DFSI magazine

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DREDGING FOR SUSTAINABLE INFRASTRUCTURE

Sustainability in project initiation, **planning and design**

Designing sustainable solutions with added value.

Local stakeholders play a vital role in the success and sustainability of mangrove restoration and conservation projects. AquaForest in Ecuador is a prime example, where, with the help of local volunteers, Jan De Nul is creating 50 hectares of mangrove habitat.

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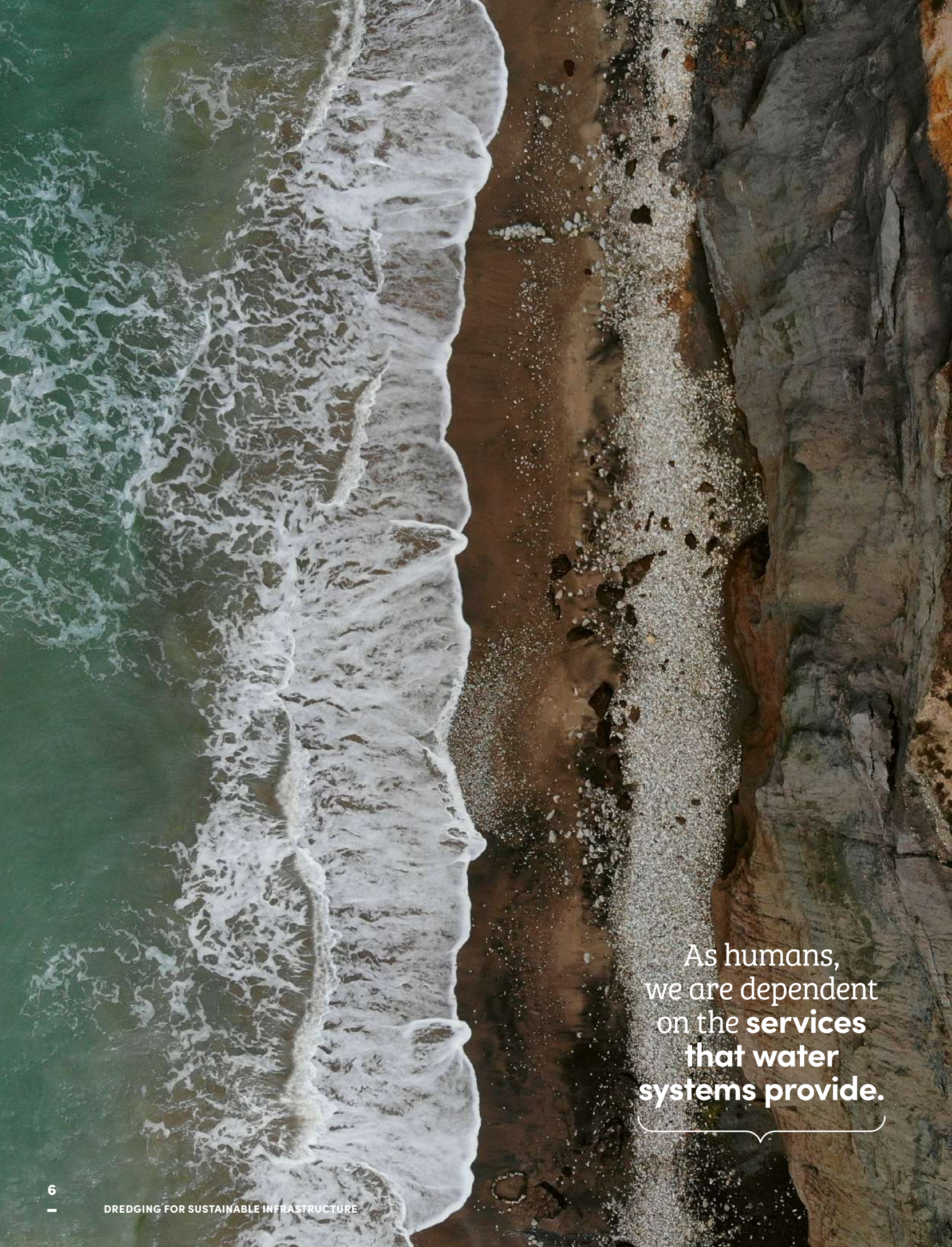
The immersed tunnel connecting Scandinavia and Central Europe is a state-of-the-art example of the integration of technical challenges with construction methods optimised to minimise environmental impact.


As humans, we are dependent on the **services that water systems provide.**

EDITORIAL

Dredging for sustainability

Welcome to the second edition of *DFSI Magazine*. The focus of the first issue addressed the principles of sustainability and their implications for dredging projects. In this second edition, we will discuss "how" to integrate sustainable aspects in more detail.

Dredging projects are needed for the maintenance of water systems, which are often heavily modified to optimise the ecosystem services they provide to society. Water systems are therefore important assets, however, making use of them inevitably also raises pressures on the ecosystem. As humans, we are dependent on the services that water systems provide and it is essential that (asset) management ensures that the use of ecosystem services is sustainable.

There lies the challenge for water managers. And since I started my career at Rijkswaterstaat (Ministry of Infrastructure and the Environment), it is a challenge that has kept me busy. Something I did not expect when, as a student of physical geography in 1986, our professor told us that we would never find a job. In those days, unemployment was high and nobody would be interested in our knowledge he said. I'm happy to say he was wrong.

Over time, policies and regulations were put in place to protect aspects of the environment and it became a legal requirement to integrate certain environmental aspects into decision making. It also raised a need for the expertise that I and my fellow students had gained, along with other fields of expertise. For combining expertise from different specialties results in better, more integral projects.

Besides the positive effect of regulations, they can also impede the process. Regulations aimed at certain interests, for example, quality of water, soil, air and nature, will often prescribe boundary constraints for engineering and activities such as dredging. This can make undertaking projects impossible. Such a scenario does not help make our water systems resilient – executing well-designed dredging projects does. Policy makers and engineers need to work closely together to prevent regulations from making solutions impossible.

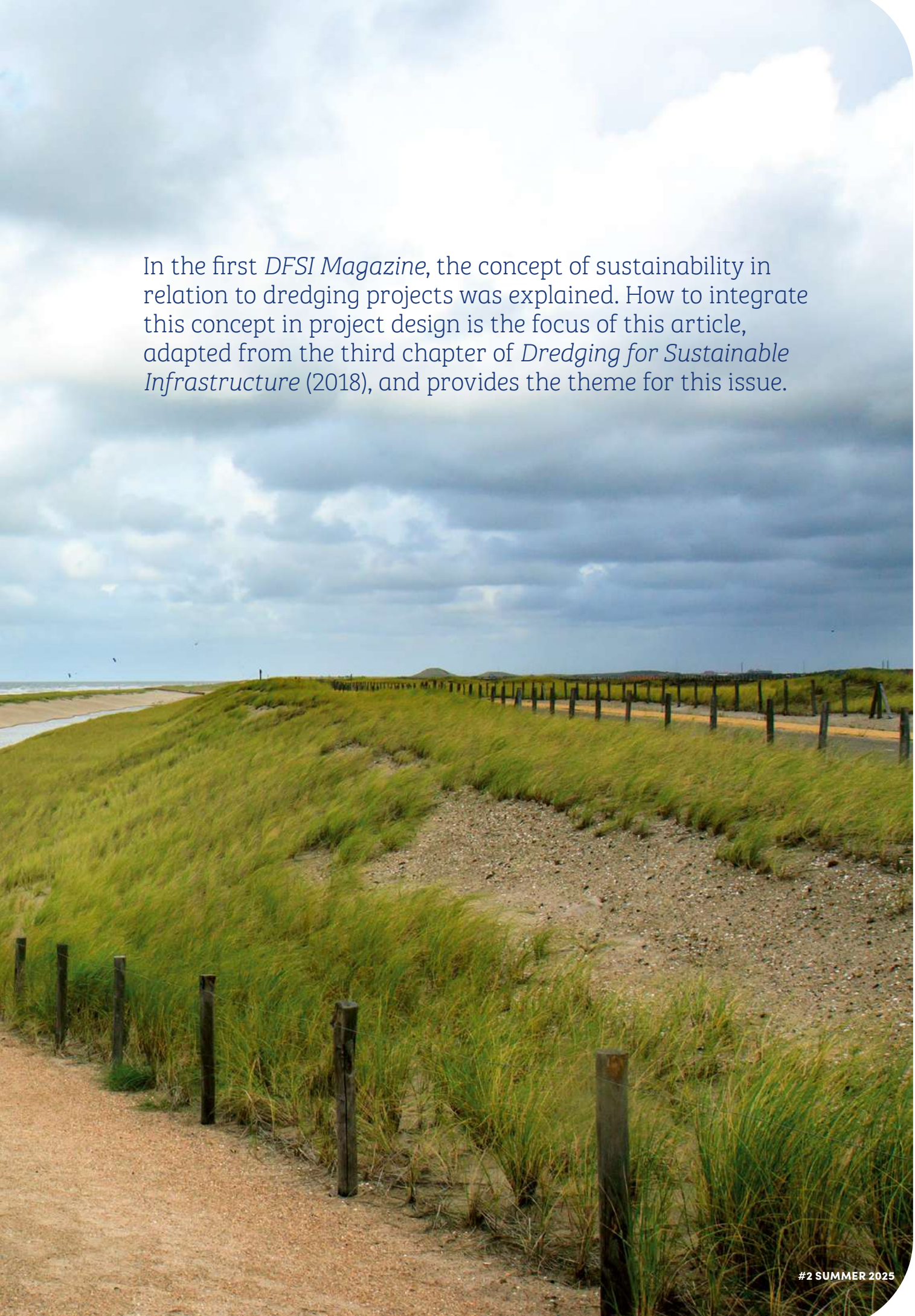
Today, the quest for sustainability is a topic for heavy political debate, but for me it is a driver for improving the quality of design and execution of dredging projects. Integrating different fields of knowledge is key and can only be done in good collaboration. Dogmatic advocation of sectoral interests should be avoided because an integral solution is not the same as the sum of sectoral interests. Choices must be made in weighing interests. Only then can the planning process result in tailor-made solutions that will best fit the needs of our water management ambitions.

Within this issue you will find articles on a host of projects from around the globe that I trust will inspire and demonstrate how we can plan and design together – in and with nature – to create sustainable infrastructure.

Guest editor
Pieter de Boer
Senior Advisor, Rijkswaterstaat

Sustainability in project initiation, planning and design: **how to design more sustainable infrastructure**

In the first *DFSI Magazine*, the concept of sustainability in relation to dredging projects was explained. How to integrate this concept in project design is the focus of this article, adapted from the third chapter of *Dredging for Sustainable Infrastructure* (2018), and provides the theme for this issue.



Sustainability and added value

It is necessary to realise that development of sustainable designs, and in particular the aspect of adding value, starts with the clear definition of project objectives. Both the primary functional objectives of the infrastructure, and the additional objectives related to the broader range of services for sustainability in the project area, should be taken into account.

Holistic view on water infrastructure

Traditionally water infrastructure projects focused on a single functional requirement only, such as protection from flooding for a dyke or accessibility for ports and waterways. Today, we realise that a dyke is also a landscape element that can provide added value for the environment (e.g. habitat, diversity, productivity) as well as society (e.g. recreation, cultural). Similarly, ports and waterways are landscape elements, located at the highly dynamic interface of land and sea, that can provide opportunities for birds foraging/resting at tidal ats and embankments, or for migratory fish that travel between rivers and the ocean.

Approaching the project design process from a more holistic point of view generally influences the choice of the system boundaries and stakeholders to involve.

The Sand Engine, a 2-kilometre-long sandy peninsula built in 2011 to ensure the long-term safety of the Delfland coast while creating space for nature and recreation, has turned into a popular kitesurfing spot in the Netherlands due to its shallow, flat water and consistent wind.

This in turn can result in different types of solutions, which deliberately incorporate ecosystem benefits. For the dykes discussed here, this could lead to the implementation of more mildly sloped vegetated foreshores for wave height reduction rather than the harder and steeper dyke reinforcements that are more traditionally used. For ports and waterways this can lead to accommodating more dynamics of tidal flats and channels in estuaries or the creation of habitats that provide shelter for migratory fish. The designs thus obtained align better with the natural system and are likely more acceptable to stakeholders that find these aspects important.

The broader range of services for sustainability in the project area and the additional objectives that can originate form that should be introduced as early in the design process as possible. Only then will there be maximum degrees of freedom in design choices . Doing so guarantees their full consideration throughout the design process and enables the development of truly sustainable solutions with added value for the environment, the economy and society. Later in the design process the various design alternatives will have to be evaluated for selection. It could be that at the end of the design process an alternative with a more narrow objective emerges as the preferred option. But at least all design alternatives will have been evaluated at a similar level of detail, enabling a fair comparison. When additional objectives are introduced too late in the design process, only marginal changes to the already considered design options can usually be achieved.

For this, early engagement of key stakeholders is crucial. They can provide important input on what is considered to be relevant in the given project area. Furthermore, they can help to specify the functional requirements as well as the preferred additional services the project would be expected to provide. The earlier such integral perspectives are included in the development process, the more influence they may have on the final outcome.

To actually put this approach into practice, a fundamentally different way of thinking, acting and interacting is needed:

Thinking – Thinking does not start from a certain design concept focusing on the primary function, but rather from the natural system, its dynamics, functions and services, and from the vested interests of stakeholders. Within this context, one seeks optimal solutions for the desired infrastructural functionality.

Acting – The project development process requires different action, because it is more collaborative and extends beyond the mono-disciplinary delivery of engineering objects. The natural and socio-economic components embedded in the project will take time to develop afterwards, and one has to make sure they function as expected. Post-delivery monitoring and projections into the future are an integral part of the project. This also creates opportunities to learn a lot more from these projects than from traditional ones.

Interacting – Sustainable project development is a matter of co-creation between experts from different disciplines, problem owners and stakeholders. This requires a different attitude from all parties involved and different ways of interaction, in interdisciplinary collaborative settings rather than each actor taking away their task and executing it in relative isolation.

The process of infrastructure development

In order to influence the design process effectively it is important to understand a few things about the process of infrastructure development, which, albeit iteratively, generally goes through a number of consecutive phases.

Initiation – The Initiation phase deals with a first definition of the problem or opportunity at hand and the scoping of potential solutions. Most influence can be exerted in this phase.

Planning and design – Where the Initiation phase focused on the problem definition and project scope, the more detailed planning and design phase deals with developing alternative strategies within this given scope and handles the selection of the preferred alternative(s). Compared with the Initiation phase the degrees of freedom are reduced..

Construction – In previous phases the problem definition, project scope, project strategy and design have been addressed. The construction phase encompasses the project execution approach. As the most important design choices are now fixed only incremental improvements to the design itself can now be achieved. The incremental improvements, however, may still provide win-win opportunities for other local interests (e.g. recreation, nature development).

Operation and maintenance – The design process obviously should be extended as far as the operation and maintenance phase. Considering maintenance aspects early on in the design process may optimise the design and reduce life-cycle cost significantly. Furthermore sustainable design considerations may lead to forms of adaptive management and development that generate additional environmental and cost benefits.

Although there is room for improvement of a design in any phase, the earlier the approach is embraced in the project development process, the more significant

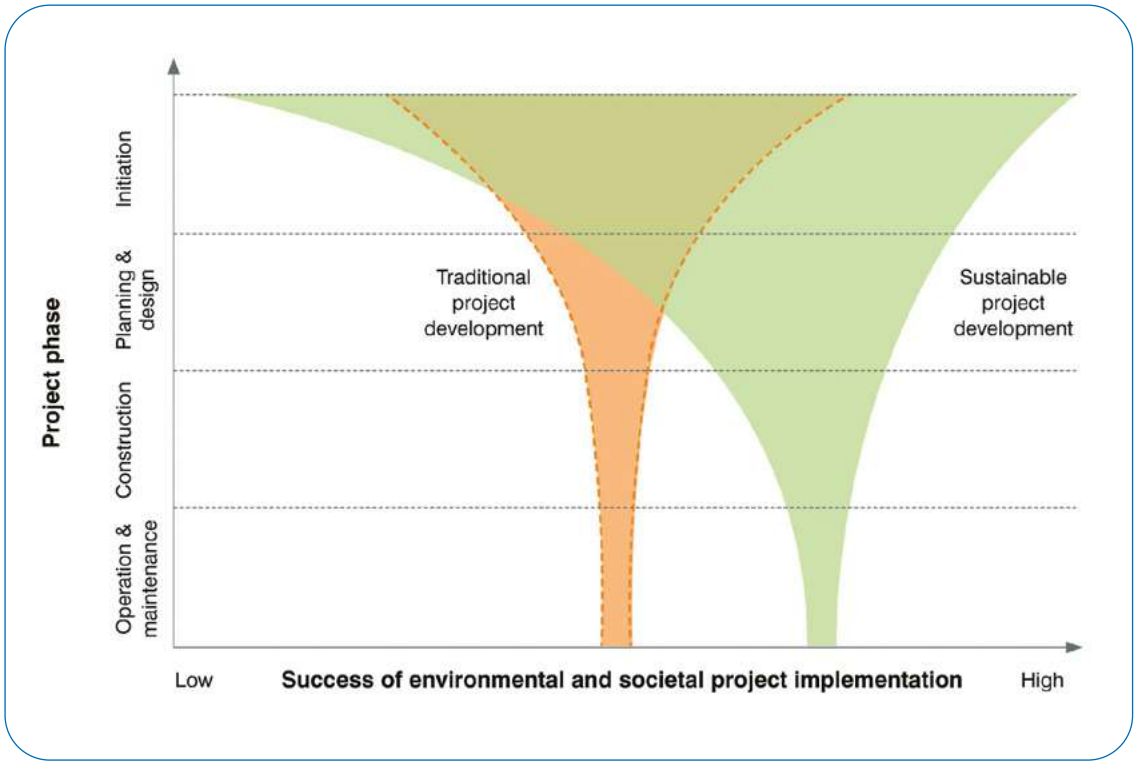


FIGURE 1
Reduction of degrees of freedom during consecutive stages of project development. Adopting a broader approach that allows for prolonged stakeholder inputs, a sustainable project development is likely to result in a more successful environmental and societal project implementation.

its potential impact. Ideally several alternatives are detailed simultaneously from the start, allowing selection of the most suitable option later in the process. Rapid selection of a preferred solution early on in the design process may initially be perceived as an efficient work process – however, as time proceeds the design enters a restriction and narrowing of options, like a journey down a funnel, and it becomes increasingly difficult to change direction when necessary. These reduced degrees of freedom of various design funnels are illustrated in Figure 1. Once inside such a funnel, it becomes very difficult to fundamentally revise a design.

A late redesign may lack societal support or may fail to qualify for the required environmental permits. Application of sustainable design principles helps to avoid the occurrence of such awkward situations, and the associated unexpected cost increases in the later stages of the project development process. Considering the major impact of decisions taken in the early stages of project development, it is crucial that all key stakeholders, with different perspectives, are involved from the very first start of a project development.

Different perspectives on infrastructure design

For the design process, it is important to think from different perspectives. In general:

The (natural) environmental perspective – In any project, a good starting point to look for added value is the natural environment or ecosystem in which the project is to be embedded. Each environment is unique, with its own characteristics, values and associated opportunities.

The project perspective – Each phase of a project generally comes with a specific scope/goal. As such it represents the starting point for considering opportunities to add value.

The governance perspective's – The governance context, i.e. the complex set of legislation, regulations, institutional arrangements and decision-making processes, etc., is a third perspective from which opportunities to add value have to be developed.

Different actors have different preferential perspectives when starting design iteration. An ecologist, for example,may take the natural environment as a starting point and consider what kind of human use the environment can support – if any. A project proponent might reason from a functional project goal where a certain trigger or ambition is formulated, and the challenge is to fit this into the environment in the most sustainable manner. A civil servant might reason from the governance perspective and analyse what kind of design is feasible from a regulatory

and decision-making perspective. The challenge is then to come up with a design that fits with the governing regulations and would be acceptable given the political landscape.

Involving these different perspectives (the (natural) environmental perspective; the project perspective and the governance perspective) throughout the project development process, enriches the final design and broadens the base of support with stakeholders.

Design process for sustainable infrastructure

Strategic scoping

A starting point in any design process is to think about the strategic scoping of the challenge at hand. It might be tempting and even seem logical to take the expected final solution (i.e. the project that will be built) as a starting point for the definition of the objectives. Though perceived as a short-cut to rapid success at first glance, such a focused, solution-driven approach is often found to generate resistance in society, which may even jeopardise the

BOX 1

Project success through realisation of integral objectives

The Sigma Plan, established in 1977 in response to a major storm surge flood in 1976, was developed by the Flemish government as an integrated river basin management plan to protect the areas surrounding the Scheldt river and its tributaries from flood risk. The plan combined grey infrastructure measures such as stengthened dyke protection with green measures to make more "room for the river" and to support conservation and biodiverstiry objectives. The flood risk of more than 20,000 ha of land are adrdressed under the Sigma Plan and around 3,000 ha of natural habitiats will be restored by 2030.

While the Sigma Plan's main purpose is flood control, it is based on an integrative perspective on river management, which acknowledges a variety of river functions including flood protection, nature development, shipping and recreation.This integral development of functions and values has been the leading principle throughout the entire project development. The concept of ecosystem services was used to enable integral evaluation of project benefits and impacts. An open communication strategy involving intensive stakeholder engagement was adopted to maximise public acceptance and support. Besides safety against flooding and improved navigability, the project has resulted in important, non-hydraulic outcomes, such as nature areas, cultural values and economic activities.

Depoldering in the Kalkense Meersen along the river Scheldt, carried out by the Sigma Plan.
Photo © Vilda YvesAdams Sigma Plan Kalkense Meersen.

The development of sustainable infrastructure solutions with added value for nature and society **involves interplay of physical, ecological and governance processes.**

continuity of the complete project. A narrow definition of the project objectives consequently limits the range of solutions that is taken into account. Instead, the integral problem at hand in its broadest sense should be taken as a starting point for the definition of solutions and project objectives. In other words, be careful not to focus on solutions too early.

Conceptual design

Pilot experiments and projects have played an important role in the development of knowledge and experience for the conceptual (and detailed) design of sustainable infrastructure solutions. A five step approach for sustainable design (see box 2) can be used in the conceptual as well as the detailed design of infrastructure projects.

To illustrate the use of this approach in practice, box 3 presents a hands-on interpretation of these steps for a straightforward dredging project.

Detailed design

The process described in box 2 and 3 has been called a process of "objectification", underlining the need to specify clear objectives on the one hand, and

BOX 2

Five step approach towards design of sustainable infrastructure

Step 1 Understand the system (including ecosystem services, values and interests).
- The system to be considered depends on the project objectives. The project objectives are inuenced by the system (problems, opportunities);
- Information about the system at hand can/should be derived from various sources (e.g. historic, academic, local etc.); and
- Look for user functions and ecosystem services beyond those relevant for the primary objective.

Step 2 Identify realistic alternatives that use and/or provide ecosystem services.
- Take an alternative perspective and change more traditional reactive perspectives into proactive ones utilising and/or providing ecosystem services; and
- Involve academic experts, field practitioners, community members, business owners, decision makers and other stakeholders in the formulation of alternatives.

Step 3 Evaluate the qualities of each alternative and preselect an integral solution.
- More value does not necessarily imply higher construction cost;
- Dare to embrace innovative ideas, test them and show how they work out in practical examples;
- Perform a cost-benefit analysis including valuation of natural benefits; and
- Involve stakeholders in the valuation and selection process.

Step 4 Fine-tune the selected solution (practical restrictions the governance context).
- Consider the conditions/restrictions provided by the project (negotiable/non-negotiable); and
- Implementation of solutions requires involvement of a network of actors and stakeholders.

Step 5 Prepare the solution for implementation in the next project phase.
- Make essential elements of the solution explicit to facilitate uptake in the next phase (appropriate level of detail varies per phase);
- Prepare an appropriate request for proposals, terms of reference or contract (permitting);
- Organise required funding (multi-source); and
- Prepare risk analysis and contingency plans.

Guidance on the conceptual design of basic dredging projects

In planning for dredging projects, the main (functional) purposes/goals of the project will be leading the focus of the conceptual design, together with possible environmental and societal constraints to the project. Usually the main purpose of a project is either excavation (a deepening needs to be made) or placement (dredged material is needed somewhere).

- **Excavation –** When excavation is the main driver for the works, a decision will need to be made where to place the dredged material. Placement in open water or on land is usually controlled or regulated by national, regional and international rules and legislation.

- **Placement –** When placement of dredged material is the main objective, like for reasons of land formation or product use, a main design item will be where to excavate, where to take the material from? Often material borrow or mining sites can be identified after thorough investigations, while prevailing laws and regulations nee to be obeyed to. Landscaping of sand mining pits may help to improve the ecological value of the area after completion of the dredging works.

In both cases, the characteristics of the natural system (Step 1) will play an important role in the development of alternatives approaches (Step 2) for excavation and placement. In most cases it will be preferable when material from an excavation project can be used for a nearby placement project. That way the objectives of two operations can be combined. Such beneficial use of dredged material will normally deliver both economic as well as environmental benefits, as will appear from the evaluation of benefits and costs (Step 3).

BOX 3

the isolation of design components that can become objects of study on the other, both with the aim to rationalise the project development process. Its application in practice generally involves the following stages:

1. Define the concept's strategic objective and identify crucial individual design components;
2. For each design component specify operational objectives, boundary conditions and performance indicators;
3. Check if design components individually achieve their operational objective(s);
4. Check if design components collectively achieve the strategic objective as intended in the conceptual design phase; and
5. Check how the final solution fits in the local governance context.

Key elements for successful sustainable infrastructure development

The described conceptual and detailed design steps are generally undertaken in an iterative manner throughout the project development process; both diverging and converging repeatedly. During diverging activities alternative solutions can be developed and proposed. These are often intuitive processes where decisions can be guided by professional judgement. During the converging activities decision-making should increasingly be guided by an evidence-based approach: what are the costs, what are the anticipated benefits, how will the solution achieve its objectives in practice and how can this be monitored properly? For the primary objectives of water infrastructure developments a proper evidence base is often available in the form of empirical data and well-tested models. For the additional objectives that are associated with sustainability, this is often not yet the case. Uncertainties have to be dealt with during the proces of designing a sustainable infrastructure project.

Key elements to facilitate such a design proces are:
- multi-disciplinary collaboration;
- stakeholder engagement;
- alignment with legislation, regulations and institutional arrangements; and
- good contractual arrangements for design and realisation.

Added value through multi-disciplinary collaboration

The development of sustainable infrastructure solutions with added value for nature and society involves interplay of physical, ecological and governance processes. The combination of these disciplines can yield new opportunities, which will improve the feasibility of hydraulic infrastructure projects (engineering perspective), in sensitive environments (ecologist perspective), while meeting societal wishes and legislative constraints (governance perspective). Setting up collaboration between representatives of these disciplines is already challenging of itself, yet it becomes even more challenging when you realise that the development and implementation of new, innovative solutions typically generates its own resistance.

Sustainable infrastructure solutions developed over the last years (e.g. Sand Engine Delfland the Netherlands, mangrove-protected shorelines Demak Indonesia, Amazonehaven Rotterdam the Netherlands, Horseshoe Bend Dredging Atchafalaya River United States, amongst others) have shown that it usually takes several years of intense collaboration to achieve the realisation of a project in practice. The experience gained from these projects allows for the formulation of generic guidance for setting up successful, multi-disciplinary collaborations:

1. Integral approach – Set up a project team that covers all relevant disciplines. The team should at least represent engineers, ecologists, policy makers and legislators; note that developing a better solution in itself is not enough, it should also be feasible within the existing legislative framework and acceptable to society. Missing out on key disciplines, even if only of secondary importance at first glance, may initiate risks and uncertainties that in the longer run can seriously hamper a project.

2. Knowledge level – Make sure all members of the team bring in sound expertise from their own discipline and are sufficiently familiar with the project or case study at hand. Integrated design of innovative solutions relies on the capability of making scientifically-robust, in-depth assessments of each key discipline. Requiring a minimum level of expertise for all members strongly facilitates interaction amongst team members and smooth decision-making during for instance integral design workshops.

Close engagement of key stakeholders **is fundamental to the success of a water infrastructure development.**

3. Attitude – Besides a thorough understanding of individual disciplines, true multi-disciplinary collaboration also requires team members to be open-minded towards other disciplines. Awareness of the broader scope will help enormously in identifying and exploring innovative solutions at the interface of different fields. A similar attitude is also needed for the translation of third-party requirements into boundary conditions for more detailed mono-disciplinary studies, and vice versa the translation of the outcomes of these expert studies into meaningful findings for the broader project context.

4. Interaction – Multi-disciplinary collaboration inherently implies interaction between professionals of diverse background. Make sure sufficient time is allocated to familiarise with the other team members and become acquainted with different habits and cultures. Most notably, collaboration between hands-on professionals with a strong focus on solutions and rapid outcomes versus consensus-oriented professionals who put high value on a balanced process resulting in broadly supported solutions deserves attention. Needless to say the long time needed to arrive at a balanced compromise solution is perceived to be totally different by the two groups of professionals. The importance of a careful process of team building can therefore not be underestimated.

Early involvement of all key actors is a prerequisite for success. In addition, the design process should be open and transparent in every project phase, and the integral design workshops should be populated with the right participants. Once these aspects are in place, careful process management is needed to guide the project development process to a successful end.

Stakeholder engagement

Sustainable infrastructure projects operate on the boundaries of physical, ecological and socio-economic domains. As a consequence a multitude of interests and backgrounds are involved in the successful development of such projects. This is why they are usually complex and of high exposure. Thoughtful management of these interests – as well as combining them as much as possible in a specific design – is essential for project success. Effective incorporation of interests can only be achieved by careful engagement of stakeholders. Today, more and more projects are developed in a stakeholder-inclusive way. However, due to their novel and innovative nature, sustainable solutions can encounter resistance, as unfamiliarity often triggers a conservative response. Attentive identification and involvement of stakeholders can help make dynamic, sustainable solutions feasible.

Stakeholders can be defined as "any group or individual who can actively affect or be affected by the project development". As such, stakeholders can be anything from individuals affected by a project through to large-scale NGOs whose organisational goals are related to aspects of the project. A practical approach for stakeholder analysis is available, which essentially relies on a systematic identification and classification of relevant stakeholders, followed by the assessment of their interests and power.

Step 1: Stakeholder identification

The decision which stakeholders should be involved in a project development process is a strategic choice. In general, people

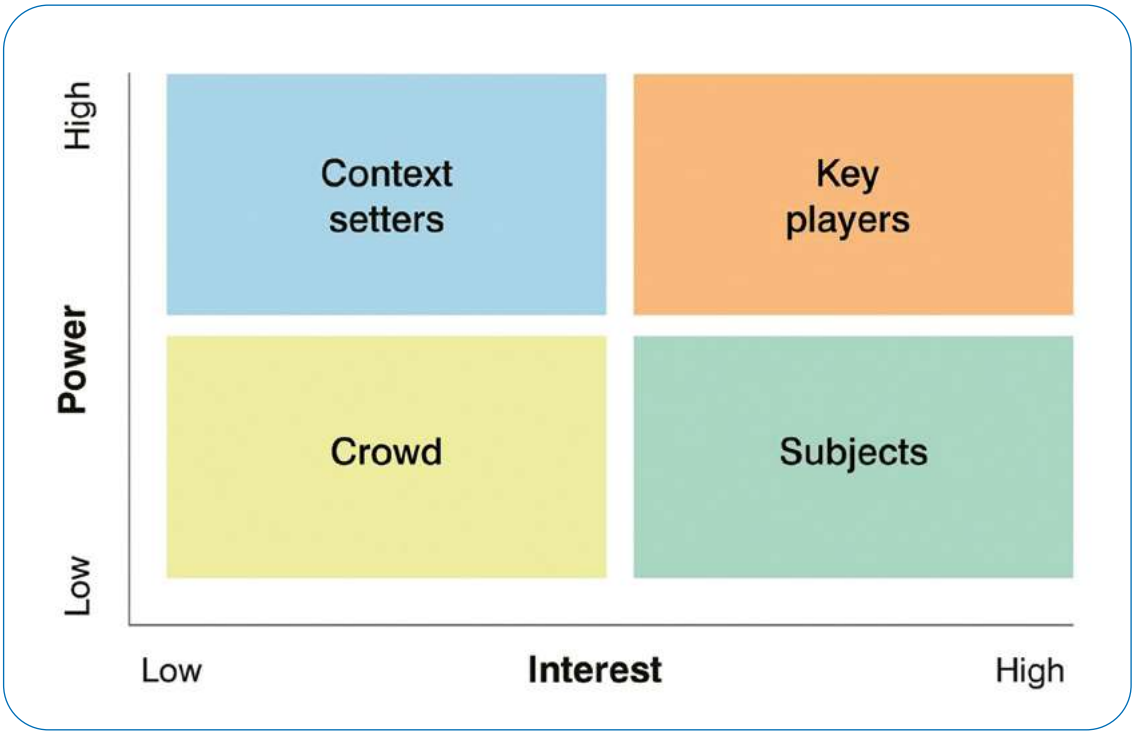


FIGURE 2
Classification of stakeholders via interest-power matrix.

should be involved if they have information that cannot be gained otherwise, or if their participation is necessary to assure successful implementation of the initiative. Normally, stakeholders are identified through structured brainstorming sessions by the project initiators, taking into account both existing networks as well as new actors gained from public hearings. Considering the innovative nature of sustainable water infrastructure solutions, it is suggested to be very open-minded about involving interested stakeholders, including those you may initially not think of. They may turn out to be the deciding factor for project acceptance and a driver for project success.

Step 2: Stakeholder assessment

In participation processes, a large number of stakeholders can be present. Not all of these stakeholders have the same attitude towards the project, and they are not equally important either. Therefore, it is important to identify the role of different stakeholders in the envisaged project development, so that specifuc management strategies can be utilised for their involvement. Stakeholder analysis can easily be done using stakeholder matrices, such as "power versus interest" or "problem-frame versus stakeholder".

By combining interest and power, it is possible to map each actor in one of four positions in a matrix (i.e. key players, context setters, subjects and crowd) and prioritise them according to their importance for the project (see Figure 2).

Step 3: Strategies for stakeholder engagement

Generally speaking, stakeholders wish to be involved in the process of project development. However, not all stakeholders are equally concerned with the project. Close engagement of key stakeholders is fundamental to the success of a water infrastructure development, which justifies a substantial effort to ensure their involvement. Open stakeholder engagement is supported and recommended, however, it is also recognised to be costly and time consuming so, inevitably, resources will need to be focused on the main groups. It is helpful to categorise the stakeholders and adopt different engagement strategies for each category. The position in the interest-power matrix (Figure 2) provides a basis to decide which action to take. It is important to realise that the four different stakeholder groups identified in Figure 3 have a very different position and attitude towards the project. For that reason, different strategies should be followed to ensure appropriate involvement:

Key players (high power, high interest): Important to keep them fully involved and satisfied with the project plans. These are stakeholders with high power and high interest. Their involvement can relate to the actor's own interest as well as the project developer's interest in what the actor can add to the project in terms of relevant knowledge, perspectives and resources. These are the people to fully and intensively engage in the processes and as such warrant and require the most effort. They should be actively involved in the project development and consulted regularly.

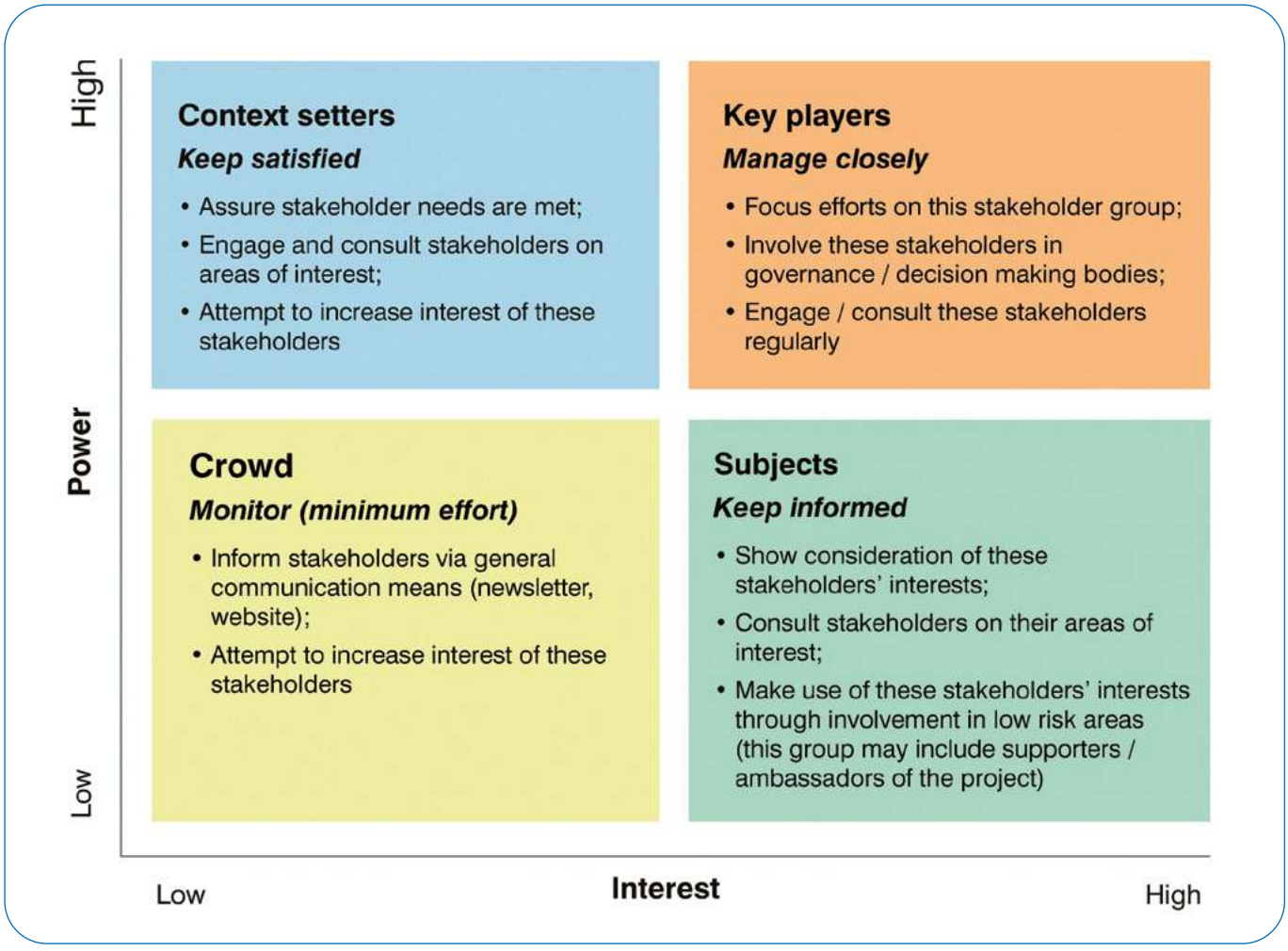


FIGURE 3
Strategies for stakeholder engagement.

Context setters (high power, low interest): Keep included and well informed. These are stakeholders with high power but less interest. Their power provides part of the context in which a development is pursued. It is important to invest enough effort to keep them included. When possible, try to increase their level of interest as this is of benefit to all.

Subjects (high interest, low power): Keep informed. These are stakeholders with low power but high value. Often these actors can be helpful with identifying opportunities for further improvement of the design for the project and often include supporters/ ambassadors to the project.

Crowd (low interest, low power): Monitor. These are stakeholders with low power and low interest. These should be monitored and informed passively via general communication means (website, newsletter). When possible, try to increase their level of interest. The identification of stakeholders that might become key players is especially crucial to a project's success. They have a high political interest and are powerful enough to stop the project completely or make sure that it succeeds. Economic interests are often secondary to the position actors take.

Legislation, regulations and institutional arrangements

Environmental legislation and regulation (or at least their interpretation) can pose an impediment to successful implementation of sustainable solutions, for instance, if they are exclusively focused on reducing environmental impact in a way that reduces opportunities to create environmental gains. This was often the case with many earlier regulations on sediments that originated from dealing with sediments that were subject to high levels of contamination. Sediment quality is much improved in many areas today. However, the past regulatory focus has led to circumstances where excessive concern is sometimes focused on very low levels of contamination, making it economically and/or logistically infeasible to use that sediment beneficially to create much needed aquatic habitat.

On the other hand, a well-developed system of environmental legislation can encourage the development and implementation of sustainable infrastructure solutions. Such a system guides the development of sound project requirements which realistically reect the perspectives of project proponents, contractors and other stakeholders. A good example comes from the London Convention, which requires countries to consider beneficial use of dredged material prior to granting a disposal licence. In the UK for instance, this was successfully implemented through the Marine Management Organisation for offshore disposal activities. In that sense, the regulatory regime in the UK is an enabling factor for the implementation of sustainable infrastructure solutions.

As nature-inclusive solutions promote the development of rich communities of ora and fauna, future maintenance of the infrastructure becomes a potential concern if that maintenance will be constrained due to the presence of the very communities of ora and fauna that the project produced. This circumstance could make maintenance more complex and costly, thus reducing the motivation to include nature-inclusive components as part of sustainable strategies for infrastructure projects. Similar considerations apply to the maintenance of land reclamations during the period before they are actually put into use. If habitat improvement leads to the introduction of rare vegetation and/or species, it might hamper future use of the infrastructure asset. In such a case, early discussion and formal agreements amongst partners, regulators, sponsors and other stakeholders should be encouraged to alleviate such concerns, and hence to avoid hampering the sustainable solution.

In addition, it is not just legislation and regulations that can impede the process, rigid institutional arrangements can also obstruct the implementation of sustainable infrastructure solutions. The other way around advancing practice related to sustainable, for example Nature-based Solutions (NbS) can

BOX 4

Options for water related infrastructure project procurement

Commonly used contract arrangement for the implementation of hydraulic infrastructure projects:

1. Design-only/Build-only – This is the traditional model, where project development and design is done solely by the project proponent, supported by engineering consultants. Contractors are only involved when the plan is finished, and the scope is fully detailed. Contractors compete on price only, possibly with bonus points to be gained for quality elements such as planning, risk management, minimisation of societal impacts and others (so-called Best Value Procurement). Generally there is little scope for early contractor involvement.

2. Design and construct, with early contractor involvement – In this model, contractors are already involved early in the design phase, taking over the design responsibility from the project proponent. Usually, the preferred contractor is already selected however there is also the possibility of multiple tenderers and a competitive dialogue process. During project procurement, market parties compete on their ability and competence to develop and design water infrastructure, in combination with cost-effective realisation. Being able to identify, assess and control risks is vital.

3. Performance-based contracting (PBC) – Performance-based contracts are often applied for maintenance of acess channels to ports, where the contractor is responsible for a guaranteed draught over a longer period of time. Payment is done for delivering this result instead of payment by volume of dredged material. Payments are linked to meeting clearly defined performance indicators regarding the depth of the waterway. A PBC requires higher quality standards for the contractor than a traditional contract. Potential advantages include increased efficiency, lower costs, and room for the contractor to develop and introduce innovative solutions. Considering the role and responsibility of the private sector in PBC, this contract form can be considered a stepping-stone towards the PPP model.

4. Public-private partnership (PPP), alliance contracts – In this model, project proponents, consultants/designers and contractors truly collaborate during all the phases of a project preparation, design,engineering and realisation. The model predicts the sharing of risks and opportunities; it particularly works for situations where projects have large uncertainties in the final solution.It is seen in concession contracts where the PPP or contractor collects the toll for vessels using a navigation channel in return for the contractor keeping the channel to the required depth. This model is no longer associated with a fixed price but often a toll arrangement; the procurement process often starts with a frame of reference that just indicates the qualities and values that are of relevance to successful project realisation.

Rigid institutional arrangements can also **obstruct the implementation of sustainable infrastructure solutions.**

help improve institutional practices across multiple levels of government and other organisations.

Least but not last, it is important to pay attention to financial arrangements. Also this aspect should be adressed early on in the process of project development. As sustainable solutions usually address multiple objectives and governmental responsibilities are often spread across different agencies and/or departments, integral solutions can also demand for integral financing schemes. In the Netherlands for instance, truly integral financing of a sustainable solution to guarantee safety against flooding with simultaneous benefits for nature and recreation would require participation of at least the national Ministry of Infrastructure and Water Management as well as regional and local public bodies, such as the province, council and the water board. Setting up such arrangements can be time consuming.

In summary, it is essential to identify possible project enablers and/or impediments related to legislation, regulations and institutional arrangements at the earliest stage possible, and to actively engage the actors involved in all successive steps of project development.

Contractual arrangements for design and realisation

Application of sustainable development principles in hydraulic infrastructure projects can introduce new challenges for successful project procurement. Two key issues play a role in that respect:

1. Evaluation of integral costs and benefits – Sustainable solutions usually address more than one objective, and aim to include extra benefits for nature and society next to the primary function of the proposed infrastructure. This implies such solutions cannot be evaluated on the basis of monetary costs alone, but require a broader, more integral evaluation. Project contracting on the basis of Most Economically Advantageous Tender (MEAT) offers a good basis for that.

2. Handling project risk – As previously stated, sustainable solutions are inherently associated with a degree of risk. These risks can cover a variety of issues, including fears on future natural development, its operational effectiveness during the lifelime of the infrastructure, the outcome of the envisaged cost-benefit analysis and the societal acceptance of innovative, sustainable solutions. Whereas the more traditional arrangements (Build-only, Design and construct) aim to assess and allocate risk between the parties prior to contract award, new arrangements like early contractor involvement and alliance contracts (public-private partnerships (PPPs) aim to settle these on the basis of increased knowledge and insights developed during project preparation. Setting up and operating of either early contractor involvement or an alliance type contract relies on open collaboration and demands a different procurement process. Guidance for the latter is provided in box 5.

Further information on procurement and contractual arrangements in relation to water infrastructure projects can be found in IADC Facts about Procurement (2008), Alliance Contracts (2008) and Early Contractor Involvement (2013).

Considering the integral and innovative nature of sustainable infrastructure projects, the selected contract arrangement should allow the involvement of specialists from different backgrounds (knowledge institutes, consultants, government, contractors) during the early stages of project development. This can be achieved through all arrangements listed in box 4, albeit that early contractor involvement generally offers more direct benefit and flexibility than the traditional procument approach. Furthermore, it is important to assess the preferred contracting method early on in the process of project development, as this will govern the degrees of freedom available to introduce nature-based elements in the project design and timings for when this should be achieved.

Check out the *Dredging for Sustainable Infrastructure* book.

Implementation of public-private partnerships

Projects with key risks, especially those that are difficult to assess upfront generally benefit from early contractor involvement. Doing so requires a fundamentally different approach and attitude as compared to the more traditional procurement arrangements. The following guidance can be taken into account:

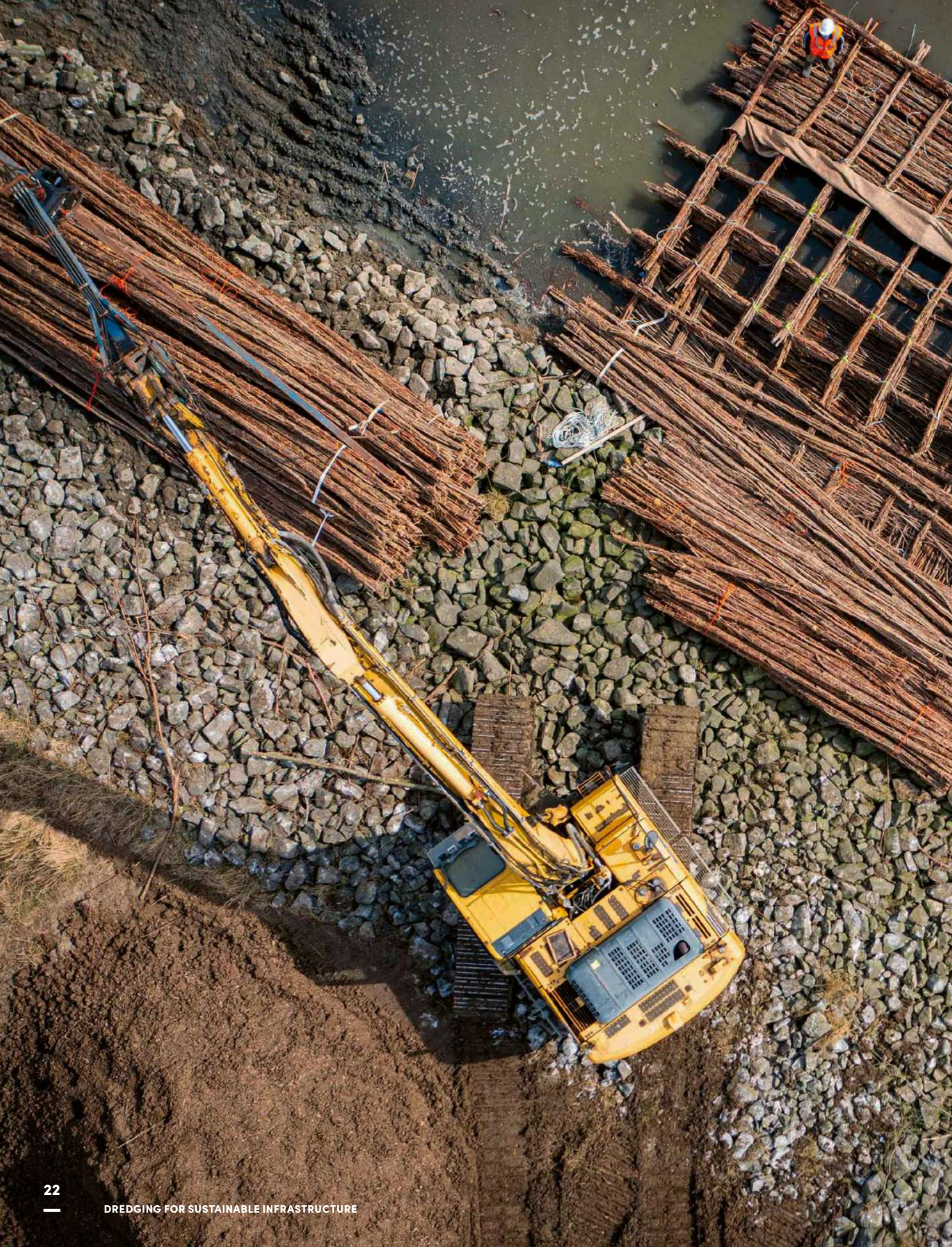
1. **Think about procurement early and proactively:**
   - Focus on the procurement process and contractual framework right from the start.
   - Contact the authorities at an early stage to discuss the needed perspective with regard to (organisation of) procurement.
   - Aim for a clear and shared perspective with regard to the envisaged procurement process and the roles of public and private in every project phase.
   - Anticipate the consequences of different options for each of the project phases.
   - Anticipate the consequences for the required contractor arrangement and act accordingly.

2. **Keep an overview of the procurement process. In the most ambitious model the process might include four phases:**
   - In the first phase, shortlisting of project participants with a lead party that outlines the situation in a short document, based on analysis, and shows his/her ability not only to identify and manage risks (which are a traditional procurement criterion) but also to understand mutual perspectives and connect opportunities to de-risk such risks. The latter might even include relation management working towards consensus between contracting parties and all stakeholders.
   - In the second phase, the detailed planning will proceed with close collaboration between the contractor and the authorities.
   - In the third phase, the actual procurement will take place. This starts with the pre-selection. Interested suppliers will position themselves on price, knowledge, competences (including management of perceived risks and perceived opportunities). After the pre-selection the procedure continues with one or two selected consortia. Next steps are not so much about competing but about negotiations. Showing competences in perceiving, connecting and handling opportunities is of equal importance to perceiving and handling of risks. Avoiding delays requires starting the procedure early or imposing strict deadlines.
   - In the fourth phase, final decision-making takes place followed by construction.

3. **Realise effective management of the procurement process. Effective handling of the process as described requires:**
   - Settlement of sound functional requirements based on system engineering as necessary (instead of technical specifications). Sound functional requirements at least include spatial and time boundaries. In a layered perspective these criteria should anticipate subsequent steps in working towards specifications for implementation.
   - Though sound functional requirements should be sought after, also procedures for incremental changes of functional requirements should be described with regard to their consequences for the cooperation and procurement processes.
   - Define and describe the process: clearly state who is responsible for what, the set of performance indicators as agreed upon, how compliance to performance indicators is measured, the allocation of risks over partners and the pain and gain settlements. Be aware that these monitoring, verification and counting schemes should be regularly updated while the early contractor involvement arrangement works itself through the project phases.

4. **Feasibility of innovative procurement. Some further issues to take into consideration:**
   - As the traditional model of procurement suits single-organisation contractors very well, the more innovative procurement procedures with demanding criteria will often require consortia of organisations that pool expertise, competences and available resources. For innovative projects involving sustainable solutions (and associated uncertainties), the definition and application of such criteria for contractor selection requires careful attention.
   - Making the added value for nature and society "tangible and verifiable" is a prerequisite for reordering roles and responsibilities during the project phases. This includes both added values with regard to an integral perspective (serving multiple goals), as well as the economic perspective demanding optimisation of total costs during construction and over the project lifelime.

BOX 5



Bankbusters

Ecosystem-based riverbank management

Estuarine tidal wetlands offer vital ecosystem services, including flood protection, erosion control and water purification. However, these estuarine ecosystems actually face significant pressures caused by both human activities and natural forces, leading to habitat and ecosystem degradation and loss. The Bankbusters project adressess these issues by reusing soft dredged sediments to restore tidal marshes and mudflats as natural riverbank systems. As such, this initiative promotes biodiversity, enhances flood resilience and supports sustainable economic growth through innovative, eco-friendly and resilient solutions in the Scheldt estuary.

Designing a marshland

The project aimed to create a more sustainable and resilient integrated river management plan that addresses the diverse interests of all stakeholders involved. Such an ecosystem-based estuarine flood protection can only be brought into large-scale practice on condition that:

- sufficient space is made available in the estuary to accommodate the creation and development of (additional) ecosystems;
- a better understanding of the complex estuarine processes identifies relevant key engineering species and its habitats to enhance relevant natural dynamics; and
- local stakeholders support the development of ecosystem services.

Once these conditions are met, solutions can be designed to translate the desired ecosystem engineering functionality into an integrated part of the estuarine flood protection management. On the one hand, such development requires a generic framework to select the appropriate measures based on the spatial and temporal scale of the overall estuary system. On the other, it requires knowledge on the ecology and ecosystem services delivered by the wetland (both marshland and mud flats) forming ecosystem.
For these reasons, the design process integrates numerical modelling and experimentation, adheres to legislation and emphasises the beneficial reuse of sediment and biosafe materials to achieve optimal groundwater dynamics to facilitate proper morpho dynamics. Explicit seeding and active soil management reflect active ecological engineering measures to guide vegetation development as a crucial success factor for an efficient kick-start of the on-site marshland application.

Location of the Bankbusters pilot site, along the left bank of the Scheldt estuary.

Given the explicit multidisciplinary interaction, the success of the Bankbusters project relies on continuous interactive engagement with clients and stakeholders. Key stakeholders include the Port of Antwerp, Vlaamse Waterweg and the Flemish Maritime Access Division, among others.

Modelling and experimentation

As a first step, we defined a series of ecosystem hydrodynamic and geomorphological boundary conditions to facilitate and enhance tidal wetland creation and development. Numerical modelling provided insight into potential (critical) riverbank erosion effects of structures being designed. Simulated (turbulent) flow impacts and erosive forces were taken into account in the design, engineering and installation procedures of the riverbank configuration. Some additional laboratory experiments were conducted to evaluate the proposed stepped river emba nkment configurations of mud flats and/or marshlands. These experiments were performed at the Mesodrome facility, a hydraulic laboratory test flume located at the “Drie Eiken” campus of the University of Antwerp.
The Mesodrome facility and the adopted flow measurement techniques were crucial in assessing the performance of different schematised geometries inspiring both technical and ecological design ideas.

Bankbusters site

The Bankbusters pilot site is located at the “Ketenisse” wetland spot along the

The Bankbusters consortium combines the operational excellence of the marine contractors DEME Group and Jan De Nul with the frontrunning knowledge and site experiences of the academic partners University of Antwerp and Ghent University as well as the dedicated expertise of iFLUX. The Bankbusters research project is facilitated under the Flemish spearhead cluster for Blue Growth (Blue Cluster) and supported by the Flemish agency for Innovation and Entrepreneurship (VLAIO).

Bankbusters

The Bankbusters project aims to restore and create tidal marshland using **dredged sediments and natural "biosafe" material.**

The experimental river, The Mesodrome, forms the hub of innovative aquatic research platforms that address converging issues, such as eutrophication, pollution and flooding. A standout feature is the flume – a 20-metre-long, 2-metre-wide experimental river. This facility enables precise manipulation of hydrology, water quality, sediment characteristics and plants and animals, serving as a vital tool to study the interactive effects of anticipated changes on the functioning of river ecosystems.

Erosive cliffs at the test site (left) and a typical reference marsh (right).

left bank of the Scheldt estuary, next to the Waterbus stop at Kallo (Belgium). This area, just downstream from the Kallo sluice entrance, is known to be highly erosive and susceptible to both strong local tidal flow patterns and explicit ship induced wave impacts. Local riverbank profiles are currently protected from this excessive erosion by means of rock deposit on both the tidal water shoreline and higher at the toe of the dyke. The pilot site currently shows very little vegetation due to the high erosive impacts. As a result, explicit vertical erosive cliffs are observed at the high-water line. The soil of the pilot site is characterised partly by sandy sediments with areas of grey alluvial heavy clay. Further downstream of this erosive spot – just around the estuary corner – the Ketenisse natural wetland is used as a nearby natural reference riverbank profile site.

Beneficial reuse of sediments

The Bankbusters tidal marsh restoration project emphasises the beneficial reuse of sediments; both to promote a circular economy of building materials and to optimally enhance the ecosystem services as delivered by stable and healthy wetland riverbank systems along the estuary.

The choice of backfill material for the upper marshland soil massive is a critical determinant for the success of the wetland restoration scheme, as it directly impacts morphodynamic status, fine sediment retention, the groundwater dynamics, the gully system, organic content, pioneering vegetation and marsh habitat vegetation growth development. The key objectives for the fill material selection included:

- Ease of handling and positioning of the soil in the pilot test setup:
- Acceptable geotechnical stability of the upper marshland as part of the adapted river cross profile:
- Granulometry reflecting natural marsh conditions with fine sediments typical for tidal wetlands:
- Appropriate organic matter levels supporting vegetation growth and nutrient cycling: and
- Reusing locally available (dredged) materials to minimise environmental impact and promote circular economy principles.

Limited availability and complex environmental permitting, in the end, became the determining factors for fill material selection. Given strict boundary conditions and the existing operational constraints, available and fully compliant silty sandy material was chosen for the pilot setup of Ketenisse.

DRECO units

Based on the initial assessment of the boundary conditions and the actual, updated intertidal observations and experiences along the river Scheldt, we prioritised the marshland part of the intertidal cross profile restoration due to its technical feasibility and ecological value.

Structural integrity analysis of the Dredged Ecological Compartments (DRECO units) led to engineering optimisations for soil stabilisation, hydrodynamic loads, vegetation development and performance under extreme tides. Conceptual designs included erosion control, sediment fluxes and vegetation conditions. Collaborating with Van Aalsburg BV, we developed a final containment bund configuration, addressing challenges like scour protection, sediment retainment and modular willow matrices for tidal conditions. Further detailed design revealed additional technical opportunities and challenges.

Biosafe materials

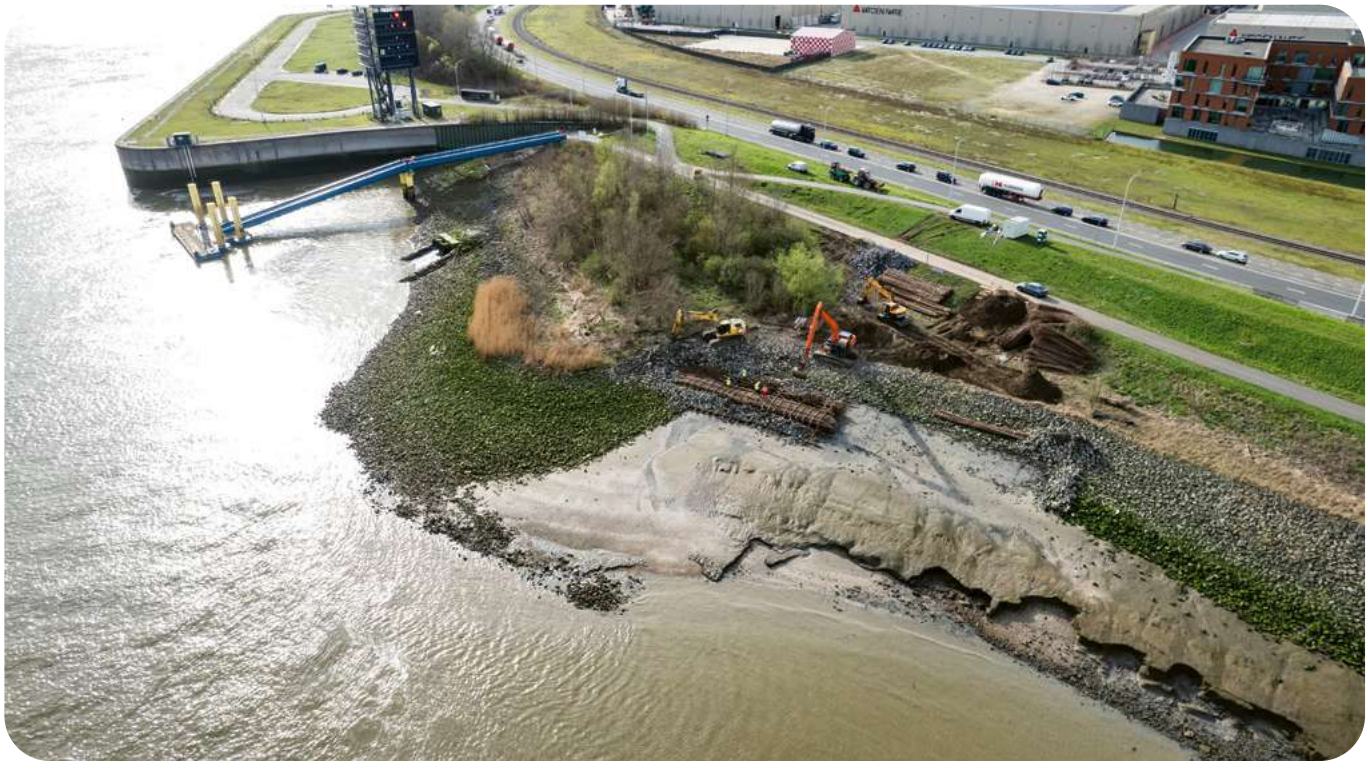
Bankbusters materials are entirely natural and can withstand harsh environmental conditions to form tidal marshlands in a riverbank setup. They need to be biosafe, enhancing structural integrity, natural resilience and biodiversity. Meaning only materials that do not harm the environment through weathering or leaching should be used. Furthermore, targeting a more sustainable riverbank ecosystem, judicious material selection reduces the carbon footprint as well as the overall production impact.

Legislation

The first Bankbusters field pilot project finally received an integrated building permit in th e autumn of 2023. Taking into account the complex applicable legal provisions, an extensive time-consuming application has been elaborated for the pilot setup. Following assessments were made as part of an integrated environmental and social impact evaluation.

As the project location is situated within the habitat directive area Scheldt and Durme estuary from the Dutch border to Ghent (BE2300006) and the bird directive area “Salt marshes and polders of the Lower Scheldt” (BE2301336), the permit required a specific legal status and falls under the provision of an intertidal site with “wet and dry infrastructure”, nature

The basic of the DRECO units are fascine mattress layers made up of wedges. Fascines form an excellent foundation for nature inclusive engineering applications. They have been used for over 100 years to protect soils and banks against erosion by water and are a time-tested solution.



Pilot site during installation.

Building the retaining wall and aiming for the right dewatering conditions.

conservation and the natural environment, and waterways and non-navigable watercourses within a certain category.

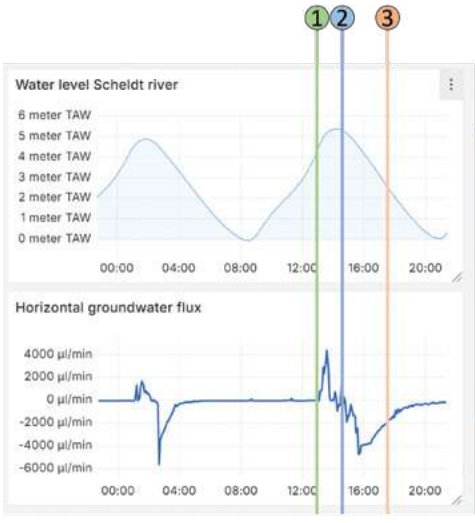
Dewatering: key to enhance marshland development

Natural drainage of the soil massive is crucial for tidal marsh restoration and creation. Effective drainage is essential to assure overall stability at the start of the marshland development, to facilitate the settlement of the marshland soils, to grow pioneer vegetation and to maintaining the overall ecological integrity of the system towards a robust riverbank ecosystem. Proper drainage helps regulate both groundwater and surface water level, prevents waterlogging and allows for the natural movement of tidal and groundwater flows. Additionally, managing drainage in a way that mimics the natural processes of tidal marshes (for example, through dedicated gully systems) can promote vegetation growth, reduce erosion and support biodiversity.

Several drainage solutions can be implemented in tidal marsh construction to mimic natural tidal flow (Ndongo, 2024). The selected silty sand material aids efficient marshland development. Our DRECO units act as containment bunds but with the specific aim to allow optimal groundwater drainage and rewetting of marshland. The Bankbusters structure ensures marsh sediments are kept in place and dynamically dewatered, supporting tidal marsh restoration and enhancing riverbank ecosystem services and biological value.

Monitoring

The marshland at the pilot site has a dynamic character. Short-term field monitoring records the pilot setup's performance during kick-off and initiation phase of marshland development, while long-term monitoring aids further operational management of the (nature-based solution) riverbank flood protection schemes. The actual integrated monitoring approach includes a field measurement protocol to assess – in the initial development phase – the overall ecosystem status of the marshland and the level of flood risk protection as a riverbank system. Other ecosystem services will be observed as part of the further wetland riverbank environment development.



Monitoring results showing the groundwater dynamics of the Bankbusters site.

Tidal wetlands are an indispensable part of the riverbank for maintaining ecological balance, supporting flood protection and economic activities.

Key developments in the actual Bankbusters monitoring framework include a real-time groundwater flux sensor, modular telemetry data infrastructure and a monitoring protocol roadmap. Drone observations and bathymetrical recordings provided insights into the marshland's morphodynamics, highlighting erosion, sedimentation and soil compaction. The permanent operational camera system adds value by visualising tidal processes and aiding flood frequency analysis. The monitoring programme aims to develop a scientifically underpinned strategy and detail the marsh's ecological and morphological evolution, ensuring the long-term success of tidal marsh restoration efforts.

Ecosystem services business model

Tidal wetlands provide essential ecosystem services, acting as natural buffers against storm surges and flooding, improving water quality by filtering pollutants and supporting biodiversity. They also sequester carbon, helping mitigate climate change. These services are crucial for balancing economic activities, ecological values and flood protection. The Bankbusters brand, allied with Coastbusters, focuses on Nature-based Solutions (NbS) for more environmentally friendly riverbank systems. These projects aim to restore disturbed river cross-profiles, offering a new business model for estuarine river management.

Future potential

Bankbusters' nature-based solutions have global potential, integrating digitalisation and experimental approaches with smart engineering to protect eroded riverbanks. The innovative modular concept, using biosafe building materials, adapts traditional natural elements for marshland restoration in estuarine habitats.

Emphasising circular economy and resource reuse, particularly in dredging and navigation, Bankbusters uses cutting-edge monitoring techniques to optimise marshland recovery. The Bankbusters projects connect to the growing need for more resilient, sustainable and healthy estuarine ecosystems which are a valuable source of ecosystem services. The market for this kind of ecosystem restoration is burgeoning, with future scenario projections indicating a high potential NbS growth driven by the increasing recognition of the critical role biodiversity and ecosystem services can play in our adapted socio-economic system.

Bringing Bankbusters solutions to the market

The valorisation paradox of Nature-based Solutions (NbS) lies in their complexity and long-term commitment, which deter investors seeking immediate returns. NbS benefits like biodiversity, carbon sequestration and water purification are hard to quantify. Traditional economic systems undervalue these ecosystems, underestimating risks to human welfare and economic growth. A paradigm shift is needed to recognise NbS as valuable, high-potential alternatives in decision-making processes.

Bankbusters marshland immediately after installation.

Bankbusters consortium during seeding operation.

Download the Coastbusters article on sustainable coastal management.

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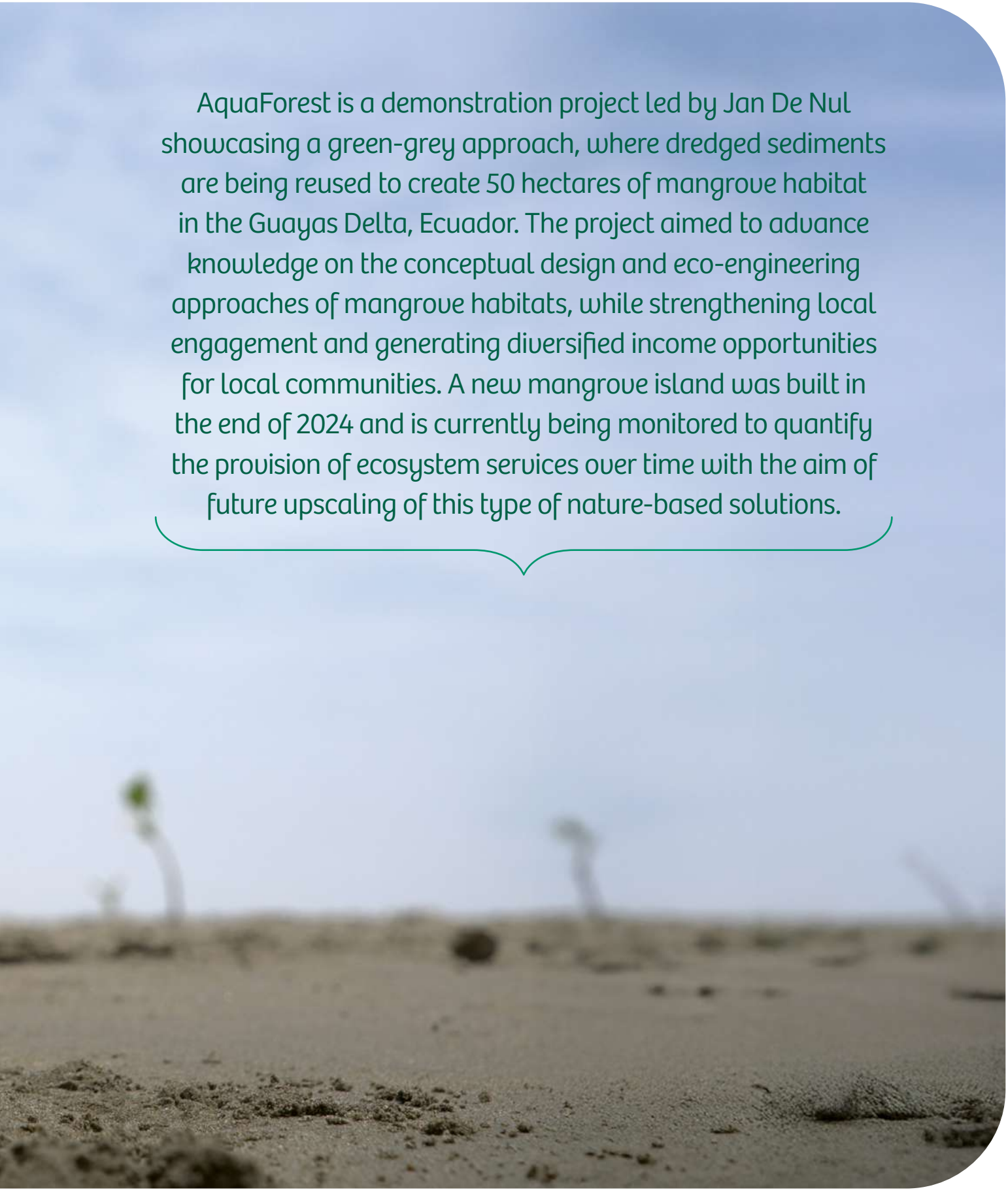
AquaForest:

A nature-based solution for dredged sediments



AquaForest is a demonstration project led by Jan De Nul showcasing a green-grey approach, where dredged sediments are being reused to create 50 hectares of mangrove habitat in the Guayas Delta, Ecuador. The project aimed to advance knowledge on the conceptual design and eco-engineering approaches of mangrove habitats, while strengthening local engagement and generating diversified income opportunities for local communities. A new mangrove island was built in the end of 2024 and is currently being monitored to quantify the provision of ecosystem services over time with the aim of future upscaling of this type of nature-based solutions.

El Morro Port: The perfect spot for drone flight demonstrations during the survey workshop with the local authorities, NGOs and local community leaders.

Designing and eco-engineering a mangrove forest on dredged sediments

Dredged sediments tend to be overlooked as disposable and unwanted material from port, channel and estuary maintenance, which may pose significant environmental and logistical challenges. Traditionally, they are disposed of at sea or stored in containment sites, where potential environmental impacts on marine and coastal ecosystems are considered as an inherent side effect. However, driven by the realisation that primary resources are finite and scarce, the value of dredged sediments is being nowadays reassessed with a number of promising examples.

In many cases, dredged sediments are reused on land, particularly along coastlines or for island creation. Such applications rely on a combination of physical, chemical and engineering techniques, such as rock protection and compaction. These methods aim to ensure material cohesion, limit erosion and guarantee long-term hydraulic stability.

To develop a sustainable and innovative alternative for the reuse of dredged sediments, we drew inspiration from nature's most effective coastal stabilisation systems: mangrove forests. These natural ecosystems offer a combination of key functions that traditional fixed and non-adaptive stabilisation structures often lack. These functions, or else, "mangrove ecosystem services" include coastal protection and erosion control, biodiversity support and habitat creation, water quality improvement, carbon sequestration, climate change mitigation and adaptation, and even socio-economic benefits.

Jan De Nul's 25-year concession for maintaining the access channel to the port of Guayaquil in Ecuador provided a suitable location within the Guayas Delta for implementing this concept. Subsequently, the idea of developing a new island with mangroves by elevating an existing sand flat, received financial support from the government of Flanders and the International Union for Conservation of Nature, also widely known as IUCN.

Local stakeholder engagement

Local stakeholders play a vital role in the success and sustainability of mangrove restoration and conservation projects. Their involvement ensures that projects are ecologically effective, socially acceptable and economically viable and sustainable during their lifetime. Therefore, the location for the pilot project implementation was selected also based on the opportunities for local stakeholder engagement. From the outset, local stakeholders were identified and assessed as part of the environmental and socio-economic assessment, paving the way for the development of a strategy plan for local engagement.

The potential locations for project implementation fell within a protected area under the authority of the Ministry of Environment of Ecuador. Within this protected area, the mangrove habitat is subject to a custody programme, whereby it is leased by the state to fishing associations for sustainable exploitation in exchange for mangrove habitat conservation actions. The Ministry of Environment appointed crab fishing associations from the village of Puerto El Morro to be involved in the pilot project.

We identified relevant authorities, crab fishing associations and NGOs as context setters, key players, and subjects, respectively, and involved them at different levels in the project, using various communication channels. To facilitate good relations with the local community, we appointed a community relations officer who organised information committees where the project was explained and community concerns were addressed. The relationship with the authorities was nourished by reporting on time, identifying key contact persons and keeping them informed and engaged about the project.

In total, we consider that the project implementation created 59 full-time jobs for 4 months. In addition, approximately 500 individuals, representing different age and gender groups in the local community, received training on topics related to mangrove restoration and around 1,000 individuals attended a project communication activity.

Feasibility phase

The feasibility phase lasted one year and resulted in a successful permitting process, including a positive environmental feasibility assessment and the receipt of the environmental permit and various approval letters. These letters were provided by key stakeholders in the project area, such as the Municipality of Guayaquil, the Ecuadorian Navy, Ministry of Environment and the National Chamber of Aquaculture. Notably, these approval letters were not statutory requirements, but rather a self-imposed measure to ensure project sustainability. The complete process required a time-consuming yet detailed approach. The primary causes of this long process were identified as changes in contact personnel within administrations, often triggered by departures or reforms following new elections and communication challenges between cooperating administrations. And, as is often the case with innovative and unique projects, we encountered the recurring challenge of navigating the regulatory framework, which can struggle to accommodate novel initiatives.

Nevertheless, this provided us with valuable know-how for the implementation of similar projects in the area.

During the project feasibility phase, we conducted field investigations to derive initial boundary conditions for the island design. A baseline study assessed the environmental and socio-economic aspects of the project. For example, the presence of the bottlenose dolphins in the project area necessitated extensive monitoring of its population during our operations.

We also visited similar mangrove areas in the Guayas Delta to identify key parameters for mangrove growth. In addition, various protection measures against erosion of the planned land mass (island), such as geotextiles and temporary semi-permeable bamboo structures, were tested to determine the most sustainable design. Furthermore, two experiments were planned and conducted with partner universities to validate mangrove nursing in dredged sediments in both laboratory and in situ conditions.

Based on the information gathered during the feasibility phase and co-creation between the project partners and local stakeholders, an in-house eco-engineering of the mangrove island has been performed leading to an innovative eco-design of the new habitat. Our target was to achieve the optimal conditions for mangrove habitat development, incorporating protection against wave action, ideal conditions for land elevation, a suitable sediment medium and a tailored afforestation plan. The hydraulic stability of the design was verified using hydrodynamic modelling and presented to the relevant authorities.

Construction and afforestation phases

In March 2024, we commenced mobilising the equipment for our construction operations and the first shiploads of dredged sediment were deposited in June 2024. The construction phase lasted 4 months, during which a 50 hectare intertidal zone (an existing tidal flat) in the Guayas River delta was raised by an average of 1 metre. Coarse sediment was selected to shape a sand dyke, measuring 1.5 kilometres in length, which protects the new land mass (island) from ship-induced waves along the side of the nearby access channel. The other side of the island is protected by a temporal semi-permeable structure, made from natural materials.

Following natural compaction and drainage of the reclaimed island area, a first mangrove planting campaign was organised. The afforestation plan includes three native mangrove species: Rhizophora mangle, Avicennia germinans, and Laguncularia racemosa. As part of both scientific research and practical implementation interest, we created different zones where we tested various planting densities and techniques, such as propagule release, propagule planting and sapling planting. In total 12,000 saplings and 21,500 propagules of mangrove were planted.

A local nursery provided the mangrove saplings, while crab fishing associations collected and sorted the mangrove propagules, and participated in the 5-day planting event.

Social impact actions

Socialisation of the project

In March 2024, a socialisation workshop was held in Puerto El Morro to share project information, address questions and foster community relationships. This was followed by a meeting to discuss the contracting of local labour for the construction activities.

In total **12,000 saplings and 21,500 propagules of mangrove** were planted.

Fishermen from the partner associations building the locally designed, semi-permeable structure using natural materials.

6 months after the initial planting, the plant survival rate at AquaForest is 90%.

Women volunteers planting mangrove saplings at AquaForest.

Capacity building workshops

During the project preparation and construction, several stakeholders' events were organised:

- In July 2024, a topographic and bathymetric survey workshop was organised, where local authorities, NGOs and local community leaders could learn more about the surveying techniques used for the AquaForest follow-up.
- The same month, two other workshops were held in Puerto El Morro and Guayaquil to discuss climate change, its impacts and the challenges for mangrove ecosystems with local communities and authorities. During these workshops, testimonies were shared regarding the restoration and conservation of mangroves, highlighting the importance of local community involvement in environmental stewardship.
- In December 2024, a workshop with international participants presented sustainable aquaculture solutions to members of the National Chamber of Aquaculture of Ecuador, including mangrove integration strategies in aquaculture ponds.
- Local workers were trained for the construction of the semi-permeable structure, propagule collection and sorting, and mangrove planting on AquaForest.

Local communication and awareness-raising workshops

- In July 2024, activities to raise awareness of the benefits of mangrove ecosystems were organised at the Puerto El Morro college, further strengthening ties with the local community and enhancing social engagement efforts.
- In September 2024, a workshop for children on mangrove birds was organised with the local NGO "Aves y Conservación" to provide educational opportunities about local biodiversity and mangrove conservation efforts.
- In October 2024, a technical visit to the AquaForest mangrove island was arranged at the end of the afforestation works for stakeholders, including authorities and the presidents of the fishing association.

Mangrove clean-up

Floating debris and garbage is often trapped in the mangrove root systems, inadvertently turning them into a sight that incites pollution. Clean-up is crucial for maintaining the health and functionality of mangrove habitats. On AquaForest, 4 days of mangrove clean-up were organised in 2024. We foresee future clean-ups being undertaken at least twice a year.

Signature of commitment acts

In early 2025, more than 80 persons, including AquaForest partners, local associations, local NGOs and authorities, gathered for a socialisation of the project progress and the official signing of the commitment acts of the project. The objective of the acts is to promote collaborative work between the members of the AquaForest consortium, the protected area administration and the local community through the fishing associations of Puerto El Morro, for the protection of mangroves in general, and of the AquaForest island specifically. The acts aimed to align the AquaForest calendar with the institutional planning of the protected area and with the interests of the crab fishing associations.

Monitoring of the new mangrove habitat

Quantification of the provision of ecosystem services over time is validated with field monitoring of the new habitat. Monthly topographic drone surveys track land mass stability, while mangrove habitat development is assessed through in situ measurements, multispectral drone flights and LiDAR (Light Detection and Ranging) scans. Currently, the Coastal Engineering Research Group of Ghent University (Belgium) evaluates the wave-dampening effect of the semi-permeable wall within a Master-Thesis work. In addition, the 'WETCOAST - Blue Cluster VLAIO' research project, coordinated by the University of Antwerp (Belgium), evaluates carbon sequestration in soil and plants. Monthly benthic inventories and

Nothing better than a craft activity to help children discover the diversity of endemic mangrove birds in Ecuador.

bird observations led by ESPOL, the local university in Ecuador, assess biodiversity colonisation. The involvement of local communities in biodiversity monitoring at AquaForest is crucial to foster long-term habitat stewardship and provides a unique opportunity for capacity building and knowledge sharing.

Early results from our monthly drone monitoring campaigns indicate high survival rates and normal growth for the mangrove saplings and sediment compaction on the new mangrove island. Six months after the initial planting, the plant survival rate at AquaForest is 90%. Monthly biodiversity assessments by ESPOL will further refine the evaluation of ecosystem services, currently estimated to generate approximately 570,000 EUR annually upon the full maturation of the mangrove habitat. AquaForest's rich biodiversity will also be showcased in a biodiversity guide, developed in collaboration with local NGOs and fishing associations, to enhance ecological awareness and support the growth of potential eco-tourism initiatives around AquaForest.

Potential for upscaling

The initial results of the AquaForest demonstration project are highly encouraging and prove that innovative restoration initiatives have positive impact on local biodiversity and community resilience. We place great emphasis on local involvement, as we firmly believe that long-term sustainability is achieved when innovative projects are firmly embedded within the local context. Finally, AquaForest exemplifies a nature-based solution that can provide important ecosystem services such as: flood protection, biodiversity enhancement and climate adaptation and mitigation. With this project we hope to inspire authorities, researchers, project developers, consultants, contractors and stakeholders around the world to enable , support and implement similar projects.

Acknowledgements

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Jan De Nul coordinates AquaForest and the project consortium of eight partners (MANTIS CONSULTING, HAEDES BV, South Pole, Escuela Superior Politécnica del Litoral (ESPOL), Universiteit Antwerpen (UA); Vrije Universiteit Brussel (VUB), Fundación CALISUR).

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Belgium

TALKING HEADS

Text by Elske Swets

René Vrugt

Director of Soil, Spatial Planning and Climate Adaptation at the Ministry of Infrastructure and Water Management

René joined the Rijkswaterstaat (Ministry of Infrastructure and Water Management) in January 2023 as Director of Soil, Spatial Planning and Climate Adaptation. Previously, he led "Zuid-Holland Bereikbaar", promoting sustainable mobility in combination with fewer traffic jams. With 25 years in several functions at Rijkswaterstaat and as Programme Director for Airspace Redesign, he brings extensive experience in infrastructure, mobility, and environmental policy. René studied political science and law.

Alex Hekman

NL2120 Programme Director and Business Director Water at Sweco

At NL2120, Alex leads one of the world's largest collaborations on nature-based solutions. The 10-year programme funded by the National Growth Fund unites science, business, nature organisations, and education to scale up nature-based solutions and make the Netherlands climate-proof and nature-inclusive. He studied Soil, Water and Atmosphere at Wageningen University and brings 25 years of water sector experience, using his expertise to drive innovation in water and climate adaptation.

Can you explain what NL2120 is?

Alex NL2120 is the world's largest knowledge programme focused on Nature-based Solutions (NbS). The programme has two main objectives: first, to generate economic value by integrating NbS into existing business cases and revenue models of companies; and second, to develop the knowledge required to remove the existing barriers to scaling up NbS.

Climate adaptation is a key focus area of the programme, because we believe that nature is our most important ally in becoming climate resilient and in protecting ourselves against the effects of climate change. NbS are the means to achieve that. They aim to ensure that everything we do to adapt to climate change aligns more closely with natural processes, such as the natural functioning of water, soil, and ecosystems. By aligning closely with, and even leveraging, those natural processes, we can avoid unnecessarily large impacts from climate change and use these processes to become more resilient.

At present, NbS are not yet the default. There are several reasons for this. Generally, there is still a strong belief in the idea of full control – manipulating water and soil systems to enable the functions we desire. This applies to the dredging sector as well.

In addition, there are numerous barriers that prevent NbS from being more widely and broady implemented. These include physical and ecological challenges: sometimes, we lack the evidence that NbS are effective or whether they meet the standards required for specific functions. There are also socio-economic questions: financing can be a challenge, particularly with viable revenue models in sectors like agriculture. NL2120 is committed to researching, generating, and applying knowledge to remove these barriers.

"Nature is our most important ally in becoming climate resilient and in **protecting ourselves against the effects of climate change.**"

What are your roles in the programme?

René I'm Director of Soil, Spatial Planning and Climate Adaptation at the Directorate General for Water and Soil, and I'm also responsible for the knowledge and innovation portfolio. That means I'm involved in this National Growth Fund programme. My department manages the grant relationship, accountability and funding. My other responsibility is ensuring the impact and integration of the programme's outcomes. In line with NL2120's aim to scale up NbS and make them the default, we as the national government must ensure that the programme's results are implemented in other projects for which we are responsible, such as dyke reinforcement programmes, river management, coastal development, the energy transition housing and biodiversity initiatives.

René Vrugt speaking to NL2120 leaders, participants and partner organisations, gathered to celebrate the start of the NL2120 programme (Dordrecht, 28 May 2024).

Alex I'm the director of NL2120 and lead the consortium of over 25 organisations and around 400 experts. In this role, I define the strategic direction and vision for the programme, establish our collective long-term goal and ensure coherence across all activities.

Is every relevant discipline involved in NL2120?
Alex We are a programme with representatives from five core groups: government bodies, knowledge institutions, engineering firms and contractors who apply the knowledge, educational institutions that will train the future workforce in NbS and nature organisations that contribute practical knowledge. Together, we cover the entire knowledge chain.

The Netherlands is a man-made country. We've modified natural systems such as our water systems to our advantage. Should we, in hindsight, regret those changes?

Alex The Netherlands was originally a natural system. If we had relied solely on that, the country would be uninhabitable and constantly at risk of flooding. So we certainly shouldn't regret the excellent work we've done through technical interventions.

There's a helpful metaphor comparing the natural system to a human body. Technical solutions are like prosthetics. They work best when they're closely aligned with the body's natural function. From that perspective, some past interventions have been so extensive that they've disrupted the system. NL2120 focuses on how technical solutions, which we will always need, can better align with natural systems.

René It's an ongoing evolution. Building with Nature isn't new. The Netherlands has been doing this for some time, for instance, with the Noordwaard polder – part of the Room for the River – and the Sand Engine in the North Sea. These are cost-effective approaches that we also share internationally. We started taking these steps about 10 years ago and we continue to learn from them. Yet NbS still hasn't become mainstream.

We are now ready for the next phase, which is all about climate change. Conditions are becoming more volatile. This volatility means we need to improve our resilience to extreme weather and rising sea levels. Purely technical solutions won't be enough. We must understand and dare to use the power of natural systems. NL2120 helps by developing knowledge, generating experience and identifying the barriers to broader deployment of NbS. What I find especially strong about NL2120 is that it links this to our economic potential. The Netherlands already holds a great deal of expertise in NbS. I hope that in 20 or 30 years,

The Overdiepse Polder, one of over 30 Room for the River projects run by Rijskwaterstaat, where the river was widened in order to enlarge the drainage capacity during high water.

Dutch companies will proudly showcase how we applied NbS to tackle societal challenges globally.

Alex The Dutch have a strong reputation in the water sector, but we must be careful not to be overtaken by other countries. We need to keep innovating. NL2120 also has an international ambition. We want to deploy Dutch knowledge on NbS worldwide and position our businesses globally. We're in talks, for example, with the WACA network (West Africa Coastal Areas Management Programme) and are preparing a collaboration to explore natural solutions for coastal protection in Indonesia – solutions that also support biodiversity and ecosystem services for local communities.

Regulations while important can also present obstacles. Is NL2120 looking into removing such regulatory barriers?

René Yes, we're also examining whether we can remove governance-related obstacles that hinder the rollout of NbS. We're looking into procurement rules, subsidy frameworks and existing laws and regulations. But it's also about changing our perspective – learning how nature functions and how to use that. Just as we learned from the Sand Engine about coastal morphology, we need to learn how NbS work across different landscapes. The strength of this programme is that we can create time, scale and volume to experiment and learn in practice. Room for the River 2.0 and the Sea Level Rise Knowledge Programme are excellent opportunities for this, and they now also include NbS.

We need to improve our resilience to extreme weather and rising sea levels. Purely technical solutions won't be enough. We must use the power of natural systems.

Hegewarren polder: the NL2120 pilot in the Frisian peat meadow area is experimenting with wet crops such as cattail to investigate how food and fibre production is possible in a wet and ecologically healthy peat landscape. Photo © Binne-Louw Katsma.

"Room for the River has shown that nature-based approaches add **significant ecological and economic value."**

Alex One major barrier is the lingering doubt about whether NbS are as effective as technical solutions. For centuries, the Dutch have managed the coastal system with large-scale technical interventions, such as the Delta Works that were built after the 1953 floods and those from the era of Cornelis Lely, responsible for designing the Zuiderzee Works - the largest hydraulic engineering project undertaken in the Netherlands during the twentieth century. These provide safety but also cause negative effects, such as disrupted sediment balance in rivers, leading to land that no longer keeps pace with sea-level rise. Water quality also suffers. The conclusion of our nature-based trajectory for sea-level rise is that growing with the sea level is not only possible but results in more robust solutions. It has positive effects on ecology, water quality, recreation and the local economy. The costs appear to be comparable to technical solutions.

René already mentioned Room for the River, the largest NbS programme ever in the Netherlands and now widely known. We could keep raising dykes forever, but Room for the River has shown that nature-based approaches add significant ecological and economic value. We've added about 10,000-12,000 hectares of river nature and seen the return of dozens of species that had disappeared from the Netherlands. It's only a start, but a very important one.

Do we need a new Cornelis Lely to lead the transition from technical dominance to nature-based leadership? Is someone brave enough to drive that shift?

René No, I don't think we need one main leader, not in today's world. But we do need pioneers who dare to lead. That's the beauty of NL2120 – it can act as a frontrunner. We can do this with a large group of people: the consortium itself, the Ministry of Infrastructure and Water Management, Rijkswaterstaat and businesses. The financial sector is also showing interest in supporting these developments and strengthening the Netherlands' NbS earning power.

So could we say that the entire NL2120 movement is the new Lely?

Alex We did recently receive the prestigious Grote Maaskant Prize. According to the jury, we've succeeded in forming new coalitions around a positive, innovative and inspiring vision for the future of NbS, especially in a time when climate change discourse often focuses on doom scenarios.

Could NL2120, with EcoShape as a partner, be seen as a follow-up to Building with Nature?

Alex There are some nuances, but yes it's part of the same movement. EcoShape focuses strongly on bringing knowledge into practice and has a lot of experience. We're building on their work and also on efforts such as Room for the River.

We aim to align with the IUCN definition of NbS – the most widely used global standard – which states that climate adaptation interventions should also benefit biodiversity and ecosystem services. Building with Nature puts more emphasis on using natural forces and processes to achieve water management goals such as flood protection.

Alex Hekman at Hondsbossche Dunes: an exampe of a nature-based infrastructure climate adaptation solution providing flood protection with an artificial beach and dune landscape. Photo © Bisonder Producties, Sabine Bison.

NbS, such as Room for the River and the Sand Engine cannot be realised without involvement of the dredging industry. Is the dredging community sufficiently involved in NL2120

Alex Two major dredging companies, who were also founding partners of EcoShape, are involved in NL2120. We're also engaging the broader sector, because scaling up requires sharing knowledge widely including with other market players. For example, we are preparing a regulation that enables initiators of projects or area developments to make use of the knowledge that has been developed by NL2120 to apply NbS.

In the dredging community, we promote interdisciplinary design; to consider all aspects during the decision-making process. Do you think the best solution is always an NbS?

René No, you always have to assess what is most cost-effective. Especially in this transitional phase, I expect we'll often see grey (technical) solutions supplemented by green (nature-based) ones, such as the Hondsbossche and Pettemer sea defence, which was a hard structure, later enhanced with a soft coastal defence.

Read the Sustainable Asset Valuation (SAVi) of nature-based coastal protection in the Netherlands.

Alex I agree. NbS are a means, not an end. It's essential to assess them based on the objectives of a project. Having said that, at the moment, standard tender procedures can eliminate ambitious sustainability goals early in the process. This is partly because NbS are not yet mainstream – they may take longer, involve more stakeholders, or not fit into current permitting systems.

Finally, should the conditions that now prevent sustainable solutions from being chosen be revised? After all, policy and regulation also need maintenance.

Alex Yes, I believe so. René and I work closely on this. We've established a strategic interdepartmental dialogue at director level to ensure NbS are better embedded in policy, implementation programmes and guidance documents and tendering. But this isn't just about government. If you revise the frameworks, the private sector must be ready to provide solutions and prove they are just as safe and sustainable as technical ones. So, we're working on both fronts: government policy and expanding the NbS offering in the private sector.

René I'd add that it's also important to integrate the NbS philosophy into education and professional training. We need a new generation that can carry this forward and help shape a safe, climate-resilient Dutch delta with nature as the foundation.

EcoShape focuses strongly on bringing knowledge into practice and has a lot of experience. **We're building on their work.**

RESTORING OYSTER REEFS with nature-inclusive marine infrastructure

While essential to coastal development and maritime industries, dredging and marine construction activities can unintentionally disrupt marine ecosystems. At Van Oord, we aim to deliver solutions for marine infrastructural developments that protect and enhance habitats and biodiversity. Over the past few years, we have explored how nature-inclusive designs can transform traditional marine infrastructure into ecosystem-supporting assets. The reintroduction of the European flat oyster to the North Sea is a key example.

Oysters are a vital species for maintaining marine ecosystem health, as they provide both habitat and food for other marine life. Two centuries ago, oyster reefs covered approximately 20% of the Dutch North Sea seabed. Today, however, those reefs have become rare. Significant bottom-trawl fishing destroyed large parts of the natural reef structures, but the fact that oysters once thrived in the North Sea means suitable environmental conditions are present, giving us a real opportunity to restore them.

As a global maritime contractor, Van Oord has accumulated years of experience in developing innovative and sustainable marine solutions. Through our Ocean Health initiative, we apply this knowledge to restore the health of seas and oceans, with projects covering the restoration and rehabilitation of oyster and coral reefs, seagrass meadows and mangrove forests.

Our general approach to nature-inclusive marine infrastructure follows two key phases: landscaping and inducing life. In the landscaping phase, we provide suitable substrates for the ecosystem development, utilising the infrastructure. In the inducing life phase, we overcome the lack of connection between natural reefs and the newly built habitat, by actively introducing the targeted species in the area. Careful planning of the areas where you want to develop ecosystems is crucial.

Before scaling up, it's essential to ensure that the ruling legislation, environmental conditions and suitability of the newly built infrastructure are aligned. This is why pilot projects are so important – they provide the necessary information to confirm that scaling up can be successful. Following several pilot projects for oyster reef restoration that provided crucial insights, we conducted targeted research to further optimise our strategies, resulting in a five-step approach.

Flat oysters used for the restoration and rehabilitation of oyster reefs.

Designing nature-inclusive marine infrastructure

From 2020 to 2024, we partnered with Delft University of Technology to explore ways to scale up and optimise our solutions for nature development. Building on this collaboration, we adopted a step-by-step approach to designing nature-inclusive marine infrastructure that delivers a widespread impact. This process can be applied to various types of marine and coastal infrastructure, including offshore wind farms, dykes, breakwaters and dredging and reclamation activities.

Step 1: Define objectives

Establishing clear operational objectives is the essential first step when designing nature-inclusive marine infrastructure. These objectives should consider policies, environmental conditions and foreseen infrastructural development. They should also be embraced by all stakeholders involved, including authorities, developers, contractors and environmental organisations.

Step 2: Identify potential

Identifying suitable environments requires focusing on features that can support ecosystem restoration and development. Past, present and projected environmental conditions, such as the (historic) presence of the targeted species or habitats and water dynamics and seabed conditions, should all be taken into account. When assessing these conditions, it is recommended to follow established standards, such as the EU's Environmental Impact Assessment Directive or the International Association for Impact Assessment.

When assessing the suitability of the environment, it is important to keep the objective in mind. Depending on the objective – enhancing overall biodiversity, supporting threatened species or restoring specific habitats – specific design features may be required for success.

Step 3: Identify suitable design modifications

Marine infrastructure can serve dual purposes: meeting human needs while supporting marine life. Structures, such as dredged channels, breakwaters, seawalls and scour protection can be modified to enhance ecological values through small adaptations in materials, texture and shape.

The process begins by identifying suitable design modifications. Each proposed adaptation should then be evaluated through a quantitative assessment to determine whether nature-inclusive

designs can have the intended effect on the ecosystem. This process also enables developers to make informed decisions by weighing the ecological benefits against associated costs.

Step 4: Apply interventions

Once viable and effective modifications are identified, they should be applied to marine infrastructure to enhance ecological value. Marine infrastructure offers long-term opportunities for habitat development due to its durability and persistence. By embedding nature-inclusive features in the marine infrastructure, these can support the settlement, growth and resilience of marine life over time.

Step 5: Achieve scale by combining scientific knowledge with industry practices

Achieving impact at scale remains one of the most challenging but also essential components of marine restoration. To scale restoration efforts effectively, it is essential to combine scientific knowledge with industry-based approaches. We defined the following five "golden principles" that demonstrate how collaboration between scientists and industry partners can enhance marine ecosystem restoration:

1. Pursue upscaling
To achieve positive impact at scale, use industry-based equipment and techniques instead of smaller-scale manual practices that are commonly used.

2. Landscaping
To replicate complex habitats cost-effectively and at scale, use nature-friendly designs of marine infrastructure instead of standalone artificial reef structures.

3. Induce life
To overcome the lack of connection between natural reefs and the newly built habitat, actively introduce the targeted species and habitats by installing broodstock instead of relying upon nature to slowly repopulate reef areas.

4. Support self-sustainment
To create suitable conditions for ecosystem restoration, use ongoing natural processes instead of one-time human interventions.

5. Ensure continuity
Shift from short-term restoration efforts during construction projects to long-term continuation of initiated efforts by local partners.

Van Oord colleague inspecting an oyster table prior to installation.

Droppable oyster structures ready to be placed in an offshore wind farm.

Following these principles for combining scientific knowledge with industry-based approaches increases the likelihood of achieving meaningful and long-lasting impact.

Applying the approach to oyster reef restoration in the North Sea

With this step-by-step approach, we investigated how offshore wind farms can contribute to European flat oyster reef restoration in the North Sea. By applying nature-inclusive design principles, we developed practical interventions that integrate ecological restoration with large-scale offshore wind farms.

Our review of policies and laws showed both the need for and support of oyster reef restoration in the North Sea, such as the Dutch government's commitment to recovering flat oyster beds as part of the European Marine Strategy Framework Directive.

In assessing the potential of offshore wind farms in the North Sea, we found that these sites typically have hard substrates in the form of scour protection around turbine foundations and at cable-crossings. The presence of these hard substrates provides settlement opportunities for oyster larvae, while the absence of bottom-disturbing fisheries allows oyster reefs to develop without habitat disruption.

We then considered various design modifications that leverage the features of offshore wind farms. In doing so, we evaluated their potential effects across multiple spatial scales. These scales help us understand the project's impact at different sizes, from the entire North Sea region (mega-scale) to the areas between turbines in the wind farm (macro-scale), the protection around turbine bases (meso-scale) and the materials used in construction (micro-scale).

From this evaluation, we learned that oysters prefer hard, stony substrates, such as granite and concrete. Granite, already commonly utilised in offshore wind farms, proved the most favourable material for oyster settlement, making these sites particularly well-suited for oyster reef restoration efforts.

Offshore wind farms as promising sites for restoration

Offshore wind farms have rocky scour protection at the base of turbine foundations and cable crossing, providing hard surfaces that support reef formation. Additionally, offshore wind farms are closed to bottom-trawling, a fishing method that drags heavy nets across the seafloor, destructing seabed habitats such as oyster reefs. By incorporating nature-inclusive designs, which integrate ecological needs into built infrastructure, these offshore wind farms can serve a dual purpose: generating renewable energy while also supporting marine biodiversity.

Our initial pilot projects involved the development and installation of oyster tables: large concrete structures onto which hundreds of adult oysters were attached. Oyster tables provide a solid foundation for this oyster broodstock to initiate reef development and are designed to remain intact for the lifetime of a wind farm. However, they are also heavy, and a vessel equipped with a crane is required for installation. This significantly increases cost and operational complexity. Though the oyster tables have proven to be a successful method for ongoing and future oyster reef initiation, cost considerations also resulted in the development of an alternative approach.

Droppable oyster structures as a scalable alternative

Our research resulted in an alternative to the oyster table: the droppable oyster structure (DOS). The DOS weighs up to 50 kilogrammes, making it nearly 100 times lighter than the oyster tables. Its manageable weight allows for manual deployment by two people using a small, standard vessel. In comparison, the oyster tables required advanced and costly equipment outfitted with a crane.

The DOS design was made possible through physical scale model studies conducted at Delft University of Technology, which identified two optimal shapes for the structure: the tetrapod and the cube. The design and shape of the structure were developed to meet the needs of the oysters while ensuring a controlled deployment. The structure should descend vertically, allowing for precise placement on targeted spots. Once landed, it should remain stable and avoid tumbling. This approach enables oysters to be introduced easily, affordably and on a large scale.

Developers can make a significant positive impact **on marine ecosystems.**

Oyster table installation at Luchterduinen offshore wind farm in the North Sea.

Oysters are attached to the structure before being lowered into the sea near rocky areas. Once placed, the oysters produce larvae that can settle on nearby hard surfaces, gradually contributing to the formation of a self-sustaining reef.

In the fall of 2024, these structures were deployed at the Borssele 1 and 2 offshore wind farm. To evaluate the methods' effectiveness and monitor oyster settlement and reef formation, we collected video footage using a remotely operated vehicle (ROV). While it is too early to assess the full impact, the initial footage confirms that the structures landed as planned and remain undamaged after deployment. More importantly, the oysters are thriving. We will continue monitoring through the coming years, collecting valuable insights into the project's long-term impact.

Continuous innovation

In January of this year, we began working on a new initiative that could significantly impact future oyster restoration efforts. It involves designing mobile basins where oyster larvae can pre-settle on rocks. This so-called remote setting allows us to nurture oyster larvae in controlled environments, increasing their chances of survival and successful settlement in natural habitats, which could lead to more efficient and scalable restoration of oyster reefs.

Installation methods for these rocks are being developed and tested to identify the most effective solution. Later this year, we will install oyster larvae on rocks in a Dutch port, followed by another installation in 2026 at a cable crossing in the North Sea. We will monitor through 2027 to assess the effectiveness of the method.

Collaboration as the key to success

Over the years, governments and environmental organisations have increasingly encouraged the development of nature-inclusive marine infrastructure. However, many well-intended initiatives aimed at promoting ecosystem restoration fall short of their desired impact because they lack alignment within a broader, cohesive strategy designed to achieve scale. As the need for sustainable solutions to protect marine biodiversity grows, the ability to integrate ecological principles into infrastructure development becomes ever more critical.

Collaboration is the key to successful outcomes. The knowledge of reef restoration is really developed within the scientific community, particularly at universities and research institutes. However, the feasibility of implementing these solutions at scale can only be confirmed by engineering companies and project developers. It is also vital that all relevant stakeholders in a given area commit to the same objectives and approach. This collaboration ensures that all necessary knowledge and expertise from various disciplines are included and limits the risk of conflicting efforts that could work against each other.

Nature-inclusive designs, such as those applied to offshore wind farms and other marine infrastructure, show that economic development and environmental preservation are not mutually exclusive. By rethinking traditional approaches and incorporating ecological restoration into the planning and development of marine projects, developers can make a significant positive impact on marine ecosystems.

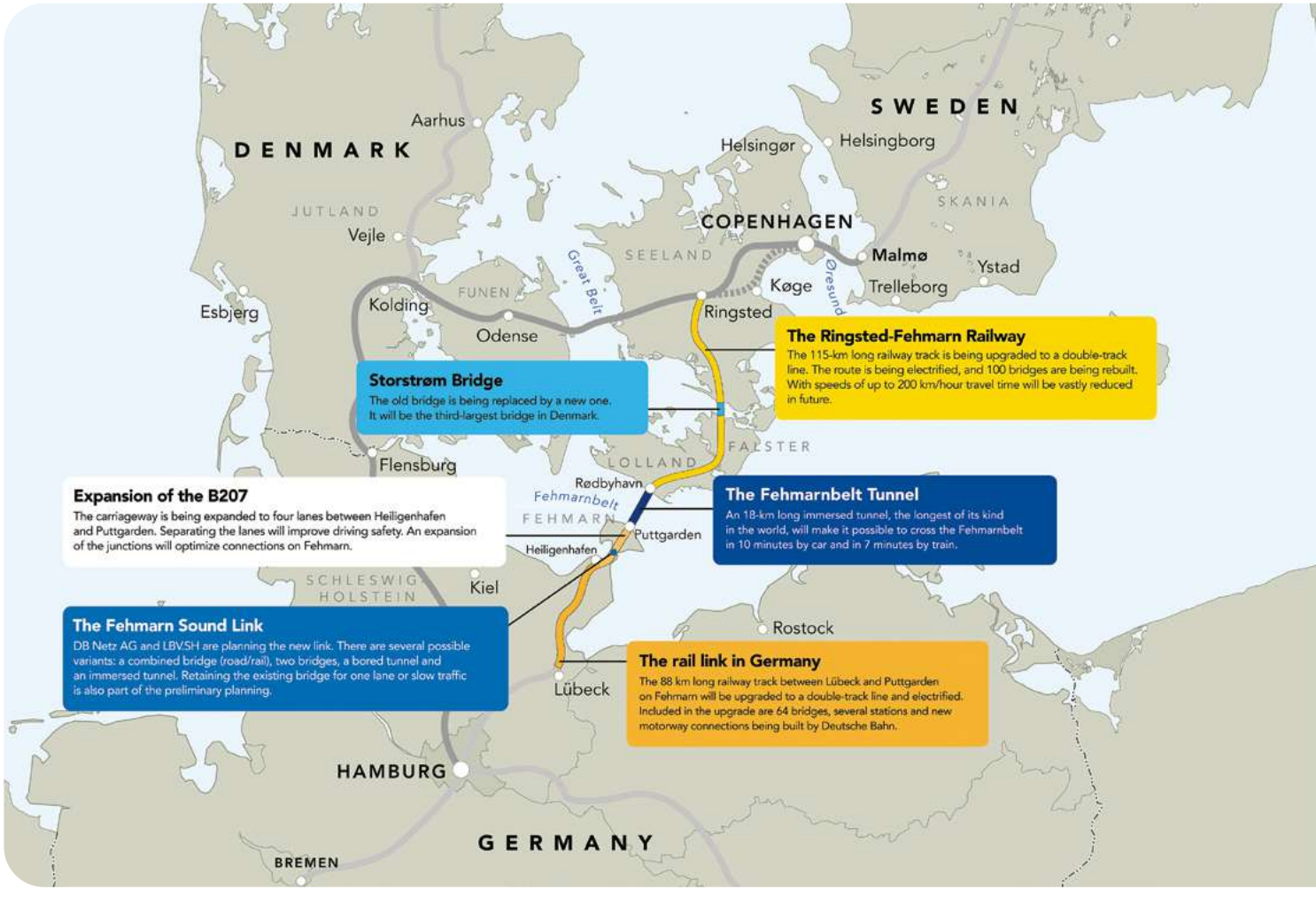
The application of the methods presented has the potential to lead to the realisation of truly effective nature-inclusive marine infrastructure, driving lasting, impactful solutions for marine restoration. By leveraging the combined strengths of science and industry, we can lay the foundation for a future where marine infrastructure not only meets human needs but also contributes to the restoration and preservation of our oceans.

Remment ter Hofstede

Engineering Specialist, Van Oord, the Netherlands.

Fehmarnbelt tunnel trench dredging project: a multifaceted sustainable approach

A fixed and direct transport connection between Scandinavia and Central Europe has been an enduring vision for many decades. This vision is now about to be realised with the construction of the Fehmarnbelt Fixed Link – an immersed tunnel that will cross the approximately 18-kilometre-wide Fehmarnbelt sea strait between Rødbyhavn in Denmark and Puttgarden in Germany.



Trans-European Transport Network (TEN-T).

The Fehmarnbelt Fixed Link is designed and planned by Femern A/S, a subsidiary of the Danish state-owned company Sund & Bælt Holding A/S. The political background for the link is a state treaty signed by the Danish and German governments in 2008. The Fixed Link will improve the connection between Central Europe and Scandinavia by means of an efficient and high-quality transport infrastructure. Not only will it fill the infrastructural gap with a combined motorway and railway connection between Scandinavia and mainland Europe, it will also result in the highly needed release of the Danish East-West rail connection. Freight trains from the Danish island of Zealand, Sweden and Norway will be able to take the tunnel to Germany and mainland Europe instead of following the current longer route via Southern Jutland and Northern Germany (Hamburg), shortening the rail freight distance by 160 kilometres. The Fehmarnbelt Fixed Link is part of the TEN-T network that aims to enhance the efficiency of the European infrastructure so that the EU's single market functions better and with less environmental impact. The tunnel will also offer a new strong link to the Fehmarnbelt region itself, which will stimulate growth and prosperity. Nine million people currently live in the region, which extends between the cities of Hamburg, Kiel, Lübeck, Copenhagen and Malmö.

After an international competitive bidding process, the Tunnel Dredging and Reclamation (TDR) contract was awarded to Fehmarnbelt Contractors (FBC), a joint venture between Boskalis and Van Oord. FBC started preparations in 2019 and actual operations commenced in June 2020 when the first rock was placed to start the construction of the breakwaters around the Lolland work harbour. Dredging of the tunnel trench was completed in 2024. Other contractors are responsible for the construction and placement of the concrete tunnel elements (Fehmarn Link Contractors FLC) as well as the construction of the motorway, railroad and tunnel management systems (Femern SICE Cobra FSC). The Fehmarnbelt tunnel is planned to open in 2029.

Project design

Femern A/S was responsible for designing and providing the basis for the official approval of the coast-to-coast section of the Fehmarnbelt Fixed Link. After a series of investigations between alternative solutions (an immersed tunnel, a bored tunnel, a cable stayed bridge and a suspension bridge), an

immersed tunnel was recommended as the preferred technical solution for the Fixed Link. Femern A/S, advised by a consortium of consulting engineers consisting of Ramboll, Arup and Tunnel Engineering Consultants (TEC), provided a basic design of both the tunnel trench and all the facilities associated with the early construction works of the FBC scope of works. These included work harbours, land reclamations, coastal protection works, site roads and several large stockpiles. These designs were detailed by FBC, thus allowing for optimisation of the design towards, for instance, the chosen work methods and the results of detailed field investigations.

To align with upcoming (strict) legislative and regulatory arrangements that logically come with such bilateral project development, minimisation of environmental impact was an important design requirement, with an aim of creating added value. This focus in the initiation phase resulted, for instance, in the requirement to reuse all dredged material onshore to minimise spreading of sediments in the Fehmarnbelt and to use these materials to create natural value within reclamations, predominantly on the Danish side.

Since physical parameters such as strength or bulking of material after dredging are depending on methods chosen for dredging, transport or placement of the same material, involvement of the contractor in defining these parameters is of utmost importance to assure that such value creation stays economical. Therefore, design of some horizontal and all vertical dimensions of land reclamations and stockpiles were the contractors' responsibility. In this arrangement, optimised storage and reuse of dredged material was achieved in the most sustainable way. At the same time, the land reclamations were to be constructed using dredged material usually considered unsuitable for such construction works in view of poor remoulded strength of the materials. As the ultimate use for the land reclamations was to create natural values, at least for the majority of its areas, playing with strength requirements in alignment with final use became another aspect of increasing the project's sustainability.

Environmental Impact Assessment

The Fehmarnbelt is an area of outstanding natural beauty and importance. The tunnel trench dredging works were executed in the vicinity of several Natura 2000 sites and other nature protection sites. The trench is running parallel to one of the most important bird migration routes between Scandinavia and mainland Europe. The belt itself is home to protected species, such as harbour porpoise, harbour seal and grey seal. Seagrass meadows and boulder reefs are located at some distance from the works.

To protect these nature values, an extensive environmental impact assessment was undertaken, satisfying both the Danish and German authorities responsible for the protection of the environment as well as international treaties for the protection of marine environments, such as the Helsinki Convention and OSPAR. This assessment resulted in extensive requirements related to the execution of the works, including reporting requirements, training requirements for crews operating the dredging equipment, thresholds and limits to be adhered to, and calendars governing actual operations. In this way, the stakeholders' needs (with stakeholders being broadly defined as both natural, socio-economic and legislative stakeholders) could all be addressed, while still allowing the execution of the construction works.

In order to effectively manage the operations while complying with these requirements, a method of adaptive execution management was selected by FBC. The contractual arrangements between Femern A/S and FBC allowed for such an approach.

Adaptive execution management

Fine sediment control

In view of previous experiences with large-scale marine infrastructure development projects in Denmark, the proper control and management of fine sediments originating from the dredging and reclamation activities were a crucial aspect of all preparations and execution of the project, aligning with expectations from both countries' legislative and regulatory context. Following from extensive environmental research performed during the environmental impact assessment, a

Spill engineer taking water samples for calibration and verification of instruments.

total sediment spill budget was defined in advance. This sediment spill budget was split into smaller parts, distributed over time (months and seasons) and space (eight spill monitoring areas along the alignment of the tunnel trench, including nearshore areas at Lolland and Fehmarn). Spill budgets range from negligible or zero in certain environmentally sensitive areas in the summer season to allowable levels in less sensitive areas over the winter period. Overall compliance is monitored at all these levels and at the totals. FBC had the responsibility to ensure compliance using extensive field monitoring and numerical modelling, including verification of achieved accuracies at the end of all dredging operations.

To achieve this, FBC set up a robust management process to control spill: the Plume Clarity Management Programme. This management framework consists of several feedback loops connecting spill monitoring and spill modelling as well as execution of the works and mitigating measures. All dredging activities were combined into 35 scenarios consisting of combinations of dredging methods and soil units. Each scenario was extensively monitored using specialised vessels and equipment. A specific spill impact reduction and identification tool was developed to take account of the spill generated by dredging operations on a daily basis based on monitoring as well as modelling. Continuous reporting using internal and external dashboards, including a traffic light strategy, was part of the spill management framework.

In practice, sediment spill control governed all dredging and reclamation operations in detail. Dredging planning over weeks and seasons was based on predictive modelling of spill amounts as well as field monitoring results. By adapting the planning based on actual data, the entire operation was optimised by FBC to minimise spill. Ultimately, the dredging works were concluded well within the overall spill budget.

Underwater noise management

Underwater noise is a significant theme in the Fehmarnbelt, potentially impacting local marine species as harbour porpoise, grey seal and harbour seal as it could mask biological signals, changing animal behaviour and causing physiological impacts in extreme situations. Underwater noise is subject to EU legislation, Danish and German legislation as well as several international conventions, including the Helsinki Convention and OSPAR. The topic was extensively discussed during the planning stage of the project because of a lack of national and internal standards to measure and assess noise from shipping and dredging. These discussions resulted in specific requirements that were verified through modelling by independent experts.

Willem van Oranje bunkering biofuels.

Acoustic pingers are used to keep marine life such as seals away from the construction works. Photo © Femern A/S.

> Critical success factors for this collaboration included **the early involvement of all parties during the design process.**

In practice, compliance with the underwater noise requirements did impact the construction works. These impacts ranged from the need to take precautionary measures, such as the installation and deployment of acoustic pingers during piling operations to significant planning impacts on dredging operations. FBC provided results of detailed underwater noise measurements of all major equipment involved in the project, measured onsite to ensure relevance to local conditions. This data was used to update underwater noise modelling, which in turn resulted in the need for adaptive management of dredging operations in order to secure compliance with the requirements.

Environmental management

Bird protection measures

The Fehmarn belt is the bottleneck of Scandinavian bird migration. Every spring and autumn large numbers of birds migrate across the belt and large areas in and around the belt are of international importance for water birds.

One of the key elements in protecting birds from the possible negative impacts of the works is related to light emission from the vessels. Requirements included the shielding of lighting, installation of filters on deck lighting and the timely switching on of lights during twilight to avoid shock effects for birds and attraction or barrier effects for fish. In practice, specific lighting plans were produced for each vessel involved in the construction operations. All vessel crews were trained to be aware of requirements and instructed on dealing with fatigued birds resting on board and disoriented birds. This included shutting down of lights in case of birds perching on the vessel. The crews were required to report daily on this topic during the bird migration seasons.

Greenhouse gas emissions

In an effort to reduce greenhouse gas emissions, FBC took several noteworthy steps in addition to common measures, such as the deployment of well-maintained equipment, selection of fuel-efficient equipment and optimised working practices and office management. These additional steps included the application of an energy regeneration system on a wire crane deployed for dredging of the deeper parts of the tunnel trench. This system stores a surplus of energy during the lowering of the crane's bucket, to be used for the hoisting process. Another optimisation aimed at reducing greenhouse gas emissions included the contractor induced adoption of a sand borrow area closer to the project site than the area included in the impact planning process, significantly reducing greenhouse gas emissions during transport. Last but not least, greenhouse gas emissions were reduced through the use of biofuels during the mobilisation of the trailing suction hopper dredger Willem van Oranje.

Record-breaking project

The Fehmarnbelt tunnel construction project is about to set records in many different ways. Upon completion, the tunnel will be the longest immersed tunnel worldwide. The dredging of the tunnel trench itself also required record-breaking achievements such as the dredging accuracies that met unprecedented requirements. At the same time, the construction has to adhere to the strictest environmental standards as set out in the environmental impact assessment and German plan approval process. As such, the tunnel trench dredging project can be seen as a state-of-the-art example of the integration of technical challenges with construction methods optimised to minimise the impact on the environment. These achievements were made in close collaboration between FBC as the contractor, the project owner Femern A/S and the consortium of consulting engineers Ramboll, Arup and TEC. Key elements of this collaboration included the establishment of joint project objectives, open communication in the best interest of the project and mutual trust in the capacity and capabilities of each partner. By applying these principles, each partner was tasked with the management of risks and challenges closest to its own field of expertise and sphere of influence. This resulted in the successful completion of this challenging dredging project.

Critical success factors for this collaboration included the early involvement of all parties during the design process to enable the integration of construction methods with added value creating design objectives, such as storage of all dredged material onshore while creating land reclamations using materials usually considered unsuitable for such purposes. Adaptive execution management was implemented during the execution of the dredging operations to safeguard adherence to the strict environmental requirements related to fine sediment dispersion and underwater noise generation.

Erik van Eekelen

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Project Control Manager, Royal Boskalis and Director EcoShape, the Netherlands.

Elevate your expertise with the **Dredging for Sustainable Infrastructure course**

The course was a game-changer. It provided practical tools and fresh perspectives that transformed the way I approach marine and freshwater infrastructure projects. The interactive group sessions were particularly enlightening.

The world of water infrastructure is evolving at an extraordinary pace, driven by the need for sustainability, environmental stewardship and societal advancement. To meet these demands, professionals in dredging and infrastructure development must embrace innovative methodologies that go beyond traditional approaches. The IADC-CEDA Dredging for Sustainable Infrastructure course provides state-of-the-art guidance to master the skills and insights necessary for transforming projects into sustainable success stories.

Built on a strong foundation

This course is inspired by the book Dredging for Sustainable Infrastructure, which represents the collective knowledge and experience of the international dredging community. Initiated as a response to the United Nations' 17 Sustainable Development Goals (SDGs), the book challenges readers to rethink the role of dredging from a narrow technical perspective to a broader, system-wide approach. The course brings these ideas to life, making the methodologies accessible and actionable.

A hands-on journey into sustainability

Facilitated by experts from IADC member companies and CEDA members, you'll delve into the core principles presented in the book, gaining firsthand experience through interactive lectures and workshops.

During the course you will:

- explore sustainability principles: Understand how to integrate sustainability in all project phases;
- navigate stakeholder dynamics: Learn strategies for engaging diverse groups early in the project lifecycle to achieve shared objectives; and
- address real-world scenarios: Dive into innovative equipment, techniques, sustainable solutions and collaborate in simulated projects that mimic the complexities of real-life infrastructure development.

Whether you work as a regulator, consultant, contractor or equipment manufacturer, this course illuminates the pathways to sustainability, enabling you to turn theoretical philosophies into actionable strategies.

Feedback from participants

Participants of this course leave inspired and equipped with a renewed perspective. More than just a technical workshop, the course offers a paradigm shift: moving from project-centric thinking to exploring how projects can serve as catalysts for ecological and societal improvement.

Your next step

Transform your professional journey today and enrol in the Dredging for Sustainable Infrastructure course to redefine the way you approach water infrastructure development. Together, let's create solutions that balance the economic, environmental and social needs of our planet.

The next course will take place in Singapore from 18-20 November 2025. To register visit https://bit.ly/DfSI-SGP25.

If your organisation would like to arrange an in-company course, then please contact Ria van Leeuwen (vanleeuwen@iadc-dredging.com).

COMING SOON...

New DFSI website to launch this autumn!

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Colophon

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