populated areas.⁴⁷

⁴⁷ Veldhuis Chr., "Methanol as an Energy Step towards Zero-Emission Dutch Shipping (MENENS)", *Marin Report* 133 (2022), 11.

5. OPERATIONAL LEVEL IMPACTS AND THEIR MITIGATIONS

This chapter focusses on project implementation. It summarises the negative impacts of sand extraction and how these impacts can be significantly mitigated on an operational level with increased understanding of physical, chemical and biological processes, with the right regulations and incentives, and with technological advancement.

5.1. ACCIDENTAL IMPACTS

Dredging equipment is large and massive to withstand the forces of the sea and to take advantage of economies of scale. Unskilled handling, lack of maintenance and unfit equipment may lead to accidents that have severe consequences to operators (personal injury), the environment (oil spills, waste) and stakeholders (loss of livelihood).

The most basic requirement is that during their operational life, vessels are certified by an internationally recognised classification society. Their certificates confirm that design and calculations meet their standards, and that the ships are surveyed during construction, commissioning and their operational lifetime.

The regulatory framework for shipping is issued by the International Maritime Organisation (IMO), a United Nations agency. Its regulations are enforceable in its 175 member states and concern safety equipment (SOLAS), safety management (ISM), security (ISPS), training (STCW), and pollution and energy efficiency (MARPOL).

Even with certified equipment operated by skilled personnel, accidents can happen. Mandatory insurance of dredging operations includes employer's liability, workmen's compensation third party/public liability and professional indemnity.

Project owners verify potential contractor's compliance with these regulations during the prequalification phase of a project.

The risk of non-performance is checked by requesting financial information of previous years, corporate structure, credit scores and performance bonds.

Unexploded ordnance (UXO) is a recurring concern for dredge operations in sand extraction areas. Impact and pressure changes may trigger detonation leading to damage to equipment and physical injury. The standard procedure consists of four steps: First, a historical study is performed to identify the probability of occurrence and type of ordnance. Next a magnetometer survey is performed of the extraction area to identify exclusion zones and remove identified objects. Then the grid in the suction mouth of the dredgers is matched with the ordnance size. Finally, when ordnance is found on board a dredger, a procedure is initiated in which operations are halted, the appropriate authorities are alerted and they dispose of the objects properly.

Example:

Before dredging the fairway between the Polish ports of Swinoujscie and Szczecin, an extensive UXO detection and removal campaign was conducted. The area was the scene of various World War II operations. More than 1,800 objects were identified, including one of the largest WWII bombs, an RAF Tallboy, weighing more than 5 tonnes. After more than a year of preparation, the object was neutralised on the spot by the Polish Navy Explosive Ordnance Disposal (EOD) team, using the low order deflagration technique. During the operations, marine traffic was halted and inhabitants of two neighbouring islands were evacuated.⁴⁸

5.2. SEDIMENT SPREADING

During the dredging process, fine sediments are dispersed in the water column by the stirring up of the seabed and overflowing of the hydraulic-transport process water, causing so-called turbidity plumes. Apart from mineral particles, these sediments may also contain biologically and chemically active substances and may

FIGURE 8A & 8B

Examples of ordnance found on the seabed.



⁴⁸ Mietkiewicz R., "High explosive unexploded ordnance neutralization – Tallboy air bomb case study", *Defence Technology* 18 (March 2022) 3, pp. 527-535.

be polluted (e.g., heavy metals, organo-chlorine compounds and TBT's in ports). Suspended sediments absorb sunlight and thereby limit primary production of phytoplankton and may introduce oxygen depleting substances in the water column. Turbidity may also disturb visual abilities of marine mammals and fishes. On the other hand, the release of nutrients in the water column may boost primary and secondary production and therefore the overall food web.

The spatial and temporal extent of sediment spreading is determined by the length of time the particles remain suspended and the distance they travel. This in turn depends on grain size, currents and turbulence.

When suspended sediments disperse over a large area, they potentially affect a large quantity of organisms in the water column, yet their impact reduces with diluting concentrations. Large particles – that settle fast – may have a greater impact when settling on benthic communities than small particles.

The impact of suspended sediments from dredging is different for different sensitive receivers and depends on the ecosystem in which dredging is taking place. Setting threshold values for suspended sediments therefore requires a general understanding of dredging processes as well as of the surrounding environment.⁴⁹

The strategy to reduce impact of suspended sediments will therefore be different depending on the response of the targeted

species and the conditions of the site. Restrictions are usually project based and defined as part of an ESIA that forms the basis of an environmental permit.

Sediment spreading can be reduced significantly by adaptive management of the activities based on dedicated monitoring and modelling. On board the dredging vessel, the sediment-loaded process water is re-introduced in the water column through an overflow duct at the keel of the ship instead of being released at water surface level. Inside the overflow duct, an anti-turbidity valve avoids air entrapment and turbulence, which leads to a reduced dispersion of suspended sediments.

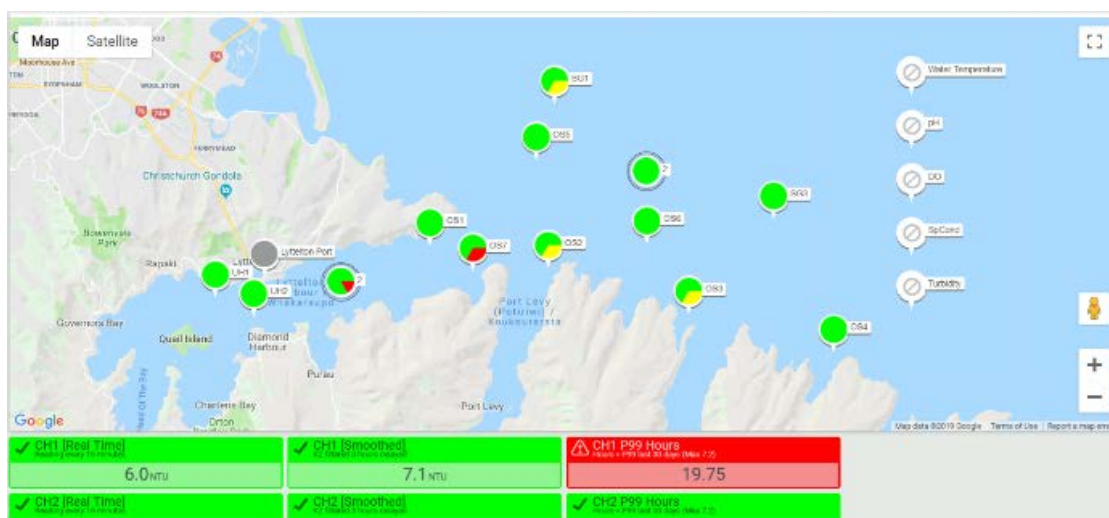
Dredging activities that produce fine-grained suspended sediments, such as mud, clay- and mudstone and coral debris require specific measures. Such measures may include direct reclamation into stilling basins, dredging without overflowing and mechanical dredging. Mixing polluted or harmful sediments with the surrounding water is avoided by using mechanical tools (grabs and excavators) and silt screens. Polluted sediments can be dewatered and either stored in a confined deposit or treated and reused. Since some of these alternative methods may exacerbate other impacts (e.g., they require more energy and therefore cause more emissions), responsible dredging is about finding the optimal balance between impact mitigation measures.

Example:

After an earthquake caused significant damage in 2011, Lyttelton Port, New Zealand, was expanded and its access

FIGURE 9

Monitoring network used during channel deepening works at Lyttelton Port, New Zealand



⁴⁹ CEDA, *Assessing and Evaluating Environmental Turbidity Limits for Dredging*, CEDA Information Paper, 2020.

channel deepened. An extensive monitoring network was used to avoid damage to the surrounding reef ecosystem during dredging activities. Sixteen buoys and stations monitored real-time meteorology, waves, current, suspended sediment and water quality. All data was processed in real-time and presented on a web-based interface. It was also publicly available in a simplified format. The system enabled the dredging contractor to fine tune operations and avoid interruptions due to exceedance of set limits.⁵⁰

5.3. SOUND AND LIGHT

Dredging and reclamation operations produce light and sound that potentially can disturb humans and fauna in the surrounding area, both under and above the water.

Dredging often takes place 24/7 and artificial light is used to ensure the safety of operations. Typical remedial measures are shading, intermittent use of light and suspending the operations at night.

The main sources of sound during dredging activities are the main engines (500 Hz) and propellers (300 Hz) of the dredger. The intensity of the sound is expressed as sound pressure level (SPL), a logarithmic measure of the effective sound pressure relative to a reference level. The airborne sound emitted by a dredging vessel is between 100 and 120 decibel (dB) re 20 micropascal (μPa) at 1 metre (m), underwater sound between 170 and 190 dB re 1 μPa at 1 m.⁵¹

The sound pressure level (SPL) is attenuated following a logarithmic function of distance to source, depending on directional spreading, atmospheric absorption, water depth, ground effects, etc. Because many species of marine fauna communicate via sound and light, disturbance of underwater communication can endanger aquatic life. This disturbance may limit how fish or marine mammals search for prey or avoid being preyed upon, or seek a mate. Usually, four levels of impact on the receptor species are defined: Audible threshold, behavioural threshold, temporary shift threshold and permanent shift threshold, beyond which damage is permanent. Thresholds are different for specific affected species.⁵² Damage to hearing

organs of marine mammals and fishes occurs above 150 dB re 1 μPa . Sounds from 100 dB re 1 μPa trigger avoidance response.⁵³ Typical measures are installation of acoustic deterrent devices, sound barriers on board and suspending the operations at night. In the vicinity of marine mammal feeding or nursing grounds, a permanent observation watch is stationed on board, which can trigger suspension of operations.

Airborne sound is perceived as disturbing when operating at night close to residential or wildlife areas. A typical limit is 65 to 75 dB re 20 μPa at the sensitive location.

Example:

The beaches of the German Wadden island Sylt are regularly reclaimed using locally sourced marine sand. The area is however an important breeding area for harbour porpoises. Passive acoustic monitoring devices deployed over a period of 5 months revealed a short-term avoidance by porpoises in the vicinity of the dredging ship, possibly due to acoustic disturbance. The measured sound level of 150dB at 300 metres distance from the ship exceeds the audible threshold. In comparisons of three reference areas, no significant difference in the long-term use of the impact area by harbour porpoises could be detected.⁵⁴

FIGURE 10

Deployment of an underwater sound monitoring buoy.



⁵⁰ Anderson L.E. and Petterson J., *Real time monitoring for Lyttelton Port of Christchurch channel deepening project*, Australasian Coasts & Ports, 2017.

⁵¹ Robinson S. et al., *Measurement of underwater noise arising from marine aggregate dredging operations*, MEPF report 09/P108, Marine Aggregate Levy Sustainability Fund, 2011.

⁵² WODA, *Technical Guidance on Underwater Sound in Relation to Dredging*, 2013.

⁵³ National Marine Fisheries Service (2016). Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: Underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Dept. of Commer. NOAA. NOAA Technical Memorandum, NMFS-OPR-5.

⁵⁴ Diederichs A., Brandt M. and Nehls G., "Does sand extraction near Sylt affect harbour porpoises?" *Wadden Sea Ecosystem* 26 (2010), pp. 199-203.

FIGURE 11

Development of the ripening of clay: (a) 5 weeks (b) 13 weeks (c) 35 weeks.



5.4. GREENHOUSE GAS EMISSIONS

The emission of greenhouse gases (GHG) has a major impact on global warming. Of the six greenhouse gases covered by the Kyoto Protocol, three are relevant for dredging activities – carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Particulate matter also has a significant climate impact.

Lifecycle analysis (LCA) calculations of GHG emitted by dredging equipment show that combustion of fossil fuels is the largest contributor by far (about 99%).⁵⁵ The entire worldwide maritime fleet produces about 1,000 MT CO₂⁵⁶; the world dredging fleet is estimated at about 6.3 MT CO₂.⁵⁷

Technical improvements can significantly decrease energy consumption. Variable speed propellers, Computational Fluid Dynamics (CFD)-guided design of hull and appendages, automation of operations, waste heat recovery, and battery-powered peak shaving can achieve a cumulative reduction of 10 to 30%.⁵⁸

Combusting LNG instead of marine fuel oils results in significantly lower emissions of CO₂ and NO_x. Non-fossil fuels, such as green methanol and ammonia, have the potential to provide long-term solutions, but are not yet available on the

market in large quantities at an economically feasible price level. Biofuel can be considered as a readily available solution, but is limited by its feedstock.⁵⁹

With the introduction of a CO₂ tax, an emission trading system, or project-based award mechanisms, renewable low-carbon fuels are becoming a viable option for dredging contractors.

Stirring up fine marine sediments can also cause carbon emissions. Carbon is stored in phytoplankton, macroalgae, benthic fauna and other organic material settled on the seabed. The release is most pronounced in fine sediments with high organic content and have both positive and negative effects.

Disturbance of the seabed damages benthic communities, suspended sediments complicate primary production and organic carbon is exposed to oxygen. On the other hand, nutrients in the suspended sediments promote primary production, sediments may be transported to deeper waters and redeposited sediments may bury organic carbon. Current studies are inconclusive whether and under which conditions bottom disturbance has a significant negative or positive impact on carbon sinks.⁶⁰

⁵⁵ Goncalves Castro M.B., Holtkamp M.J., Vercrujse P.M., van Woerden D, van der Blom E.C., "Using Life Cycle Analysis Methodology To Assess The Sustainability Of Dredging Equipment And Its Manufacturing Processes", Conference Proceedings, CEDA Dredging Days, 2011.

⁵⁶ International Maritime Organisation, Fourth IMO GHG Study, 2020.

⁵⁷ EUDA, Position Paper on Emission Reduction of Greenhouse Gases by the European Dredging Sector, 50-007-2, 2009.

⁵⁸ CEDA, Energy Efficiency Considerations for Dredging Projects and Equipment, Information Paper, 2022.567

⁵⁹ Zhou Y., Pavlenko N., Rutherford D., Osipova L., Comer B., "The potential of liquid biofuels in reducing ship emissions", ICCT Working Paper 2020-21.

⁶⁰ Epstein, G., Middelburg J.J., Hawkins, J.P., Norris, C.R., Roberts, C.M., "The Impact of mobile demersal fishing on carbon storage in seabed sediments", Global Change Biology 28 (2022), pp.2875-2894.

The carbon balance of a project that makes use of extracted sand entails more than emissions from dredging vessels and seabed disturbance. A larger carbon release during construction phase may be counterbalanced by an efficient design that reduces emissions during the operational life. Also, reducing emissions in one place or activity may lead to increased emission in another. It is therefore necessary to look at the effects on a system level.

Example:

At the clay ripening project in Groningen (Netherlands) soft sediment from the Eems-Dollard estuary was stored in test beds where different methods were evaluated to dewater, desalinate and reduce the organic content. Based on an organic matter content of about 9%, CO₂ emissions were estimated between 12 and 50 kg CO₂/tonne, depending on the environmental conditions and sediment management.⁶¹ The upper boundary of these emissions is the same order of magnitude as a one-way transport of the sediment by truck over 200 km.

5.5. AIR POLLUTION

At 70%, air pollution is the largest contributor to pollution related deaths.⁶² In contrast to merchant shipping, dredging activities are usually close to ports and densely populated areas, and that makes air pollution a prominent issue for the sector. Main pollutants are particulate matter (including Black Carbon), NO_x and SO_x. Emissions of air pollutants are regulated by the International Maritime Organisation (IMO-MARPOL) and project-based award mechanisms.

Emissions from dredging vessels can be reduced by increasing efficiency and using cleaner fuels like VLSFO, ULSFO, LNG, and biofuels.⁶³ NO_x, CO₂ and particulate matter can be captured after combustion by using Diesel Particulate Filters (DPF) and Selective Catalytic Reduction (SCR) units.⁶⁴

Example:

The environmental permit for dredging works in the Western Scheldt (Netherlands) (2022-2028) requires a standardised calculation of NO_x-emissions (AERIUS). Exceedance of the deposition budget is avoided by deploying Ultra Low Emission Vessels (ULEV),⁶⁵ a Bureau Veritas certified notation.⁶⁶

FIGURE 12

ULEV installation. Credit Jan De Nul.



⁶¹ Kox M. et al., "Ripening of Dredged Marine Sediment: Study of Greenhouse Gas Emissions", Terra et Aqua 164 (Autumn 2021), p 20-29.

⁶² Landrigan P., Fuller R. et al., "The Lancet Commission on Pollution and Health", The Lancet 391 (10119), Oct 2017.

⁶³ EIA Bioenergy, Biofuels for the marine shipping sector, task 39, 2017.

⁶⁴ Zhu Y., Zhou W., Xia C., Hou Q., "Application and Development of Selective Catalytic Reduction Technology for Marine Low-Speed Diesel Engine: Trade-Off among High Sulfur Fuel, High Thermal Efficiency, and Low Pollution Emission", Atmosphere 2022, 13.

⁶⁵ Rijksdienst voor Ondernemend Nederland, Definitief Besluit Vergunning onderhoud vaargeul Westerschelde 2022-2028, 11-2-2022.

⁶⁶ Bureau Veritas, <https://marine-offshore.bureauveritas.com/sustainability/ultra-low-emission-vessels>.

6. THE WAY FORWARD

This paper responds to UNEP's call⁶⁷ to contribute with best practices and presents a wide range of initiatives the dredging industry has taken to counteract concerns and impacts related to sand extraction and reclamation. These contributions include initiatives on both project and operational levels.

Key takeaways are:

- Performing and adhering to an Environmental and Social Impact Assessment are key to finding consensus about conditions and requirements for sand extraction.
- Impact mitigation and nature-inspired design start with monitoring and understanding the physical and ecological processes involved.
- Dredging in or near sensitive sites with high natural or cultural value is only feasible with extensive monitoring, adherence to strict limits and adequate supervision.
- Beneficial use of dredged sediment from capital and maintenance dredging projects is an alternative to sand extraction.
- Stakeholder engagement addresses concerns and unlocks potentials.
- Adaptive management counters risks and uncertainties associated with dredging projects.
- Appropriate procurement processes are able to prioritise project objectives.
- Large marine infrastructure projects entail opportunities to involve the local socio-economic community.
- Incentives for investment in innovation, safety culture and impact mitigation measures encourage improved practices.
- Transparency about activities, with publicly available monitoring data and warning triggers, helps to maintain focus on impacts and to obtain project acceptance.

The dredging industry is committed to help build a better future and continues to:

- Contribute to the understanding of the ecosystems by exchanging information and know-how with knowledge institutions and scientific communities, by encouraging research and participating in joint research programmes;
- Invest in innovations that increase sustainability and biodiversity, reduce accidents and impacts, and improve operational excellence;
- Contribute to new and upcoming standards and regulations, and
- Engage in dialogue with a wide group of stakeholders to ensure that the public's concerns are addressed and projects benefit the entire society.

⁶⁷ UNEP, *Sand and Sustainability: 10 strategic recommendations to avert a crisis*, 2022.

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