IADC stands for International Association of Dredging Companies and is the global umbrella organisation for contractors in the private dredging industry. IADC is dedicated to promoting the skills, integrity and reliability of its members as well as the dredging industry in general. IADC has over one hundred main and associated members. Together they represent the forefront of the dredging industry.

www.iadc-dredging.com
IADC conceived its Safety Award to encourage the development of safety skills on the job and reward individuals and companies demonstrating diligence in safety awareness in the performance of their profession. The award is a recognition of the exceptional safety performance demonstrated by a particular project, product, ship, team or employee(s).

As of this year, two Safety Awards will be granted: one to a dredging contractor (also non-IADC members) and one to a supply chain organisation active in the dredging industry. This concerns subcontractors and suppliers of goods and services.

IADC’s Safety Committee received 15 submissions in the running for the 2021 Safety Awards. Each one is assessed on five different categories; sustainability; level of impact on the industry; simplicity in use; effectiveness; and level of innovation.

Read the full list of contenders on page 30.
EDITORIAL

SPEEDING UP THE FIGHT AGAINST CLIMATE CHANGE

The searing heat that scorched western Canada and the US this summer was ‘virtually impossible’ without climate change, say scientists. All across the region, multiple cities hit new records far above 40°C. Beating the previous national high temperature by more than 4°C, as happened in Canada at the beginning of July, is unprecedented.

In the same month, the deluge in central Europe raised fears that human-caused climate disruption is making extreme weather even worse than predicted. Starting on 13 July, historic rainfall caused devastating flooding across North-western Europe, swelling rivers that then washed away houses and triggered massive landslides, and claimed the lives of hundreds of people.

These extreme downpours are one of the most visible signs that the climate is changing as a result of warming caused by greenhouse gas emissions. A warmer atmosphere can hold more moisture, generating more, and more powerful, rainfall. The floods that cut a wide path of destruction, devastating towns across western Germany and Belgium, as well as in Austria, parts of the Netherlands, Switzerland and Luxembourg, make the importance of water management clearer than ever.

‘We have to speed up the fight against climate change,’ said German Chancellor Angela Merkel when she visited the stricken town of Adenau, Germany.

Flooding is a major issue all around the world: the intense rainfall in Kerala, India (2018) and the swollen Yangtze River in China (2020) caused untold damages. The costs – both human and economic – are staggering.

It takes a commitment from many key players to make sustainable marine infrastructure a reality. If clients, contractors and stakeholders make choices that support this commitment, then water infrastructure can be sustainable. IADC and CEDA’s joint study to explore the role that investors can play in sustainable waterborne infrastructure projects will be launched during CEDA’s Dredging Days, 28–29 September 2021. The report, Financing Sustainable Marine and Freshwater Infrastructure, explores private financing of green coastal, river and port projects. There is no alternative to green infrastructure if we want to tackle the challenges of climate adaptation and reduce the occurrence of the recent devastating events.

As increasing greenhouse gas (GHG) emissions contribute to global warming, it is becoming more important to consider the carbon footprint of hydraulic engineering projects. A study of greenhouse gas emissions during ripening of dredged marine sediment in the article on page 20 does exactly that.

Also in this issue, read the full list of submissions in the running for IADC’s Safety Awards 2021, the benefits of applying the Ecosystem Services approach throughout a project cycle, and how a method was developed to assess impacts and risks in Guatemala while having limited data at hand.

Frank Verhoeven
President, IADC

SOCIODEMOGRAPHIC

Applying the ecosystem services concept in marine projects

The maximum benefit from using ES concepts can be expected when applied from the beginning of a project. However, applying it throughout the different phases of a project can still provide significant context and insights.

TECHNICAL

Balancing project progress and limited system knowledge

How a method was developed to assess the potential negative impacts on seagrass habitats in Amatique Bay, Guatemala while having limited real-time and location-specific information at hand.

SAFETY

Submissions for IADC’s Safety Awards 2021

Review of all 15 submissions in the running for the 2021 Safety Awards. Each one aims to improve routine processes and situations encountered in the dredging industry.

PROJECT

Study of greenhouse gas emissions during ripening of dredged marine sediment

This study provides a first approximation from sediment-related GHG emissions of dredged sediments, using the clay ripening pilot project in Groningen, the Netherlands.

EVENTS

Back to the classroom

Why not get back into the classroom and join IADC for one of its Dredging and Reclamation Seminars in Delft this autumn or in Singapore next spring.

The floods that cut a wide path of destruction, make the importance of water management clearer than ever.
The development of a new marine project demands a system approach in which all aspects, including technical, economic, environmental and social, are considered and integrated equally and at an early stage. While insufficient information may be available to make informed decisions, choices need to be made to progress a project, assess impacts and risks, and engage stakeholders. This article explores the case of a new port terminal in Amatique Bay, Guatemala.

A method was developed to assess, at an early stage, the potential negative impacts on seagrass habitats from the disposal of dredged material at different locations, while having limited real-time and location-specific information at hand.

The development
Amatique terminal is a new port in a greenfield location along the Caribbean coast in the bay of Amatique, north of Puerto Barrios, in Guatemala (Figure 1). The terminal is designed for handling containers, general cargo and liquid bulk. The development consists of a port basin (dig-in), storage and handling areas. A new navigation channel will be dredged over a length of 4.3 kilometres (km) and will connect the existing navigation channel to the ports of Santo Tomás and Puerto Barrios with the Amatique terminal.

Amatique Bay is locally rich in biodiversity, especially in the shallow coastal areas where there are habitats of mangrove and seagrass, important for various marine wildlife including the manatee. These coastal areas are for a large part, protected by Guatemalan Law (Decreto 4-89). Just north of the proposed terminal is the Punta de Manabique Wildlife Refuge, which is also recognised as a Wetland of International Importance under the Ramsar Convention ([www.ramsar.org](http://www.ramsar.org)). Information on habitats and species is scarce.

The bay is no longer a pristine natural system, as human activities have a negative effect on the habitat. The towns of Puerto Barrios and Santo Tomás, with their ports (and access channel), industrial activities and urban population concentrations generate wastewater that drains into the bay. There are cargo and passenger sea vessel movements, as well as commercial and artisanal fishing activities ongoing in the bay. In addition, mangrove habitats are often affected by recreational and agricultural practices. Hence the fact that the bay is only locally rich in biodiversity.

Port location and design
Different locations and designs were considered to develop the best alternative matching the requirements for the port and the value of the environment. Amatique terminal is proposed to be located north of Puerto Barrios (Figure 1). Here, the terminal will be protected from waves, with a good connection to hinterland infrastructure and away from various protected areas as much as possible.

A choice was made for a compact, inland (dig-in) port which reduces the visual impact of the port and integrates the terminal in the natural land- and seascape. The effect on the wildlife refuge would be reduced by limiting the permanent intrusion of the protected area and providing an opportunity to dig a large part of the port in a contained area, reducing plume extension and risks of spills. The downside of this choice is that the volume of earthworks is relatively large.

The challenge is determining the optimal disposal site in relation to dredging method, seagrass beds to be protected and potentially large disposal plumes.
Dredging works

By dredging the navigation channel and the inner basin, a total volume of around 10 million m$^3$ of dredged material will be generated. It is expected that the dredging operation will last between 12–15 months.

Reuse of the dredged material has been considered for landfill and the creation of an artificial island. Disposal on land was also considered. However, the dredged material appeared not suitable for reuse and no land was available for disposal purposes. Bringing the spoil to a marine disposal site appeared to be the only feasible option.

The proposed dredging equipment is largely determined by the minimum water depth required by the dredgers. At a water depth of less than 7 metres, a Backhoe Dredger (BHD) or Cutter Suction Dredger (CSD) can be used. In deeper sections of the access channel a Tailing Suction Hopper Dredger (TSHD) is preferred. The different types of dredgers are shown in Figure 2.

The challenge

The map in Figure 3 shows the different aspects related to the dredging and disposal activities for Amatique terminal in its environment, showing the challenge of this project. Alternative dredge spoil disposal sites have been identified which have to be analysed for the environmental effects resulting from the use of each site. Navigational charts of the bay showed two designated disposal sites (C and D) relatively close to the dredging location. The actual regulations regarding these disposal sites could not be confirmed with the authorities in Guatemala. Next to these designated sites, a potential disposal site E has been proposed, outside the protected area and large enough to accommodate all dredge spoil. The map also shows the location of the seagrass meadows and the ecologically sensitive areas in Amatique Bay. The relevant ecological conditions are elaborated on later in this article.

The challenge is to determine the most optimal disposal site in relation to the dredging equipment and method. Seagrass beds to be protected and the fine soil, potentially resulting in large dredging and disposal plumes of high turbidity. All this in an environment with little data available and low (and therefore difficult to predict) dynamics in the bay. On the other hand, the project developers wanted to understand the feasibility of the project, inform relevant stakeholders and start the approval process with the local authorities.

Extensive survey campaigns were not opportune at this stage, forcing us to develop a practical and effective approach to select the optimal disposal site.

The sensitivity of the observed seagrass species to increased sedimentation and turbidity levels was based on literature review. To predict the suspended sediment concentrations (SSC) which will affect the overall turbidity levels and the sedimentation of the released dredge spoil, a schematised numerical plume model was set up. As input to the model, a source term (elaborated on later in this article) is required. By combining soil conditions, the proposed dredge and disposal locations and the type of dredging equipment to be deployed, source terms were determined.
In this article, we will focus on the impact of disposal of dredge spoil at the different proposed disposal sites and the selection of the optimal disposal site. The impact of the dredging itself was added to the disposal impact when applicable. With the sensitivity criteria of the seagrass and the outcomes of the plume modeling, the effects of using the alternative disposal sites were compared to select the preferred one.

Baseline
Physical conditions
The bay is characterised by limited tidal difference and weak currents. At the dredging location, the sediment is very fine. Limited data on tidal currents, turbidity and soil characteristics in the bay were readily available.

According to the Admiralty Tide Tables, the tidal variation is limited: MLUW–MHHW range is 0.3 m, with a limitation around 0.5 m and the MLHW–MHL W range is 0.3 m. The project location, in the south-western area of the bay, is only 0.5 m and the MLHW–MHL W range is 0.3 m. The project location in the south-western part of the bay is sheltered against waves from the Caribbean Sea. The waves are regularly alternating locations near the project area. The measurements were conducted in the period April–June 2018, just before the start of the wet season.

The results are shown as current roses in Figure 5. For 95% of the time, the velocities were smaller than 0.3 m/s.

Current directions measured with a hand-held instrument in a low-velocity environment are usually invariably inaccurate. Nonetheless, the measured current directions in the three survey locations do show evidence of a circulation pattern along the western shore of Amatique Bay, although variation in the direction is large. Figure 6 shows the measurement locations and our interpretation of the measured current conditions as used in the schematised plume model.

The current in Amatique Bay is likely a combination of tidal filling and emptying, wind variation. The currents are the sum of large-scale wind-induced circulation patterns and small-scale disturbances due to bathymetry, topography and local wind variation. The currents are the sum of several subtle processes, whilst the relevant importance of each process will vary in both time and space. Such low-dynamic, complex systems are extremely difficult to simulate accurately with a numerical flow model.

Together with the current measurements, turbidity levels were also measured. Except for occasional peak values of up to 50 NTU (Nephelometric Turbidity Units), the turbidity levels were generally low resulting in average turbidity levels of around 1 NTU. The turbidity measurements were conducted in the same period as the current measurements. The few rain showers that occurred did not result in increased turbidity levels. Turbidity levels during the wet season may be higher than measured in the dry season, due to more sediments entering the bay with the run-off.

Water samples were collected to establish dissolved in the waters of the bay. These explanations could be locally occurring tannins in the system (Figure 7A). The extent of tannins in the system varied along the coastline and occasionally made the observation of seagrass difficult (see following section and Figure 7B).

In March 2018, several vibrocores in the bay were taken of which a selection was analysed on physical characteristics. The percentage of fines (<63 µm) ranged between 70–99% with an average value of 92%. The median grain size d50 was correspondingly small with values between 16–22 µm being in the range of clay and medium silt. The in situ wet density was estimated to be 1400 kg/m³. Distribution of seagrass beds
Seagrass beds are highly productive ecosystems, which play an important role in preventing coastal erosion, siltation of coral reefs and enhancing fish productivity. In Amatique Bay, the seagrass beds are an important food source for manatees. Based on local observations, manatees were known to gather in the area near Punta de Rincón. However, no manatees were observed during the drone surveys. Sightings are rare, as the animals are elusive by nature and difficult to see. However, local fishermen indicated that they see the manatees regularly.

A first drone survey was executed in August 2018 to determine the extent of seagrass beds. With the Map Plus application (iOS), the targeted sections/areas of investigation were preloaded into the base-map. These sections consisted of tracks parallel and perpendicular to the coast, using georeferenced waypoints for the drone flights (Figure 8). The planned drone tracks and actual flight coordinates were merged with the recorded video. These drone surveys were augmented with dive surveys in specific locations to verify assessed species, maximum extent of seagrass beds and local conditions. The drone survey footage was analyzed by detailed viewing and notes taken for each transect flown. From these notes, an overall summary was made on the extent of seagrass beds and patterns identified.

Drone surveys for the extent of the seagrass beds were confirmed by diving surveys to determine species and their condition.
The surveys show that the seagrass grows close to the coastline and extends approximately 200 m into the bay. The seagrass is found up to an approximate water depth of 6 m. On the south-western coastline near Punta de Palma, patches of seagrass have also been observed (Figure 3).

A second drone survey was executed in September 2018 to determine the extent of the seagrass along the western coastline near Punta de Palma. During this survey, only parts of the coastline were surveyed. The footage shows that the seagrass beds have a patchy distribution along all coastlines. The drone survey showed that seagrass was present all along the surveyed coast, with the highest densities observed in very shallow waters (Figure 8). When seagrass was not visible, it was assessed that this was most likely due to local turbidity and/or discoloration of the water due to planktont extracts (tannins) coming from the mangrove coast.

Plume modelling

Source terms

One of the most important parameters to be considered when assessing environmental impact of dredging is the generated turbidity. Source terms, being the mass of fines released per second, are needed as input for turbidity modelling. Source terms can be calculated deterministically, although the input parameters involved are variable and uncertain.

As various disposal locations are reviewed with different water depths, as well as different types of equipment, multiple situations have been considered in the source term determination (see Table 1). Four types of equipment have been examined: Disposal sites are located at C, D, D’ and E. Disposal sites will be disposed with either one of the equipment types. The CSD is deployed in combination with non-overflowing barges, the CSD disposal source term is relatively small due to the large volumes of process water in the barges. The TSHD can be loaded most efficiently, hence the relatively large disposal source term. Note that the peak source terms of the two BHDs are equal but the cycle time differs with a factor of approximately two, because of which the two BHDs will have different impacts.

Plume spreading

Following the determination of the source terms, the spreading and associated sedimentation of fines is determined. The current pattern in Amalou Bay is complex and difficult to reproduce with a numerical model; especially due to the absence of accurate bathymetric data spatially and temporally varying wind fields and more accurate current and water level measurements. We therefore chose an approach using a schematised Delt3D model rather than a model of the actual bay. The schematised numerical model was based on uniform representative depths and schematised flow patterns (Figure 8). This enabled us to isolate the influence of parameters and processes and provide valuable insight into the model sensitivities.

The schematised model, the tidal flow is strictly bi-directional, ensured by imposing water levels at one end and flow velocities at the other end of the domain. Boundary conditions are imposed in such a way that the average current velocity represents the measured current velocities of approximately 0.2 m/s. Wind-driven currents are neglected.

The model domain has a length of 20 km in the direction of the flow and a width of 5 km perpendicular to the tidal axis, with a grid resolution of 50 m in both directions. A 3D modelling approach was adopted to accurately simulate the slowly setting fines, resulting in a variation in concentration over the water column. Ten vertical layers were used over the water column, each containing 10% of the water depth. The seabed level is uniform but may vary for the considered locations, resulting in water depths ranging between 5–10 m.

The release of fines during the different disposal activities was simulated by adding the source terms in the middle of the model domain. A far-field situation was considered so the sediment source term was divided equally over the ten vertical layers. The discharged soil typically has a particle size ($d_{50}$) of 10 µm, with an associated settling velocity of 0.08 m/min. For each location, a schematised model was set up and the appropriate source term was imposed representing the different dredging methods and cycle times.

The numerical model predicts the variation of suspended sediment concentrations and sedimentation layer thickness, both in time and space. Due to the recurring tidal flow pattern, the released fines flow back and forth while slowly settling to the seabed. This symmetric pattern in the sediment plume is clearly visible in the maximum (or average) concentration of suspended fines over a period of 4 days (Figure 10) for disposal at site E with the TSHD. It should be noted that the maximum (or average) values shown here do not occur simultaneously. The concentrations and sedimentation thickness are highest close to the dredging location and quickly decrease in the flow direction (Figures 10A and 10B). At a distance of 2 km, the maximum concentration has decreased to 86 mg/l.

Table 2 summarises the results of the sediment plume dispersion model for all simulations, the maximum and mean suspended sediment concentration (SSC, $SSC_{max}$ and $SSC_{mean}$) in 4 days is given for locations at 2 km and 3.5 km away from the disposal location. These distances have been chosen to provide a general overview of the results of the different simulations and to support the ecological assessment. In addition, the mean and maximum lengths (Lp) and the widths (Wp) of the SSC plume have been listed, where the edge of the plume is assumed to be at a suspended sediment concentration of 1 mg/l. Furthermore, the average sedimentation thickness over the entire area where sedimentation occurs was calculated ($D_s$). Only the average sedimentation thickness...
The suspended sediment concentration at methods and locations are compared (Table 2). SSC the ambient SSC should be added. SSC are excess SSC and that for the total once on the bottom, spreads out easily and is presented, because this fine material, around it.

The schematicised model results were transformed into impact maps (Figure 10 and 11) using the interpretation of the measured current conditions (Figure 6). These maps show the 1.0 and 50 mg/l contour line of the mean suspended sediment concentration based on disposal in the centre or at the edge of the disposal location. In these maps, the general flow direction is considered as well the plume extent was rotated in such a way aligning it with the dominant flow direction following the circulation pattern in the bay as shown in Figure 6. As disposal can in principle take place anywhere within the boundaries of the disposal site, an impact area around the edges of the disposal site was indicated, covering the area of the disposal site and the maximum extent of the plume around it.

In this assessment, the sensitivity of the plume dispersion and deposition to flow velocity, sediment particle size, dry density of deposited sediment and assumptions in the source term determination were assessed in order to account for natural variations in the system. For example, the maximum measured flow velocity of 3.3 m/s results in a longer but more diluted sediment plume. When the disposed sediment is finer, the sediment plume is significantly larger in extent, both due to advective and diffusive processes. When determining the source term, the percentage of fines reaching the far field (via the far-field factor) needs to be estimated, but this estimate can have a large effect on the plume extent.

The actual impact of dredging and disposal activities on seagrass beds depends on multiple factors such as ambient levels and changes to light availability, turbidity levels and sedimentation rate. Not only are the levels of those different parameters important but also the duration at which the seagrass species is exposed to increased levels of turbidity and sedimentation. Temporary exposure to high turbidity levels is less harmful compared with a long term exposure as this can cause degradation of seagrass beds. Seagrass can tolerate sediment plumes (and therefore elevated turbidity levels) for relatively long periods. Tolerance levels vary between species based on their growth strategy and morphology (e.g. amount of starch reserves in the roots). However, most species are less tolerant to increased sedimentation with only the fastest-growing species capable of outpacing sedimentation rates for a limited period before eventually exhausting their resources. Based on the literature reviewed, the tolerance of the species to increased levels of turbidity and sedimentation showed a large range and differed per location.

No studies were found specifically on the tolerance of seagrass in Amatique Bay. The imposed source terms that were used in the model were based on multiple assumptions, including seasonal changes, within which the species occur were unclear as there was only limited data on natural turbidity levels and light availability. Ideally, critical thresholds should be determined in terms of light availability close to the seafloor (1% SL) and suspended sediment concentrations (SSC).

Impact on seagrass beds
Methodology
The tolerance of seagrass to increased turbidity and additional sedimentation is species and location specific. Larger slow-growing species with substantial carbohydrate reserves show greater resilience to such events than smaller opportunistic species of seagrasses. However, the latter display much faster post-dredging recovery when water quality conditions return to their original state (Erftemeijer and Lewis, 2006). The species present in Amatique Bay, Thalassia testudinum and Syringodium filiforme belong to the larger, slow-growing species. Literature, for example Erftemeijer and Lewis (2006) reviewed to determine the tolerance of these species to dredging activities.

Without robust survey data a critical threshold could not be determined to assist in the selection of the disposal locations. Therefore, to enable an assessment, the impact of disposal activities on the seagrass bed was based on the total area of seagrass exposed to both the maximum extent of the sediment plume and the extent of the sediment plume with an average increase of SSC levels of 1.0 and 50 mg/l over a period of 4 days. These levels were chosen based on a practical basis, with 1 mg/l dictating the maximum plume extent. 10 mg/l indicating an area of influence and 50 mg/l indicating an area with potential for impacts.

Selection of the optimal disposal site
At first, disposal sites were compared based on the total area exposed to the maximum extent of the sediment plume. The maximum extent is the maximum area that could have raised SSC levels (of at least 1 mg/l) at one point in time during disposal activities. The extent of the plume was based on the equipment that was most likely to be used at the disposal site. For disposal site E and D, the TSHD is proposed, while for disposal site C, the CSD is suitable due to the location of its shallower water depth.

Figure 7 shows an example map of the maximum extent of the sediment plume at disposal site E with different concentration levels. Table 3 shows the maximum area of seagrass which could have SSC levels of at least 1 mg/l at one point in time during disposal activities.

Site E was selected as the most favourable disposal site for the following reasons:

- Site C: Shows the highest potential overlap (3.4 km²) of the sediment plume with the seagrass area.
- Site A shows suspended sediment concentrations and sedimentation from disposal accumulate with those from dredging in the navigation channel (INC) and
- Effort of maintenance dredging increases as the navigation channel crosses this disposal site.

Site D: Generates a substantial area (2.0 km²) of seagrass to be exposed to the sediment plume.
- Site B Is located within the Punta de Manabique Wildlife Refuge and
- May create exposure of known feeding areas of manatees to the sediment plume.

Site E: Shows the smallest area of seagrass exposed to the sediment plume (1.3 km²)
- Is located outside Punta de Manabique Wildlife Refuge and further away from Dx Tonga (a known manatee area) and
- Is further away from the dredging site than the other sites.

Sensitivity analysis
The imposed source terms that were used in the model were based on multiple assumptions, such as the amount of material reaching the far field and the settling velocity of the spoil. A sensitivity analysis was performed to show the effects of the choices in (input) parameters on the suspended sediment concentrations and the amount of sedimentation.

In addition, the location where the dredge spoil is disposed within the area of the disposal site

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**Table 2**

<table>
<thead>
<tr>
<th>Disposal Site</th>
<th>Equipment</th>
<th>Flow velocity</th>
<th>Settling velocity</th>
<th>Overlap maximum extent plume with seagrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>CSD</td>
<td>0.2 m/s</td>
<td>0.08 mm/s</td>
<td>3.4 km²</td>
</tr>
<tr>
<td>D</td>
<td>TSHD</td>
<td>0.2 m/s</td>
<td>0.08 mm/s</td>
<td>2.0 km²</td>
</tr>
<tr>
<td>E</td>
<td>TSHD</td>
<td>0.2 m/s</td>
<td>0.08 mm/s</td>
<td>1.5 km²</td>
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</tbody>
</table>

**Table 3**

<table>
<thead>
<tr>
<th>Equipment Location</th>
<th>SSCmax (mg/l) in layer 5</th>
<th>Wmax (km)</th>
<th>Lmax (km)</th>
<th>Dmax (mm)</th>
<th>Wmax (km)</th>
<th>Lmax (km)</th>
<th>Dmax (mm)</th>
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<tr>
<td>C</td>
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<td>BHD A</td>
<td>80</td>
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<td>3.5</td>
<td>3.6</td>
<td>16</td>
<td>0.4</td>
<td>2.3</td>
</tr>
<tr>
<td>BHD B</td>
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<td>2.0</td>
<td>3.4</td>
<td>3.2</td>
<td>19</td>
<td>0.6</td>
<td>2.3</td>
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<tr>
<td>TSHD</td>
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<td>3.6</td>
<td>3.0</td>
<td>3.9</td>
<td>17</td>
<td>0.7</td>
<td>2.3</td>
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<tr>
<td>TSHD E</td>
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<td>3.9</td>
<td>3.9</td>
<td>18</td>
<td>0.7</td>
<td>2.8</td>
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</table>

**Table 4**

<table>
<thead>
<tr>
<th>Disposal Site</th>
<th>Equipment</th>
<th>Flow velocity</th>
<th>Settling velocity</th>
<th>Overlap maximum extent plume with seagrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>CSD</td>
<td>0.2 m/s</td>
<td>0.08 mm/s</td>
<td>3.4 km²</td>
</tr>
<tr>
<td>D</td>
<td>TSHD</td>
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<td>0.08 mm/s</td>
<td>2.0 km²</td>
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<tr>
<td>E</td>
<td>TSHD</td>
<td>0.2 m/s</td>
<td>0.08 mm/s</td>
<td>1.5 km²</td>
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</table>
(either in the centre or at the edge of the disposal site) can have a significant effect on the extent of the dredging plume.

Table 4 shows the difference in maximum extent of the sediment plumes with a variety in source terms, setting velocity and disposal in the centre or at the edge of the site. The maximum extent of the sediment plume increases slightly if the current is increased from 0.2 m/s to 0.3 m/s and if the percentage of fines in the far field increases from 5% to 25%. When applying the 5% source term, after 4 days, the disposal plume does not overlap with the seagrass beds when disposing in the centre of the site. However, when disposal near the edge is modelled, a small area of seagrass is potentially affected.

Based on the plume modelling results, we cannot rule out the possibility that during the 12-16 months of disposal, some areas of the seagrass might be exposed to increased SSC levels more than 1 mg/l when the disposal would be undertaken near the edge of the disposal site (Table 4). Based on our analysis, a maximum area of 0.1 km² of seagrass will be exposed to these increased levels of SSC. However, the seagrass will not be exposed for a significant amount of time because the actual disposal location will vary over the dredging period. It can be concluded that the seagrass will experience minimal exposure to any appreciable elevated turbidity and sedimentation levels for longer periods.

**TABLE 4**

<table>
<thead>
<tr>
<th>Flow velocity</th>
<th>Far-field factor (for source term determination)</th>
<th>Setting velocity</th>
<th>Maximum extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 m/s</td>
<td>5%</td>
<td>0.08 mm/s</td>
<td>1.3 km²</td>
</tr>
<tr>
<td>0.2 m/s</td>
<td>10%</td>
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</tr>
<tr>
<td>0.2 m/s</td>
<td>25%</td>
<td>0.08 mm/s</td>
<td>2.6 km²</td>
</tr>
<tr>
<td>0.2 m/s</td>
<td>5%</td>
<td>0.2 mm/s</td>
<td>0.6 km²</td>
</tr>
<tr>
<td>0.3 m/s</td>
<td>5%</td>
<td>0.08 mm/s</td>
<td>0.44 km²</td>
</tr>
</tbody>
</table>

**Lessons learned**

By sharing some lessons learned from this case of the Amatique terminal, we hope to provide insight to all stakeholders involved in similar projects around the world.

- **Multi-disciplinary team involved at an early stage**

One of the most important lessons learned was the need for a multi-disciplinary team in a very early stage of the assessment. Experts in port design, dredging methods, ecology, coastal hydrodynamics and morphology need to be involved at the same time. An integrated system approach should be developed together.

**Source term determination using a Monte Carlo approach**

The source terms as input in the plume dispersion model were, in this case, calculated in a deterministic manner, which is one source term for each unique combination of port type, production and source conditions. However, the parameters determining the source term are uncertain, vary in time and space and/or have limited accuracy. A probabilistic source term calculation does more justice to the uncertainty in these parameters.

A way to do this is to apply a Monte Carlo simulation in which a large number of random samples are drawn from a pre-defined range of parameter values with an associated distribution (e.g. uniform or triangular). The result is a source term probability of exceedance curve. A typical example of which is shown in Figure 15.

**Key considerations of the drone survey method**

The drone survey provides some important opportunities. Drones can cover large areas in a relatively short timeframe with minimal interference in the natural environment. The results include a valuable ecological and morphological database, useful for the whole project cycle.

However, there are also some important considerations and limitations to make. Drones flights require in-situ validation of observed or assumed species, densities and other metrics. Satellite images can also support the outcomes of the drone survey. The principle of lateral continuation can help to interpolate the seagrass presence/absence, even if it appears to be absent due to low visibility for example.

**Application of the plume model**

The advantage of a schematised model is that it is efficient and can be used to model the transport of chemical and physical properties in a relatively short timeframe.

**Moving forward**

The results of this study have been included in the Environmental Impact Assessment and when the dredging operation starts on the Amatique terminal, an adaptive management approach will be applied. Adaptive management ensures that the effects of the dredging activities will remain within environmental boundary conditions with the aim to prevent any negative impacts to the seagrass beds. This is done by adapting the operation based upon the monitored ecosystem’s actual health, particularly of sensitive receivers such as the seagrass beds.
### Summary

In present times, the development of a new marine project demands a system approach, in which all aspects from technical, economic, environmental and social are considered and integrated equally and at an early stage. This process from a first project idea to actual implementation is complex, iterative and time-consuming with many (unknown) variables. For some aspects, there may not be sufficient information available (yet) to make a fully informed decision to feed the project development process. However, choices need to be made to progress the project, assess impacts and risks, and engage stakeholders. This is a dilemma common to those working in marine project development.

This article explores the case of the greenfield development of a new port terminal in Amatique Bay, Guatemala. We developed a method to assess, at an early stage, the potential negative impacts on seagrass habitats from the disposal of dredged material at different locations while having limited near-time and location-specific information at hand. This method relied on back-calculating and the application of a simplified numerical plume dispersion model. We hope to inspire readers to think about similar cases and share these, so we can learn from each other and enhance our projects, contributing to sustainable development locally and globally.

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Livingstone, approximately 20 km NW of project area).
As increasing greenhouse gas (GHG) emissions contribute to global warming, it is becoming more important to consider the carbon footprint of hydraulic engineering projects. This carbon footprint is more complex than previously thought however, as it can also include the carbon dynamics of the sediments from which projects are built. The purpose of this study was to provide a first approximation from sediment-related GHG emissions of dredged sediments. Using the case study of the clay ripening pilot project (‘Kleirijperij’) in Groningen, the Netherlands, one phase of sediment processing was examined: the ripening of dredged sediments for use as a clay material in dyke construction.

When calculating GHG emissions from dredging and dyke infrastructure developments, the focus is on the emissions arising from operations and transport (e.g. fossil fuel combustion). However, the carbon stock concealed in ecosystem sediments, has the potential to be released as GHGs by dredging, drying, processing and further use. To date, these sediment-related GHG emissions arising from disturbance are often not accounted for in life-cycle analysis (LCA) of hydraulic engineering projects. It is also not known how much of the stored carbon is released via GHG emissions upon disturbance.

Clay ripening pilot project (‘Kleirijperij’): a win-win

The aim of the clay ripening pilot project (‘Kleirijperij’) is to study innovative methods to transform locally dredged soft sediments into clay soil suitable for dyke construction. The pilot project monitored a range of physical and chemical characteristics over 2 years and assessed the suitability of the clay product for dyke construction. Two clay ripening pilots were constructed in the province of Groningen: Delfzijl and Kwelder established in 2018 and 2020 respectively (Figure 1). Both pilot projects consisted of multiple test beds to test whether the conditions, such as the deposition layer thickness, the ploughing frequency and the presence of plants, aid the ripening process and eventually the clay quality. Ultimately, the finished ripened clay product will be used for the construction of the Breda Groene Dijk (The Wide Green Dyke). Clay ripening from soft sediment is a form of beneficial use of dredged sediment. The Eems-Dollard estuary has to be dredged annually for transport purposes (mainly for the harbours of Delfzijl and Eemshaven) as well as ecological purposes. The high turbidity of the estuary is an ecological concern. Structurally removing approximately 1 million tonnes of sediment per year can have significant effects on this turbidity (van Maran, 2016) which is a driver for larger scale future dredging. To evaluate large-scale use on land of dredged Eems-Dollard sediment in the future, several pilots are being conducted within the Eems-Dollard 2050 programme. The clay ripening pilot is one of them (Sittens, 2019) and is executed by the Province of Groningen, Groninger Landschap foundation, Groningen Seaports, Rijkswaterstaat north Netherlands, water authority Hunze en Aa’s and the EcoShape foundation.

Two clay ripening pilots were constructed in the province of Groningen: Delfzijl and Kwelder, established in 2018 and 2020 respectively.
How ripening can result in GHG emissions
Coastal estuarine sediments are carbon sinks (McRoberts et al. 2015). Multiple conditions in the coastal estuary, including anoxic (oxygen-free) conditions in sediments, result in this long-term storage. Dredging activities in the coastal estuary disturb processes both in these ecosystems and in the dredged material. This can result in the release of the stored carbon in the form of GHG emissions. GHG emissions are likely to vary depending on the dredging method, approaches to deposition and the composition of the dredged material. Oxygen is the key element that, when available, facilitates fast microbial degradation of organic carbon stored in the fine sediment. This results in loss of organic carbon as GHG carbon dioxide (CO2).

During and after dredging, DHDs escape from the dredged material as a result of microbial degradation of organic matter. Following dredging, increased availability of oxygen to the sediment speeds up the degradation process, resulting in the reduction of organic carbon content through increased CO2 emissions. There is a growing awareness that this source of GHG emissions might be significant for hydraulic engineering infrastructure projects (dikes, harbours, aquaculture, etc.) (Fiksel et al. 2018). However, few reliable measurements or assessments of GHG emissions due to ecosystem-derived carbon losses in hydraulic engineering projects are available.

In this study, we made a preliminary assessment of the carbon loss and resulting GHG emissions from dredged sediments during the clay ripening phase of a hydraulic engineering pilot project. Our goals were to illustrate an approach to assess carbon losses, GHG emissions and key processes involved. In the end, we hope to propose a framework to illustrate an approach to assess carbon losses, GHG emissions and key processes involved.

Monitoring GHG emissions during the clay ripening pilot project
GHG emissions were measured in the first 3 months of the ripening of fine coastal sediments at the clay ripening pilot project Kwelder. Measurements were performed both in the field and in the laboratory. In March 2020, the clay ripening pilot Kwelder was established and filled with fine sediment.

This sediment originated from eldest Breevaart, a salt marsh area connected to the Eems-Dollard estuary and thus subjected to (closed) tidal effects, which resulted in an increase in sediment over the years. The material was removed using a cutter dredger and pumped at a low density (ca 105–110 kg/m3) to the test ripener over ca 10 km, where it was deposited in ten test beds (K1-H10) (see Figure 2).

Sampling sites to gather GHG emissions were carefully selected to contain fine sediments that made up the largest part of the deposit. These sites were far away from the entry point of the sediment, as they were far away from the entry point of the sediment, as many heavy particles (sand) settled near these locations. In two of these test beds (K1 and H10), GHG measurements were taken. These test beds were not treated by ploughing, desalinisation methods or introduction of plants. In each test bed, three sediment sampling points were selected and respiration flux chambers (see Figure 2) were installed. Measurements were performed in April and June 2020. 5 and 13 weeks, respectively after deposition of the material.

To monitor GHG emissions in the flux chambers, gas samples were collected and analysed for CO2 and CH4 using a gas chromatograph containing a Thermal Conductivity Detector (TCD). CO2 and CH4 concentrations in the gas samples were measured using a gas chromatograph containing a Thermal Conductivity Detector (TCD). CO2 and CH4 concentrations in the gas samples were measured using a gas chromatograph containing a Thermal Conductivity Detector (TCD). CO2 and CH4 concentrations in the gas samples were measured using a gas chromatograph containing a Thermal Conductivity Detector (TCD).

Change in organic matter and field GHG emissions
Over the first 3 months, the moisture content decreased on average from 65% in April (±3% SD) to lower values in June: 44% (±4% SD) in the top layer, 55% (±5% SD) in the intermediate layer and 69% (±6% SD) in the deep layer. Chloride and sulfate concentrations increased in the top layer due to evaporation of water (Electrical conductivity (EC) was used as a proxy for salinity and increased over ten times during the initial 3 months of ripening (April 10 ± 0.9 mS/cm, June 137 ± 69 mS/cm). Furthermore, the redox potential decreased, reflecting increasingly reduced conditions (average redox potential -92 ± 25 mV vs SHE in April and -179 ± 17 mV in June) and low availability of oxygen. Analysis of sediment along a depth gradient showed that after 13 weeks sediment was similar in terms of pH (range of averages 7.3–7.5), temperature, EC (range of averages 137–189 mS/cm) and redox potential (range of averages −162–192 mV). All average values are based on six measurements per sampling points.

In some analyses in the first period 75 cm.
Anoxic conditions create high potential for methane [CH₄] production. The physical and chemical data of the ripening clay showed that oxygen penetration was low and redox potential remained low from April to June in the entire sediment profile. The fact that no considerable CH₄ emissions were observed from the clay ripening might be due to inhibition of CH₄ production by high sulfate concentrations in the estuarine sludge. This result is in more favourable conditions for sulfate-reducing microorganisms (that produce sulfide) rather than methane-producing microorganisms. Sulfate reducers are known to outcompete methane-producing microorganisms under anaerobic conditions (Oremland and Taylor 1975), resulting in limited CH₄ formation. Similar results were found in laboratory measurements of methane emission in 100 ml flask incubations with 80 ml of fresh estuarine sediment, estuarine rippled freshwater sediment. Methane emissions from estuarine sediment and clay were negligible, whereas methane emissions from freshwater sediment were significant (ca 12 µg methane (g wet weight)⁻¹ day⁻¹).

To conclude, for the period of this study we measured relatively limited decline in organic matter (less than 10% of the initial amount) ([results not shown]). This shows that also for the Delfzijl pilot, organic matter degradation remained limited during 2 years of ripening and alternative methods of ripening might show significant increase in degradation.

Potential GHG emissions based on changes in sediment carbon stock

Based on the decrease in organic matter concentrations, carbon stock of sediments and the concomitant GHG emissions of the ripening process can be estimated. This is similar to many studies that have quantified carbon stocks of ecosystems, such as salt marshes and mangroves (Kauffman et al., 2020a; Kaufman et al., 2020b). This is the stock-change approach (SCA) that is also described in the Intergovernmental Panel on Climate Change (IPCC) as an approach to measure carbon stock losses and emissions.

In this assessment, this SCA approach was performed for two scenarios:

- **Scenario 1**: This scenario represents the results obtained from the field. As described in the results section, transport of oxygen to the sediment and of GHGs out of the sediment likely actively emitting GHGs. For this scenario, we assumed the organic carbon degradation values obtained from the clay ripening pilot Helder.

- **Scenario 2**: This scenario assumed the clay to reach target values of organic matter content, which were set for the final stage of ripening of sediment (5% organic matter of dry weight). Starting with 10% of organic matter content in the freshly dredged sediment, this equals a decrease of 5% organic matter (mass). For this scenario, the loss of organic matter was assumed for the whole sediment mass. As illustrated with the 2-year data for the Delfzijl pilot, organic matter degradation was not found in practice, despite efforts to reach the target by aeration through ploughing and the addition of plants. Therefore, this scenario represents a case scenario, not likely to be reached in practice in a short time frame of 2 years. As the Delfzijl pilot showed, even ploughing did not result in this degradation over 2 years.

**Results**

**TABLE 2**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>CO₂e emission (kg CO₂e m⁻²)</th>
<th>CO₂e emission (tonne CO₂e test bed⁻¹)</th>
<th>CO₂e emission (tonne CO₂e tonne⁻¹ clay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Shallow, low DM loss (represents field data)</td>
<td>8</td>
<td>4.3</td>
<td>0.012</td>
</tr>
<tr>
<td>2. Deep, high DM loss (desired quality)</td>
<td>27</td>
<td>149</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Calculation**

In order to calculate GHG emissions for the entire test bed for scenario 1, the data collected from specific sampling points and depths were assumed to represent certain characteristics within the ripening sediment:

- **10 cm sediment samples**: representative of the bulk density and soil organic matter at the 0–30 cm depth.
- **50 cm sediment samples**: representative of sediments at the 30–60 cm depth.
- **100 cm sediment samples**: representative of sediments at the 60–100 cm depth.

Organic carbon was determined from measured organic matter concentrations from the Helder pilot using a relation presented by Fourqurean et al. (2012) and Howard et al. (2014).

\[
Y = 0.21 + 0.6X
\]

Where \( Y \) is organic C (%) and \( X \) organic matter (%), \( Y > 0.87 \).

As apparent through photos taken at the time of sampling, dramatic changes in soils between the different time periods were observed: in a period of less than 3 months, large cracks had formed in surface layers and a concomitant increase in soil bulk density was observed. Soil bulk density of the surface layers was 1.35 g/cm³ in April compared to 1.07 g/cm³ in June. Similar responses were found at the middle depths (30–60 cm) and to differences in the soil bulk density between time periods, comparisons of carbon stocks through examination of the same soil volume would yield incorrect estimations of carbon flux through time.

Therefore, to compare soil carbon stocks adequately, emissions were sized using equivalent masses of the mineral soil fraction for April and June (Kauffman et al., 2016; Aartgies et al., 2020). The mineral soil mass is determined through subtraction of the soil organic matter mass from the total soil bulk density. Then, the total mass of the mineral fraction is determined for the top 100 cm of sediment in April followed by calculation of the mineral soil mass for the June samples.

We assumed that losses in carbon stock were largely due to loss of CH₄ based upon our field and lab experiments and given the high salinity contents of sediments. Under this assumption we report the ecosystem carbon losses as potential CO₂e emissions, CH₄ equivalents (CO₂e), or obtained by multiplying C values by 3.7, the molecular ratio of CO₂ to C.

**Methane emissions from estuarine sediment**

Methane emissions from estuarine sediment were negligible, whereas methane emissions from freshwater sediment were significant.

**References**


decreases. There are currently no indications down to 0.012 tonne CO₂ per tonne of clay. The depth and degree influence that environmental conditions, for the two scenarios demonstrates the estimates of GHG emissions.

This scenario assumed higher loss of OM in scenario 1. In general, the CO₂ emission of GHG is most likely much higher in freshwater sediments. As can be expected, the estimated CO₂ emission in this scenario was significantly higher (27 kg CO₂/tonne km) than in scenario 1. In general, the CO₂ emission will be proportional to the depth to which the organic matter will be degraded and the extent to which the sediment organic content decreases. There are currently no indications such a scenario is taking place when ripening sediment from the East-Diërden estuary 4.

The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions.

The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions.

The urgency of all business sectors to address climate change mitigation through reduction of emissions and the sequestration of GHGs is well recognised. If we are to attain the target of the Paris Agreement, all stakeholder must act. In line with this, the Dutch government aims to reduce the Netherlands greenhouse gas emissions by 49% by 2030, compared to 1990 levels, and a 55% reduction by 2050. In addition, the Ministry of Infrastructure and Water Management adopted a target to achieve net-zero emissions by 2050. Companies in the maritime and dredging sector have started to adopt net-zero targets. This has already resulted in serious efforts to minimise emissions from hydraulic engineering, particularly in relation to minimising use of fossil fuels and optimising construction materials. The presented analyses in this study demonstrate a useful methodology and indicative numbers for sediment-related GHG emissions. However, many uncertainties remain that deserve further attention. Improved approaches to the sampling of GHG emissions and quantification of the carbon mass within the sediments would facilitate accurate quantification of carbon stock and GHG emissions from the ripening process.

Direct measurements of GHG emissions are needed to confirm the findings and validate the range of applicability both in the field and in the lab (see Siebert et al., 2013). The use of portable infrared gas analysers would facilitate accurate field measures of gas emissions (CO₂, CH₄, N₂O). Furthermore, intense sampling of sediment carbon pools during the entire clay ripening process is recommended to obtain more precise estimates of GHG emissions from the clay ripening process. This would entail repeated sampling of carbon concentrations and concentration bulk density at varying depths of the sediment beds over time.

The carbon composition and quality are also unknown. The carbon quality is a measure of the quantity of labile and recalcitrant fractions. This is important as microorganisms can readily decompose labile forms while recalcitrant carbon may indefinitely persist in sediments. Knowledge of carbon quality provides information on the time required and potential to reduce organic matter in dredged sediments. In addition, other components of the sediment, such as clay and salt, may have an impact. Once salts are washed out of the clay and with greater oxygen penetration (via plant roots, bioturbation or after soil is mixed with sand), the degradation of the organic material will be enhanced. However, this could increase methane emissions, which would increase the global warming potential of the gases arising from this ripening process. The sediment in the two pilot projects described here is both estuarine, salt-water sediment from the same region, which could differ in several more specific parameters such as organic matter quality. For other cases, sediment differences as well as variability in the carbon stock and GHG emissions from the ripening process might be different and it is recommended to take this into account.

If the objective of a project involving hydraulic engineering is to minimise GHG emissions or even sequester carbon, then building with nature based solutions can be applied, such as using the soft sediments for salt marsh creation where vegetation could uptake CO₂ and store organic carbon in sediments. Silt marshes not only sequester carbon but also reduce wave heights. When dyes are combined with engineering forrestries, they can be lower and still provide safety (Temmerman et al., 2013). Low dyes require less clay and thus involve fewer emissions from clay ripening.

In this pilot study we only focused on processes during the first stage of the ripening of the sediment and a transition from dredged sediment to clay material. Microbial degradation of organic carbon will result in loss of this organic carbon as CO₂ and/or CH₄. Our pilot study already suggested some parameters that affect the sediment-related GHG emissions during ripening of soft sediments: the concentration of carbon in the sediment, the quality of that carbon and the salinity that affects whether emissions will be limited to CO₂ or not. The slow transport in and out of the sediment probably also affects degradation conditions, resulting in low availability of oxygen and slow breakdown of organic matter and slow emission of greenhouse gases. These and other factors might differ with different dredging methods and ways of deposition during ripening. However, there are many process steps before and after the ripening period in the project where GHG emissions arise (Figure 1). In addition, sediments-related GHG emissions from pre-dredging up to the moment the clay has been implemented in the dikes and the further fate of carbon, should be quantified. Finally, the use of relevant reference scenarios in the life cycle analysis is essential, e.g. of natural ecosystems or alternatives of the sediment use.

Conclusions

Our study aimed to assess GHG emissions from ripening soft sediment to dyke clay and to identify key processes involved. Given the small sample size, short sampling time and indirect measures of carbon loss, our results must be considered as a first exploration. The estimated CO₂ emissions suggest that carbon emissions from the clay ripening process are potentially significant and that these emissions can be affected by the type of sediment and ripening conditions. Emissions from clay ripening ranged between 0.012 tonne CO₂/tonne of clay for this specific clay sample up to 0.05 tonne CO₂/tonne of clay if the desired clay quality with an organic material content of 5% would be reached. Alternatively, if a similar amount of clay would have been collected from abroad, GHG emissions from transport alone may equal these emissions.

The results from this study offer an approach to compare GHG emissions from soft sediments to alternatives and give information on control parameters by which GHG emissions from soft sediments can be minimised. Firstly, working with saline sediment is less likely that organic matter is converted to CO₂ instead of into the more potent GHG CH₄ while working with freshwater sediment. Secondly, gas exchange between sediment and atmosphere can occur directly, and indirectly by maintaining anaerobic conditions. However for freshwater sediments anaerobic conditions are achieved very quickly due to the high salinity of the much stronger GHG CH₄. Minimising gas exchange works against the aim to reduce the organic carbon loss. Therefore, studies are performed with ripened to see whether saline clay with a higher than desired OM content (T emmerman et al., 2013). Lower dyes require less clay and thus involve fewer emissions from clay ripening.

We recommend that sediment-related emissions are addressed in life cycle analysis (LCA) of hydraulic engineering projects, so that different scenarios can be compared and well-informed decisions can be made. To achieve this, GHG emissions from and sediment sequestration in sediments need to be integrated into existing tools, such as the ones used by the Dutch government ‘DuboCalc’ or the ‘CO₂ performance ladder’. Meanwhile, hydraulic engineering projects that involve soft sediments should measure and report carbon stocks and fluxes of GHG emissions to build up the required knowledge base.
Summary

The urgency to address climate change through reduction of emissions and sequestration of GHGs is well recognised. To attain the target of the Paris Agreement, stakeholders must act now. Companies in the maritime and dredging sector have started to adopt net-zero targets. This has already resulted in serious efforts to minimise emissions from hydraulic engineering, particularly in relation to minimising use of fossil fuels and optimising construction materials.

The carbon footprint or life cycle analysis (LCA) of a hydraulic engineering project focuses mostly on emissions arising from operations and transport (e.g. fossil fuel combustion). However the carbon stock concealed in ecosystem sediments has the potential to be released as GHGs by dredging, drying, processing and further use. The extent to which GHGs are released upon disturbance is not known. These sediment-related GHG emissions are often not accounted for in the LCA of hydraulic engineering projects.

Using the case study of the clay ripening pilot project (Kleirijperij) in Groningen, the Netherlands, we studied sediment-related GHG emissions during the ripening of dredged estuarine sediment. The local marine clay ripening pilot seems more favourable in terms of CO2 and CH4 emissions than collecting clay from abroad or ripening of freshwater sediment, despite significant amount of organic matter during ripening. For a complete LCA, a thorough analysis of all alternatives should be done and uncertainties should be clarified. There are indications that sediment-related GHG emissions during ripening of clay can be reduced depending on type of dredged material and the ripening conditions.

REFERENCES


When individual employees, teams and companies view everyday processes and situations through a continuous lens of safety, they can each contribute to making all aspects of operational processes, whether on water or land, safer. For the 2021 Safety Awards, IADC’s Safety Committee received 15 submissions. Each one is assessed on five different categories: sustainability; level of impact on the industry; simplicity in use; effectiveness; and level of innovation.

Affirming the importance of safety
Dredging activities can be risky operations with hidden dangers amongst heavy machinery. In response, the dredging industry proactively maintains a high level of safety standards. A representative of contractors in the dredging industry, IADC encourages its own members, as well as non-members participating in the global dredging industry, to establish common standards and a high level of conduct in their worldwide operations.

IADC’s members are committed to safeguarding their employees, continuously improving to guarantee a safe and healthy work environment and reducing the number of industry accidents and incidents to zero.

Recognising adventurers of safety
IADC conceived its Safety Award to encourage the development of safety skills on the job and reward individuals and companies demonstrating diligence in safety awareness in the performance of their profession. The award is a recognition of the exceptional safety performance demonstrated by a particular project, product, ship, team or employee(s).

As of this year, two IADC Safety Awards will be granted: one to a dredging contractor (also non-IADC members) and one to a supply chain organisation active in the dredging industry. This concerns subcontractors and suppliers of goods and services. In total, 15 submissions were received. Each one aims to improve routine processes and situations encountered in the dredging industry.

The winners of both awards will be announced during IADC’s virtual Annual General Meeting on 16 September 2021.
Dredging contractor safety award submissions

SIMOPS between two TSHD dredgers by Jan De Nul

Jan De Nul’s first submission is a tool that visualises and controls the maximum distance between two TSHD dredgers based on the length of a floating pipeline and live position of both vessels. Due to the nature of the works on a project in Germany, JDN’s dredgers TSHD Pedro Álvares Cabral (PA) and Tristan da Cunha (TC) had to be connected by means of a floating pipeline. Dredged material was then pumped via the pipeline from the larger TSHD (PC) into the smaller TSHD (TC).

The operation, carried out on the river Elbe, presented several challenges, primarily maintaining the vessels positions with difficult site conditions. Other challenges included the smaller TSHD being pushed out of position due to the current, changing weather conditions and having to maintain a certain length of floating pipeline. Coordination of the relative movements of both TSHD dredgers is crucial in this type of SIMOPS. The position of the TSHD (PA) was transmitted in real-time to the TSHD (TC) by means of Rajant wireless network set-up, making it possible to ensure the bow of the TSHD (TC) remained within the predefined circle. The diameter was adjusted when current or weather conditions changed.

By means of this active monitoring system, increased forces at the couplings and in the floating pipeline could be prevented. Additionally, the smaller TSHD (TC) did not have to drop its anchor resulting in reduced cycle times without compromising an operational control. Crew, having used the tool consistently on the project, found one of its greatest benefits is its use at night when no direct visibility of the pipeline was possible.

Self-moving traffic barrier by Boskalis

The idea of a Self-Moving Traffic Barrier (SMTB) came about during Boskalis’ Houtribdijk project when, due to ecological restrictions, it was not possible to move barriers during the night. This meant everything had to be done during the daytime, which not only caused traffic congestion but also, on occasion, unsafe situations.

The Self-Moving Traffic Barrier (SMTB) is a barrier that can easily be moved and creates a safe work environment for all its employees. The design of the barrier is robust making it a safe construction and its use can also prevent having to close a road, in turn avoiding possible inconvenience to road users.

A prototype has since been built for the A9 project in the Netherlands, where its implementation will play a role in the safe continuation of the project activities next to regular traffic. Dredging projects with infrastructure related aspects can also benefit from the SMTB.

CSD mobilisation at the beginning of the COVID-19 pandemic by Dredging International and Van Oord

At the start of the COVID-19 pandemic and with the situation uncertain, it appeared impossible to continue with project activities. Nevertheless, the joint-venture team of Dredging International and Van Oord managed to mobilise a cutter suction dredger (CSD) to the ‘Modernisation of the Świnoujście – Szczecin fairway’ project site to begin dredging and reclamation activities.

Implementation of increased measures to protect the health of employees at a time when there was not yet a standard practice and no clear information on the actual exposure risks, made the task extremely difficult. Strict follow up of the determined safety measures put in place were maintained throughout the project duration. During a 12-month period, the project managed to continue without any delays due to the COVID-19 pandemic.
Bollard step by Jan De Nul

Jan De Nul's bollard step provides a solution that is both easy and quick to use, and is low on maintenance. Designed by crew, the bollard step transforms mooring equipment into a safe and secure step on which to make marine transfers.

The main materials used are steel and anti-slip grating. The latter creates a safe surface from which a safe vessel-to-vessel or ship-to-shore transfer can be made. The fact that the bollard step is quick and easy to use is reflected in the way it is mounted: two people can effortlessly carry the step and put it in place without extra securing measures. Not being a fixed structure also provides an operational advantage: the deck space is not restricted as the bollard step can be dismounted at any time (e.g. when cargo needs to be lifted on deck) nor does it need to interfere with mooring operations.

There are several step designs to cope with different locations and scenarios, all of which can be used on a variety of vessels. The simple and clever design solution is adjustable to different types of bollards, creating a safe and steady platform where there could never be a step-over zone. The innovation will also increase safety of crew transfers on small CTVs. In addition, CTVs that otherwise might not be suitable during a project could be used thanks to the bollard step resulting in potential savings.

Draghead access platform by DEME

Access to the draghead for maintenance or repair purposes is usually done by climbing a steep ladder with no attachment point for a fall harness. Climbing on the draghead to carry out such works carries many risks when working on heights. Dragheads usually have lots of jetpipes, cables and other obstacles that need to be navigated. After investigating and trying several different possibilities, DEME came up with the design of an access platform that provides a safe working space during maintenance and repair works.

DEME’s simple and effective custom-made, lightweight platform attaches to the side of the draghead providing easy access. Made from aluminium for easy manipulation and assembly, the platform is designed with collective protection to improve the work area. To access the platform, a tailor-made ladder attached to the platform is used instead of a steep ladder. The platform provides a safe area in which to work with increased manoeuvrability and workability of crew. The designed platform is lightweight, easy to manipulate and removable when not in use. Additionally, it is within reach of the on-board crane which allows storage within one movement of the crane.

The simple and clever design solution is adjustable to different types of bollards, creating a safe and steady platform where there could never be a step-over zone.

Aerial drone to monitor excavation works by Jan De Nul

An excavation operation is typically monitored by topographical surveyors. Jan De Nul employed the use of aerial drones to monitor the excavation works of soil contaminated with asbestos. By using an aerial drone, possible SIMOPS with heavy equipment is avoided. Additionally, the topographical surveyor does not need to walk or work on contaminated soil.

The use of drones in such activities is part of Jan De Nul’s QHSE values to provide a safe environment for all persons working for or on behalf of Jan De Nul Group, taking into account physical and mental health.

What makes this innovation unique is that the project team did not rely on standard survey procedures, but utilised a solution that guaranteed the safety and health of the topographical surveyor. Using this technique is relatively easy and can be used after a day’s in-house training.

Retractable boat landing by Van Oord

Using a boat landing at sea normally requires manual handling which is a high-risk operation. Sometimes many vessel-to-vessel transfers are required and the conditions at sea can be challenging. Van Oord therefore came up with a design to provide a safe alternative for vessel-to-vessel transfer.

Its design of a retractable boat landing, which can be deployed without the use of a deck crane, means high-risk operations, such as rigging and hoisting at sea are avoided. The boat landing is deployed by the push of a button, therefore eliminating the manual handling element. The hydraulically driven system is integrated into the vessel’s installation and deployment of the landing takes about a minute.

Aside from the safety element, another benefit is that since the boat landing can be stowed easily on deck and is deployed in a time efficient manner, it can be used frequently even during short stretches of sailing, reducing drag and thus saving fuel.

A unique piece of equipment to the industry, Van Oord is the first to have the retractable boat landing installed on one of its vessels. Fitted on flexible full-pipe vessel Bravories, it has been in use for one year. The boat landing has been built according to the standards in place and can be used during the entire operational life of a vessel. The only requirement for fitting is having the necessary deck space required.
Pipeline walkway by Jan De Nul and DEME

SeReAnt (a joint venture between Jan De Nul and DEME) co-designed and delivered a floating pipeline approx. 200 metres long, equipped with a walkway to facilitate the safe transfer of personnel. The pipeline and walkway are hinged and able to rotate, and serve as a hang-up system for the high-voltage electric cable powering the CSD. The walkway provides a unique way to transfer personnel from ship to shore and can be used during any weather conditions where CTVs are limited. The multifunctional floating pipeline both decreases the risk of falling into the water and provides a positive impact on fuel consumption and CO2 emission compared to traditional methods of marine transfer.

Retractable ladder for track excavators by DEME

Stepping on and off machinery is not without risks. Following an LTI, DEME carried out a thorough investigation and found a lot of operators had scars on their shins caused by contact with the tracks when stepping on and off track excavators. The existing steps on an excavator are located inside the boundary of the tracks, which is the cause of many injuries and near misses. Bringing the steps outside the tracks is not an option however, since this creates other risks both operational and for transport. The solution – a retractable ladder that can be folded up just above the upper structure of the crane cabin. Located on a safety area besides the excavator door, this innovative design needs almost no maintenance. The ladder is made out of one piece of metal and retracts by itself after use. It can be positioned in the location of the original platform and both a bolted or welded connection is possible. The benefit of the design is that you only need one type of ladder. DEME foresee one standard ladder with a maximum length that can be adjusted on smaller type of track excavators.
Supply chain organisation safety award submissions

Quick coupling floating pipeline by APT Global Marine Services

APT Global Marine Services’ quick coupling system creates a safer, faster and watertight floating pipeline connection. The innovative system for floating pipeline reduces the manual handling to one single operation. Furthermore, the pipelines are floating during the coupling, which results in minimal use of the crane and excludes any (heavy) lifting. All this while the connection is solid and watertight.

By excluding lifting operations, the potential safety threat from working underneath the pipeline is eliminated. In addition, the hands-free connection reduces the risk of hand injuries from the flanges. Furthermore, the connection of two sections of pipeline is established by one single spanner operation in a matter of minutes, which reduces the amount of handling to the bare minimum.

The system is both simple and intuitive for crew to use and operate. The male and female part of the quick coupling attaches to the existing flanges of a pipeline, meaning no additional equipment is necessary.

Non-nuclear Slurry Density Meter (SDM) by Rhonsonics

The Rhosonics Slurry Density Meters (SDM) are a new sustainable solution for the mineral processing industry. The ultrasonic-based measuring instrument can determine the slurry density in real time to check the amount of solids in a liquid. This innovative way of measuring slurry densities is challenging the status quo, i.e. the radiation-based instruments currently used in the industry. The Rhosonics SDM operates in the same accuracy and repeatability ranges as the nuclear density gauges, however the device is safe to use, can easily be calibrated and has a more compact design.

For radiation safety reasons the nuclear source is located in a capsule surrounded by a source holder (a radiation protection shielding). This shielding is usually made of lead and can weight up to 500 kilos or more to protect the employees working with those instruments. The SDM is always the same weight, which is only 6.8 kilos and the size is very compact as well, since it is an all-in-one design. The transmitter and transducer are connected by a tri-clamp, therefore no cables are used in between the SDM sensor and analyser.

The SDM is a real game-changer for slurry density measurement applications, especially in the mining and dredging industries, where it is increasingly being used to optimise processes.

Safety Plus Programmes and National WSH Vision 2028 by Keppel FELS

Anchored in its Safety Plus Programmes and Singapore’s National WSH Vision 2028, Keppel FELS continues to consistently improve and enhance its existing Health, Safety and Environment (HSE) management systems. Safety is a key priority in its operations and the company is committed to ensuring everyone goes home safe at the end of each workday.

Keppel FELS has robust HSE management systems in place and invests in building HSE competency and capabilities through training, outreach activities and empowering every individual in its workforce to intervene and stop any unsafe acts. The shipyard adopts a set of 10 ‘Measuring rules and performs an assessment of high impact risk activities (HIRA) prior to the execution of work.

Technology and innovation are ingrained in the culture of Keppel FELS. It is essential in building a strong safety culture and constantly enhancing safety standards for work processes. The company invests in its design, engineering, planning and construction processes by adopting digitalisation and smart asset technology to further value-add to its products by simplifying processes, tracking operations, improving safety considerations and supporting its customers.

Tetris challenge campaign Jan De Nul

When the Zurich police published a photo of all the equipment that they carry in a patrol car, you would have thought that this was nothing special. However, they placed the material in such a way that it all fitted perfectly together in the picture frame and so the Tetris Challenge was born.

Reframing from the idea of lining up all its vessels to create the best Tetris challenge picture ever, Jan De Nul wanted to focus on what really counts – the safety of its people. As the dredging industry is typically characterised as a busy and demanding work environment, very clear and visual communication is key for success. The existing means of communications, such as safety posters, QHSE notices and incident bulletins are an effective way to transfer information, but with this Tetris challenge, Jan De Nul triggered its employees on another level.

Trends come and go and social media advances at a speed that even the company’s design department cannot follow. They quickly jumped aboard with the trend and reached employees with a safety message in a way that they may have not expected.
Including ecosystem services (ES) during project development ensures that the engineering aspects are developed considering interactions with hydrodynamics, biodiversity, fisheries, recreation, etc. This identifies project dependencies and vulnerabilities, and helps to avoid unintended impacts and achieve broader benefits to society and nature. ES framing can thus identify critical capital and values to be sustained, opportunities for nature-based solutions and win-win scenarios, while serving as a vehicle for stakeholder outreach and communication. The ES concept can help clarify and integrate these considerations into project design and evaluation, enhance sustainability, provide a framework for the integration of disciplines, and play a role in the overall cost-benefit analysis of projects.

The ecosystem services concept
Nature provides processes for human health and well-being, including clean water, air, and food. We use and exploit this natural environment to derive its resources. Given global population and climate change projections, there is a continuing need to provide for growing resource demands in a sustainable manner. A full consideration of ecosystem services (ES) impacts, interactions and improvements can result in more sustainable and adaptive solutions for dredging and marine construction projects. Furthermore, the benefits can be translated in monetary terms, providing returns on investment and highlighting the links between ecology and economy. For some however, the ES concept is too theoretical. This article seeks to show how the ES concept can actively be applied at any point during a project and the benefits of doing so. Its purpose is to provide a framework for integrated and interdisciplinary thinking throughout the different steps of the project cycle.
Ecosystem Services (ES) are defined as the benefits people obtain from ecosystems (MEA, 2005). The application of the ES concept is based on the idea that nature represents value to humans (through natural capital accounting). The links between biophysical aspects of biodiversity and human well-being are represented in the ecosystem services cascade model (Figure 1). The recognition that human well-being and economic development is dependent on the preservation of natural resources is certainly not new, but the ES concept is for everyone a means or even an underlying principle of global environmental policy, legislation and management (Aptitz, 2013). By framing the costs and benefits of natural resource management, ES concepts can be used to evaluate, justify or optimise management decisions.}

**Table 1**

<table>
<thead>
<tr>
<th>Ecosystem Services</th>
<th>ES categories</th>
<th>Examples of negative impacts from dredging/marine construction projects</th>
<th>Examples of positive impacts on the ES from dredging and marine construction projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provisioning services</strong></td>
<td>Food</td>
<td>Reduction of available fishing grounds and number of fishes.</td>
<td>Creating, maintaining or restoring nursery areas for fish, incorporating aquaculture facilities or supporting facilities into the project design.</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Reducing the access to water by the installation of breakwaters or natural habitat.</td>
<td>Improving the access to water for navigation.</td>
</tr>
<tr>
<td></td>
<td>Raw materials</td>
<td>Destruction of mangrove forests that are used for wood.</td>
<td>Dredged material as a resource.</td>
</tr>
<tr>
<td><strong>Regulating and maintenance services</strong></td>
<td>Water purification</td>
<td>Destruction of natural habitats.</td>
<td>Dredging and maintenance projects impact contaminant dynamics; design can optimise this function.</td>
</tr>
<tr>
<td></td>
<td>Air quality regulation</td>
<td>Destruction of natural habitats.</td>
<td>Creating, maintaining or restoring forests (terrestrial or riparian).</td>
</tr>
<tr>
<td></td>
<td>Coastal and riverine protection</td>
<td>Destruction of natural habitats, changes to hydrodynamics and sediment balance.</td>
<td>Coastal development through the use of both hard and soft engineering solutions; riverbank design and maintenance.</td>
</tr>
<tr>
<td></td>
<td>Climate and weather regulation</td>
<td>Destruction of natural habitats.</td>
<td>Enriching carbon storage through natural restoration (e.g. mangroves, marshes).</td>
</tr>
<tr>
<td></td>
<td>Ocean nourishment</td>
<td>Destruction of natural habitats.</td>
<td>Creating, maintaining or restoring natural habitats.</td>
</tr>
<tr>
<td></td>
<td>Life cycle maintenance</td>
<td>Destruction of natural habitats.</td>
<td>Creating, maintaining or restoring fish nursery areas; e.g. seagrass beds, mangrove areas and salt marshes.</td>
</tr>
<tr>
<td></td>
<td>Biological control</td>
<td>Destruction of natural habitats.</td>
<td>Creating, maintaining or restoring marine ecosystems.</td>
</tr>
<tr>
<td><strong>Cultural services</strong></td>
<td>Symbolic and aesthetic values</td>
<td>Alteration of historically or culturally valuable landscape or infrastructure.</td>
<td>Design and infrastructure of waterways/ports; sediment management (incl. handling of dredged material); nature-based solutions.</td>
</tr>
<tr>
<td></td>
<td>Recreation and tourism</td>
<td>Alteration of recreational landscape environment or infrastructure.</td>
<td>Incorporating infrastructure with recreational value into the design of e.g. coastal protection projects.</td>
</tr>
<tr>
<td></td>
<td>Cognitive effects</td>
<td>Loss of or damage to stratigraphic or archaeological records.</td>
<td>Sharing of information on the impact of the project through media, information panels, etc.</td>
</tr>
</tbody>
</table>

By framing the costs and benefits of natural resource management, ES concepts can be used to evaluate, justify or optimise management decisions. By taking both natural and societal effects into account, EBM provides a mechanism for making decisions about marine infrastructure and dredging activities with the goal of including and maintaining contiguous ecosystems in a healthy, productive and resilient state. From this perspective, the focus is on the diverse interactions between societal systems and ecosystems rather than a specific project goal or activity. The drivers and pressures affecting ecosystems are varied and numerous; solutions must be holistic and adaptive to avoid negative impacts and to benefit from an integrated multi-sectoral approach. The focus on ecosystems should not be constrained as the elevation of ecosystems over people, nature or jobs or of fish and wildlife over progress. Rather, the focus on ecosystems recognises that humans and their systems are part of ecosystems and reveals the inherent dependence of people on the services provided by the ecosystem (ES) and its functions (Table 1). The ES concept has become increasingly important for the dredging and marine construction sector (Boelens et al., 2017a; Labbé et al., 2018). However, ES impacts and dependencies are not yet generally considered in project-related cost-benefit analyses due to a lack of standard guidelines and methodologies (PIANC, 2018).

Added values for your projects and business:
- Including ES concepts in marine construction and dredging projects improves and communicates the understanding of the natural and socio-economic context for such projects. Hence, on the one hand, it articulates project dependencies upon ecosystem functions and services. On the other hand, it identifies both desirable and undesirable impacts that the project may have on other local/regional/global services and objectives. As a result, project opportunities, risks and vulnerabilities are identified. The improved understanding and focus on ES concepts may have the following, partially overlapping, beneficial consequences:
  - Enhancing the positive effects of any project on the surrounding natural and socio-economic environment, such as increasing biodiversity, improving natural functions and societal well-being.
  - Reducing the negative impact of any project on the surrounding natural and socio-economic environment, thereby enhancing the positive effects of any project on the surrounding natural and socio-economic environment.
Examples of benefits from applying the ES concept

Understanding and optimising the natural processes of the system in which a port or dredging work is planned may reduce costs and increase benefits in the long run. These approaches may also help to mitigate the detrimental effects of port construction on the environment, improve legislative consent procedures and enhance acceptance by the local community. The socio-economic benefits of measures and their related effects can be evaluated and communicated to involved project parties by applying the ES concept. Although identifying and designing for such synergies may require more up-front planning and assessment effort (soft costs), such efforts can reduce construction and operational costs. They are beneficial not only for the owners or contractors working on the project but also for various stakeholders indirectly impacted by a project.

Support decision-making

Information garnered from ecosystem service-based assessment (ESA) can be decisive, supporting or informative (April, 2013). Decisive information implies that it can generate critical information for scenario selection. ESA will seek to evaluate or even quantify the extent to which various design alternatives may result in ES gains or losses. Trade-offs can be used to frame the decision-making process. Less strictly, it can also be supporting, providing technical information for ES optimisation or compensation decisions. In such a case, risks or opportunities (such as in NES) can be identified, and ES concepts can be used to mitigate undesirable impacts or seize win-win opportunities. Lastly, it can be an information and awareness tool to communicate with and inform stakeholders, providing a framework for discussions, without necessarily requiring the same level of in-depth analysis. In these cases, ES framing may help provide the social licence to operate by engaging stakeholders in evaluating how their values might be affected and how a project might fit into broader personal or regional objectives.

Steps of the ESA framework

An ES Assessment (ESA) evaluates how ES for which projects? for which ES? are affected by a project in the societal context instead of considering ES for projects and greenfield projects. This highlights any added value, both in the short and long term, for the project. Examples are beneficial reuse of material and generation of indirect income through habitat creation (e.g. tourism, fisheries, quality of life, blue carbon). It also demonstrates the project's dependencies on ES (e.g. sediment and water transport, storm protection, water quality).

- Avoiding mitigation measures and compensation costs;
- Reducing project breakdown risk by identifying project dependencies and vulnerabilities, building resilience against extreme natural events and effects of global and climate change, and improving adaptability of infrastructure and supporting environmental security;
- Contributing to the re-establishment and restoration of degraded ecosystems through applying nature-based solutions (NES);
- Identifying opportunities to capture/ use natural processes to obtain functional benefits, e.g. reduced maintenance dredging, this can identify and optimise opportunities for NES;
- Better alignment of a project in the societal context instead of considering predominately economic targets (e.g. navigation);
- Reducing social costs or negative impacts in the societal context of the project;
- Facilitating the consent process and stakeholder dialogue (e.g. mitigation of negative impacts in Environmental Impact Assessments). This may reduce project risks (e.g. not obtaining a licence and not requiring ex-design processes) and allow for more support/acceptance from the local/regional community;
- Better alignment of a project with international guidelines for sustainable development, which increasingly matters for project financing (green/ blue finance); Environmental and social governance; Principles for responsible investment; such as the World Bank and other international investors; and
- Improving green/blue and societal reputation of a given project and its stakeholders.

Understand and optimising the natural processes of the system in which a port or dredging work is planned may reduce costs and increase benefits in the long run.
that projects are designed to optimally and cost-effectively deliver their primary objective – enabling navigational passage or installation of soft or hard infrastructure in support of a port or coastal protection. However, such works and infrastructure can also affect, positively or negatively, other site-specific, regional or regulatory objectives. An ESA as described in Table 2 supports the decision-making process when going from one project cycle stage to the next. The maximum benefit from using ES concepts can be expected when applied from the beginning of a project. However, even if the ES approach is only applied in later phases of the project, it can still provide significant context and insights. As will be described below, the purpose of the ES framing and the chosen approach may change, depending upon the project stage and phase, and the decisions being made.

Project cycle phases require different levels of resolution and detail and more importantly, address different questions. Within a project cycle, four types of ES assessment (ESA) types can be defined. As can be seen in Figure 3, each of these ESA types informs decisions and bridges different project cycle phases.

### ESA steps

1. **Formulate starting points and end goals**
   - Determine the project phase and identify which decisions need to be taken to go to the next phase(s) in the project cycle. Identify the questions the ESA is to inform (establish assessment objectives).
   - Determine the major stakeholders who (may) interact with the project (possibly indirectly, e.g. in case of other geographic regions or other generations).
   - Involve relevant stakeholders in describing the baseline and setting goals.
   - Identify, describe and communicate and goals of the ESA to be applied.

2. **Collect data**
   - Compile relevant project information, technical and operational information, both historical and current data and future goals.
   - Identify the major ecosystem components of the project’s environment and the related processes (habitat/species, abiotic environment, etc.).
   - Identify the societal environment in which the project is to be realised and identify relevant actors (iteratively with Step 1 determine stakeholders).
   - Determine the regulatory setting.
   - Collect relevant information from stakeholders (partners involved, local experts, end-users, local government, etc.).
   - Determine data availability and quality.

3. **Connect the project to the Natural and Social Environment**
   - Identify and link causes and effects of project on the environment and societal/economic system.
   - Check habitats or species a project may affect (or create in case of habitats).
   - Look at disrupted flows (e.g. currents) of functions (e.g. light, water temperature) – need to know how this affects ES and function dependences and interactions.
   - Identify and describe project aspects that might drive ES impact.
   - Set priority ESA commonly based on regulations and stakeholders’ interests.
   - Iterate data collection if necessary.

4. **Determine impacts and opportunities**
   - Perform impact analysis using preferred methods (qualitative, quantitative, valuation).
   - Identify and enhance opportunities and win-win situations.
   - Determine undesirable interactions can be prevented or mitigated and identify trade-offs (involve stakeholders). Address uncertainty.
   - Discuss the methodologies applied and the results with stakeholders and iterate data collection and analysis if necessary.
   - Are the ESA goals achieved as they were identified and agreed in Step 1? Does the outcome of the ESA sufficiently inform the project decisions? What is the outcome of the ESA and how would it impact the project decisions? What are the lessons learned and will the force future projects in terms of ESA?

5. **Evaluate ESA**
   - Determine and link environmental, societal and other gains that will be gained by implementing the project.
   - Determine and link environmental, societal and other gains that will be gained by implementing the project.
   - Determine ES monitoring.
   - Perform ES monitoring.
   - Review ES monitoring.

### Actions

- **ESA steps**
- **Collect data**
- **Connect the project to the Natural and Social Environment**
- **Determine impacts and opportunities**
- **Evaluate ESA**

### Table 2

**The five generic steps of the ESA framework and the actions that support them.**

<table>
<thead>
<tr>
<th>ESA steps</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Formulate starting points and end goals</td>
<td>- Determine the project phase and identify which decisions need to be taken to go to the next phase(s) in the project cycle. Identify the questions the ESA is to inform (establish assessment objectives). - Determine the major stakeholders who (may) interact with the project (possibly indirectly, e.g. in case of other geographic regions or other generations). - Involve relevant stakeholders in describing the baseline and setting goals. - Identify, describe and communicate and goals of the ESA to be applied.</td>
</tr>
<tr>
<td>2. Collect data</td>
<td>- Compile relevant project information, technical and operational information, both historical and current data and future goals. - Identify the major ecosystem components of the project’s environment and the related processes (habitat/species, abiotic environment, etc.). - Identify the societal environment in which the project is to be realised and identify relevant actors (iteratively with Step 1 determine stakeholders). - Determine the regulatory setting. - Collect relevant information from stakeholders (partners involved, local experts, end-users, local government, etc.). - Determine data availability and quality.</td>
</tr>
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<td>3. Connect the project to the Natural and Social Environment</td>
<td>- Identify and link causes and effects of project on the environment and societal/economic system. - Check habitats or species a project may affect (or create in case of habitats). - Look at disrupted flows (e.g. currents) of functions (e.g. light, water temperature) – need to know how this affects ES and function dependences and interactions. - Identify and describe project aspects that might drive ES impact. - Set priority ESA commonly based on regulations and stakeholders’ interests. - Iterate data collection if necessary.</td>
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<td>- Perform impact analysis using preferred methods (qualitative, quantitative, valuation). - Identify and enhance opportunities and win-win situations. - Determine undesirable interactions can be prevented or mitigated and identify trade-offs (involve stakeholders). Address uncertainty. - Discuss the methodologies applied and the results with stakeholders and iterate data collection and analysis if necessary. - Are the ESA goals achieved as they were identified and agreed in Step 1? Does the outcome of the ESA sufficiently inform the project decisions? What is the outcome of the ESA and how would it impact the project decisions? What are the lessons learned and will the force future projects in terms of ESA?</td>
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</tr>
</tbody>
</table>

### Figure 3

**Key features of each ESA type are described below.**

#### Baseline/scoping ESA

Carried out during planning and design phase, aims to answer questions such as ‘What are my priority ESS?’ and ‘What is my current status?’ This bridges the initial concept phase to the conceptual design phase. Any idea for developing a project goes through a very early stage (conception of a plan) in which a quick-scan or reconnaissance-level decisions need to be made on further development of the plan. The scope of work is made up of the biophysical environment of the project area and how the plan would interact with this area, illustrating the cause and effect relationships and how these affect ES. This provides an opportunity to think about goals other than the pricinity technical project goals that can be achieved. Essential stakeholders should be identified and potential risks and benefits identified. The goal of a project is formulated at this point and discussed with the key stakeholders.

#### Prospective ESA

Carried out during the design phase, investigates how ES might be impacted by potential design scenarios. This bridges the conceptual to the technical design phase, introducing ES during the conceptual design gives the project more freedom to consider ES risks, opportunities and trade-offs when choosing and optimising a design alternative. If ES concepts are introduced in the technical design, the focus will be on what gains can be expected from adapting the design within the already rather fixed technical design specifications. In a Prospective ESA, the extended set of goals (technical goals, ES goals, societal goals) are more quantitatively assessed. This is an assessment based on knowledge of the biological state of the project environment, cause and effect relationships between the technical design and the biophysical environment, affecting near-field and far-field natural (biotic and abiotic) processes and functions. This results in an overview of trade-offs of ES impacts, their likelihood and extent. A prospective ESA may also consider project vulnerabilities to changing ES provision, due to climate and other changes. This phase should include plans on how to monitor the impacts of the project on the natural (and socio-economic) environment in the context of ES. It should be noted that such a Prospective ESA can be developed even at a relatively low information level, e.g. based on stakeholder interviews or workshops.

#### Retrospective ESA

Carried out during and after construction and operation, aims to evaluate whether ES were impacted during the evaluation phase of the project, based upon monitoring data. The reason for doing a retrospective ESA is to learn and adapt.

#### Adaptive ESA

Assesses how ES might be affected by adaptive scenarios. Adaptive ESA also uses prospective (rather than retrospective) approaches. However, as it is carried out far into the project cycle, benefits from all previous scoping, assessment and data is focused in scope locally. At least one round of ESA has taken place and technical and communication lessons have been learned. If the overall project stops here, only to be picked up again when the project is decommissioned (if ever).
Freedom and potential benefits of an ESA are smaller than in a full Prospective ESA; however, the use of ES in considering adaptations to the project can still be beneficial.

The generic approach of the ESA framework (as described in Figure 2) remains constant throughout the project cycle, no matter which ESA type is undertaken. As one moves through the project cycle, more detailed information (if available) is required. Information developed in one stage can be built upon in the next. While the first three steps in the framework are more in the focus during the design phase of the project, the last two steps gain importance in the implementation and evaluation phases of a project. The exact ESA approach will also depend not only upon the phase and stage of a project, but also upon the phase and stage of the ES concept and preparation phase.

SOCIO-ECONOMIC

### TABLE 3
Eight case studies considering ES in one or more phases of the project cycle.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Region</th>
<th>Type of project</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maasvlakte II</td>
<td>Europe – Netherlands</td>
<td>Port extension</td>
<td>Coastal</td>
</tr>
<tr>
<td>Western Scheldt</td>
<td>Europe – Belgium</td>
<td>Maintenance dredging</td>
<td>Estuary</td>
</tr>
<tr>
<td>Horsehoe Bend</td>
<td>North America – USA</td>
<td>Maintenance dredging</td>
<td>River</td>
</tr>
<tr>
<td>Sigmaplan</td>
<td>Europe – Belgium</td>
<td>Flood management, inland waterways, dam/ dyke</td>
<td>Estuary</td>
</tr>
<tr>
<td>Nicaragua Canal</td>
<td>Central America – Nicaragua</td>
<td>Construction of navigation channel, inland waterways</td>
<td>River, Lake</td>
</tr>
<tr>
<td>Ems estuary</td>
<td>Europe – Germany</td>
<td>Environmental restoration of a port, inland waterways</td>
<td>Estuary</td>
</tr>
<tr>
<td>Coffes Harbour</td>
<td>Asia Pacific – Australia</td>
<td>Harbour breakwater upgrade, recreation infrastructure</td>
<td>Coastal</td>
</tr>
<tr>
<td>Blue Carbon</td>
<td>North America – USA</td>
<td>Managing port blue carbon coastal ecosystems</td>
<td>Coastal</td>
</tr>
</tbody>
</table>

### TABLE 4
List of case studies showing the ES concept applied in several of the project stages.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Initial concept and preparation</th>
<th>Conceptual design</th>
<th>Approval appraisal</th>
<th>Technical design</th>
<th>Construction</th>
<th>Operation including maintenance</th>
<th>Adaptation/ expansion</th>
<th>Decommissioning</th>
</tr>
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<td>4. Sigmaplan</td>
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<td>7. Coffes Harbour</td>
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### Case 1: Maasvlakte II
- **Prospective ESA** of design solution trade-offs.
- Legislation-driven inclusion of natural and social values identified opportunities to mitigate or compensate for impacts.
- Early consideration would save time and money, facilitating approval.
- Baseline ESA informed conceptual design phase.
- Monitory societal cost-benefit analysis sought highest net benefits, considering flood safety, navigation, agricultural regulation, and cultural services.
- Alternative choice differed from choice based upon flood control alone, demonstrating benefits of early ES consideration.
- Early explicit consideration of ES facilitated communication and future planning.

### Case 2: Western Scheldt
- Full-cycle (baseline, prospective, monitoring, evaluation, adaptation) selective, non-explicit ESA to design beneficial, synergistic dredged material disposal and management.
- WSF to enhance habitats and optimise hydrologic function, balancing multiple goals.
- Broader ES consideration, e.g., water quality regulation, could enhance benefits.
- Baseline ESA informed conceptual design phase.
- Monitory societal cost-benefit analysis sought highest net benefits, considering flood safety, navigation, agricultural regulation, and cultural services.
- Alternative choice differed from choice based upon flood control alone, demonstrating benefits of early ES consideration.
- A broader range of ES could increase impact.

### Case 3: Atchafalaya
- Retrospective ESA identified multiple, serendipitous ES benefits from a mid-channel disposal strategy.
- Channel stabilisation reduced dredging requirement, while providing beneficial habitat for critical species.
- Earlier consideration of ES may identify more such opportunities for future projects.

### Case 4: Sigmaplan
- Prospective ESA identified multiple, serendipitous ES benefits from a mid-channel disposal strategy.
- Channel stabilisation reduced dredging requirement, while providing beneficial habitat for critical species.
- Earlier consideration of ES may identify more such opportunities for future projects.

### Case 5: Nicaragua Canal
- Baseline ESA informed conceptual design phase.
- Monitory societal cost-benefit analysis sought highest net benefits, considering flood safety, navigation, agricultural regulation, and cultural services.
- Alternative choice differed from choice based upon flood control alone, demonstrating benefits of early ES consideration.
- Earlier and explicit consideration of ES in design phase may reduce impacts and the need for mitigation.

### Case 6: Ems estuary
- GIS-based retrospective baseline and prospective ESA (1930, present, and 2050) evaluated provisioning and regulating ES, and a restoration master plan.
- Early explicit consideration of ES facilitates communication and future planning.
- A broader range of ES could increase impact.

### Case 7: Coffes Harbour
- Prospective, non-explicit ESA informed multi-criteria assessment to balance use values (safety, recreation and economics) of shoreline protection plans.
- Values were gathered through early, multi-disciplinary stakeholder engagement.
- More explicit consideration of potential ES may have broadened criteria.

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TERRA ET AQUA
The maximum benefit concept can be expected when applied in each project phase, starting from the very beginning of a project.

In the project cycle, the role that information plays in a decision-making or communications effort but also upon the socio-environmental context means, the concept of ES may also provide added value to a project. Examples of applying the ES concept across a project cycle Overall, we found no dredging/marine construction case study that applied the ES concept across the entire project cycle. Nevertheless, each of the selected case studies demonstrates some aspects of adapted practice (Table 3). Some projects have been completed; others are in the process of design or are still at a conceptual stage. The cases address a part of a total project, illustrating the application of the ES concept that part or phase. The geographic spread includes areas with countries in transition to include that at this level of information and means, the concept of ES may also provide added value to a project. Possible effects. After evaluating the impact of the project on each ES, a multi-criteria analysis can be applied to make an integrated evaluation for the multiple ES. For a smaller set of ES, impacts can be quantified in biophysical units, such as cubic meters of water purified or tons of carbon stored. When a total habitat area along a river gets lost due to a new infrastructure project, the capacity of the tidal area to, for example, purify water (m³) or to store carbon (tonnes C/yr) will be lost. Ideally, primary data (field measurements) are collected or modelled to calculate effects (e.g., using software such as INVEST, ARIES, MMES, ECODPLAN, SEAPURSES). Secondary data can be used for a quick calculation or when primary data cannot be generated; however, the outcomes are less accurate, as they are not site-specific. Literature data from similar cases can be used, e.g., a range of tons of carbon stored in temperate marshes. Mapping ES with quantitative data gives a good spatial overview of the effects of a project. After evaluating the impact of a project on each ES, different tools are available to make an integrated evaluation (multi-criteria analysis, cost-effectiveness analysis). For a smaller subset of ES, monetary and non-monetary valuation is possible. Non-monetary valuation methods allow for the estimation of the value of societal benefits (marginal benefits) and costs (marginal costs). Monetary valuation methods allow for the estimation of the economic monetary value of ES. Benefit transfer uses data from other (similar) studies. This results in large uncertainty because the data are not specific for the project and location, however it can be useful as first indication for a quick assessment or if primary data are lacking and cannot be generated. Several meta studies provide global monetary ES values for several biomes. After evaluating the impact of a project on each ES, the monetary values can be calculated in a cost-benefit analysis. This allows for the addition of ecological and societal benefits (or negative effects) into a classical cost-benefit analysis that usually only looks at direct costs and benefits of the project. It is essential to define system boundaries for a given project e.g. to define the spatial and temporal boundaries of analysis, the processes to be considered and the appropriate level of data and analytical detail. Furthermore, the level of quantification possibly be limited by project conditions and resources, but need only be as detailed as required to inform the decision at hand. Often detailed, quantitative assessments are not necessary to provide useful information for complex different stages in dredging and marine construction projects. Analyses should be no more complex than needed to identify and distinguish between alternatives. Given that no model, in this case for deriving and generating ES is more precise than its least precise component, a focus on only parameters that are quantifiable in detail may result in blind spots. Benefits of analysis can be more important than precision in ensuring all environmental, social and economic risks and opportunities of a project are identified and considered. In some projects, a tiered approach, with increasing levels of quantification or detail to reduce critical uncertainty or as a project moves through the cycle may be appropriate.

Conclusions ES concepts allow project planners and proponents to put data they have already collected in a different context, identifying risks and opportunities; and supporting engagement. ES thinking supports consideration of project impacts on broader spatial and temporal boundaries of...
objectives, which may help in stakeholder engagement, as well as informing project acceptance and support. In fact, using ES framing to place stakeholders into the centre of the discussion can be one of the keys to success.

Since ES can be used to help place projects within their broader regional social and economic context, and frame impacts in terms of stakeholders’ priorities, considering ES concepts has the most impact if incorporated as early in the process as possible. When addressing this manner, an ES-framed impact assessment broadens from a consideration of risks alone to one that also looks at the benefits and opportunities of a project, as well as potentially identifying project vulnerabilities to future changes in ES provision due to climate and other drivers.

To solidify the application of the ES concept in decision-making, there is a need for more demonstration projects in the broader dredging and marine construction sector. This will support growing appreciation by the project owners, developers, operators or managers, public authorities and financiers, and result in an increased application. This, in turn, should trigger more legal and regulatory demand and standard setting for the use of ESA (e.g., biodiversity strategy). Ultimately, ESA should become a standard component in planning and realisation of dredging and marine construction projects within the broader environment, as such becoming an intrinsic part of development and good governance.

Summary
Throughout the project cycle, a series of decisions and actions need to be carried out in order to ensure that projects are designed to optimally and cost-effectively deliver their primary objective. Incorporating the ES concept and performing Ecosystem Services Assessment (ESA) supports the project decision-making process in each project cycle stage.

A full consideration of ES impacts, interactions and improvements in marine construction projects can result in more sustainable and adaptive solutions for dredging and marine construction projects, providing returns on investment. ES framing can therefore identify critical capital and values to be sustained, opportunities for nature-based solutions and win-win scenarios, while facilitating the consent process and stakeholder dialogue.

The maximum benefit from using ES concepts can be expected when applied from the beginning of a project. However, even if applied only in later phases of the project, it can still provide significant context and insights. The purpose of this article is to provide a framework for integrating and interdisciplinary thinking throughout the different steps of the project cycle.

Acknowledgments
This article is a summary (with slight adaptations) from the PIANC W195 report ’Weaving ecosystem services into impact assessment: A step-by-step method’. Washington, USA.

REFERENCES


PIANC (2016) Opportunities to apply the concept of ecosystems services (ES) to the waterborne transport infrastructure (WBT) sector. PIANC Publication.

TERRA ET AQUA

For (future) decision makers and their advisors in governments, port and harbour authorities, off-shore companies and other organisations that execute dredging projects, IADC organises its International Seminar on Dredging and Reclamation for the 60th time. Since 1993, this week-long seminar has been continually updated to reflect the dynamic nature of the industry and is successfully presented in cities all over the world. The five-day course covers a wide range of subjects, from explanations about dredging equipment and methods, rainbowing sand and placing stone to cost estimates and contracts. There is no other dredging seminar that includes workshop exercises covering a complete tender process from start to finish.

Programme
The in-depth lectures are given by dredging experts from IADC member companies, whose practical knowledge and experience add an extra value to the classroom lessons. Subjects covered include topics such as the development of new ports and maintenance of existing ports, and environmental aspects of dredging. Activities outside the classroom are equally as important. An on-site visit to the dredging yard of an IADC member gives participants the opportunity to see dredging equipment in action and to gain a better feeling of the extent of a dredging activity. A mid-week dinner where participants, lecturers and other dredging employees can interact, network and discuss the real, hands-on world of dredging provides another dimension to this stimulating week.

Certificate and registration

COVID-19
Due to the COVID-19 pandemic, events can be postponed or cancelled. We advise checking the IATA website regularly to see the COVID-19 travelling regulations for every country (https://www.iatatravelcentre.com).

Save the date!
Dredging for Sustainable Infrastructure course
2, 3, 16 and 17 December 2021
Half-day online sessions
www.iadc-dredging.com

For professionals involved in dredging related activities for water infrastructure development, CEDA and IADC present the Dredging for Sustainable Infrastructure course over four half-day online sessions. This course, just like the book it is based on, fills a gap: it gives guidance to professionals on how to bring into practice the new thinking that in many ways has transformed dredging in the last decade. Therefore, the course is essential for professionals driven by the ambition to achieve sustainable and resilient water infrastructure with a dredging component that contribute to the UN’s Sustainable Development Goals.

Participants will learn how to achieve dredging projects that fulfil primary functional requirements while adding value to the natural and socio-economic systems by acquiring an understanding of these systems in the context of dredging as well as stakeholder engagement throughout a project’s development. Experienced lecturers will inform about the latest thinking and approaches, explain methodologies and techniques as well as demonstrate, through numerous practical examples, how to implement this information in practice with challenging workshops and case studies.

Back to the Classroom

Dredging and Reclamation Seminar
8–12 November 2021
Delft, The Netherlands
IHE Delft Institute for Water Education
www.iadc-dredging.com

For professionals involved in dredging related activities for water infrastructure development, CEDA and IADC present the Dredging for Sustainable Infrastructure course over four half-day online sessions. This course, just like the book it is based on, fills a gap: it gives guidance to professionals on how to bring into practice the new thinking that in many ways has transformed dredging in the last decade. Therefore, the course is essential for professionals driven by the ambition to achieve sustainable and resilient water infrastructure with a dredging component that contribute to the UN’s Sustainable Development Goals.

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2nd Seminar
4–8 April 2022
Singapore
Venue to be confirmed