

# TERRA ET AQUA

## **WATER STORAGE**

Potential subsurface freshwater storage in land reclamations

## **BESMART TECHNOLOGIES**

Bio-Engineering Sediment Management And Removal of Turbidity

## **SMARTSEDIMENT QGIS TOOL**

# **EVALUATING ECOSYSTEM SERVICES IN ESTUARINE AND DELTA SYSTEMS**



# **EVALUATING ECOSYSTEM SERVICES IN ESTUARINE AND DELTA SYSTEMS**

---

Managing sediments, especially from dredging, disposal, nourishments and sand mining is important for the management of estuaries and coastal areas. When implemented in the right way, a sediment management strategy can be qualified as a nature-based solution as it uses the physical processes of erosion and sedimentation to create added value. There is a need for an evaluation of sediment strategies and the habitats that are created for a wider range of objectives than only biodiversity and nature conservation. The concept of ecosystem services provides this broader framework.

With the Smartsediment Ecosystem Services QGIS tool, users can assess ecosystem services in an estuary and compare scenarios with different sediment measures or developments. Read more on page 20.





---

Photo © Edwin Parez Rijkswaterstaat



## CONTENTS

### TECHNICAL

#### Bio-Engineering Sediment Management And Removal of Turbidity Technologies: BESMART Technologies

A research team at Deltares is developing a portfolio of technologies dedicated to the management of the finest and most challenging fraction of soft sediments. Read an overview of these technologies that make use of natural processes.



### ENVIRONMENT

#### The Smartsediment tool: a QGIS plug-in for evaluating ecosystems services

A QGIS plug-in enables users to make a first numerical evaluation of the impact of sediment management on ecosystem services in an estuary. The development of this tool and what it can offer are the subjects of this article.



### INTERVIEW

#### 'We should always try to strike a balance between economic development and environmental preservation and/or sustainable development.'

Stéphanie Groen, Director of Coastal & Climate Change in Asia for Aurecon in Singapore, tells us about sustainability and her appointment to the prestigious FIDIC Sustainable Development Committee.



### SOCIO-ECONOMIC

#### Land reclamation: The potential for subsurface freshwater storage

Research on sediment grain sorting leads to the conclusion that the subsurface of land reclamations can potentially be used for freshwater storage. A closer look at how land reclamations are formed shows the opportunities and benefits that new lands harbour for water provision.



### EVENTS

#### Save the date

Join the Congress Hydraulic Engineering Structures and Dredging or one of IADC's two upcoming seminars on Dredging and Reclamation.



### BOOK REVIEW

#### Building with nature: creating, implementing and upscaling nature-based solutions

A book to inspire both policymakers and practitioners to scale up nature-based solutions by showing their full potential in six landscapes. We ask EcoShape's editor to tell us more.



# HOW CAN THE DREDGING INDUSTRY ACHIEVE ITS SUSTAINABLE AMBITIONS?



**Frank Verhoeven**  
President, IADC

The Annual General Meeting (AGM) of the IADC once again took place in September 2020. Like many associations that have had to move their activities online, our event too was held digitally. As much as it was proof that an AGM can be held online successfully, we do hope that we can see each other in person at our next meeting. Additionally, this AGM proved that IADC and its companies are keeping up with the times, and in keeping with responsible management of progress, the theme of the AGM was sustainability.

The newly formed IADC Sustainability Committee and Young Management prepared a lively and thought-provoking programme. During online breakout sessions, four topics were the focus of discussions:

- The added value of the industry to social and environmental developments;
- Nature-based solutions;
- Green financing; and
- Carbon neutrality.

The input from the AGM was compiled and will determine the course of IADC over 2021 and the coming years.

## Finding green funding for sustainable ambitions

If the industry's lofty ambitions are translated into projects and real infrastructure, funding is needed. Financial institutes and investors however are still not familiar with sustainable marine infrastructure projects. There is so much opportunity to support sustainable maritime infrastructure with green funds and there is clearly a match to be made, but it needs to be made now.

The answer to this lies in effective communication and making the world aware of the dredging industry's ability to help protect people and environments from climate change. And in the knowledge companies possess to create living spaces, habitats, recreational areas, financial centres, coastal defenses and transport possibilities in a way that takes into account the many parties with a vested interest,

including those parties that do not have a voice such as the environment, oceans and animals. Projects must therefore be assessed for their total impact: economic, social and environmental. A holistic approach is necessary in order to identify both visible and invisible effects.


The topic is never far from our own minds; now we must launch it so that it reaches others. During the AGM, it became apparent that a good communications strategy is of prime importance. And IADC is tasked with this mission. Simply put, if we make the world aware of the knowledge that goes into projects, how much research has been done into the environmental impact and how we include all stakeholders in decision-making, projects can start far more quickly.

## Sustainability from the ground up

Many steps have already been taken towards informing people. Just think of *Dredging for Sustainable Infrastructure*, the book and the course with the most up-to-date information about project implementation. There are online factsheets and this very issue of *Terra et Aqua* contains articles and an interview which all, in some way, relate to the topic. I believe however, that the lag we see in communicating our message to a broader audience is that we have to tackle the problem from the ground up. That's a big task, but one we're good at.

And in this respect, allow me to draw your attention to *Terra et Aqua* itself. This issue is being published online only, but we will return to a printed version in the future. You may ask yourself if this is sustainable and we can wholeheartedly answer affirmatively: yes, most definitely. Our printer is the first in the Netherlands to be certified climate neutral. Paper, glue and ink pass the test. The value chain conforms to standards. The roof of the building filters NOx and in total their efforts cover 13 of the 17 SDGs. So enjoy your sustainable *Terra et Aqua*, both in print and online.





BIO-ENGINEERING  
SEDIMENT MANAGEMENT  
AND REMOVAL OF  
TURBIDITY TECHNOLOGIES:  
**BESMART  
TECHNOLOGIES**



All these bio-abiotic interactions have widely been observed in nature and discussed in scientific publications by Deltares, and also worldwide.

At Deltares in the Netherlands, a research team is developing a portfolio of technologies dedicated to the management of the finest and most challenging fraction of soft sediments. These technologies may unambiguously be called nature based because they make use of natural processes to enhance dewatering and strengthening, induce flocculation and the settling of fines, and protect the muddy bed from erosion.

Some of these technologies are already at an advanced stage of research and development, the reason that we can already report about them. For the present, the team refer to the portfolio of innovations as the Bio-Engineering and Sediment Management And Removal of Turbidity Technologies (BESMART Technologies) portfolio, though this has led to confusion. This research at Deltares explicitly does not involve techniques associated with classical biotechnology, such as gene manipulation or genetic engineering. The approach may be seen as holistic, and it does not interfere with nature but attempts to bring about a synergy with it.

The weakness of the naming of this research is presently a topic of discussion, but we do not want it to interfere with a presentation of the natural technologies that have already been brought to market or that will soon be ready for application. Examples of these technologies are:

- worms for soft sediment dewatering and strengthening;
- algae as a bio-flocculant;
- Kaumera® as a bio-flocculant;
- *Beggiatoa* (bacteria mats) as bed protection; and
- vegetation for mud dewatering, strengthening and bed protection.

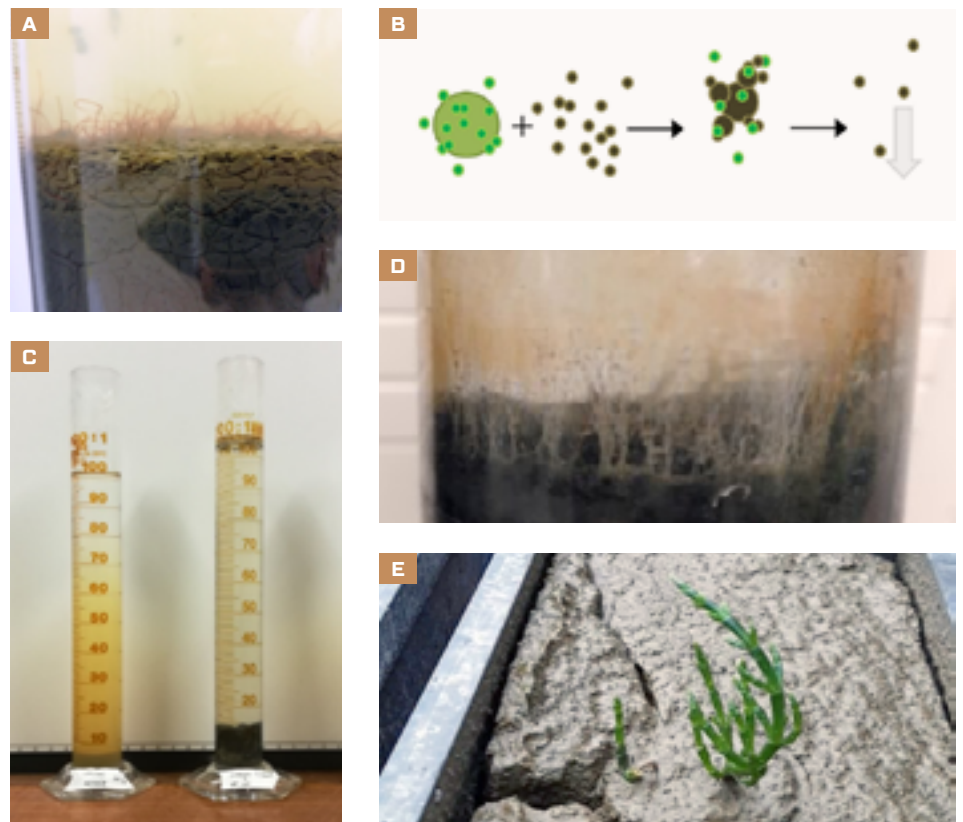


FIGURE 1

Overview of the BESMART Technologies as discussed in this article: (A) Worms for soft sediment dewatering and strengthening, (B) algae as a bio-flocculant, (C) Kaumera® as a bio-flocculant, (D) *Beggiatoa* (bacteria) as bed protection and (E) vegetation for soft sediment dewatering, strengthening and bed protection.





**FIGURE 2**

Deposition of soil in a land reclamation project (<https://publicwiki.deltares.nl/display/BTG/Strategically+placing+mud>)

**Over the coming sections each of the technologies in the portfolio will be discussed, and their technological goal introduced.**

All these bio-abiotic interactions have widely been observed in nature and discussed in scientific publications by Deltares, and also worldwide. Ours is an on-going and thus far successful attempt to make use of these natural processes for achieving engineering goals.

**Current sediment management techniques can be improved**

Soft sediments are mixtures of fine sediments (clay and silt), water and organic matter with a high water content. Typically, these soft sediments have a consistency ranging from chocolate milk to yogurt. Worldwide, soft sediments are transported and deposited in the context of mining operations, maintenance and capital dredging in ports and navigational channels, land reclamation projects, and beneficial reuse of sediment applications. Soft sediment, and sediments generally, therefore play a key role in human development activities. Pressure to use and reuse locally available resources (i.e. the circular economy), to work towards climate mitigation and adaptation, the development of nature and on resilient and sustainable infrastructures demands an optimal and integrated management of these sediment flows.

Though they are extremely common in industrial and engineering operations and are potentially a precious resource for sustainable

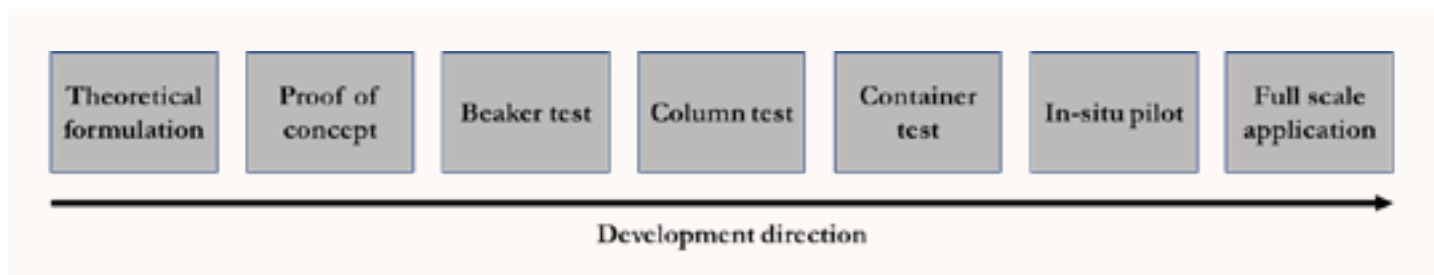
development, these soft sediments present significant management challenges. Varying feed properties and segregation of the coarse and fine fractions cause heterogeneity of deposits, and consequently varying consolidation, strength and total settlement characteristics. The finest, low-dewatering and low-strength fraction poses the greatest challenges. In re-suspension soft sediments are typically easily erodible, and once brought into suspension in the water column its fines exhibit their characteristic large residence time and associated turbidity issues.

There are several traditional measures to overcome these sediment management issues. First, there is the use of flocculants and chemicals to induce flocculation and the settling of a suspension, but also to thicken and strengthen soft sediments. Second, carrying out sediment re-working hardware interventions, like physical compaction, to increase the strength of soft sediments and minimise the re-suspension of fines. Finally, applying geo-textiles and other types of bed protection to control the erosion of fines. Typically, these measures are labor intensive and therefore expensive and environmentally impacting.

Scientists from Deltares are developing innovative and naturally based technologies dedicated to the management of the finest and most challenging fraction of these soft sediments. These technologies make use of natural processes to enhance dewatering and strengthening, induce flocculation and the settling of fines, and protect the muddy bed upon deposition of the soft sediments. These are all being developed under the umbrella of the same research initiative, the BESMART Technologies portfolio. Apart from their obvious savings (these interventions are mostly natural and therefore passive) and environmental care, these technologies all take a real and sound technical ability to solve sediment management issues as their starting point. In fact, they all have a very specific technological goal. Over the coming sections each of the technologies in the portfolio will be discussed, and their technological goal introduced.

A final important point of consideration is that the integration in the local ecology of the system is a necessary condition for considering any of our technologies.





**FIGURE 3**

The technological development cycle.

The technologies may not make use of non-endemic biological factors, and their development must ensure either a safe continuation or even the restoration of the main ecological functions of the system. Bypassing biological manipulation and investing in ecological integrity is therefore an axiom of the fine BESMART Technologies portfolio.

### The seven steps of the technological development cycle

The technologies discussed here are the products of a technically sound research process. Their efficiency has been demonstrated in a laboratory setting, and they are now transitioning into intermediatescale and even full-scale application. Others have, however, only successfully completed the proof-of-concept tests. And other technologies are still in the phase of theoretical formulation but have been included in this overview given their consistency with the philosophy of the portfolio. To cover all the different stages of development that our technologies undergo, we have defined the following phases of what we call the technology growth cycle. All the introduced technologies are currently at one of the following development phases:

- Theoretical formulation of a sediment management bio-technology, based on observations of biotic-abiotic interactions in nature (e.g., plants strengthening a soil via their root development);
- Proof of concept in a laboratory. The objective of the proof of concept is to qualitatively demonstrate that the technology has an impact in the targeted engineering goal. In other words, its aim is to turn the theoretical formulation into a

simple and qualitative laboratory test;

- Beaker tests to quantitatively assess the performance of the technology. Once the proof of concept has confirmed that the technology can deliver an engineering goal we set up a number of small beaker tests of approximately 0.5 l in volume per beaker to make a first assessment of the parameter space best suited for the technology to attain its engineering goal;
- Column tests of larger (but still smaller than in application; for example, approximately 2-20 l of soft sediments) sediment volumes, for in-depth analysis of the engineering performance of the technology for a selection of initial parameters as determined by the beaker tests;
- Container tests of relatively larger volumes of soft sediments (in the order of 1 m<sup>3</sup> or 2 m<sup>3</sup> to study spatial effects and effects for greater depths. This is also where operational considerations like the application method start playing a role;
- On-site pilot test to evaluate the performance of the technology under field conditions, including the feasibility of the method when integrated into the existing engineering or industrial operations; and
- Full-scale application.

### BESMART Technologies compared with nature-based solutions

It is necessary to position BESMART Technologies in relation with the popular nature-based solutions discipline which is currently subject to many research and application studies. Nature-based solutions can be defined by their use of natural processes to realise hydraulic infrastructure. Moreover, the development of a nature-based solution is often accompanied by

the ecological restoration of the system. BESMART Technologies on the other hand are focused on one particular engineering process helping us to realise an infrastructure, but may not be the actual infrastructure itself. And though it needs to be respectful of

**The technologies discussed here are the products of a technically sound research process. Their efficiency has been demonstrated in a laboratory setting, and they are now transitioning into intermediatescale and even full-scale application.**



local ecological dynamics it does not aim for ecological restoration per se. This becomes more explicit when defining examples of nature-based solutions and BESMART Technologies in contrast with their grey engineering equivalents. A nature-based solution could, for example, be a vegetated foreshore (to lower the height of the design of a dyke next to it), and its grey equivalent would be a higher dyke. A BESMART Technology could be the effective strengthening of soil under trees against erosion, with its grey equivalent being mechanical soil compaction or the placement of a geo-textile. The goal of the nature-based solution is to protect the coastline, while the goal of a BESMART Technology applied similarly is simply to strengthen the bed at the shoreline (which ultimately can address a coastal safety goal and also a water quality goal via a decrease in sediment re-suspension and turbidity). BESMART Technologies are thus meant to either replace or optimise certain engineering processes such as compaction, dewatering, bed protection and flocculation but not necessarily to become hydraulic infrastructure.

### Worms for soft sediment dewatering and strengthening

Applying natural worms to soft sediment deposits enhances dewatering and the strength of soft sediment deposits. This is the most advanced technology within our portfolio when positioning it on the technological development cycle, as it is currently transitioning from large column tests to container scale, and as there are already concrete discussions about a potential future pilot with some of the involved stakeholders. The technology is inspired by observations of natural sediment dynamics in Dutch water bodies, where oligochaete worms were found to qualitatively speed up dewatering of freshly deposited soft sediments (de Lucas Pardo, 2014). The basic principle is that worms, which feed on the organic matter present in the soft sediments, produce tunnels within the soft sediment matrix, enhancing dewatering. Worms appear also to change the geochemical structure of the soft soil matrix with their biological functions, enhancing strength. The type and amount of organic matter in the sediment influences the behaviour of the worms. Here we define two types of soft sediments, based on the availability of organic matter in them:

1. derived from industrial operations with very little organic matter, for example, from mining operations. In this article we call this 'tailings'; and
2. organic-rich sediment from natural systems that was transported because of engineering activities, for example, from deepening navigational channels or from land reclamation projects. In this article we call this 'natural sediments'.

In tailings, organic matter is scarce and worms must travel up and down the sediment throughout its entire thickness, seeking suitable food. This results in a tunnel network through the entire layer of soft sediments which creates a substantial increase in its hydraulic permeability, notably speeding up dewatering. The disadvantage of applying worms in this type of soft sediment is that they die from starvation after few months, ending their favorable effect on the sediment. The initial research phases for the use of worms to dewater tailings were published by Yang in 2016 and 2019 in research projects led by Deltares scientists. In natural



**FIGURE 4**

Image of an oligochaete worm population at the waterbed interface of soft sediment. The tunnels made by the worms that help to dewater the soft sediment are visible through the glass.



**Preliminary exploratory tests in natural soft sediments dredged from a European port revealed that in only 3 days worms can lead to the dewatering of 15% of the initial volume of soft sediments.**

sediment where organic matter is abundant, worms stay in the uppermost 15 to 20 cm of the bed. Worms survive indefinitely in this type of soft sediment, but their beneficial effect is confined to the uppermost centimetres of the bed. Optimising conditions for the worm-enhanced dewatering in these two types of soft sediments requires different approaches.

In tailings with little organic matter worms were demonstrated to increase solid content from 43% to 61% in only one month (for a layer of 30 cm of soft sediment in the laboratory). This is equivalent to an increase in the soft sediment's bulk density from 1,350 kg/m<sup>3</sup> to greater than 1,600 kg/m<sup>3</sup>. Without worms, self-weight consolidation of the exact same type and volume of tailings would result in a final

52% solid content, but after approximately three months. This means that the increase in solid content with worm treatment is 100% greater relative to how many more are absent, and it happens in one third of the time. This positive effect is explained by the tunnels that the worms dig throughout the entire thickness of the soft sediment when seeking food, which becomes an easy and fast route for water to escape the bed, therefore speeding up dewatering and strengthening.

Yet worms start dying in tailings after one month due to food scarcity, and end up disappearing after approximately a month and a half. To overcome the problem of limited food for worms in tailings, the Deltares research team incorporated into the tailings a small portion of easily available and cheap organic matter, such as straw or hay. The amount of matter added is approximately 0.5% in mass of the solids in the soft sediment. This organic matter is uniformly distributed throughout the entire thickness of the soft sediment. In real operations this would necessitate, for example, the injection of small amounts of hay where the soft sediment is discharged from the pipe. When organic matter was added to the soft sediment, worms reproduced by a factor of 3 after 4 months. This method should be a way to increase the beneficial dewatering and strengthening effect of worms over time. In fact, preliminary results from on-going laboratory experiments at Deltares suggest that the highest dewatering rates result from adding organic matter to tailings.

Preliminary exploratory tests in natural soft sediments dredged from a European port revealed that in only 3 days worms can lead to the dewatering of 15% of the initial volume of soft sediments. This is a high daily dewatering rate when compared with the results in tailings, taking into account the fact that the previously reported increase of solid content was equivalent to almost 40% of the initial volume of the soft sediments but needed more than 30 days to develop. This is particularly remarkable when compared with the 0% compaction that the soft sediments exhibited in the absence of worms. A 0% dewatering after a few days under self-weight consolidation is not that uncommon, given the capacity of certain clay minerals and certain organic matter types to form large aggregates with a very high water content, which are unlikely to lose water and compact.



**FIGURE 5**

A scientist at the Deltares sediment laboratory setting up laboratory experiments on worm dewatering of tailings.

In the presence of worms however, significant dewatering did not occur after the initial 15%. The worms, which initially travelled up and down the entire thickness of soft sediments to explore and adapt to their new environment, slowly started to concentrate at the surface over time, where we presume they found everything they needed to live. Therefore in natural sediment with more organic matter, the challenge to optimise the effect of worms on dewatering the soft sediments is fundamentally different. In this type of environment worms do not experience food scarcity and live indefinitely, but their action is confined to the top of the soft sediments and therefore their beneficial effect becomes limited. Recent testing in other types of natural sediment collected in other industrial contexts indicates an even higher performance of the worms following the optimisation and adjustment of the worm density to the characteristics of the local mud. Finally, a worm re-worked bed has very recently also proved to dewater (or ripen) via evaporation in a more rapid and efficient manner as the result of a dense tunnel network in the upper region of the bed.

To prevent the worms' concentrating at the surface of natural sediment, and to optimise their effectiveness as a dewatering tool, the Deltares research team have engineered a new solution similar to that applied in tailings.

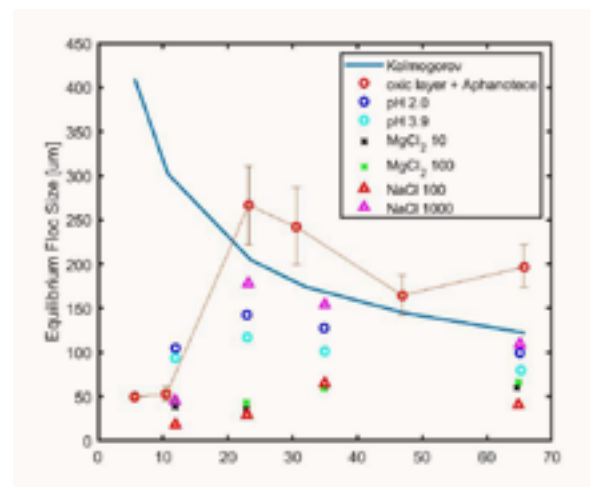
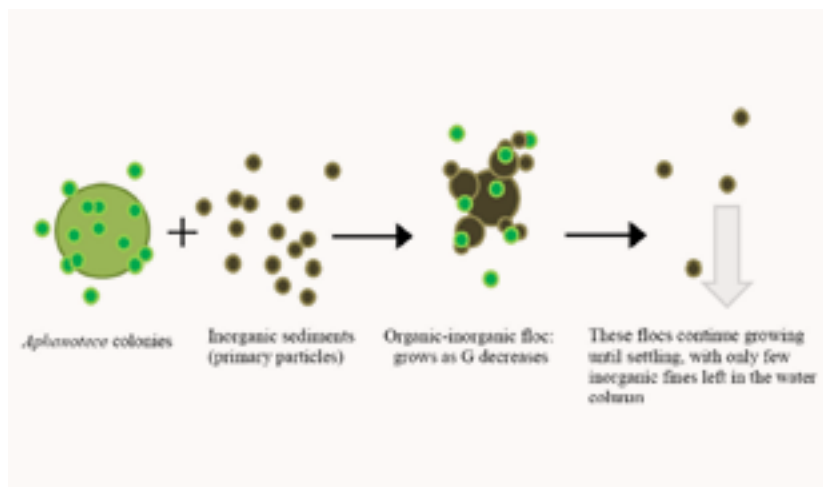
It is easily available and uses cheap organic matter mixed with the soft sediments. This time it was not distributed throughout the entire thickness, but placed at depth in the soft sediments. Assuming that added food is desirable for the worms, researchers strategically place the matter such that it motivates the worms to dig tunnels over the entire depth of the soft sediments, likely achieving similar long-term performance as in tailings. The latter is currently being tested at the Deltares sediment laboratory and will soon be evaluated as a technical possibility for managing soft sediments at important European ports.

Worm-enhanced dewatering of soft sediments is therefore a promising sediment management technology that displays very competitive results in the laboratory and also contains the promise of being an engineering tool that is free of chemicals and minimises carbon emissions in sediment management projects. Subsequent research efforts, which are already being developed, will address its suitability for field applications, and build upon the success collected at the laboratory phase.

**Algae as a bio-flocculant**

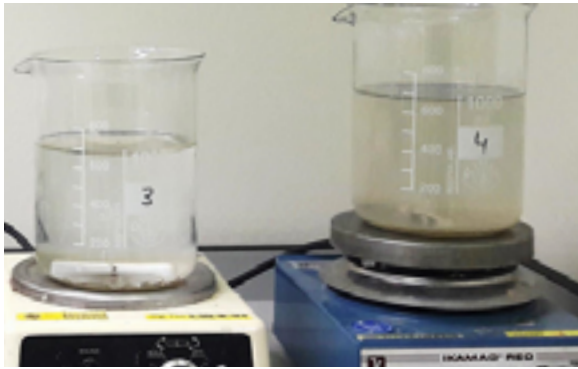
The second BESMART Technology is the application of algae to flocculate fines in the water column to ultimately solve potential

turbidity issues. Adding phytoplankton to a turbid water column is a feasible and viable alternative method for enhancing flocculation and sedimentation rates of suspended cohesive sediment. In particular, this technology has been tested for oil sands tailings via the execution of a proof of concept in the laboratory. Phytoplankton do not only rapidly form large aggregates (de Lucas Pardo et al., 2015), but they also increase the capacity to capture and precipitate the finest sediment fraction. Numerous species of phytoplankton have the tendency to flocculate with suspended cohesive sediments. *Aphanotece* sp. is a cyanobacteria (a sub-type of algae) endemic to natural bodies of water worldwide that revealed that it could form large flocs and induce sedimentation in very turbid bodies of water (de Lucas Pardo et al., 2015). This was shown over a number of experiments, where *Aphanotece* sp. was mixed with suspended cohesive sediment. When the phytoplankton and sediments were vigorously mixed, plankton-clay flocs reached an equilibrium floc size twice that of flocs without the plankton, surpassing the maximum theoretical size that a floc can reach for a given turbulence level (e.g. creating extraordinarily large flocs for such conditions). When mixed under moderate energy levels, the large plankton-clay flocs cannot be kept in suspension anymore, thus settle.



**FIGURE 6** The left panel summarizes the results from de Lucas Pardo (2015), where extraordinarily large flocs (red dots) are obtained for a mixture of algae and sediment (oxic layer is just surficial lacustrine sediment). All other markers represent salt induced flocculation, and results in smaller equilibrium floc sizes than algae. The right panel shows a conceptual picture of the aggregation between algae and fines.





**FIGURE 7**

Comparison between algae treatment (beaker 3) and the absence of it (beaker 4). Both beakers contained a concentration of 250 mg/l of suspended tailings. Beaker 3 also contained a concentration of  $1 \cdot 10^5$  cell/ml (i.e. a very small concentration) of *Aphanotece* sp. algae. The picture was taken after gently mixing at a minimal energy level and after allowing for settling after mixing. The differences in turbidity after treatment are striking.

These are results that illustrate the extraordinary physical features of biotic-abiotic flocs summarised in the left panel of Figure 6 and conceptualised in the sketch in the right panel of Figure 6; the actual mixing level needed in the field to achieve optimal results is yet unknown. Moreover, the study also showed that the rate at which aggregation occurred was much faster when plankton were present. *Aphanotece* sp. is organised in colonies, with its individual cells being 1 to 2  $\mu\text{m}$ . This allows the cyanobacteria to form large but flexible colonies embedded in extracellular polymeric substances (EPSs). The EPS gives the colonies its ability to bind to clay particles, whereas the small size of the individuals enables colonies to change shape and adapt to specific inorganic floc shapes. The catching capacity of *Aphanotece* sp. can be studied and hereafter adjusted, so that *Aphanotece* sp. can be used to a range of fines concentrations. Our plans are to subsequently scale up our test to beaker volumes and to study the flocculation capacity of similar species of algae with natural fines or suspended tailings in a jar testing set-up, where turbulence level can be adjusted to resemble field conditions and potential mixing methods. Furthermore, the EPS around algae can bind dissolved cations from the water column and this requires further research. Finally, it is not well known for how long these large biotic-abiotic flocs persist. The durability of these flocs will therefore become a subject of future studies.

Over the past years Deltares has studied this technology by funding the development of a

proof of concept. The context of this proof of concept was oil sands tailings management, in particular turbidity mitigation at what are called end pit lakes, where thick oil sands deposits are capped by a fresh-water lake. Suspended oil sands tailings concentrations of 125 mg/l and 250 mg/l were efficiently flocculated and settled upon gently mixing (at the minimum mixing energy allowed by our mixing instrumentation) with a small concentration of *Aphanotece* sp. algae of  $1 \cdot 10^5$  cells/ml. A picture of the jars from the 250 mg/l tests at the end of the test is shown in Figure 5.2. Our preliminary conclusion is that suspended tailings were efficiently settled upon treatment with algae. Further analysis confirmed that in the absence of algae, flocculation and settling did not happen (see Figure 3). Note that typically occurring concentrations of *Aphanotece* sp. in natural water bodies are of about  $50 \cdot 10^7$  cells/ml (de Lucas Pardo et al., 2015), 5,000 times higher than the tested concentration.

Natural lakes with similar algae concentrations could provide a cheap and large input of

flocculant if found within a transport range that is financially attractive. An alternative source in the absence of lakes within reasonable distances would be to cultivate the algae on site, which according to our expertise should be feasible both technically and financially. Considering that higher concentrations occur in both culturing reactors and natural water bodies than the concentration we tested, the potential of the technology to treat a water column in tailings ponds and/or pit lakes becomes a tangible and attractive possibility.

We also foresee similar efficiencies in dealing with turbidity in other types of systems, or with natural sediment. Not only is this a fully natural solution, but its performance is also competitive. When produced on site, we recommend adopting the bulk-type culturing reactor, which though subjected to episodically low performances can on average provide the type of high concentrations needed for this application. Producing algae in a local reactor could be a competitive alternative to expensive chemical flocculants. Finally, mixing the algae



**FIGURE 8**

Comparison in turbidity between algae treatment (right) and the absence of it (left).

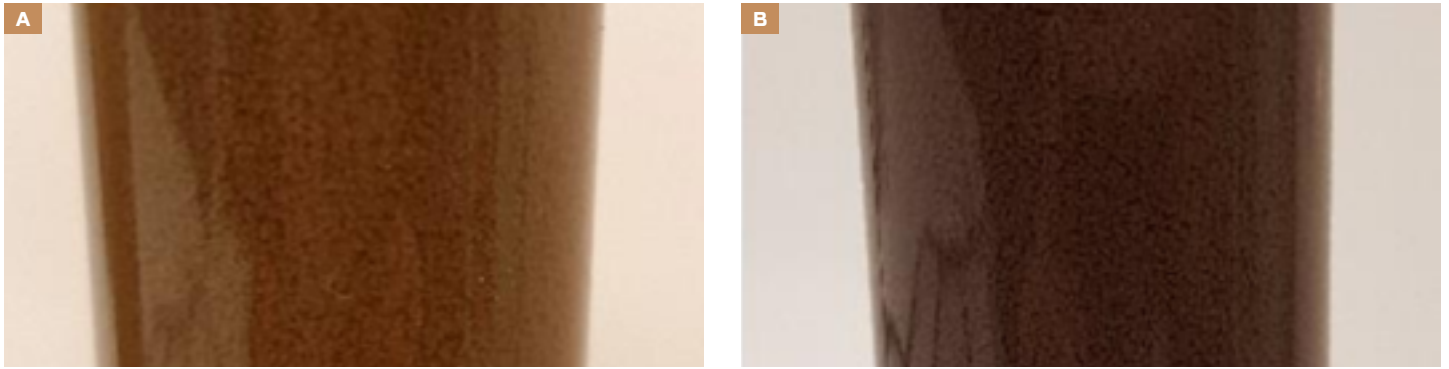


FIGURE 9

Floc created (A) 2 minutes and (B) 30 minutes after addition of Kaumera® to tailings.

obtained with tailings in the field can be done by depositing them under a mixing engine from a pontoon.

To conclude, the technological performance of bio-flocculation by algae has been successfully tested at the laboratory scale, via a proof of concept (and the associated knowledge and research generated at our laboratories). Subsequent research steps should consider carrying out column to container experiments, seeking to quantify the performance of algae when they are studied for the operational parameters of a selected stakeholder.

**Subsequent research steps should consider carrying out column to container experiments, seeking to quantify the performance of algae when they are studied for the operational parameters of a selected stakeholder.**

### **Kaumera® as a bio-flocculant**

Kaumera® is an Extracellular Polymeric Substance (EPS) extracted from aerobic granular sludge from the Nereda® wastewater treatment process. 'Kaumera' is a word in the Maori language that can be translated as 'chameleon' (<https://kaumera.com/>). Delft University of Technology (TU Delft) in the Netherlands is leading the development of the process of the extraction of Kaumera®, and is currently also looking for a wide scope of applications for a new bio-based raw material that is extracted during the Nereda® purification process. Specialized in sediment characterization and conditioning, Deltares collaborates with TU Delft in finding uses for sediment management applications with Kaumera®. This collaboration came to be over the course of several proofs of concept in our research.

Kaumera® is biodegradable and therefore can also be used as fertilizer or as a food source for other organisms (e.g., worms), thus ultimately preparing sediment for biological development. The technology of using Kaumera® to manage fine sediment has the same applications as our algae technology (e.g., flocculation and turbidity mitigation, discussed previously), plus the possibility to biologically improve the properties of settled sediment. The bio-flocculant can potentially help sediment management projects to enhance the consolidation properties of dredged sediment (since adding Kaumera® leads to a drop of pH, which can affect the surface charge of clay particles and ultimately modify its consolidation behavior and strength development) and to decrease

turbidity of water columns in natural muddy bodies of water.

The potential of Kaumera® as a bio-flocculant for tailings has been evaluated during a proof of concept that consisted of flocculation experiments (Wyszynska, 2020). Figure 9 shows the development of flocs that was observed in the sample containing Kaumera® 2 minutes and 30 minutes after adding the bio-flocculant to 1 wt% tailings sample. Though not visible in the reported figure, the experiments also showed that the turbidity of the supernatant obtained after the addition of Kaumera® was better than the one for the control sample.

Successful flocculation experiments in the form of proof of concept have also been conducted for stable clay mineral suspensions. Pure 1 wt% kaolinite and 1 wt% bentonite clay samples were used for testing the effectiveness of Kaumera®. The left panel in Figure 10 illustrates a clear difference between the flocculation of kaolinite and bentonite with Kaumera®. A radical improvement in the flocculation of bentonite has been detected. The formation of a more compact bed and lower turbidity of the supernatant is observed in a Kaumera-treated bentonite sample. The flocculation tests on the kaolinite sample show that the bio-flocculant improves the settling of kaolinite clays. The thickness of settled mud is more pronounced in the Kaumera-treated kaolinite sample than in a control sample. The change in the color of Kaumera-treated supernatant is attributed to the addition of the Kaumera® extract. This proof of concept can be applied



to predict and understand flocculation of natural sediments, and as a function of their dominant clay mineral.

Finally, Kaumera® was also evaluated as flocculant for suspended fines at a mining operation in a river near Medellín, Colombia. The mining operation consists of dredging of the alluvial sediment at confined river sections. The turbidity at these sections was a severe environmental issue, and thus Deltares developed a proof of concept to test the efficiency of Kaumera® in flocculating the suspended river sediments. The right-hand panel in Figure 10 shows the results of conducted laboratory experiments with Kaumera®. The sample in the middle was treated with Kaumera®. The other two samples were not treated and thus constitute two replicates of the reference situation. The suspended sediment concentration was 10 mg/l in all three samples. Kaumera® successfully managed to flocculate and settle the small concentrations of fines.

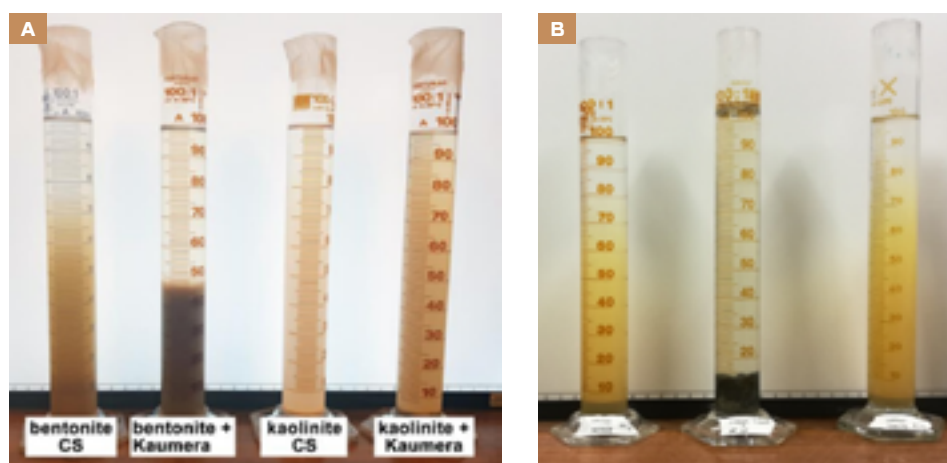
Overall, the proof of concept experiments show that Kaumera® can potentially be

used as a bio-flocculant to help sediment management projects. The bio-flocculant has a great potential to expand the portfolio of applications, especially for tailings management since tailings are mainly considered a waste product with no economic value. Raising awareness of environmental impacts might limit the use of chemical flocculants in the future. Because Kaumera® is bio-degradable, the development of Kaumera® as a bio-flocculant can lead to environmental benefits in sediment management projects. Combining this bio-flocculant with other technologies discussed in this paper is considered promising for the biological development of treated sediment.

### **Beggiatoa (bacteria) as bed protection**

The engineering goal of *Beggiatoa* technology is to protect muddy beds from erosion by currents or waves, thus stopping re-suspension events and the generation of turbidity. We envision this technology to be best suited for contaminated sediment deposits (upon successful results from our on-going proof of concept research and

**Because Kaumera® is bio-degradable, the development of Kaumera® as a bio-flocculant can lead to environmental benefits in sediment management projects.**

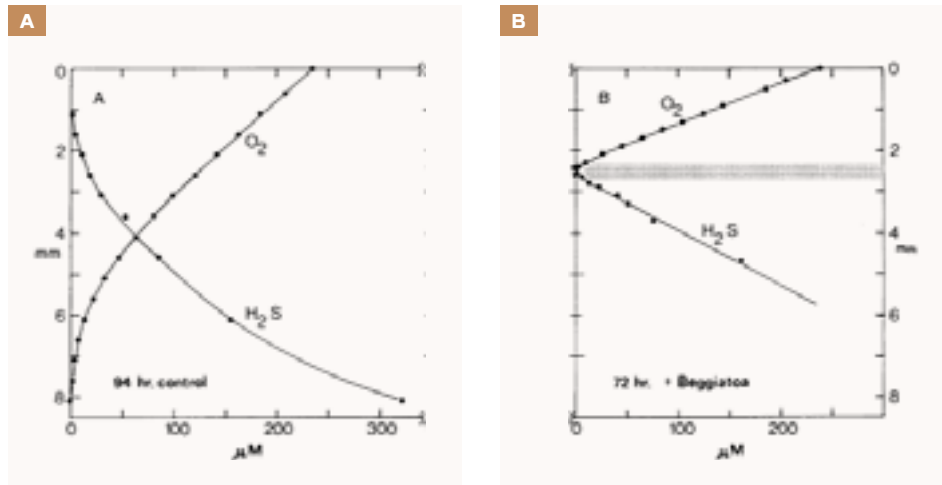


**FIGURE 10**

(A) Flocculation experiments of bentonite and kaolinite clay suspensions containing 1wt.% of clay minerals. The bentonite control sample (CS) shows higher turbidity than Kaumera-treated bentonite sample. Furthermore, there is more kaolinite clay settled in the graduated cylinder with Kaumera-treated sample than in the one with the kaolinite control sample (change in the color of Kaumera-treated supernatant is attributed to the addition of the Kaumera® extract). (B) The results of using Kaumera® to flocculate suspended fine sediments from a river mining operation. The sample in the middle was treated with Kaumera®. The other two samples were not treated and thus constitute two replicates of the reference situation. The suspended sediment concentration was 10 mg/l in all three samples.

subsequent research phases) where anoxic conditions have developed right under the top centimetres. This happens because anoxic (or near anoxic) conditions are necessary for *Beggiatoa* to establish and survive. Due to these particular requirements, there are few ecosystems or waterbodies where the bacteria might be applied. Of course the technology can still be applied as an intermediate mechanism for restoration in systems that are suffering from ecological deterioration, but its application would not be ideal at a hypothetical restored configuration. The technology is currently transitioning between a proof of concept and a column study.

Sulfide ( $S_2^-$ ) oxidizing bacteria of the genera *Thioploca* and *Beggiatoa* form dense mats in the top layer of the sediment bed, both in marine and freshwater sediments (Teske and Nelson, 2013). The organisms typically oxidize hydrogen sulfide ( $H_2S$ ) as an electron donor into elemental sulfur ( $S_0$ , which is stored inside the bacteria's cells) with oxygen ( $O_2$ ) or nitrate ( $NO_3^-$ ) as electron acceptor. Sulfide oxidation detoxifies the sediment, creating better habitat for other organisms to grow. In nature both genera occur at the oxic-anoxic interface, preferably in micro-oxic to anaerobic conditions ( $O_2$  0–2.5  $\mu m$ ). Furthermore, they are photophobic, requiring dark conditions for growth (Teske and Nelson, 2013).

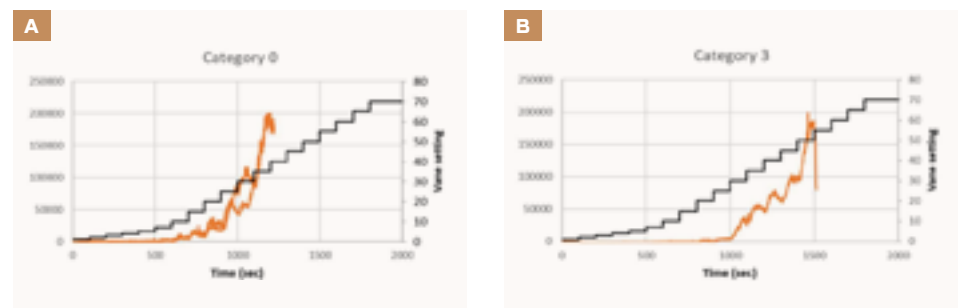


**FIGURE 11** Showing the oxygen (O<sub>2</sub>) and hydrogen sulfide (H<sub>2</sub>S) concentration (µM) along the depth (mm) in a control medium (A) and created by *Beggiatoa* (B) after 3 days in this medium. Zero depth indicates the air-plate interface. The grey area shows the location of the *Beggiatoa* mat in the medium. (Source Teske & Salman 2014; Nelson et al., 1986).

What is so special about these bacteria is that they both grow as filaments, vertically in the sediment and can glide from an electron acceptor (O<sub>2</sub> or NO<sub>3</sub><sup>-</sup>) to an electron donor pool (H<sub>2</sub>S), giving them competitive advantage over non-mobile microorganisms that use the same resources. Due to their metabolism these organisms strongly contribute to separating an electron acceptor from the electron donor pool (Nelson et al., 1986). Because of these advantages, their filamentous growth can form dense mats, from a few millimetres thick (as observed in Markermeer, the Netherlands) up to several centimetres (only observed in the ocean floor). Mat thickness appears to depend on dynamics and the stability of the sulfide/oxidant interface (Teske and Nelson, 2013). It is precisely to the mat and its thickness that we attribute the bacteria's function in protecting the bed.

Within Deltares, sediment strength with and without natural sulfide oxidizer mats was tested in resuspension experiments (Kauhl, Roskam and Noordhuis, internal communication). Sediment was collected from the lake Markermeer, where natural dense mats of sulfide oxidizers occur. Sediment with dense sulfide oxidizer mats showed greater strength and could withstand higher shear stress before resuspending than sediment

without these mats (see Figure 12). Also, sediment with bacterial mats displayed maximum erosion rates at a higher shear stress. These preliminary results show that sulfide oxidizer mats in sediments can strengthen a fine sediment bed. Developing such mats in natural sediment therefore can contribute to a decrease of erosion from muddy beds and its associated turbidity in the waterbody, and can thereby improve water quality. Therefore, the BESMART Technologies research team has initiated both



**FIGURE 12** The increase in turbidity (left Y-axis in non-calibrated turbidity units; turbidity increases as the units do) over time (X-axis in seconds) in orange, with black being the stepwise increase of the vane setting every 100 seconds (right Y-axis in non-calibrated shear units; applied shear increases as the units do). Sediment in category 0 contains no sulfide oxidizer mat. Sediment in category 3 contains a well-developed mat.

a proof of concept and a set of column tests to prove its efficiency in addressing sediment management issues. The proof of concept consists of trying to grow *Beggiatoa* mats in sediment beds where it did not naturally occur. Upon the finalization of a successful proof of concept, the subsequent step will be to quantify the bed's enhanced strength and its greater resistance to erosion in dedicated geo-technical and erosional tests (e.g. column tests level in the technological development cycle).

**Vegetation for soft sediment dewatering, strengthening, and bed protection**

Aside from the BESMART Technologies, there is also a bio-technology that has the potential to dewater and strengthen soft sediments and protect the bed: vegetation. However, to use vegetation to dewater, strengthen and protect soft sediments and muddy beds is still in a theoretical formulation phase at Deltares. Currently, Deltares is investigating how soil strength, affected by water and clay content, influences salt marsh plant dislodgement and stability under wave impact (see Figure 13). The inverse phenomenon, how plants affect soil properties, has not been studied explicitly in our laboratories yet. Notwithstanding, investigations at the Northern Alberta Institute of Technology (NAIT), Deltares' partner in on-going research projects, revealed that plants can distinctly influence dewatering oil sands tailings (Schoonmaker, Degenhardt and Floreani, 2018). Currently, the synergistic



performance of both worms and plants on dewatering is under investigation via the execution of a collaborative project between NAIT and Deltares. Because of the potential that vegetation has in assisting with sediment management issues, and also because the BESMART Technologies research team is interested in contributing to the development of this topic, lessons learned from our partners and existing insights from literature will be shared in a concise literature review. It can be seen as our own theoretical formulation of this technology's potential to assess sediment management issues. This review derives from the balance between entrainment in the water column and retainment in the bed, to the dewatering and therefore strengthening potential of (ripened) soils.

Plants change the environment with their physical structure. They are often referred to as autogenic ecosystem engineers (Jones, Lawton and Shachak, 1994) acting in a marine environment (Crain and Bertness, 2006) and fresh-water environments (Jones, Lawton and Shachak, 1997). Their role is that of slowing down currents and attenuating waves (Coppenolle, Schwarz and Temmerman, 2018; Ghisalberti and Nepf, 2006; Norris, Mullarney, Bryan and Henderson, 2017). This results from the generation of turbulence around their roots, stems and leaves, dissipating hydrodynamic energy. This makes soils less susceptible to erosion. In these locations of hydrodynamic tranquility, fines are captured from the water column by roots, trunks and stems of the vegetation, inducing the transition from particle entrainment to its retainment in the bed.

By dissipating hydrodynamic energy, vegetation protects the bed from erosion, but plants also contribute to the strength of the soil itself. Root networks hold together the sediment particles fortifying soils up to the breaking point of the root network. The tensile strength of the roots differs per species, which affects to what extent they contribute to its soil strengthening capacity. For example, *Spartina ssp.* builds stronger cliffs compared with *Limonium ssp.* because the roots of *Spartina ssp.* have a higher tensile strength (van Eerd, 1985)

Once a soil is substantiated after an initial settling phase, vegetation aids in mediating dewatering by means of evapotranspiration



**FIGURE 13**

Pioneering plant species *Salicornia ssp.* are grown in boxes containing different sediment compositions. Ultimately, these seedlings are tested in a wave flume to quantify critical wave energy and erosion per sediment type. These tests will give insight into which locations are suitable for *Salicornia* recruitment mediating salt marsh growth. The newly sprouted salt marsh will provide ecosystem services like capturing fines, aerating and dewatering the soil.

(Smith, Banks and Schwab, 2009). Evapotranspiration is the sum of evaporation and transpiration of the vegetation and soil. Settlement can take place in nature or upland consolidation depots in which evapotranspiration contributes to expel water from the soil, inducing crack formation, which can open up the soil for oxidation processes. Moreover, plants contribute to mixing soil particles (Pons and Zonneveld, 1965), aerating the soil with oxygen, fostering oxidation (Trapp and Karlson, 2001) and removing pollutants (Duggan, 2005; Smith et al., 2009).

Plants can contribute substantially to dewatering. For example, dewatering in an upland depot with soil-plant systems with willow species was 1.28 times, up to 5.12 times, higher than control sections (Białowiec, Wojnowska-Baryła and Agopsowicz, 2007) marked by high transpiration ability—is a cheap and effective method of landfill leachate disposal. A two-year study examined the effectiveness of leachate evapotranspiration from soil-plant systems with willow species *S. amygdalina* L. Evapotranspiration from soil-plant systems planted with willow was from

1.28 up to 5.12 times higher than evaporation from soil surface barren of vegetation. This proves the usefulness of soil-plant systems with willow in landfill leachate treatment through vaporization. Evapotranspiration efficiency, as opposed to total amount of water added into the lysimeter, was not strong enough to vaporize all input of the landfill leachate in the lysimeters. This may indicate that the ground water requires isolation when soil systems remain under landfill leachate irrigation. Linear dependence between willow biomass growth and transpiration was observed to be significant ( $p < 0.05$ ). Willow species are promising dewatering agents. In search of sustainable, environmentally passive and inexpensive methods to remove leachate, evapotranspiration by willows is viewed as promising in Sweden (Börjesson and Berndes, 2006) and the U.K. (Duggan, 2005).

Therefore, given the potential of vegetation to protect the bed from erosion, to provide strength to the soil via its root network and to efficiently dewater the bed's pore water, vegetation will be subject of upcoming studies at Deltares. The subject of these will be to

quantify dewatering and strengthening potential and also bed protection potential. These quantifications will take place over a range of laboratory experiments, evolving as always from proof of concept to column tests and further. The first step will be to identify a stakeholder who owns a fine sediment management issue where this technology can be of use, as it was the case with all other BESMART Technologies.

### Continuing development of promising sediment management technology

BESMART Technologies are a promising alternative to traditional sediment management measures for dealing with the challenges of fine sediment engineering operations. All of them have been proven in the laboratory to be effective in achieving

their engineering goal within the targeted operational range. Deltares has itself carried out numerous laboratory experiments, ranging from proof of concept to column tests, to demonstrate this. So far it has covered all the BESMART Technologies named in this article with the exception of vegetation. Some of these technologies are either application-ready or require fine-tuning before application. Yet other technologies still require research and their method further validation. Many private partners worldwide are teaming up with Deltares either to develop these ideas or to test their applicability for particular engineering problems. Slowly, we foresee that the technologies will become part of our partners' standard operational practice, allowing for a smooth transition from applied scientific development to practice.

Cost-effectiveness, technical performance and integration in the local ecosystem are the main principles for the application of BESMART Technologies. Nevertheless, and though the BESMART Technologies team at Deltares strongly believes in the secondary advantages of this method (low impact and low emissions given their passive nature), we will only consider and develop ideas that are based on sound engineering and technological development. This research is based on the collaboration between various international academic and private institutions. Therefore we invite the interested reader to reach out with potential dedicated applications or scientific improvements to facilitate scale-up of these technologies to implementation.

For more information or enquiries, please contact [editor@iadc-dredging.com](mailto:editor@iadc-dredging.com)



#### Dr Miguel de Lucas

Dr Miguel de Lucas is a Senior Adviser at Deltares in the Netherlands. He holds an MSc in Hydraulic Engineering from UPM of Madrid and TU Delft, and a PhD in fine sediment dynamics from the TU Delft. During his PhD, Dr de Lucas began to study feedbacks between biotic and abiotic factors in the context of fine sediment transport. The latter materialised into commercial research projects at his subsequent position in Deltares where he leads the BESMART Technologies research team.



#### Dr Alex Kirichek

Alex developed a strong background in soil mechanics and rheology during his MSc degree in Civil Engineering (cum laude). After his graduation, Alex conducted multidisciplinary PhD research in Applied Geophysics at TU Delft, where he developed novel geophysical surveying methods. Later, he carried out postdoctoral research, testing cost-effective maintenance strategies for ports and waterways with mud. Currently, Alex is working as a Researcher/Adviser at Deltares, bridging the gap between applied research and practice.



#### Dr Martine Kox

Dr Martine Kox is a Junior Research/Adviser at Deltares, in the Netherlands. She completed an MSc degree in Environmental Biology at Utrecht University and obtained her PhD in Environmental Microbiology at Radboud University. During her PhD, Dr Kox studied the ecology of microorganisms occurring in peatlands, focusing on greenhouse gas emissions and nitrogen cycling. Within Deltares Martine applies her knowledge of microbiology to improve sediment characteristics, water and health and reduce greenhouse gas emissions.



#### Floris van Rees

Floris van Rees is a Junior Researcher/Adviser at Deltares, in the Netherlands. He started exploring the career path of a bio-geomorphologist during his Master's degree in Physical Geography at Utrecht University and continued studying bio-physical interactions at Deltares. Floris van Rees is involved in numerous sediment management bio-tech studies and one-to-one scale modelling of reciprocal actions between plants, waves and sediment.



## REFERENCES

- Białowiec, A., Wojnowska-Baryła, I. & Agopsowicz, M. (2007). The Efficiency of Evapotranspiration of Landfill Leachate in the Soil-Plant System with Willow *Salix amygdalina* L. *Ecological Engineering* 30(4), 356–61. <https://doi.org/10.1016/j.ecoleng.2007.04.006>
- Börjesson, P. & Berndes, G. (2006). The Prospects for Willow Plantations for Wastewater Treatment in Sweden. *Biomass and Bioenergy* 30(5), 428–38. <https://doi.org/10.1016/j.biombioe.2005.11.018>
- Coppenolle, R. Van, Schwarz, C. & Temmerman, S. (2018). Contribution of Mangroves and Salt Marshes to Nature-Based Mitigation of Coastal Flood Risks in Major Deltas of the World. *Estuaries and Coasts* 41(6), 1699–711. <https://doi.org/10.1007/s12237-018-0394-7>
- Crain, C. & Bertness, M.D. (2006). A New Method for Assessing Critical Thinking in the Classroom. *BioScience* 56(3), 1–8. [https://doi.org/10.1641/0006-3568\(2006\)056](https://doi.org/10.1641/0006-3568(2006)056)
- de Lucas Pardo, M.A. (2014). Effect of Biota on Fine Sediment Transport Processes: A Study of Lake Markermeer.
- de Lucas Pardo, M.A., Sarpe, D. & Winterwerp, J.C. (2015). Effect of Algae on Flocculation of Suspended Bed Sediments in a Large Shallow Lake: Consequences for Ecology and Sediment Transport Processes. *Ocean Dynamics* 65(6):889–903.
- Duggan, J. (2005). The Potential for Landfill Leachate Treatment Using Willows in the UK: A Critical Review. *Resources, Conservation and Recycling* 45(2):97–113. <https://doi.org/10.1016/j.resconrec.2005.02.004>
- Ghisalberti, M., & Nepf, H. (2006). The Structure of the Shear Layer in Flows over Rigid and Flexible Canopies. *Environmental Fluid Mechanics* 6(3):277–301. <https://doi.org/10.1007/s10652-006-0002-4>
- Jones, C.G., Lawton, J.H. & Shachak, M. (1994). Organisms as Ecosystem Engineers. *Oikos* 69(3):373. <https://doi.org/10.2307/3545850>
- Jones, C.G., Lawton, J.H. & Shachak, M. (1997). Positive and Negative Effects of Organisms as Physical Ecosystem Engineers. *Ecology* 78(7):1946–57.
- Nelson, D.C., Jorgensen, B.B. & Revsbech, N.P. (1986). Growth Pattern and Yield of a Chemoautotrophic *Beggiatoa* sp. in Oxygen-Sulfide Microgradients. *Applied and Environmental Microbiology* 52:225–33.
- Norris, B.K., Mullarney, J.C., Bryan, K.R. & Henderson, S.M. (2017). The Effect of Pneumatophore Density on Turbulence: A Field Study in a *Sonneratia*-Dominated Mangrove Forest, Vietnam. *Continental Shelf Research* 147:114–27. <https://doi.org/10.1016/j.csr.2017.06.002>
- Pons, L.J. & Zonneveld, I.S. (1965). Soil Ripening and Soil Classification: Initial Soil Formation in Alluvial Deposits and a Classification of the Resulting Soils. *International Institute for Land Reclamation and Improvement* (13):1–128.
- Schoonmaker, A., Degenhardt, D. & Floreani, T. (2018). Evaluating the Potential to Establish Plants to Aid in Dewatering of an Atmospheric Fine Drying Tailings Deposit at Muskeg River Mine. *International Oil Sands Tailings Conference*:209–20.
- Smith, K.E., Banks, M.K. & Schwab, A.P. (2009). Dewatering of Contaminated Sediments: Greenhouse and Field Studies. *Ecological Engineering* 35(10):1523–28. <https://doi.org/10.1016/j.ecoleng.2009.07.002>
- Teske, A. & Nelson, D.C. (2006). *The Prokaryotes*. Springer, New York, NY.
- Teske A. & Salman, V. (2013). The Family *Beggiatoaceae*. In: *The Prokaryotes: Gammaproteobacteria*, pp. 93–134.
- Trapp, S. & Karlson, U. (2001). Aspects of Phytoremediation of Organic Pollutants. *Journal of Soils and Sediments* 1:37–43.
- van Eerd, M.M. (1985). The Influence of Vegetation on Erosion and Accretion in Salt Marshes of the Oosterschelde, the Netherlands. In *Ecology of Coastal Vegetation* (pp. 367–73). Springer, Dordrecht.
- Wyszynska, M. (2020). Design of the Bioremediation Method for Oil-sand Tailings. PhD thesis. TU Delft.
- Yang, X., de Lucas Pardo, M., Ibanez, M., Deng, L., Sittoni, L., Ulrich, A. & Chen, Q. (2016). Addition of Tubifex Accelerates Dewatering of Oil Sands Tailings. *Canadian Journal of Civil Engineering* 43(12):1025–33.
- Yang, X., Pardo, M.D.L., Ibanez, M., Deng, L., Sittoni, L., Ulrich, A. & Chen, Q. (2019). Improving Engineering Properties of Mature Fine Tailings using Tubifex. *Canadian Journal of Civil Engineering*

# THE SMART SEDIMENT TOOL:

A QGIS PLUG-IN FOR EVALUATING  
ECOSYSTEM SERVICES IN  
ESTUARINE AND DELTA SYSTEMS

Photo @ Rijkswaterstaat/Boskalis



Managing sediments, especially from dredging, disposal, nourishments and sand mining is important for the management of estuaries and coastal areas. When implemented in the right way, a sediment management strategy can be qualified as a nature-based solution as it uses the physical processes of erosion and sedimentation to create added value. There is a need for an evaluation of sediment strategies and the habitats that are created for a wider range of objectives than only biodiversity and nature conservation. The concept of ecosystem services provides this broader framework.

**With the Smartsediment Ecosystem Services QGIS tool, users can assess ecosystem services in an estuary and compare scenarios with different sediment measures or developments.**

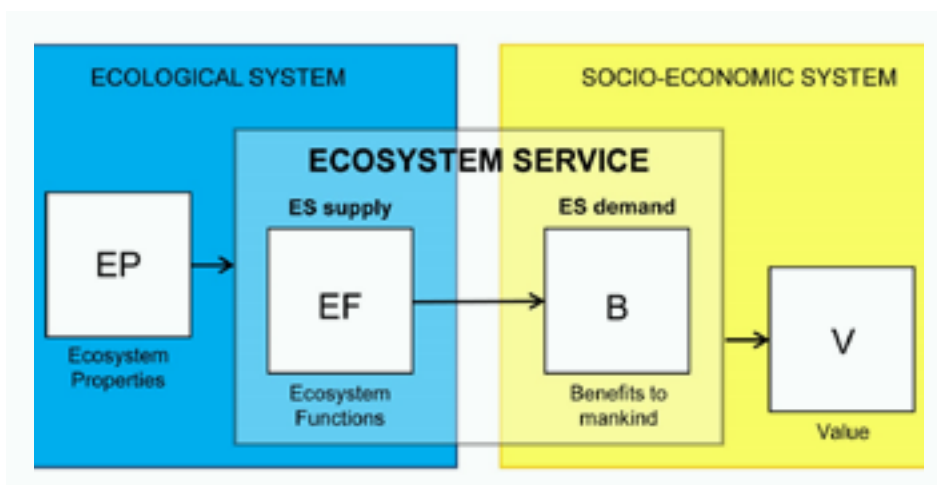
Practical tools to assess the ecosystem services effects of sediment management are not yet available. We have developed a QGIS plug-in that enables a first evaluation of the impact of sediment management on ecosystem services. Knowledge of ecosystem processes and their relationship with ecosystem services was used to develop quantification methods (e.g. for food production, water quality

regulation, climate regulation and recreation). With the Smartsediment Ecosystem Services QGIS tool, Smartsediment tool for short, users can assess ecosystem services in an estuary and compare scenarios with different sediment measures or developments. The result gives an indication of how many – quantitatively, from calculations based on expert knowledge – and where – spatially explicit in GIS maps

– ecosystem services are created. The practicability and validity of the tool were tested on a series of sediment management strategies in the transboundary Scheldt delta (project website [www.smartsediment.eu](http://www.smartsediment.eu)).

### Sediment management for ecosystem services

Sediments form an essential, integral and dynamic part of our river, estuarine and coastal systems, where they determine both patterns such as habitats and processes such as erosion and sedimentation. Human interventions such as dredging, disposal and sand mining, but also alterations in the



**FIGURE 1**

Ecosystem Services (ES) cascade framework, showing ES as the link between the ecological system which consists of ecosystem properties with certain ecosystem functions, and socio-economic systems with needs and benefits for society with a certain value (Boerema et al., 2017)

## Sediment management is an important tool for management of estuaries and coastal areas.

hydrodynamics, influence the sediment household of water bodies. This can benefit certain goals such as improved navigation but also affect patterns and processes, positively and negatively, in the specific natural system. There is a noticeable shift to sediment management strategies that are more integrated with the needs of other user functions such as the disposal of dredged material to create valuable habitats. The benefits of these strategies on ecological objectives for habitats and species are studied during design and legally required evaluation procedures. However, the creation of habitats also benefits other objectives than biodiversity. In this paper, we try to explore and unravel with which relations between sediment management and Ecosystem Services (ES) an evaluation of all benefits for society can be made.

The concept of ES was mainly founded by the Millennium Ecosystem Assessment (MEA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010) and are defined as the benefits that humans derive from nature. There are different types of ES with different benefits for human well-being. The Common International Classification of Ecosystem Services (CICES, 2020) defined three categories: provisioning (e.g. reared aquatic animals for nutrition, surface water used for energy), regulating and maintenance

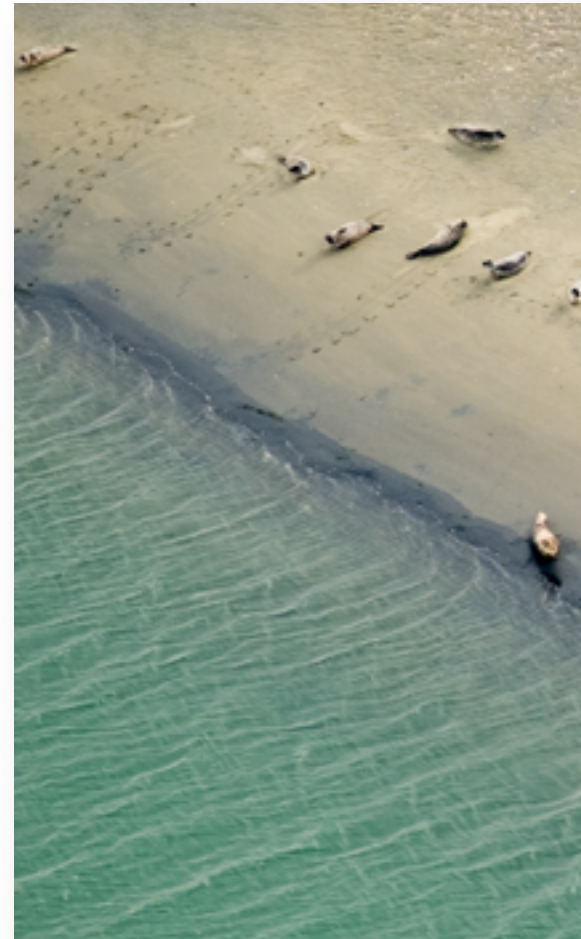
(e.g. regulation of soil quality, regulation of baseline flows and extreme events), and cultural (e.g. physical and experiential interactions with natural (a)biotic components of the environment).

The ES cascade framework illustrates the link between the ecological system and the socio-economic system (Figure 1). The ecological system consists of biophysical structure or ecosystem properties (EP) and any change or reaction which occurs in an ecosystem, being the ecosystem functions (EF). Due to the functioning of the ecosystem, ecosystem services are created and hence it benefits human wellbeing (B). This change in wellbeing brings with it certain (non-)economic value for society (V).

At a global level, ES are becoming part of important programmes since 10–15 years. Researchers and others recognise that healthy and sustainable ecosystems are critical for the Millennium Development Goals, more recent Sustainable Development Goals, since they are the source of natural resources that are essential ingredients for human survival and the ‘fuel’ and building blocks for human wellbeing and economic development (MEA, 2005; UNEP, 2009). Furthermore, the use and restoration of ES is being recognised by UN-Water (2014) to be an effective and cost-saving alternative to conventional infrastructure such as wastewater treatment plants or dykes for flood prevention. Since 2012, the independent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2012) has had an important role globally in strengthening the science-policy interface for biodiversity and ES for the conservation and sustainable use of biodiversity, long-term human wellbeing and sustainable development. IPBES is currently working on the rolling work program up to 2030 to advance the achievement of the overall objective of IPBES. This 2030 work program corresponds with the 2030 Agenda for Sustainable Development, including the Sustainable Development Goals, the biodiversity-related conventions and other biodiversity and ES processes.

### The Smartsediment tool

Sediment management, including dredging, sand extraction, sediment disposal and nourishments, is an important tool for



management of estuaries and coastal areas. Changes are induced in the water-sediment system on both on short temporal and small spatial scales, such as with sand bar nourishment and long temporal and large spatial scales, such as influencing the tidal range). The resulting geomorphological changes, on all scales, affect a variety of coastal and estuarine ES. For the specific context of dredging and marine constructions, the application of ES is acknowledged to demonstrate benefits of such projects to human welfare and the environment (CEDA, 2013 and PIANC, 2016). Yet, ES are often not considered in project-related cost-benefit analysis because there are no tools or practical guidance. We address three major challenges that should contribute to a better uptake of ES in project development:

- indicators to quantify ES based on state-of-the-art system understanding;
- spatially explicit assessment to account



- for local and system-wide effects; and
- the temporal context of effects.

These are three important aspects for a sound ES assessment, which can be used as input for an environmental impact assessment, societal cost-benefit analysis and cost-effectiveness analysis. GIS tools can enable project managers to make a first evaluation of the ES delivery of the estuarine or coastal system they are interested in. Furthermore, with such tools a comparison can be made of different strategies or project designs, including spatially (using maps). It should be possible to use local knowledge and data as much as possible. In this paper, we present the development of the Smartsediment tool that tries to address all three aforementioned aspects. The tool is based on a conceptual model to unravel impact-effect pathways. It builds on ECOPLAN-SE, a spatial decision support system to assess a wide range of ecosystem functions and services on land (Vrebos et al., 2020).

### Development of the Smartsediment tool, a QGIS-tool to evaluate ecosystem services

Four steps are needed to develop an instrument that addresses the three challenges outlined. The aim is to develop a spatially explicit tool to calculate effects of sediment management strategies on ES. The tool was developed and tested for the transboundary Scheldt delta in the frame of the EU Interreg regional Flemish-Dutch project Smartsediment ([www.smartsediment.eu/english](http://www.smartsediment.eu/english)).

#### Step 1: Selection of relevant ES

When evaluating the ES within a management context, considering all possible ES is difficult, time consuming and unnecessarily expensive. Therefore, a selection of the most relevant ES should be made. However, it is important to include a broad range of ES covering provisioning, regulating and cultural ES. Therefore a structured procedure to select the relevant

ES is required. Starting from a long list of ES based on the Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the Common International Classification of Ecosystem Services CICES (Haines-Young and Potschin, 2013), ES that are identified specifically for estuaries and the marine environment were added to this list (Barbier et al., 2011, Liqueste et al., 2013, Turner and Schaafsma, 2015, Böhnke-Henrichs et al., 2013, Jacobs et al., 2015). Next, this list of ES was screened by experts to select those that depend in some way on sediment and can potentially be affected by sediment management. Previous work on ES in the context of sediment management, dredging and port activities was also consulted (Apitz, 2012, Brils et al., 2014, van der Meulen et al., 2016, Boerema et al., 2016b and PIANC, 2016). The following ES were selected:

- aquatic animals for nutrition such as crustaceans, shellfish and fish;



- substances used for materials such as sand;
- mediation of wastes contributing to the regulation of water quality;
- regulation of baseline flows and extreme events;
- physical and experiential interactions with natural environment (e.g. shoreline recreation, swimming, recreational navigation);
- habitat protection for seals and birds; and
- additionally, effects on the navigation potential of the river.

exist between the management strategy, the functioning of the coastal zone and ES. To unravel these pathways, a conceptual model representing the relationships ‘how does the world work’ was developed. This conceptual model provides an analytical framework to give insight in the effects of sediment strategies on ecosystem functioning and on the selected ES (Figure 2). The estuarine ecosystem is divided in the soil, water and air components. The interaction between hydrodynamic and morphodynamic processes such as water flow, sedimentation and erosion forms the basis of the system structure. In addition to that, soil and water quality aspects such as nutrients, oxygen, organic material, primary production and detritus, form the basic food cycle in the system. On top of that, the food web can develop with higher trophic levels.

Step 2: Conceptual model to unravel impact-effect pathways

How do specific sediment management strategies affect the functioning of the coastal zone and hence on the delivery of ES? Different impact-effect pathways can

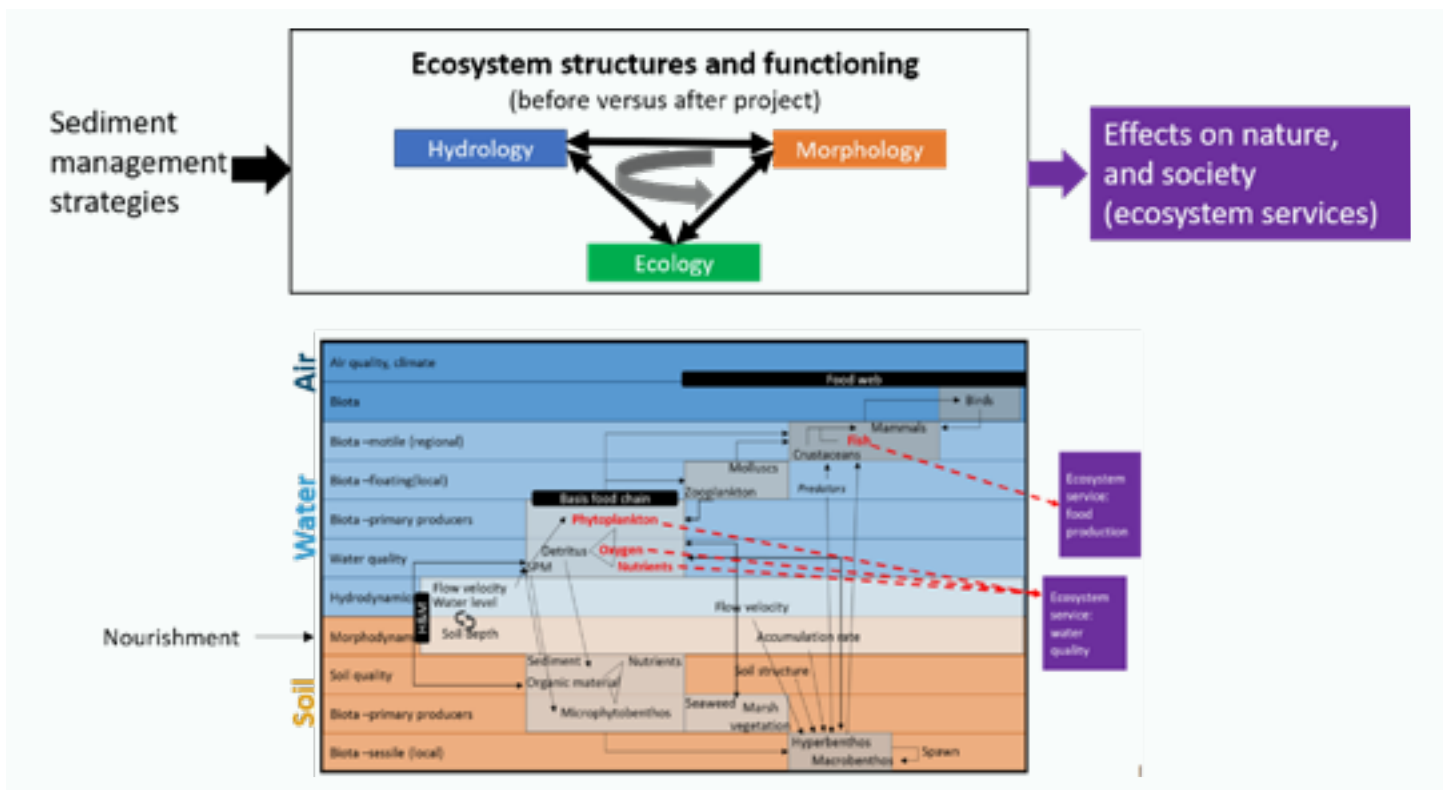
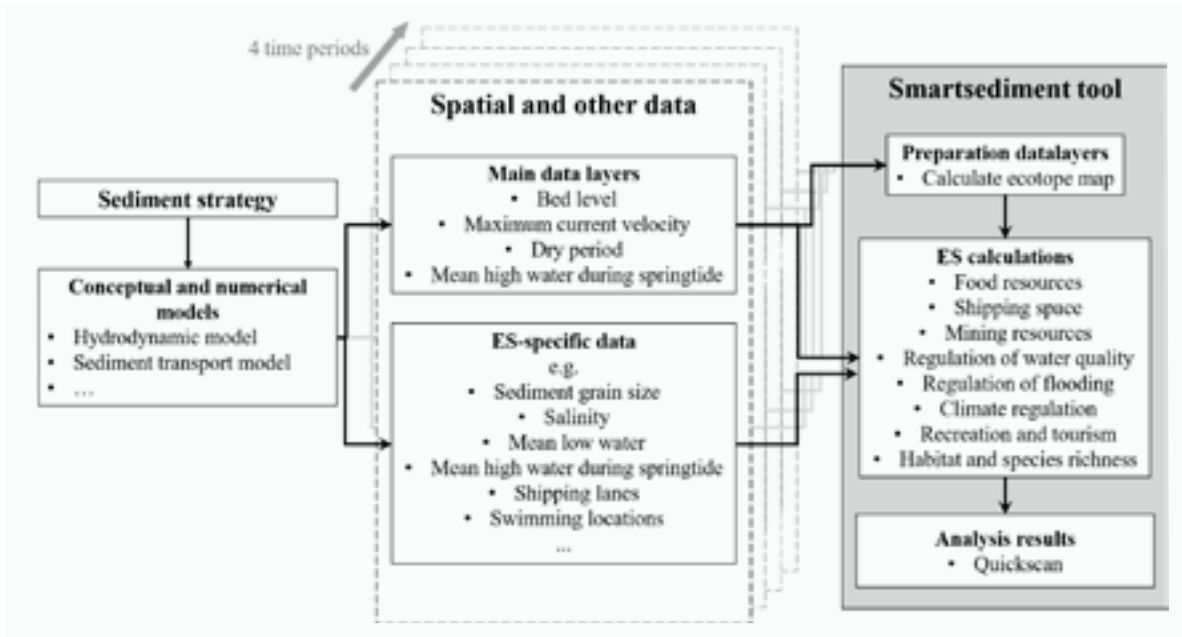


FIGURE 2

Smartsediment conceptual model, which is used to unravel impact-effect pathways. The top row shows the global concept: sediment management strategies intervene in the overall ecosystem structures and functions which results in effects on nature and society [ecosystem services]. The bottom zooms in on the complex relationships that are taking place within the ecosystem. Consequently, an intervention such as sediment nourishment results in a direct effect on the morphodynamics of the ecosystem, but through the processes between hydrology, morphology and ecology many indirect impact-effect relationships occur with effects on e.g. food production because of changing fish feeding habitat, and water quality regulation because of changing water turbidity.



**FIGURE 3**  
A schematic representation of the analysis.

This conceptual model is used to depict impact-effect pathways. First, the main direct and indirect effects of sediment management strategies on the functioning of the system are identified. Next, the functions of the system should be linked to the different ES. The latter step requires insight in the underlying ecosystem processes that form the basis for the delivery of the ES. Direct effects are related to:

- changing the local morphodynamics by dredging or disposing sediments;
- changing the local sediment characteristics by disposal of new material with different sediment composition and grain size;
- changing the water quality by dredging and disposal which can cause more turbidity when fine sediment ends up in the water column; and
- temporal visual or auditory disturbance during the project which can affect higher biota such as seals, porpoise and fish.

Direct effects could be linked to ecotopes. Ecotopes are a classification system based on the smallest ecologically distinct landscape units with relatively homogeneous, spatially explicit abiotic landscape characteristics such as a typical depth and water velocity. Ecotopes have distinct characteristics and can therefore be considered representative for other functions and for the delivery of particular

ES. It provides a practical solution for a rapid assessment, which might be needed in an early project phase when one is interested in a high-level comparison of different scenarios. In a later stage, for more detailed assessments of different designs, more detailed local information is required, which goes beyond the simple ecotope approach. This is similar with the habitat approach, which is often used in ES studies, but ecotopes are limited to units based on abiotic parameters only. Biotic parameters should be considered in addition, as these are more local specific and hence less straightforward to be considered as representative.

Besides the more obvious direct effects, also indirect effects should be considered (Figure 2). Potential indirect effects are very diverse and linked to the entire ecosystem functioning. Hydrodynamic conditions can change due to morphodynamic changes because of their strong interactions. Changes in hydrodynamic and morphodynamic conditions can result in changes in the presence and characteristics of ecotopes. Changes in hydrodynamic and morphodynamic conditions can also affect suspended matter, which is linked to water quality. Due to changes in water velocity, flow direction and sediment characteristics, more sediment can get in suspension or suspended matter can decrease in case more sediment is trapped under the new situation. Furthermore, changes in hydrodynamic and morphodynamic

conditions and soil and water quality affect biotic conditions such as benthos, birds, fish and shellfish, seals.

### Step 3: Calculation methods

The most challenging part is the quantification of the impact of sediment management on ES. The tool translates changes in the ecosystem such as flow velocity, sediment type and access for recreational activities into changes in the delivery of specific ES. The calculation methods per ES are based on ecosystem knowledge from the Scheldt delta and similar north-western European deltas and specific studies that investigate management effects. To develop the calculation methods for each ES, a balance had to be found between representing the complex reality and the ease of use. The necessity of input parameters and ease of implementation in the QGIS tool, to name a few, had to be considered. Therefore, for some ES two quantification rules were foreseen, one more advanced and one simpler. Obviously, the simpler method, based on fewer parameters, is less precise. All calculation rules and necessary input data are described in detail in the user manual (De Swerd et al., 2020).

An example is the ES climate regulation that relates to carbon capture and storage/CCS, expressed in CO<sub>2</sub>. Two calculation methods are available in the Smartsediment tool. The first method is simple and uses the mean

**An intervention such as sediment nourishment results in a direct effect on the morphodynamics of the ecosystem, but through the processes between hydrology, morphology and ecology many indirect impact-effect relationships occur.**

value for CCS for different ecotopes based on expert knowledge and literature (Boerema et al., 2016b). Based on the different ecotopes and their average CCS values, a total amount of CCS for the area of interest is calculated. Salinity is also taken into account with three categories: salt, brackish and fresh. For the Scheldt estuary, a salinity map was added to the underlying model and therefore does not need to be added by the user. The second method is more advanced and foresees a calculation of CCS based on sediment storage, soil density and emissions. The total CCS is the change in CCS via sedimentation corrected for greenhouse gas emissions from sediment (Boerema et al., 2016a). The change in CCS via sedimentation is calculated from the change in mudflat and marshes, sediment accumulation per year, soil density, suspended particulate matter and particulate organic carbon. For both methods, the output map shows the amount of CCS per year for the area of interest.

#### Step 4: Development of the Smartsediment tool

The quantification rules from Step 3 were integrated in a QGIS plug-in to make them easily available. The Smartsediment tool allows the user to calculate the impact of different sediment management strategies on the delivery of the ES and compare them with each other over a longer period of time. It has the following three functionalities:

- 1 preparation of data layers;
- 2 calculation of each of the selected ES separately; and
- 3 analysis of the results (Figure 3).

As QGIS is open source software, others can easily use our tool without a licence. This considerably increases the applicability of the Smartsediment tool in the future. The tool consists of two parts, the actual plug-in and a

GIS database. The first part, the QGIS plug-in, consists of the scripts that build the interface, and it integrates the quantification rules in a range of ES modules. The second part, the GIS database, consists of several folders needed to run the plugin. These folders contain ES-specific information and a location to store intermediate data during the calculations.

To run the ES calculations in the Smartsediment tool, information on a wide range of parameters is required. These parameters can be spatial maps or values that are consistent for the entire research area. The information can be derived from other conceptual and numerical models that can evaluate the impact of sediment management strategies on different estuarine characteristics such as hydrodynamics, sediment behaviour and others. An important parameter used in different ES calculations is a spatial description of the ecotopes. However, models or methods to calculate the ecotope map are not widely available. Therefore the tool comes with a module to calculate this map through other, usually more accessible, model-derived datasets such as current velocity and bed level.

ES often have complex relationships with many parameters. To accurately predict the impact of sediment management interventions on these ES, only specialised, numerical models can be used. However, this type of models and hence the broad range of specific data is not often available to the user, making it difficult to provide many of the required input parameters for the tool. To address this shortcoming, the ecotope map and other ES-specific data are used to calculate a range of ES. Wherever possible, the Smartsediment tool provides a multi-level approach. For some ES both a simple and a more complex calculation method is provided, allowing the user to choose the more appropriate method depending on data

availability. When only one method is available, a minimal set of parameters is required. But, if more precise data is available, the tool allows this additional data to be added, which will improve the accuracy of the ES calculation. Additionally, spatial data are not always available for all parameters. If only one value is available for the entire area, this value can be provided to the module instead of a spatial dataset. Thus the Smartsediment tool offers users a great deal of flexibility, giving a first screening of effects with the available data and knowledge. This also results in the disadvantage that the quality of the prediction is highly dependent on the quality and detail of the given input data.

The delivery of ES is not static, especially in dynamic systems such as estuaries. To understand how ES delivery evolves, the user can evaluate each ES for four time periods in one calculation run. The outcome of each calculation is a map that gives a spatial representation of the ES delivery. However, maps are often difficult to compare, especially over a range of time periods and different ES. Therefore a specific tool, created with Microsoft Excel, is made available to aggregate the spatial data in total values and mean values per hectare and present them in different tables. These tables allow the user to better compare changes between different sediment management strategies and how these strategies will impact the delivery of ES over time. By aggregating the data for only the project area or the larger estuary, comparisons can also be made between local and estuarine effects.

#### Case study: Sediment nourishment of the Roggenplaat (Eastern Scheldt, the Netherlands)

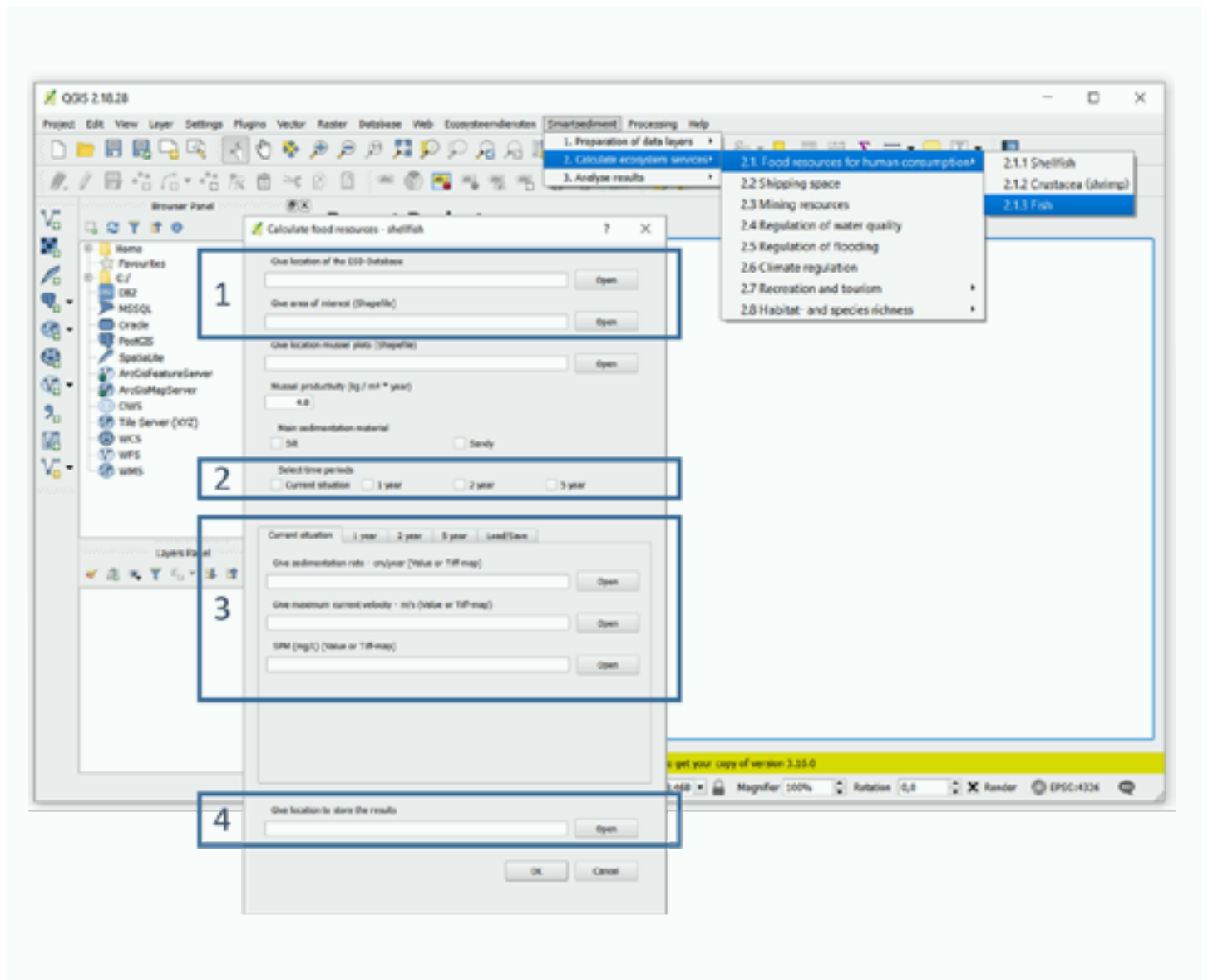
The tool was tested for a range of SMART sediment management strategies in the transboundary Scheldt delta. Sediment



nourishment of the Roggenplaat in Eastern Scheldt, the Netherlands is a good illustration.

In the Eastern Scheldt, the hydromorphological balance was disrupted around 1980 due to the construction of the storm surge barrier and compartment dams as part of the Delta plan [see Nienhuis and Smaal, 1994]. As the cross-section of the main channels was not

in equilibrium with the tidal volume anymore a net transport of eroded sediment from the tidal flats towards the channels was observed. Due to this 'sand starvation', tidal flats were gradually disappearing under the water [de Ronde et al., 2013]. This caused both available tidal flats and the feeding time for birds to strongly decrease. It was an undesirable effect because the preservation



**FIGURE 4**

Example of an ES calculator interface with the four types of information that are asked. Here the calculator interface for ES food resources from shellfish is shown: 1) The location of the ES-database and the area of interest for which the calculation should be done; 2) The time-step(s) for which the calculation has to be performed; 3) Data needed for the ES calculation for the different time-steps; and 4) The location where the results should be stored.



FIGURE 5

Picture of the Roggenplaat, located in the Eastern Scheldt in the Netherlands. Picture by Edwin Páree, Omroep Zeeland.

of these birds, in particular different types of wading birds, and benthic habitat is part of the European Habitat and Bird Directive targets. Eastern Scheldt is in fact a Natura 2000 area. Preventing erosion and sand hunger in this area is not possible because removing the storm surge barrier is not an option. Filling the channels, to moderate the sand hunger, would require too much sand. Therefore, management is orientated towards mitigating effects by elevating the tidal flats. One example is the heightening with nourishments of a part of the Roggenplaat in the north-eastern part of the Eastern Scheldt in the Netherlands (Figure 5). The aim is to preserve about 2,000 hectares of valuable intertidal area as a foraging area for the next 25 years (van der Werf et al., 2016). Additional points of attention in this region are the preservation of resting habitat for seals and prevent the southern coast of Schouwen from undesirable wave impact.

### Scenarios and input data

To illustrate the functionality of the Smartsediment tool, the impact of four scenarios on the delivery of ES was simulated: the 'Current (2016)' and 'Future (2030)' both with and without nourishments. Regarding data input, we used monitoring that was performed in 2016, before the nourishment started (Ysebaert et al., 2016 and Ysebaert et al., 2017), and environmental

impact assessment with appropriate assessment (Boudewijn, 2016). The following data were used for the calculations (de Ronde et al., 2013): bathymetry maps of the Eastern Scheldt, maps of the emersion time of the Eastern Scheldt, and a map of the maximum current velocity of the Eastern Scheldt. However not all parameters that are needed, as input data for the Smartsediment tool were available for the case-study, especially for the future situation as it requires thorough modelling to predict this. For those parameters, we added average numbers for the region or highly simplified estimates for grain size, water level, and productivity of fish, shellfish and crustaceans. As mentioned before, this allows flexibility for the user to use the tool in case of limited data, but obviously, when using such highly simplified input data, the output should be interpreted with great care.

### Calculating the ecotope distribution

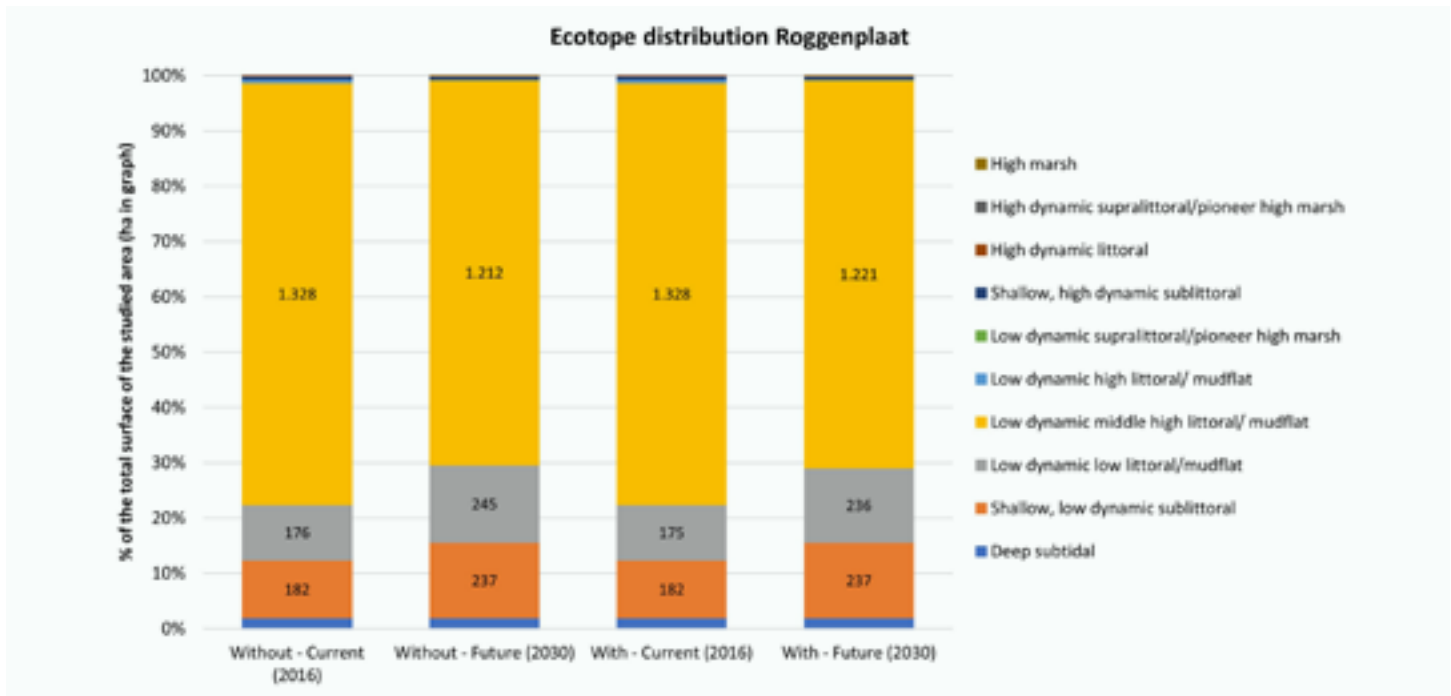
With the Smartsediment tool, ecotope maps were calculated for each scenario using the bathymetry, emersion and current velocity maps. The effect of the nourishment on the distribution of ecotopes appears to be limited (Figure 6). The expected scenario for 2030 is an increase of the shallow low-dynamic sublittoral area in comparison with 2016, both with and without the addition of nourishment. This area would originate from eroded low-dynamic middle-high littoral areas. Do note

that the low dynamic middle-high littoral area is predicted to be larger in the scenario 'Future (2030)' if the nourishment is added. It seems therefore that the effect of the nourishment on the distribution of the ecotopes is more pronounced over the long term.

### Calculating ES effects

For the following ES the tool offers a calculation method: food provision from shellfish, crustaceans, and fish, flood risk prevention, regulation of water quality, climate regulation, recreation and tourism from boating, habitat and species richness for seals and wading birds. Four scenarios, with and without nourishment, for the situation directly after the nourishment and in 2030, were input for a calculation of ES with the Smartsediment tool (Table 1).

This analysis helps to have a more integrated picture of the possible effects of this project and whether it can achieve its goal. The project is mainly designed to extend the availability of a suitable feeding area for birds and to secure it in the long term (by 2030). There was also attention paid to minimising the impact of the works on local mussel plots. The output suggests that indeed the objective of the project was achieved as the future area for birds would be higher with replenishment than without. With the nourishment put in place, the habitat for wading birds will initially disappear.



**FIGURE 6**

Ecotope distribution for the four different scenarios at the Roggenplaat and its immediate surroundings. Note the remarks on data uncertainty and limitations in the reflection section.

This is due to the burial of the macrobenthos community. In the future, the benthos will recover, leading to more foraging habitat than in the future scenario without nourishment (Figure 7). This is as expected and can be explained by the increased emersion time because of the nourishment (van der Werf et al., 2016). The Smartsediment tool predicts no effect of the Roggenplaat nourishment on the habitat for resting seals. Because the nourishment is carefully designed not to influence seal habitat, this outcome was as expected. Also, hardly any impact on shellfish is calculated. For water quality and climate regulation – two services that were not considered in the original project design but may be of additional importance – the nourishment does not seem to be important.

Such ES approach offers a much broader assessment of the project compared to the appropriate assessment (AA) (Boudewijn, 2016). The ES approach assesses in the first place the positive contributions of nature to society. In case a project results in the creation of new nature areas it will get a positive evaluation, while in case a

nature area disappears the evaluation will be negative. In comparison, in an AA only the question whether a project is harmful for nature is addressed. In the AA of the Roggenplaat (Boudewijn, 2016) it was concluded that this project will not result in harmful consequences for the natural conditions of the potentially affected area (given the conditions stated in the permit, e.g. no nourishment within a buffer of at least 600 m from the center of the known seal resting area at the edge of the tidal flat). The ES approach shows also an improvement for birds but also additional positive effects on fish and crustaceans such as shrimps (Table 1). Hence, it demonstrates the positive added value.

#### Remarks and limitations

The Smartsediment tool was developed and tested for the transboundary Scheldt delta, but the conceptual model is generally applicable to estuaries and coastal areas with similar characteristics. The relationships between the ecosystem parameters and ES can be applied on other estuaries, although this would require adaptations for the local

**This analysis helps to have a more integrated picture of the possible effects of this project and whether it can achieve its goal.**

conditions. The calculation methods should be specified for the characteristics of the studied coastal zone these being the morphological conditions, discharge, nutrient load, species types, etc. Furthermore, the applicability of the Smartsediment tool is not limited to the evaluation of sediment-related measures. The evaluation method can also be used to assess other measures



in estuaries such as changes in fresh-water management or changes in local discharges, such as for example cooling water.

The tool has some limitations. It is for screening and is not a numerical model. Since the tool pursues a broad scope of application, both large and small project areas as well as detailed and less detailed inputs, the level of detail created by the output cannot be limited in advance. Furthermore, it is important to note that the result of the simulation is largely determined by the assumptions made to generate the ecotope maps.

The user should be aware that the reliability of the output is greatly dependent on the reliability and precision of the input data. One should be aware of the different levels of uncertainty linked to the input data as well as the provided calculation methods in the tool. The methods foreseen in the tool for individual ES are rather simple to ensure that data input requirements are not too high but leading to less precise outcomes. Furthermore, the effects of different ES on each other are not considered such as recreational activities that might disturb bird habitat. The tool can be used for a high-level comparison of scenarios with only high-level estimates as input, but then the output should also be considered as a high-level screening. When tool is used to assess future situations without extensive modelling beforehand it is difficult to predict exact realistic values, leading to an uncertain outcome of the calculations.

The output values given for the ES are not exact values but must be considered in a relative way to compare between sites and scenarios. Therefore, the results should always be interpreted by an expert with knowledge about the area of interest. As demonstrated for the Roggenplaat case (Table 1), the output can be translated into positive or negative trends or impact to prevent the exact number of outputs being given too much emphasis. This places the output more in line with the status of a screening tool, giving an indication of the influence of sediment measures so that decisions about further research or communication may be objectively analysed and evaluated to support decisions for further research and/or communication.

For more information or enquiries, please contact editor@iadc-dredging.com

TABLE 1

Calculated ES in the direct surroundings of the Roggenplaat nourishment for four scenarios. ++, ++ & + means an increase of at least 50, 20 & 10 % respectively compared to the Present (2016) scenario without nourishment. ---, -- & - means a decrease of respectively 50, 20 & 10 % and '=' indicates that there is less than 10% difference between the two scenarios. Numerical output is transformed into this trend indication because the high uncertainty of the input data. Note the remarks on data uncertainty and limitations in the reflection section.

ES Roggenplaat and its surroundings	Without nourishment		With nourishment	
	Present (2016)	Future (2030)	Present (2016)	Future (2030)
<b>Food provision</b>				
Shellfish (kg/year)	176	=	=	=
Crustaceans (kg/year)	5,225	++	=	++
Fish (number x 1000)	120	++	=	++
<b>Regulating flood risk</b>				
	Ref.	=	=	=
<b>Regulating water quality</b>				
Denitrification (tonN/year)	303	=	=	=
Nitrogen uptake (tonN/year)	161	=	=	=
Phosphorus uptake (tonP/year)	45	=	=	=
Silica release (tonSi/year)	303	=	=	=
Climate regulation (tonC/year)	1,420	=	=	=
Recreational shipping (passages/year)	8	--	=	--
<b>Habitat and biodiversity</b>				
Habitat for seals (m <sup>2</sup> )	179	=	=	=
Habitat for wading birds (m <sup>2</sup> )	671	-	-	=

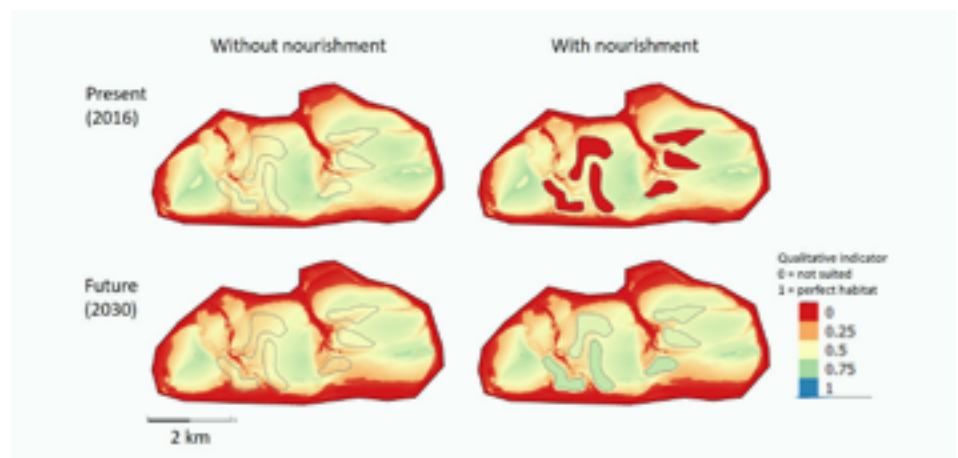


FIGURE 6

Suitability of the Roggenplaat as foraging habitat for wading birds (with 0, red = not suited and 1, dark blue = perfect habitat) for four scenarios: with and without nourishment, at present and in the future. Maps are calculated with the Smartsediment tool. The grey contours indicate where the nourishment was placed. Note the remarks on data uncertainty in the reflection section.



### **Annelies Boerema**

Annelies specialised in ecosystem services research, combining a biophysical and economic evaluation of ecosystem management practices. Her background is in economics and environmental science. She obtained a PhD in environmental science at the Ecosystem Management research group at the University of Antwerp, Belgium. Since 2020, she works as an adviser at IMDC, an international engineering and consultancy company in the field of natural waters.

## Summary

The Smartsediment tool can be used to investigate how different sediment strategies affect a range of ecosystem services in both the short and long term in a fairly simple way and with a limited data set. The tool is developed as QGIS plug-in to make a spatially explicit quantitative evaluation tool and is based on a conceptual model that allows to identify all impact-effect pathways from sediment strategies on the functioning of the coastal zone including ecosystem knowledge, and to translate this into effects onto the selected ES. However, the simplicity of the tool is not only a strength. The results need to be handled with care. Although they do not accurately reflect all details of the much more complex reality, these provide useful trends and can serve as a basis for communication, to inform decision making, or decisions for further research.

*The Smartsediment tool is realized as part of the Interreg project Smartsediment and is co-financed by the European Regional Development Fund (ERDF) and the Smartsediment project partners (<https://smartsediment.eu/>). The different reports describing all details, the manual of the tool and the tool itself can be downloaded on this website.*



### **Katrien van der Biest**

Katrien is a postdoctoral researcher at the Research Group Ecosystem Management of the University of Antwerp, Belgium. She obtained her Master's degree in Physical Geography at the University of Ghent and her Master's degree in Oceanography at the University of Liège, both in Belgium. Her current research focuses on quantifying and mapping ecosystem services as a supportive tool in environmental management, both in terrestrial and in marine ecosystems.



### **Patrick Meire**

Patrick is professor in biology and head of the research group Ecosystem Management (ECOBIE) at the University of Antwerp, Belgium. His research focuses on the environmental impact of human activities on aquatic and wetland systems and these insights are used to develop concepts for integrated water management and ecosystem management. He obtained his PhD in Biology from the University of Ghent, Belgium.



### **Sofie De Swert**

Sofie studied Environment, Health and Safety Management at the KU Leuven, Belgium. In 2019, she graduated from the Advanced Master of Science for Integrated Water Management at the University of Antwerp, Belgium, with a thesis on nourishment projects in the Eastern Scheldt in cooperation with the Royal NIOZ, in Yerseke, the Netherlands. Following her studies, she worked as a research assistant on the Interreg project Smartsediment for the Royal NIOZ, where she participated in the evaluation and application of the Smartsediment tool.



### **Marcel Taal**

Marcel works in the Resilience and Planning division of the Marine and Coastal Systems unit of Deltares. He has over 20 years experience in providing knowledge on coasts and estuaries to policy and management in the Netherlands. He manages the implementation and also develops, together with representatives of the Dutch government, national knowledge programmes for the Dutch coast and the Scheldt estuary. Marcel previously worked for the Dutch government for six years, where, amongst others, he led the coastline management programme.





**Dirk Vrebos**

Dirk is a biologist by training and since 2009 has worked at the University of Antwerp, Belgium. In his doctoral thesis, he investigated relationships between land use, water quality and ecosystem services within a river basin in Flanders. Over the past 10 years, he has analysed, within national and international projects, the effects of policy and management on the delivery of ecosystem services in Flanders, Europe and Africa.



**Frederik Roose**

Frederik graduated from the University of Ghent, Belgium, as Bio-engineer in soil and water management and as Master of Marine and Lacustrine Sciences. Since 2006, he works as a project coordinator in the Environment Team of the Maritime Access Division of the Department of Mobility and Public Works in Flanders, Belgium. His projects are related to the development of the sediment management strategy in the Schelde estuary and how it affects the estuary's morphology and ecology.



**Sebastiaan Mestdagh**

Sebastiaan trained as a marine biologist with a general interest in the interaction between humans and life in and on the seabed. He holds a Bachelor in Biology from the Catholic University of Leuven, Master of Marine and Lacustrine Science and Management from the Free University of Brussels and a Doctor of Marine Sciences from Ghent University. He has since worked at the Royal NIOZ, in Yerseke, the Netherlands where, in addition to the Smartsediment project, he worked for the DISCLOSE project, investigating the soil habitats of the North Sea.



**Tom Ysebaert**

Tom is a marine ecologist and expert on estuarine, deltaic and marine ecosystems, with special emphasis on the functional role of benthic ecosystems. He received his PhD degree in 2000 at the University of Antwerp, Belgium. He is currently senior researcher and adviser at Wageningen Marine Research and senior researcher within the Estuarine & Delta Systems department at the Royal Netherlands Institute for Sea Research in Yerseke, the Netherlands. He is also associated professor at the University of Antwerp, Belgium.

**REFERENCES**

Apitz, S. E. 2012.

Conceptualizing the Role of Sediment in Sustaining Ecosystem Services: Sediment-Ecosystem Regional Assessment. *Science of the Total Environment* 415:9-30.

Barbier, E.B., Hacker, S.D., Kennedy, C.J., Koch, E.W., Stier, A.C. & Silliman, B.R. 2011.

The Value of Estuarine and Coastal Ecosystem Services. *Ecological Monographs* 81:169-93.

Boerema, A. & Meire, P. 2017.

Management for Estuarine Ecosystem Services: A Review. *Ecological Engineering* 98:172-82.

Boerema, A., Geerts, L., Oosterlee, L., Temmerman, S. & Meire, P. 2016a.

Ecosystem Service Delivery in Restoration Projects: the Effect of Ecological Succession on the Benefits of Tidal Marsh Restoration. *Ecology and Society* 21:10.

Boerema, A., Rebelo, A.J., Bodi, M.B., Esler, K.J. & Meire, P. 2017.

Are Ecosystem Services Adequately Quantified? *Journal of Applied Ecology* 54:358-70.

Boerema, A., Van der Biest, K. & Meire, P. 2016b.

'Ecosystem Services: Towards Integrated Maritime Infrastructure Project Assessments.' ECOBE report 016-R190. Antwerp: University of Antwerp. Commissioned by IADC.

Böhnke-Henrichs, A., Baulcomb, C., Koss, R., Hussain, S.S. & De Groot, R.S. 2013.

Typology and Indicators of Ecosystem Services for Marine Spatial Planning and Management. *Journal of Environmental Management* 130:135-45.

Boudewijn, T.J. 2016.

'Passende Beoordeling Zandsuppletie Roggenplaat: Toetsing in het kader van de Natuurbeschermingswet 1998 en Natuurnetwerk Nederland'. Nederland: Bureau Waardenburg Ecologie & landschap.

Brils, J., De Boer, P., Mulder, J. & De Boer, E. 2014.

Reuse of Dredged Material as a Way to Tackle Societal Challenges. *Journal of Soils and Sediments* 14:1638-41.

CEDA 2013.

'Ecosystem Services and Dredging and Marine Construction'. Delft, the Netherlands: Central Dredging Association (CEDA).

#### CICES 2020.

'Common International Classification of Ecosystem Services (CICES) for Integrated Environmental and Economic Accounting, version V5.1 spreadsheet.' [https://cices.eu/content/uploads/sites/8/2018/03/Finalised-V5.1\\_18032018.xlsx](https://cices.eu/content/uploads/sites/8/2018/03/Finalised-V5.1_18032018.xlsx)

#### de Ronde, J., Mulder, J.P.M., van Duren, L.A., Ysebaert, T., 2013.

'Eindadvies ANT Oosterschelde (Concluding Advice Autonomous Negative Trend Oosterschelde)', Deltares Report 1207722-000-ZKS-0010. December 2013 (in Dutch).

#### De Swerd, S., Boerema A., Van der Biest K., Vrebos D., Buis K., Taal M., Maris T., Mestdagh S., Ysebaert T., Van Holland G., Depreiter D., Meire P., 2020.

'Smartsediment Ecosystem Services-tool Manual'. Version: 28 Aug. 2020. Interreg project Smartsediment. NIOZ.

#### Haines-Young, R. & Potschin, M. 2013.

'Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December 2012.' EEA Framework Contract No EEA/IEA/O9/003 (Download at [www.cices.eu](http://www.cices.eu) or [www.nottingham.ac.uk/cem/](http://www.nottingham.ac.uk/cem/)).

#### Jacobs, S., Wolfstein, K., Vandenbruwaene, W., Vrebos, D., Beauchard, O., Maris, T. & Meire, P. 2015.

Detecting Ecosystem Service Trade-offs and Synergies: A Practice-oriented Application in Four Industrialized Estuaries. *Ecosystem Services* 16:378–89.

#### Liquete, C., Piroddi, C., Drakou, E.G., Gurney, L., Katsanevakis, S., Charef, A. & Egoh, B. 2013.

Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review. *PLoS ONE*, 8, e67737.

#### MEA 2005.

*Ecosystems and Human Well-being: Current State and Trends*. Millennium Ecosystem Assessment. Washington: Island Press.

#### Nienhuis P.H. & Smaal A.C., 1994.

The Oosterschelde Estuary, a Case-study of a Changing Ecosystem: An Introduction. *Hydrobiologia* 282/283:1–14.

#### PIANC 2016.

'PIANC Orientation Paper: Opportunities to Apply the Concept of Ecosystem Services (ES) to the Waterborne Transport Infrastructure (WTI) Sector.' PIANC-EnviCom Environment Commission.

#### TEEB 2010.

'The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations.'

#### Turner, K. & Schaafsma, M. 2015.

Coastal Zones Ecosystem Services: From Science to Values and Decision-Making. *Studies in Ecological Economics*. Switzerland: Springer.

#### UNEP 2009.

'A Contribution to the United Nations World Water Assessment Programme (WWAP): The Critical Connection.' Nairobi, Kenya: United Nations Environment Programme (UNEP).

#### UN-WATER 2014.

'A Post-2015 Global Goal for Water: Synthesis of Key Findings and Recommendations from UN-Water.' United Nations (UN) inter-agency mechanism for all freshwater and sanitation related matters (UN-Water).

#### Van der Meulen, E.S., Braat, L.C. & Brils, J.M. 2016.

Abiotic Flows Should be Inherent Part of Ecosystem Services Classification. *Ecosystem Services* 19:1–5.

#### Van der Werf, J., Boersema, M., Bouma, T., Schrijvershof, R., Stronkhorst, J., De Vet, L. & Ysebaert, T. 2016.

'Definitief Ontwerp Roggenplaat Suppletie.' Delft, Vlissingen, Yerseke: Centre of Expertise Delta Technology.

#### Verheyen, B., Van Holland G. & Boerema A., 2020.

'Toepassingsmogelijkheden ESD-tool: Praktijkgeval Vogeleiland'. NO20069. Antwerp, IMDC.

#### Vrebos, D., Staes, J., Broekx, S., de Nocker, L., Gabriels, K., Hermy, M., Liekens, I., Marsboom, C., Ottoy, S., Van Der Biest, K., van Orshoven, J. & Meire, P. 2020.

Facilitating Spatially-Explicit Assessments of Ecosystem Service Delivery to Support Land Use Planning. *One Ecosystem* 5.

#### Ysebaert, T., Van der Werf, J., Boersema, M., Schrijvershof, R., Stronkhorst, J., De Vet, L., Debrot, A. & Bouma, T. 2016.

'T-O Rapportage Roggenplaat Suppletie.' Centre of expertise Delta Technology.

#### Ysebaert, T., Van der Werf, J., De Vet, L. & Bouma, T. 2017.

'Monitoringsplan Roggenplaat suppletie.' Yerseke, Delft, Vlissingen: Centre of Expertise Delta Technology.



**DIRECTOR OF COASTAL  
& CLIMATE CHANGE,  
ASIA AT AURECON,  
STÉPHANIE GROEN**

**'SUSTAINABILITY  
IS A TOPIC CLOSE  
TO MY HEART.  
I GREW UP WITH IT.'**

Stéphanie Groen works as the Director of Coastal & Climate Change, Asia for Aurecon. Based in Singapore, she was appointed to the position at the beginning of 2020. Previously, Stéphanie was involved in marine and environmental projects for more than 15 years with DHI and her education is in civil engineering and business administration. IADC also knows Stéphanie as the winner of the Young Author Award in 2007. More recently, she was appointed as a committee member to the prestigious FIDIC Sustainable Development Committee. We were interested to hear more from Stéphanie – her views on sustainability, the collaboration with the dredging industry through FIDIC and what her new role can mean for sustainable water infrastructure projects.

Photo courtesy of Aurecon.



---

### Can you tell me about your academic and professional background and experience?

Back in 2002, I completed a Bachelor of Science degree in civil engineering and a Master of Science in civil engineering and geotechnology. In 2011, I completed an MBA, which gave me more insight into business operations and running an organisation. This turned out to be very useful for my role later in my career.

### How did you end up in the South-East Asian region?

I arrived in Singapore in 2002 as a trailing spouse for a two-year stint. I was fortunate enough to find a local job in Singapore and have not looked back since. I am very thankful for the privilege to work and live in other parts of the world. It makes you agile, street-smart and broadens your experience at an extraordinary pace. And believe me, some parts of Asia are moving fast!

Living and working abroad means having to adapt to the local culture and business practices, and this has not always been easy. The Dutch are often known to be extremely blunt, direct and stubborn (with good intentions, but still...) and this is often not understood or appreciated in Asia. But we are also known for honest collaboration, taking a win-win approach and having a business mindset. These traits have been very helpful to me throughout my career in Asia.

### What do you like about working in South-East Asia?

South-East Asia is so diverse; I find it fascinating. How each country (for example, Singapore, Indonesia, Malaysia, Brunei, Hong Kong, Vietnam, Thailand, Philippines) does business is different and this means adaptability and flexibility are key. The best part of Singapore is its ability to make big decisions at high level within a relatively short time, especially with respect to economic and infrastructure developments. This is extremely powerful and generally good for business and for our industry.

### Do you speak any languages from the region?

English is fortunately still the common business language, so English, Singlish and Dutch are the languages that I currently master. I did have a go at Japanese last



year, more to be able to get around during holidays and to find out how difficult it would be to learn if I wanted to live and work in Japan. Conclusion: very difficult. Once you get familiar with some of the Hiragana and Katakana characters and you think you are starting to understand, Japanese Kanji and other conversation forms are thrown into the equation. Furthermore, COVID-19 unfortunately derailed my 2020 summer holiday plans to the Japanese Alps, so learning and practicing Japanese is going to take me a lifetime I think.

### How did you become involved with dredging and why?

Van Oord BV was the first company that replied to my traineeship application. Honestly, I had no idea what I got myself into. They initially had a traineeship position in India, but decided against it as a blond Western female at the site might have been too much of a culture shock for both parties. That's why they offered me a traineeship in Wales, UK. The two projects that I supported were related to dredging trenches for the deployment and backfilling of sewer outfalls.

During this internship, I experienced many firsts: learning about dredging, applying backfilling and surveying techniques, operating out at sea, becoming seasick way too often, experiencing delays due to bad weather, living and working in another country, driving on the 'wrong' side of the road, using a (Motorola) mobile phone for work, being on my own and being dependent on my colleagues seven days a week. I absolutely loved it.

### In 2007, you won the IADC Young Author Award with an article on environmental monitoring and managing reclamations works close to sensitive habitats ('Environmental Monitoring and Management of Reclamations Works Close to Sensitive Habitats', Terra et Aqua 108). What did winning the award do for you?

The award was a great acknowledgement that the work we had done was meaningful and was viewed as something different and positive that could be implemented in projects. The concept presented was later used and adopted by PIANC, and further described in

---

**A win-win approach: Balancing socio-economic development (through land reclamation) with environmental preservation.**

**Sustainability now comes in many forms, and as engineers and scientists, we have collective knowledge, data and expertise to make a positive difference to the communities we live in.**

the PIANC 108-2010 report 'Dredging and Port Construction around Coral Reefs'.

**What influence did winning the award have on your career?**

I think winning the award definitely helped to make the Environmental Monitoring & Management concept more visible and being endorsed in this way supported the implementation of the feedback methodology.

The focus was on forecasting environmental impacts, daily measurements at the source and quick feedback about and adaptation to local unexpected environmental conditions. This was different from what the industry was using at that point in time. The previous monitoring systems were primarily reactive and only recorded or flagged environmental issues when damage had been done. This pro-active approach was new and focused on a win-win approach: ensuring that dredging and reclamation works can continue within the boundaries of environmental compliance. Singapore has been one of the early (Asian) adopters and they still follow the same principles.

**Thirteen years later and looking back at that article, what has changed?**

The concept is still the same: identify and confirm potential positive and negative impacts to the surrounding environment, find the tolerance limits of the various habitats near the development site, model the various levels of impact, define the limits of the amount of sediment spill that various receptors (i.e. habitats, intakes and more) can tolerate over time, provide input about spill limits, vessel type and production and make sure that this is included in the contractor's tender documents. Once construction starts, continuously monitor and provide daily feedback (7 days/week) for the duration of the works.

What has changed and improved is the turnaround time for reporting and response, the digitalisation of the system, refinement of calculations, improvements of near-field and far-field modelling and the development of online dashboard systems and data streaming where clients and contractors can view information. In terms of the understanding of habitats, so much more data (especially for tropical environments) have been collected over the past 15 or more years. This is terrific and shows that there is a much better understanding of and confidence in tolerance limits for, for example, mangroves, corals, seagrass and other flora and fauna.

**Can you tell us about your present position at Aurecon? What you do there and what the company is specialized in?**

Aurecon is a leading engineering, design and advisory company. Over the past 85 years, our team of more than 5,500 experts located in over 30 cities across the globe have collaborated with our clients and partners to reimagine, shape and engineer clever, innovative and sustainable solutions to solve some of the world's most complex challenges. Recently, we have been named as Australasia's Most Innovative Company by *The Australian Financial Times*.

I joined Aurecon early 2020, and I am based in Aurecon's Singapore office. In my role, I have been tasked to establish and lead Aurecon's Coastal and Climate Change practice for Asia as well as their Advisory business.

Asia Pacific is one of the most vulnerable regions for climate change and its impacts are projected to become more intense. Furthermore, there is an increasing number of governments and industries in Asia prioritising efforts to combat climate change; be it exploring ways to reduce emissions

or investing in mitigation and adaptation initiatives.

Some examples are:

- In Singapore, ~US\$3.7b is being invested in coastal and flood protection efforts as 30% of Singapore is less than five metres above the mean sea level. The city-state is also investing in projects to generate power from renewable sources, such as microgrids, to help pave the way towards sustainable energy;
- In Hong Kong, ~US\$976m has been allocated to capital works for climate change, which includes a range of measures to ensure public infrastructure is climate ready; and
- In Vietnam, climate change adaptation is crucial, especially for natural resource-dependent farmers, and the country is adapting infrastructure to focus on developing agricultural techniques and elevate houses above flood levels.

At Aurecon Asia, we have identified climate change and sustainability as a key growth area for our business. We work with organisations and governments to protect and build resilience and adaptation by responding to the risks and opportunities presented by sustainability and climate change. Leading a team of experts, we work with our clients to understand where they are on their journey, designing solutions that are backed by our engineering and advisory experience, technical and digital capabilities and design expertise.

We are strong believers that a better future is a world that works for all of humanity and the planet. As a company, we have made a commitment to become net zero as a business by 2025, to support the United Nations Global Compact and imbue with it our strategy, culture, day-to-day operations and our engagement in collaborative projects that advance the United Nations Sustainable Development Goals. As engineers, designers and advisors, we recognise and continue to play a vital role in helping the communities and economies in which we operate transition to a net zero carbon future.

For me, personally, I feel we are living in a tough yet exciting time. In our industry we have the opportunity to help our employees, our clients and our community transition to a climate-



Photo courtesy of Aurecon

resilient future, and this work will benefit the community and the greater good.

### What is your involvement with dredging in your current role at Aurecon?

At the moment, I have little involvement with dredging in my role. However, we foresee a couple of upcoming design and build reclamation developments in both Singapore and Hong Kong, where Aurecon can support both clients and contractors. Hence this will come in due time.

### Your work has been aimed at sustainability for many years now. Where does this interest in sustainability come from?

Sustainability is a topic close to my heart. I grew up with it (even though we never officially termed it that before). As a child growing up in the Netherlands, my family home was built on one of the 'old dunes' which is still part of an extraordinary 6-km-wide stretch of sand dunes facing the North Sea. Dunes have always been a natural form of coastal protection. The dune was an ever-changing landscape of endless opportunity and the perfect place to spend time outdoors while learning about biodiversity, coastal protection and drinking water management. To date, the natural filtration system of the sand dunes

still provides the Amsterdam region with some of the best quality tap water in the country.

At home we ate mostly from the land. My mother has tended to her own organic vegetable garden since 1983. My father used to bake bread for the family and mum made us recycle biodegradable waste, batteries, paper as well as plastic. These are activities which I didn't realise were very special until I went to grammar school and discovered it was kind of unique. Besides, the internet did not yet exist, so what did you do as a kid? You went outside, ran, cycled, went camping, got dirty, etc. But I have learnt from my childhood that whatever you do, do not litter, look after nature and make sure the only thing you leave behind is your footprints. I still have this mindset today.

Sustainability now comes in many forms, and as engineers and scientists, we have collective knowledge, data and expertise to make a positive difference to the communities we live in. Whatever we do and build is very tangible and based on factual data and information, not just on emotions or opinions. I believe we should always try to strike a balance between economic development and environmental preservation and/or sustainable development. With so much collective know-how, and having seen the benefits of Environmental Impact Assessments, Environmental Monitoring works and mitigation measures, there is

sufficient proof that it is possible to have both.

### You were recently appointed as a committee member to the 11-member FIDIC Sustainable Development Committee. Congratulations! How do you hope to contribute to the committee?

FIDIC has been active in the Sustainability space for some years. The recent appointment of new members in July 2020 has been exciting and will bring new global views to the table. The goal is to identify what the most pressing issue or topic is in the infrastructure and consultancy industry, and have an agile and proactive team available that can support FIDIC in taking a position and supporting the industry, both globally and regionally.

The committee has been formulating a plan for the coming year, to make sure topics are relevant and can be addressed as soon as possible. The current plan is to focus on three areas:

- 1 Strategic partnerships and collaboration with other industry players on the topic of sustainability. FIDIC is also running other committees, so potential partnerships could be driven through various committees within FIDIC;
- 2 State of the World reports. FIDIC will relaunch its State of the World reports





On 28 October 2020, IADC signed a major strategic collaboration agreement with the International Federation of Consulting Engineers (FIDIC) that will see the two organisations working more closely together and collaborating on matters of mutual interest over the next two years.

In the Memorandum of Understanding, they agree that for two years they will:

- collaborate on the development of balanced contracts that will benefit the wider industry;
- enter into a partnership on conferences and the friendly review of contracts;
- collaborate on the dissemination of knowledge on how to develop and build sustainable marine infrastructure projects; and
- work together to bring publications to the attention of their target groups.

For more information visit the IADC website: <https://bit.ly/39ermxP>

development (roads, ports, railways, airports, water, wastewater, and power generation).

The current committee will continue to focus on sustainable infrastructure reporting, but we would also like to have the opportunity to address other topical issues, for example the agenda for COP26 and how FIDIC can best collaborate with other industry players to support the industry and make a greater impact.

**In August 2020, *The Guardian* ran an article reporting that the world has failed to meet a single target of the 20 Aichi biodiversity targets (2010) aimed to stop the destruction of nature. One of the problems mentioned is that half a trillion in government subsidies are directed at harmful activities in agriculture, fishing and fossil fuels. Do you see room for government collaboration to support sustainability in your industry and areas where presently this support is lacking?**

It is important to note that even though we have a long way to go, it is not all doom and gloom. Six targets have partly been achieved and we also see some stability and improvements in numbers if you look at the recent statistics from the UN with respect to the SDG 13, 14 and 15.

For example:

- Whilst the total global forest area as a proportion of total land area reduced by 1.4% between 2000-2020 (in practical terms, this means a net loss of ~100 million ha of the world's forests), globally certified forest, forests in protected areas, or forests under legislation and long-term management have remained stable or increased in the past 20 years;
- The risk of extinction for global species

as an annual series that will focus on a wider range of topics and be supported by webinars, social media and all of FIDIC's committees. These reports will also align to the Sustainable Development Goals of the UN to help industry and stakeholders meet the targets set by 2030; and

- 3 FIDIC is actively participating in the annual United Nations Climate Change Conference, and the committee is currently supporting the agenda for COP26 in 2021.

**Has COVID-19 had any effect on FIDIC activities?**

FIDIC's role is to advise the industry and provide guidelines. With COVID-19, FIDIC has provided various suggestions and guidelines especially relating to the FIDIC STANDARD FORMS OF WORKS CONTRACT. COVID-19

is still viewed as a force majeure in many countries. Even as the industry is working on new projects and they are aware of the COVID-19 situation, no one can foresee other national or regional restrictions that will be imposed in the future. Hence, the industry is constantly looking for legal and contractual guidance in this matter, and this is where FIDIC plays a very important role.

**What has FIDIC been doing until now on sustainable development? Does your appointment mean an increase in activities or a shift in focus?**

FIDIC has previously focused on Project Sustainability, through the publication of management guidelines, logbooks and the 'State of the World Report for Sustainable Infrastructure' (2012). The latter describes what decisions can be made to support a sustainable future in terms of infrastructure

**There is a much better understanding of and confidence in tolerance limits for, for example, mangroves, corals, seagrass and other flora and fauna.**

(Red List Index) has in fact declined by 10% between 1990-2020;

- Currently 24 million km<sup>2</sup> or 17% of global waters under national jurisdiction are covered by protected areas. This doubled between 2010-2019; and
- Further, global climate finance increased by 17% between 2013-2016 (US\$ 584b – US\$ 684b) and climate-related financial disclosures for corporations is now becoming the norm. (<https://unstats.un.org>)

The above topics are great examples of government initiatives especially with respect to the protection of terrestrial habitats (forests, nature reserves). However, protecting our oceans and life below water is more difficult to achieve and often crosses international boundaries and legislations. International government collaboration could be a solution

but public-private partnerships may have a stronger impact on the sustainability agenda.

I firmly believe that the only way to make a difference is to address the issue at the source, but realistically the scale of these biodiversity issues is often huge. Think about how best to regulate the fishing industry, or the consumer plastic waste that is making its way into the ocean. Cleaning the ocean is a much-needed initiative, but governments can help greatly to solve the problem at the source.

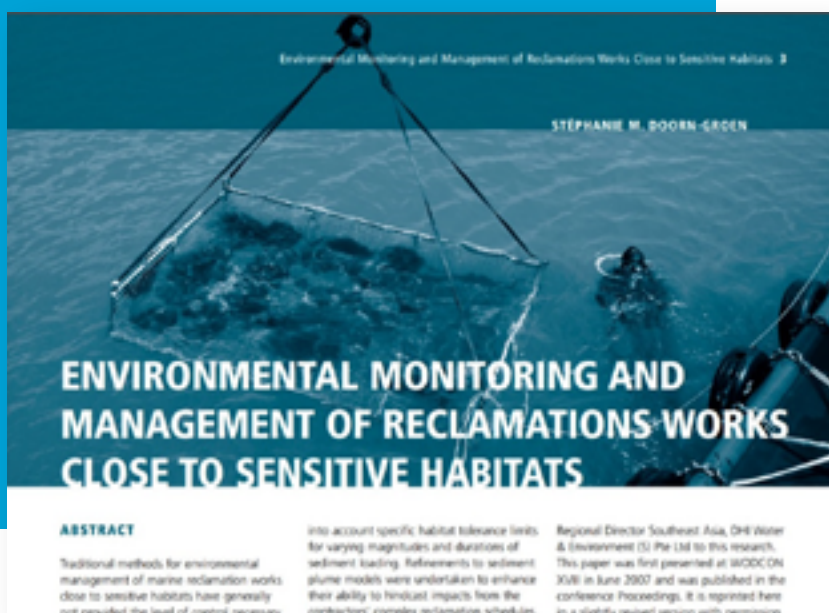
Therefore public-private partnerships could be a great long-term solution as the corporate environment is naturally geared towards long-term views, long-term plans, return on investment and overall business stability.

For example, the Tompkins Conservation ([www.tompkinsconservation.org](http://www.tompkinsconservation.org)) has provided

## Environmental monitoring and management of reclamations works close to sensitive habitats

Traditional methods for environmental management of marine reclamation works close to sensitive habitats have generally not provided the level of control necessary to ensure preservation of these habitats. Obtaining the level of control necessary to assure authorities and non-governmental organisations (NGOs) of compliance with environmental quality objectives, requires quantifiable compliance targets covering multiple temporal and spatial scales.

Of equal importance to allow feedback of monitoring results into compliance targets and work methods are effective and rapid response mechanisms. This article describes the successful implementation of comprehensive Environmental Monitoring and Management Plans (EMMP), based upon such feedback principles, which allow reclamation activities to proceed in close proximity to Singapore's most important marine habitats under third party scrutiny[...]



a couple of a fantastic examples of private investment in damaged state land affected by unsustainable agriculture. However, with time, support and re-introduction of native species, the land was turned back into its natural state and eventually given back to the state (Chile) and the people as protected natural parks. If governments could direct the half trillion in government subsidies to these types of coastal and marine infrastructure investments and partnerships instead, that would be a bold but brilliant move in the right direction.

**What are specifically Asian sustainability concerns and challenges?**

**Managing de-carbonisation and reduction of overall CO<sub>2</sub> emissions**

Furthermore, the understanding and implementation of local resource recovery principles (Circular Economy), which, if properly managed, will support local economies and the overall reduction in CO<sub>2</sub>. If COVID-19 taught us one thing, it is that in times of a global crisis (a pandemic), the individualist mindset needs to change towards one harnessing the collective power and collaborative efforts of the community to keep the local economy running. In that respect, Europe and the USA can learn a thing or two from Asia! I hope the recent shift in increased local focus will help to leapfrog some of the barriers that have prevented countries to take steps towards resource recovery, emission reduction and subsequent decarbonization.

**The production and use of plastic, managing plastic waste and recycling**

Asia is unfortunately still behind in reducing plastic production and use, and this goes all the way down to households and personal habits. Further, the ineffective management of plastic waste is often the main reason why plastic ends up in the oceans. As mentioned earlier, addressing the source is most important with respect to reducing plastic waste, as large-scale plastic removal from the ocean is a huge challenge and will become an even greater challenge in the future, since plastic tends to break down in smaller parts (microplastics) and therefore becomes more difficult to detect and remove over time. Think about the fact that fishing lines take approximately 600 years to break down, plastic bottles about 450 years (see



Photo courtesy of Aurecon

Our World in Data: <https://ourworldindata.org/faq-on-plastics#note-27>.

**Understanding and managing climate risks**

Physical climate risks and climate impacts differ per location and will require different adaptation options. The timeline for the implementation of these adaptation options is location specific. The economic, social and financial costs and benefits of physical protection and the value-add that sustainable developments and eco-shorelines could bring need to be taken into account if practically possible.

**What do you see as your biggest challenge both personally and in terms of sustainability?**

My personal challenge will be balancing work and life, continuing to enjoy what I do, staying healthy both mentally and physically, staying fit, keeping up to date with the things that I am passionate about and staying optimistic. There is still so much to learn. Fortunately we live in a time where life-long learning is possible for everyone. I am sure I will never get tired of exploring and learning new things.

To continue as an individual to make a difference to sustainability will result from being critical, asking the hard questions and staying involved in, for example, the World Cities Young Leaders network with the Singapore Centre of

**I believe we should always try to strike a balance between economic development and environmental preservation and/or sustainable development.**

Liveable Cities, supporting FIDIC, supporting start-up companies in the sustainability space, and continuing to look for opportunities to support sustainability efforts. For example, these can be speaking opportunities that help to share why sustainability is important to the industry and the community.

**Do you have a message for the dredging sector?**

What about rebranding the dredging sector, and focus on sustainability and digitalisation? The sector is very niche and not well understood. What is great about it, is that dredging and reclamation works are often the building blocks



of new major infrastructure developments. This should not be taken for granted. In addition, land reclamation has a design life of (hopefully) more than 100 years; if the effects of climate change are taken into account. This is in fact a very long-term way of working especially when compared

to other industries. This is also the reason why the design phase of new marine works is extremely important as it has to be sustainable for the next century.

For more information or enquiries, please contact [editor@iadc-dredging.com](mailto:editor@iadc-dredging.com).

## Resources:

For more information about DFSI:  
<https://www.iadc-dredging.com/publication/dredging-for-sustainable-infrastructure/>  
the DFSI course:  
<https://dfsi-course-0620-nl.iadc-events.com/>  
FIDIC: <https://fidic.org/>  
FIDIC sustainability:  
<https://fidic.org/node/781>  
Press release on relaunch of FIDIC Sustainable Development Committee:  
<https://fidic.org/node/29653>  
Aurecon: <https://www.aurecongroup.com/>

## Summary

### Thought leadership & publications

Aurecon Just Imagine: What goes up but does not come down?  
Rising Seas 10 November 2020 <https://justimagine.aurecongroup.com/rising-seas/>  
Asia Nikkei Review 29 September 2020: We can't stop climate change, but we can be better prepared.  
LinkedIn Pulse 29 July 2020: Bringing green solutions to grey areas  
New Zealand Business Scoop 29 July 2020: Appointment to FIDIC Sustainable Development Committee  
Aurecon Thinking Paper June 2020: The role of data and digital in climate adaptation across Asia

### Qualifications

MBA Business Strategy, Strathclyde University, Glasgow, Scotland, UK, 2011  
MSc Civil Engineering Management & Geotechnology, South Bank University London, UK, 2002  
BSc Civil Engineering, The Hague Polytechnic, The Netherlands, 2000

### Memberships

FIDIC Sustainable Development Committee member, since 2020  
Young Leader and Member, World City Summit Young Leaders, since 2016  
Ntultive, SRIF investment committee Engineering, since 2017

### Specialisation

Designing and implementing business strategies, executing business operations, driving improvements, managing change.  
Climate Change Resilience, adaptation and mitigation related to coastal cities.  
Dredging & Reclamation  
Water & environmental consultancy  
Project management, contract management, project deliverables, project finance, project team performance and stakeholder engagement.

### Years in industry

18+

## Resumé

### Aurecon Singapore:

2020-Present  
Director, Coastal & Climate Change Asia

### DHI Singapore:

2013-2019  
Managing Director

2012-2013  
Executive Director Operations

2010-2011  
Deputy Director, Internal Functions

2007-2009  
Manager Engineering Services

2004-2006  
Project Manager

### Fugro, Arnhem, The Netherlands:

2000-2002  
Geotechnical Advisor

# LAND RECLAMATION:

THE POTENTIAL  
FOR SUBSURFACE  
FRESH WATER  
STORAGE

---

At present too little use is made of the opportunities that the design and construction of land reclamation offer for the underground storage and recovery of fresh water. The managed aquifer recharge systems in the coastal dunes of the Netherlands are a good example of successful subsurface water storage. And it is to be expected that the sandy deposits of land reclamations could serve a similar purpose. This in turn will contribute to a sustainable development of land reclamations.

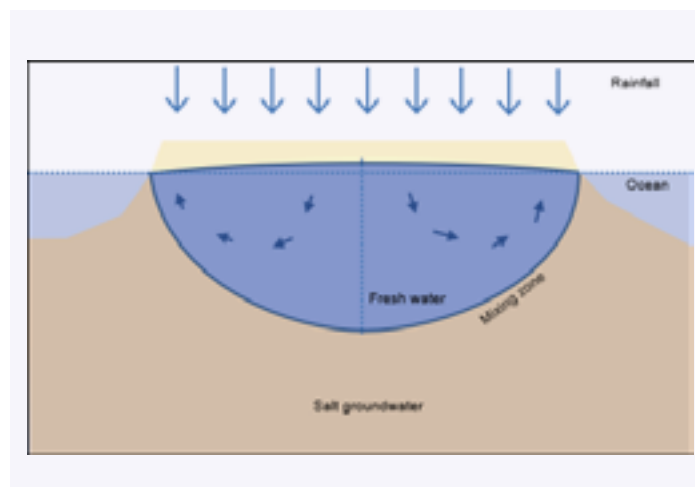
---

**Subsurface freshwater storage and recovery potentially increases the robustness of the water supply and the quality of life on land reclamations.**

---

Fresh water is vital to accommodating an urban population in its residential, industrial and recreational needs. At land reclamations, fresh water cannot always be supplied from the mainland, simply because many coastal megacities already suffer from increasing freshwater shortages due to urbanisation and ongoing climate change. This leaves desalination as only alternative for the freshwater supply of most land reclamations, but this technique is expensive and highly energy consuming. Building freshwater storage capacity on the land reclamation is an alternative. Collecting rainwater, using treated wastewater or storing desalinated water are options. With a considerable storage, the land reclamation is made less dependent on supply from the mainland or on desalination. This is profoundly important in the light of sustainability and climate adaptation.

The possibilities for storage above ground are minimal, due to the high land prices and the high costs involved with aboveground storage tanks. Subsurface storage, on the other hand, has a minimal footprint above ground and utilizes the large space that is available in the subsurface



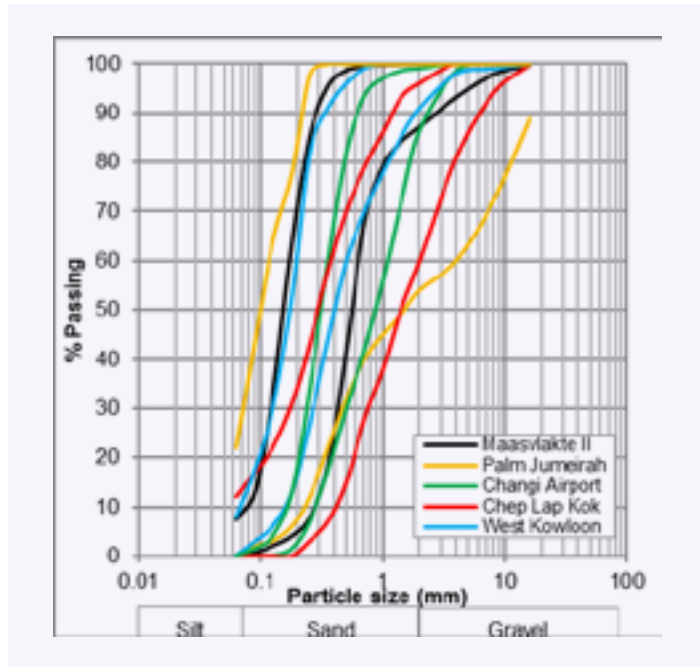
**FIGURE 1**  
A freshwater lens in an oceanic island under natural conditions.

of the land reclamation. Its conserving qualities both with respect to evaporation and water quality make subsurface storage of fresh water attractive compared to above ground storage. Moreover, fresh groundwater, if accessible to plants and trees, will immediately enhance the image of the new land in a natural way. All these benefits ensure that subsurface freshwater storage and recovery potentially

increases the robustness of the water supply and the quality of life on land reclamations.

Groundwater in land reclamations is directly connected to the sea and is, therefore, saline. In oceanic islands and dune areas, a freshwater lens can develop in a natural way by the combination of the density difference between fresh and salt water, gravity and





**FIGURE 2**  
The minimum and maximum grain size distribution curves of samples taken at land reclamations.

were constructed by a combination of bottom discharging, rainboring and pipeline discharge to determine the feasibility for freshwater storage and recovery. Pumping tests are commonly applied to determine the hydraulic characteristics of the soil. However, pumping tests were not available for this study because land reclamations have hardly been studied for their hydraulic characteristics. The literature on land reclamations contains only geotechnical data related to bearing capacity, settlement and liquefaction. Therefore, the grain size distribution curves and cone penetration tests from study area D2 in Maasvlakte II, the Netherlands were considered. These data were supplemented with the geotechnical data from the four other land reclamations that could be found in the literature. These are: Palm Jumeirah, Dubai, the United Arab Emirates, Changi Airport, Singapore, Malaysia and Chep Lap Kok and West Kowloon, both in Hong Kong, China.

Darcy's Law. Badon Ghijben (1889) and Herzberg (1901) were the first to describe the physics of a freshwater lens (Figure 1). The natural development of freshwater lenses takes many decades and requires a constant flow of fresh water. Fresh water can also be infiltrated and recovered by means of groundwater wells. This technique is applied, for example, by the Dutch drinking water companies as well as by agri- and horticulturists in the western part of The Netherlands.

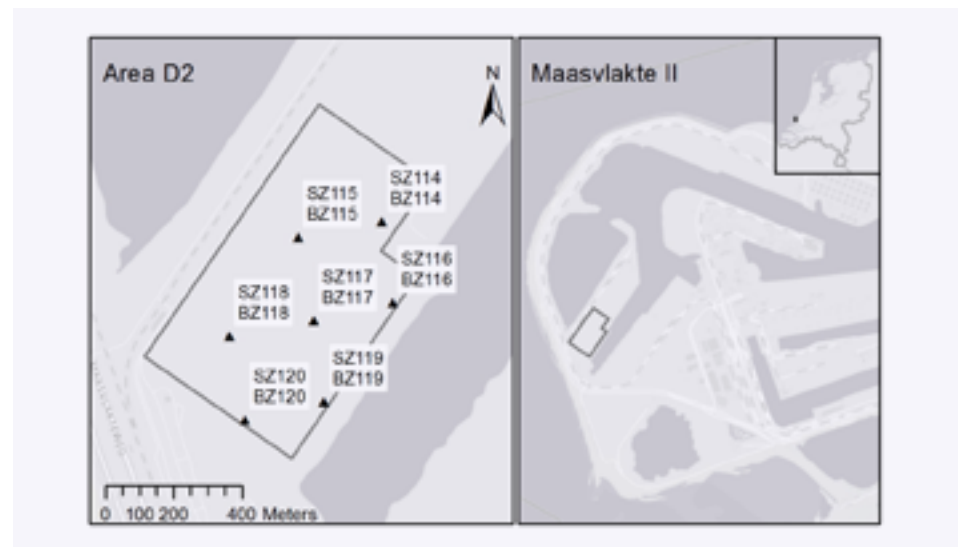
that these physical properties are part of the design of land reclamations and, therefore, this creates opportunities to better manage mixing and buoyancy to reach high recovery efficiencies from the freshwater lens.

**Geotechnical data**

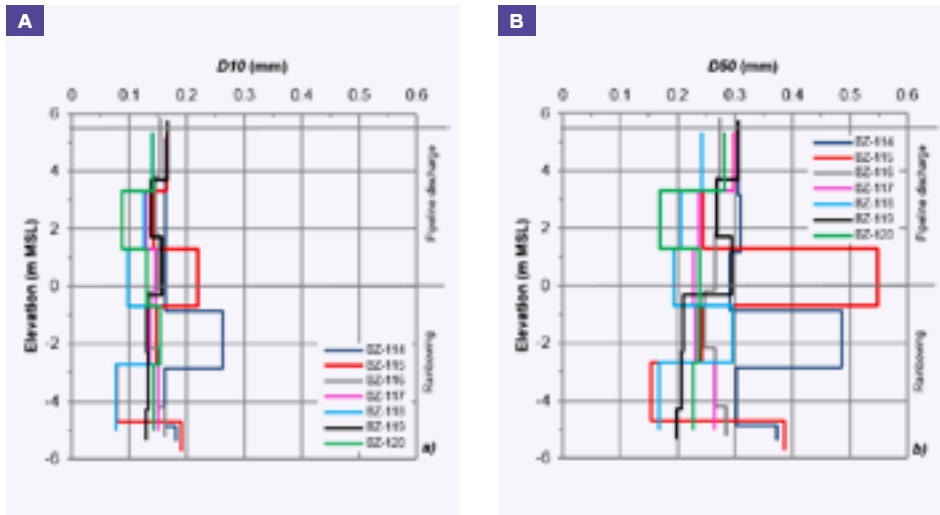
This study investigates the hydraulic properties of five land reclamations that

Figure 2 presents the minimum and maximum grain size distribution curves of the studied reclamations. These reclamations consist of fine to coarse sand. The corresponding porosity and hydraulic conductivity values are, therefore, likely to be moderate to high. At first sight, these conductivities seem to make these land reclamations suitable for the development of a freshwater lens.

The feasibility of subsurface freshwater storage and recovery requires a high freshwater recovery efficiency, which is at risk because the injected water will inevitably come into contact with saline groundwater present in the subsurface of the land reclamation. The challenge is to prevent that freshwater recovery efficiency is impacted by mixing with salt water and by buoyancy caused by the density difference between fresh and salt water. In practice as well as in scientific literature, the freshwater recovery has always been controlled by operational factors, such as injected and recovered volume, location of wells, recharge rates and storage duration. However, the properties of the aquifer that also influence the recovery efficiency, such as porosity, hydraulic conductivity and aquifer thickness, have always been considered as fixed and site-specific. New for land reclamations compared to natural soils, is



**FIGURE 3**  
Location of study area D2 at Maasvlakte II, the Netherlands.



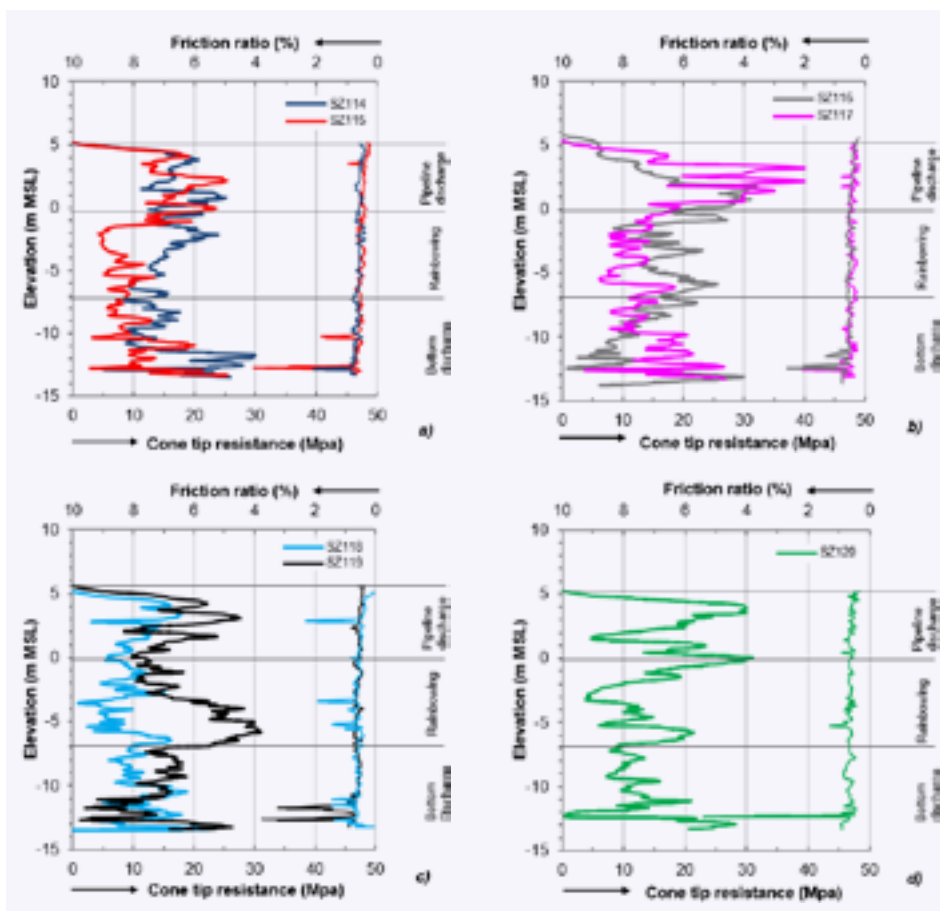
**FIGURE 4**  
 (A)  $D_{10}$  (mm) and (B)  $D_{50}$  (mm) over depth of the soil samples taken at Maasvlakte II study area D2.

**Data case study area D2  
 Maasvlakte II, the Netherlands**

Figure 3 presents the location of study area D2 in the southern part of Maasvlakte II. Bottom discharging was applied until -7 m mean sea level (MSL), followed by rainboring to bring the reclamation level up to MSL. Fill material above this level was placed by pipelines to achieve the final elevation of +5.35 m MSL.

The black lines in Figure 2 present the outer ranges of the grainsize distribution of study area D2. In study area D2 soil samples were taken at seven borehole locations, as presented in Figure 3. The soil samples were taken every 2 m depth, up to 10 m below ground level, and the sieve curves of the soil samples were determined. Figure 4 shows  $D_{10}$  and  $D_{50}$  of the soil samples and indicates which placement method was adopted at which depth.

Seven cone penetration tests (CPTs) were taken in the study area. Figure 5 shows the CPTs and indicates which placement method was adopted at which depth.



**FIGURE 5**  
 Conetip resistance (left lines) and friction ratio (right lines) at Maasvlakte II study area D2.

**Data reference cases**

Data of area D2 have been supplemented with the grainsize distribution curves and cone penetration tests that were previously presented in the work of Lees (et al., 2013), Chua (et al., 2007), Lee (2001) and Lee (et al., 1999). These land reclamations were also constructed by a combination of bottom discharging, rainbowing and pipeline discharge. The dimensions and construction details of these land reclamations can be found in the references.

Figure 2 presents the outer ranges of the grainsize distribution of the considered

reference cases. Quartz sand of marine origin was used at Changi Airport (Chua et al., 2007), Chep Lap Kok (Lee, 2001) and West Kowloon (Lee et al., 1999). Shelly carbonate sand is used at Palm Jumeirah (Lees et al., 2013). Shells are angular and typically have a wider grainsize distribution than quartz grains (Lees et al., 2013). Figure 6 shows the CPTs of the reference cases and indicates which placement method was adopted at which depth.

**Method**

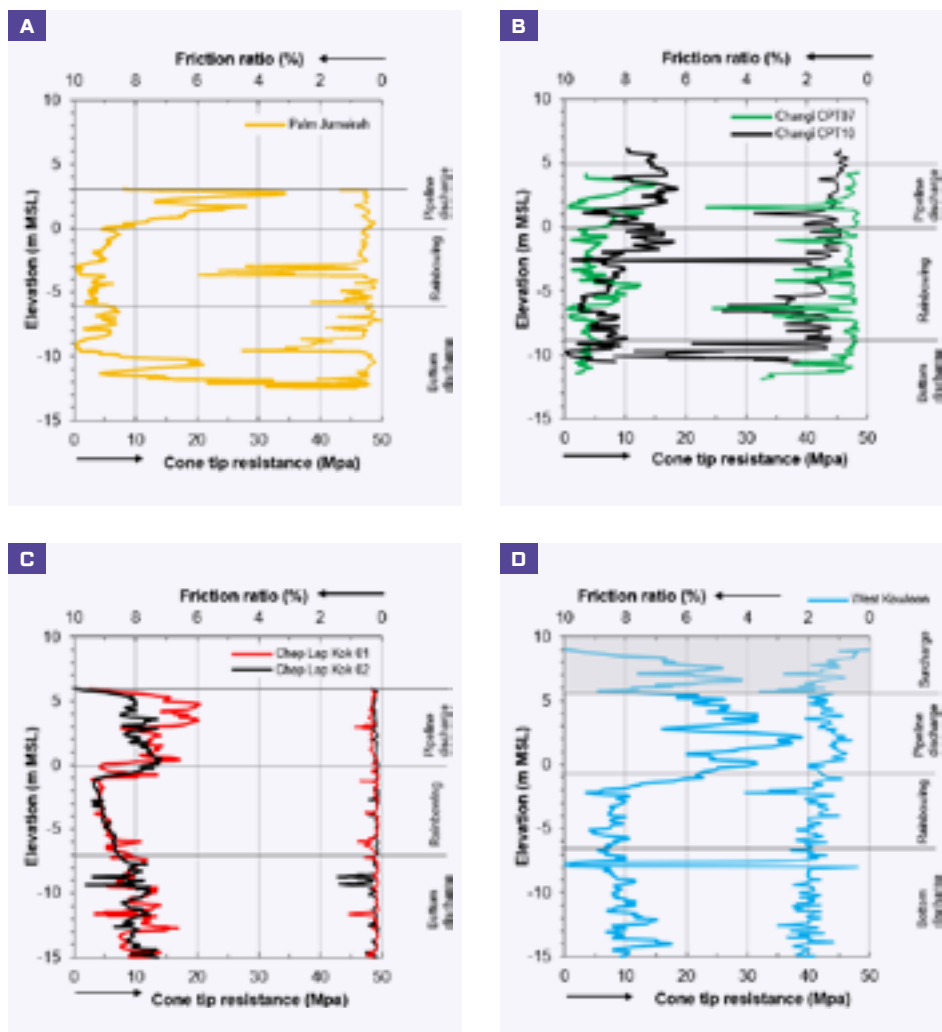
Analysis of the sedimentation from a sandwater mixture for the three placement methods gives insight into grain sorting and how it varies from place to place in the reclamation. The structures of the porous media resulting from each placement method are presented. These structures are validated by comparison with semivariograms of cone penetration tests. A semivariogram provides insight in the spatial variance of a parameter and, therefore, into its degree of heterogeneity.

**Sedimentation process bottom discharging**

As presented by Van Rhee (2002) segregation of grain sizes has already developed during loading and transport inside the Trailing Suction Hopper Dredger (TSHD). Segregation also occurs within the settling sandwater mixture, with the larger grains tending to settle faster than the smaller grains, as explained by Stokes's Law.

The ambient seawater is, in principle, displaced sideways during the settling of the sandwater mixture, allowing the mixture to descend as a single mass (see Figure 7). However, some seawater will probably escape upward through irregularities in the sand-water mixture in the following manner: random 'volcanoes' of seawater will develop spontaneously in the sandwater mixture where seawater starts to flow through the mixture. The Reynolds number of the sandwater mixture is in the turbulent regime and turbulent eddies form around the mixture, keeping fine material in suspension. However, the bulk of the sandwater mixture will quickly fall upon the seafloor.

Complete segregation can only occur in infinitely deep water. However, land reclamations are typically constructed in the



**FIGURE 6**

Cone tip resistance (left lines) and friction ratio (right lines) at (A) Palm Jumeirah (Lees et al., 2013), (B) Changi Airport (Chua et al., 2007), (C) Chep Lap Kok (Lee, 2001) and (D) West Kowloon (Lee et al., 1999).

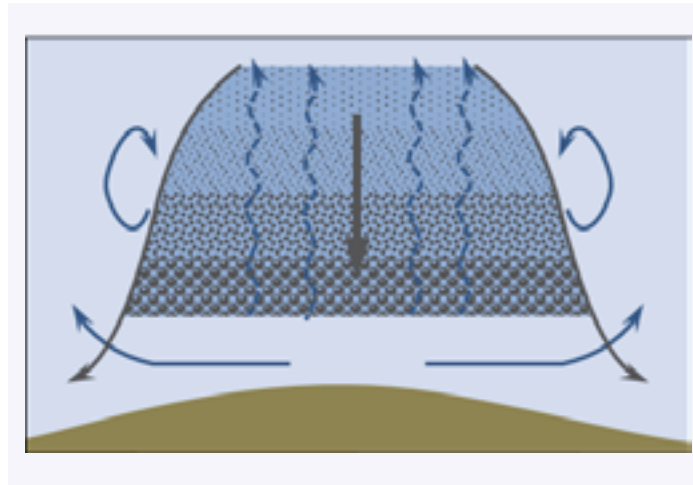


coastal zone where water depth is limited to a few tens of meters maximum, because of which it is unlikely that the mixture fully segregates. In addition, the settling velocity of the grains is hindered in accordance with the wellknown formula by Richardson and Zaki.

The sandwater mixture flows radially outward as soon as it hits the seafloor and its velocity decreases significantly due to the divergence of the flow lines. The turbulence in the sandwater mixture decreases accordingly, causing the mixture to come to an abrupt standstill causing sand to fall out of suspension. Redistribution takes place only when the angle of the bottom-discharged fill becomes more than the angle of repose, which cause sand slides along the slope.

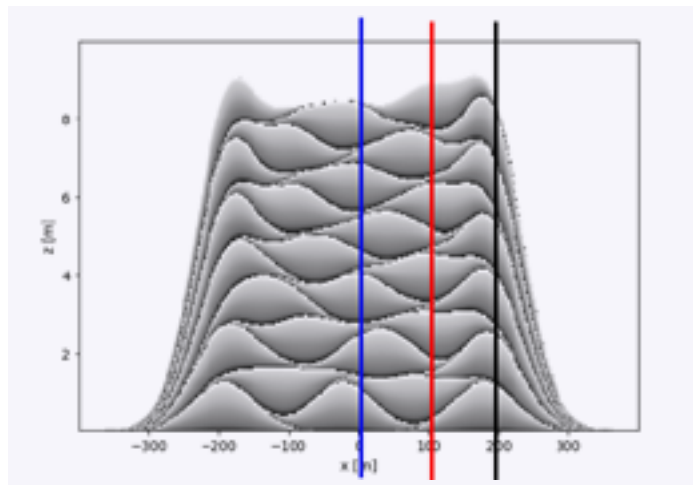
A distinct segregation mark between two bottom-discharged layers can be observed in the typical cross-section of samples as presented in Lee (2001) and Shen and Lee (1995) taken from the bottom-discharged fill at Chep Lap Kok. Lee found that the grainsize distribution of the coarser grains corresponds closely to the upper bound of the possible range of the Chep Lap Kok sand. The grain-size distribution of the finer grains, on the other hand, is close to the lower bound of the Chep Lap Kok sand.

Lee (2001) represented the shape of each discharge dump as a trapezium and suggested that dumps are randomly distributed. Lee's model was slightly modified in this study. Figure 8 was made by assuming that each dump has the shape of the normal probability density function (PDF), which, therefore, reaches from  $-\infty$  to  $+\infty$ . Its central location is the position of the TSHD and its volume equals that of the capacity of the vessel. The thickness of each dump at any location is, therefore, given by the pdf times the volume. In this study, the sieve curve of Maasvlakte II study area D2 is assumed to be completely segregated within each dump. Therefore, the grains in each dump are distributed upward from coarse to fine in accordance to the sieve curve. This is true at any  $x$ -coordinate for every dump. Subsequent dumps are added, so that the upper and lower boundary of each dump is according to the sequence of bottom discharging. It was assumed that the TSHD is placed randomly across the reclamation



**FIGURE 7**

Illustration showing the settling sand-water mixture and how seawater is displaced.

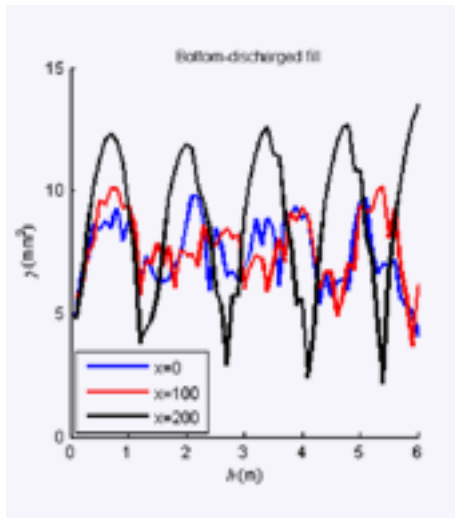


**FIGURE 8**

Crosssection of a bottom-discharged fill model in which the shading reflects the structure of the porous medium. A darker colour indicates a coarser grain size.

site for the first dumps and later placed just above the point with the maximum distance between the elevation of the dumps and the target elevation. This fills the reclamation to a uniform height. Pure random discharging will never give the desired end shape.

As Figure 8 suggests for an ideal fully segregated dump, a bottom-discharged fill will consist of thin, elongated lenses of circa 1 to 2 m high and several tens of metres wide with a characteristic vertical grainsize distribution. The occurrence of such lenses may be investigated by means of semivariograms. The semivariance ( $h$ ) is half the average squared difference between points separated at a certain lag distance  $h$  (Matheron, 1963). Figure 9 presents the semivariograms of vertical crosssections through the bottom-discharged fill model at  $x=0, 100$  and  $200$  m.



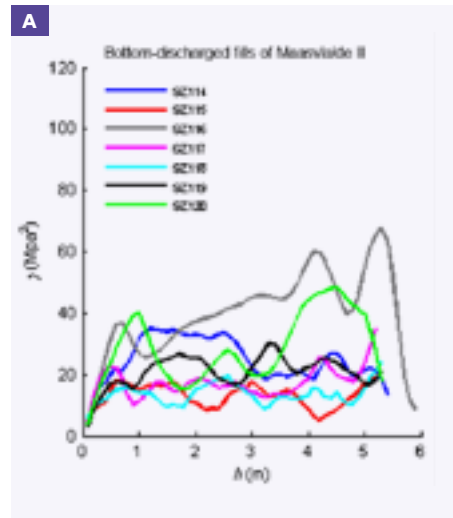
**FIGURE 9** Semivariogram at the cross-sections of bottom-discharged fill model.

The semivariance fluctuates periodically with lag distance. The periodic structure is most apparent at  $x=200$  m, showing a sinusoidal semivariance with a period of 1.5 m lag distance. According to Pycrz and Deutsch (2003), a periodic semivariance indicates regularly clustered lenses or strata of higher and lower grain size in the bottom-discharged fill. Figure 8 also shows that the characteristic distance between dumps at  $x=200$  m repeats every 1.5 m. At  $x=0$  and 100 m the periodic structure is more distorted because the stacking of the dumps is less uniform, as also appears from Figure 8.

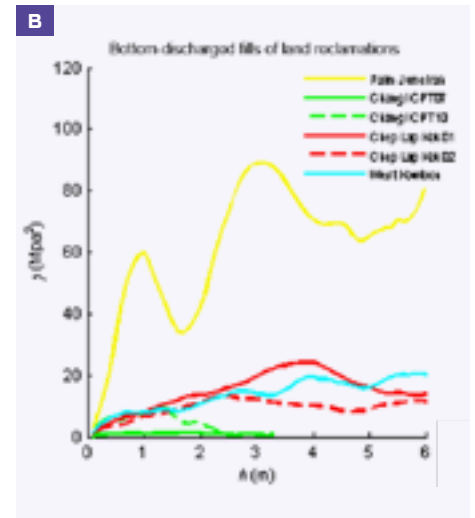
**Data analysis of bottom-discharged fills**

The occurrence of lenses in bottom-discharged fills may be investigated with semivariograms of the conetip resistance measured with conepenetration tests (CPTs) done shortly after construction. Figure 10a and Figure 10b present the semivariograms of the bottom-discharged fills of the CPTs of Figure 5 and Figure 6. Similar to Figure 9, these semivariograms exhibit a periodic structure, which now indicates regularly clustered lenses or strata of higher and lower resistance of the conepenetration in the bottom-discharged fill.

How should these CPT readings be interpreted in terms of conductivities, while CPTs are known to reflect the relative density?



**FIGURE 10** Semivariogram of CPTs of bottom-discharged fills, (A) Maasvlakte II study area D2, and (B) the other land reclamations.



Several researchers, such as Baldi et al. (1986) and Lunne and Christofferson (1983), established correlations between the cone tip resistance  $q_c$ , the vertical effective stress  $\sigma'_v$  and the relative density  $D_r$ .

$$D_r = \frac{1}{C_2} \ln \left( \frac{q_c}{C_0(\sigma'_v)^{C_1}} \right) \quad (1)$$

Where  $C_0$ ,  $C_1$  and  $C_2$  are parameters correlated in calibration chamber tests for specific sands. The relative density relates the *in situ* density to the minimum and maximum reference density values and these are inversely related to the minimum and maximum porosity  $n_{min}$  and  $n_{max}$  (Van 't Hoff and Van der Kolff, 2012):

$$D_r = \frac{\rho_d - \rho_{d,min}}{\rho_{d,max} - \rho_{d,min}} 100\% = \frac{n_{max} - n}{n_{max} - n_{min}} 100\% \quad (2)$$

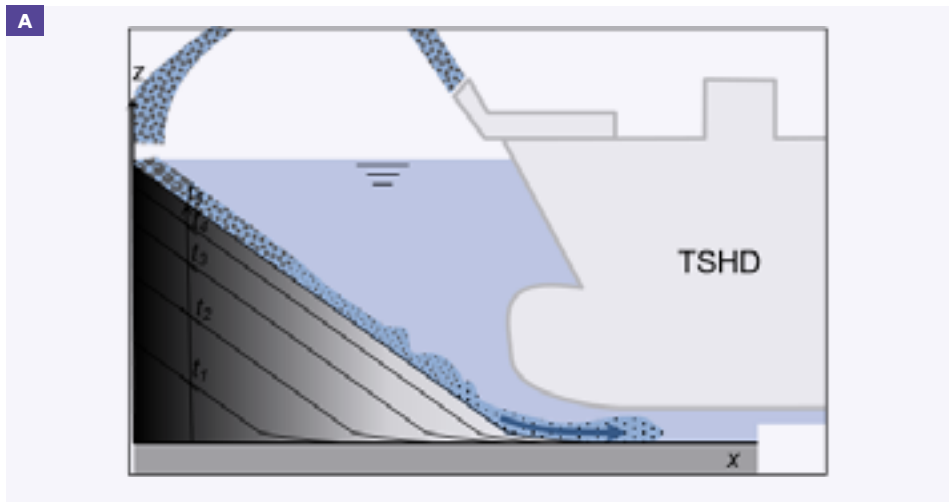
The semivariograms of the CPTs thus provide insight into the variation in porosity. A more uniform grain-size distribution and/or lower compaction will show a higher porosity. More uniform grain-size distributions in land reclamations consist of finer sediment because having come from the same borrow area, the coarse grains have been sorted out. Therefore, it is plausible that the peaks in the CPTs correlate with the better-mixed material at the bottom of each dump that consists of a mixture of coarser and finer grains. The relatively low values in the CPTs correlate with the more wellsorted,

i.e. finer, material at the tops and slopes of dumps.

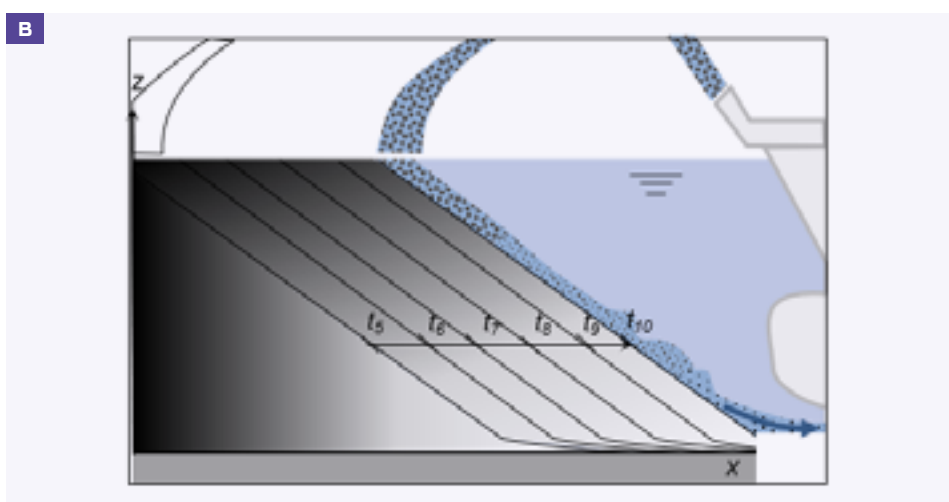
For the seven CPT readings done in the Maasvlakte II, the characteristic distance between lenses was found to be about 1.5 m. The semivariograms for West Kowloon and Palm Jumeirah for the bottom-discharged fills show a similar periodicity as Maasvlakte II. The much larger variance of Palm Jumeirah compared to the other land reclamations can be attributed to the larger gradation in grain-size caused by the broken shells that characterizes this fill material (Miedema and Ramsdell, 2011; Lees et al., 2013). The characteristic distance between lenses of the semivariograms of Chep Lap Kok O1 and O2 was found to be 2 m. This periodicity leads to the assumption that larger TSHDs were used to make this land reclamation. The bottom-discharged fill in Changi is not thick enough to register periodicity.

**Sedimentation process of rainboring**

In the land reclamations considered in this study, rainbored fill up to sea level was applied on top of the bottom-discharged fill. The sand-water mixture is fluidized and mixed on board the TSHD to obtain pumpability and the mixture sprayed through the nozzle is then well mixed, in contrast to bottom discharging. The velocity of the sandwater mixture is



**FIGURE 11**  
 (A) cross-section of a rainbow-discharged fill over time (starting at  $t_1$  to  $t_5$ ) in which the shading reflects the structure of the porous medium and (B) the buildout over time (starting at  $t_5$  to  $t_{10}$ ). A darker colour indicates well-mixed material and a lighter colour indicates more well-sorted material dominated by finer grains.



distance from the top. Because the same processes operate during the total buildup of the fill, the grain size tends to remain constant for a fixed distance to the fill centre. This implies that the grain size distribution is uniform in cylinders centred around the axis of the fill, i.e. constant along vertical lines.

Once the fill has reached sea level, the TSHD withdraws in seaward direction building the fill seaward (see Figure 11b). The grain size remains constant at the same distance from the top of the forward moving slope. This implies that the grain-size distribution will be constant horizontally, refining in downward direction. The finest grains will accumulate on the sea floor in front of the toe of the slope and are buried under the advancing slope. Fines still in suspension will settle after each interruption of the rainboring process. This is expected to cause a few cm-thick layer of fines, marking the slope at interruptions in rainboring. However, no evidence was found in the literature to support this hypothesis.

immediately reduced upon reaching the sea surface. Some segregation will occur during settling. The rainbored sandwater mixture builds up a fill as rainboring continues at that location. As the fill grows, the sandwater mixture increasingly flows as a density current over its slopes. The slopes tend to maintain a certain angle of repose, so that the fill keeps the same shape while growing.

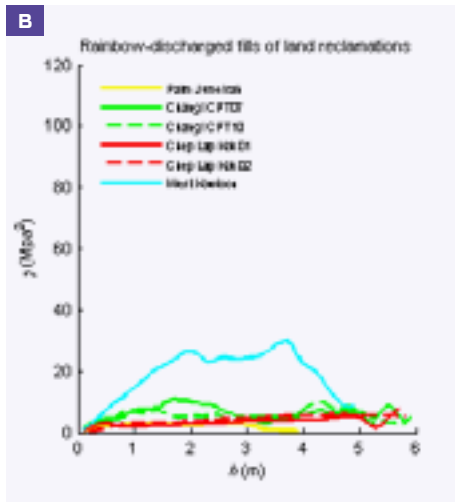
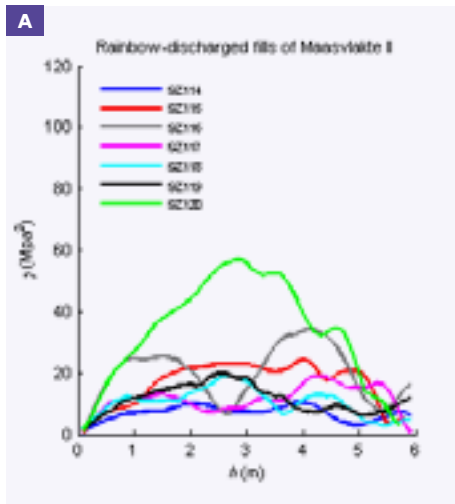
is more diluted further down, so settling is less hindered, resulting in a more segregated deposit.

Figure 11 shows the hypothetical structure of the porous medium resulting from rainboring. The increased segregation downslope, results in a finer and more uniform particle-size distribution with

While rushing down the slope, turbulent eddies generated by the density current entrain surrounding seawater into the mixture (Huppert and Simpson, 1980; Hallworth et al., 1993). As the distance from the top increases, the density difference driving the current is reduced by dilution. Settling is most hindered near the top, where the concentration of sand in the density current is high. The result is a less segregated deposit along the upper part of the slope (Lowe, 1982). The mixture

**As the rainbow-discharged fill grows, the sandwater mixture increasingly flows as a density current over its slopes.**





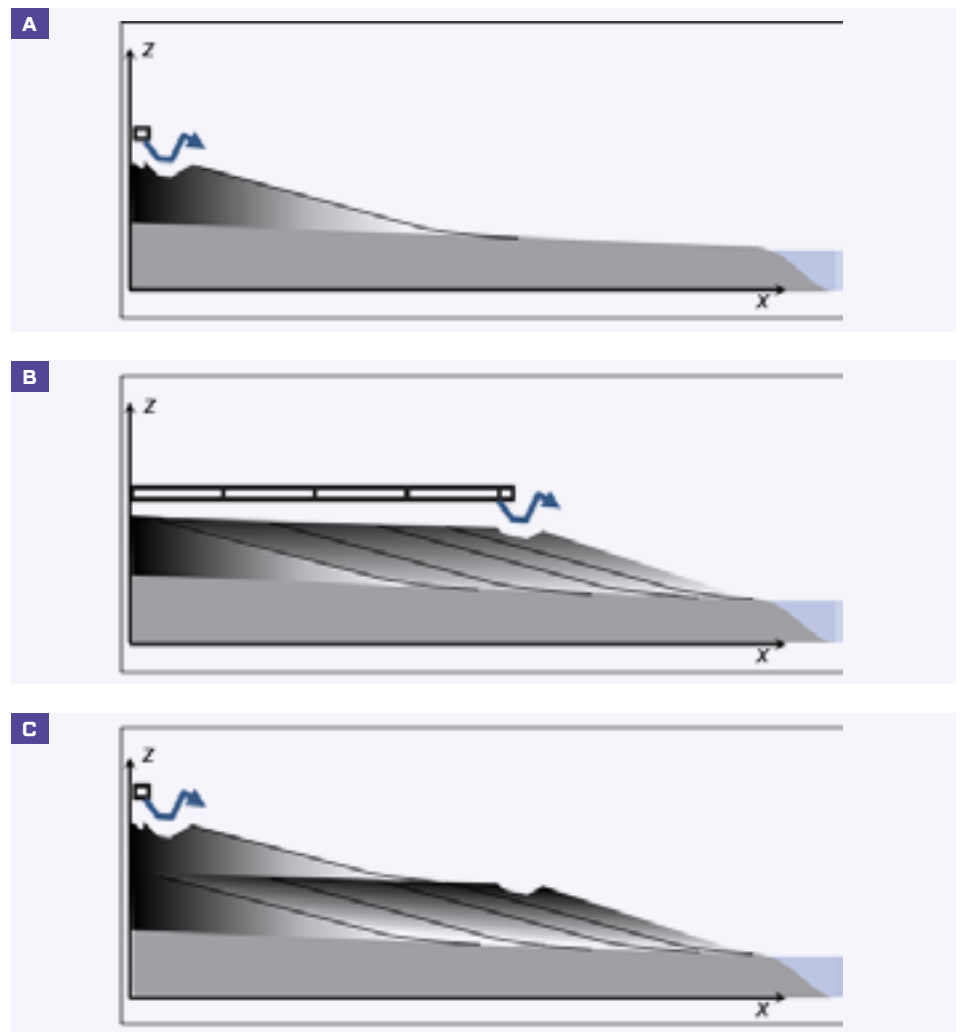
**FIGURE 12**  
Semivariogram of CPTs of rainbow-discharged fills, (A) Maasvlakte II study area D2, and (B) the other land reclamations.

**Data analysis of rainbow-discharged fills**

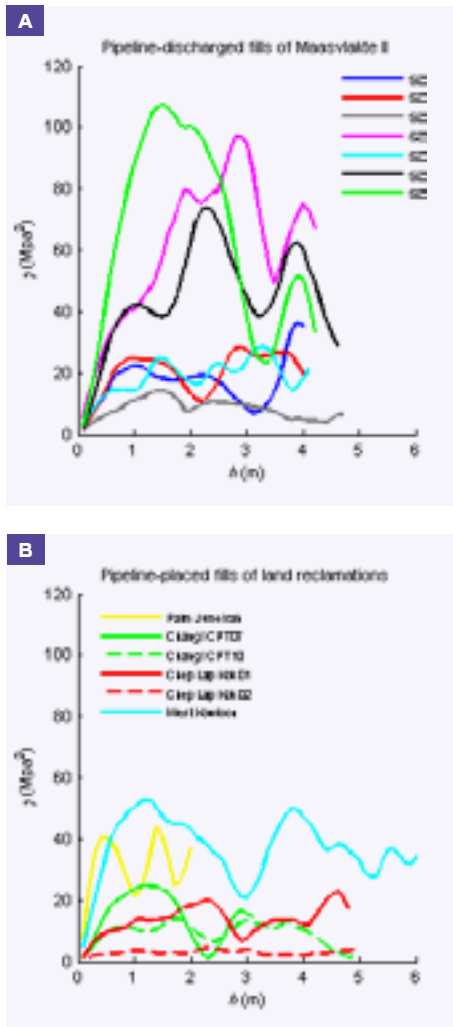
Lee (2001) and Lee et al. (1999) concluded from the CPTs that the  $q_c$  profiles for rainbow-discharged fills are generally much smoother than for bottom-discharged and pipeline-discharged fills. This implies that rainbow-discharged fills are more homogenous. The increase in average  $q_c$  over depth is less than for bottom-discharged fills (Lee, 2001).

Figure 12 presents the semivariograms of the CPTs for the rainbow-discharged fills. The variance in Maasvlakte II study area D2 and West Kowloon is comparable to the variance

for bottom-discharged fills, in contrast with the other rainbow-discharged fills, which show a lower variance than in Figure 10. Periodic structures are not apparent. It is assumed that the higher variance in Maasvlakte II study area D2 and West Kowloon compared to Chep Lap Kok and Changi Airport is caused by the larger amount of fine grains in these sands (see Figure 2) which caused more segregation during rainbowing and, moreover, more settling of finer material during interruptions in the rainbowing process. The relatively low variance in the rainbow-discharged fill at Palm Jumeirah can be attributed to the shells in the density



**FIGURE 13**  
Cross-section of a pipeline-discharged fill above water in which the shading reflects the structure of the porous medium, (A) one section, (B) several sections that coincide with the extension of the pipeline, and (C) second stack. A darker colour indicates a coarser grain.



**FIGURE 14**  
Semivariogram of CPTs of pipeline-discharged fills, (A) Maasvlakte II study area D2, and (B) the other land reclamations.

current that cause more hindered settling due to which less segregation took place.

### Sedimentation process of pipeline discharge

Above sea level, pipeline discharge was applied. Figure 13 shows the hypothetical structure of the porous medium resulting from pipeline discharge. At the pipeline outflow, the sandwater mixture forms a scour hole. The sandwater mixture flows over the edge of the scour hole. While the diameter of the pipeline is about the same as the diameter of the rainbow nozzle, the pumping rate is much lower. The degree of turbulence is so low that

## The structure of the porous medium of pipeline-discharged fills is similar to the parasequences of natural marine deposits.

coarse grains settle directly near the pipeline (Mastbergen and Bezuijen, 1988). Finer grains are transported along the slope and the finest grains accumulate at the toe (see Figure 13a). Bulldozers level the area in front of the pipeline outflow and fill the scour hole.

After a certain elevation is reached, the next pipe section is connected and the filling process continues (see Figure 13b). The segregation of grains along the slope is similar to what happens under water during rainbowing. This implies that the grain size distribution will be constant horizontally and will refine in a downward direction. As with rainbowing, the finest grains accumulate in front of the toe of the slope and are then buried as the slope advances (see Figure 13b). This creates a band of fine grains at the bottom. Fine material also accumulates before the bunds.

Once the end of the fill area is reached, the filling process may be repeated to create a following stack (see Figure 13c). As a result, the structure of the porous medium of a pipeline-discharged fill consists of stacks, which are similar to the so-called parasequences of natural marine deposits (Coe, 2002) in which each stack refines from top to bottom. These stacks may be recognised in a drilling by the band of fine material that vertically separates them, but these bands may be too thin to be recognized in a CPT.

### Data analysis pipeline-discharged fills

The conetip resistance of sand fills formed above water is substantially higher than that of sand-fills formed by subaqueous placement. The compaction is further increased by the levelling operations of the bulldozers and the impact of other construction traffic. Figure 14 presents the semivariograms of the available CPTs of the pipeline-discharged fills. The variance is higher than that of the other placement methods shown in Figure 10 and

Figure 12. All semivariograms of the pipeline-discharged fills exhibit a periodic structure. This periodicity strongly suggests that several stacks were applied; the periodicity is consistent with a general thickness of circa 1 to 2 m.

### Consequences for the hydraulic conductivity of land reclamations

At the size of a representative elementary volume (Bear, 1972), i.e. circa 20 grain diameters, the conductivity is essentially expressed by the Carman-Kozeny relation:

$$K = \frac{\rho g}{\mu} \frac{1}{CS_0^2} \frac{n^3}{(1-n)^2} D_{eff}^2 \quad (3)$$

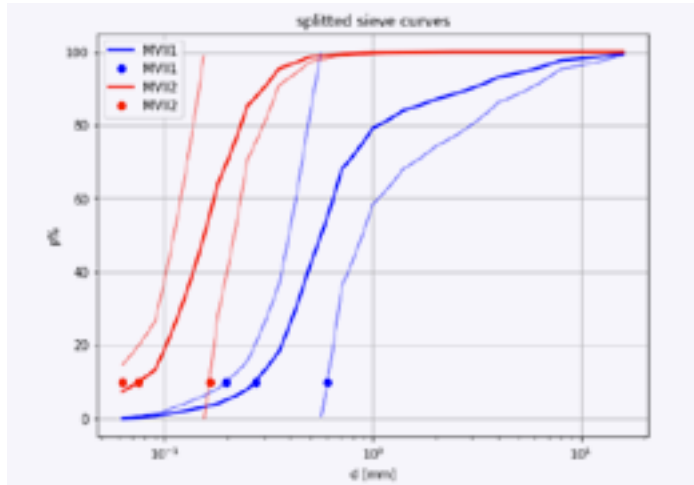
Where  $g/\mu$  is the unit weight/viscosity of water,  $n$  [-] is porosity,  $D_{eff}$  [L] is the effective grain diameter usually taken to be equal to  $D_{10}$ , and  $S_0$  [1/L] is the specific surface.  $C$  is an empirical coefficient to correct for grain ordering and grain shape to match laboratory measurements for permeability with actual porosity and effective grain diameter.  $C$  is usually taken to be equal to 5.

With a given grain-size distribution, porosity is the only unknown in estimating conductivity. Porosity ranges from 35% to 40% in most unconsolidated sediments in the Netherlands (Olsthoorn, 1977), but could be higher in freshly reclaimed land, especially in places where the grain size distribution is more uniform.

Based on equation 3 the difference in conductivity between sands with an equal grain size distribution but a porosity of 35% and 40% respectively, is a factor of 1.75. However, the difference in conductivity due to different effective grain diameters of the two most extreme sieve curves from Figure 2 is about 4 in the Maasvlakte II study area D2, about 2 in Changi Airport and even more at the three other reclamations.

FIGURE 15

The two extreme sieve curves for Maasvlakte II original (thick line) and split in their lower and upper halves to illustrate the effect of segregation, which makes the curves steeper and shifts the effective diameter away from the original value (thick line).



In the equation of Carman-Kozeny the conductivity is proportional to the effective grain diameter squared, which indicates that the effect of the effective grain size by far outweighs that of porosity. This is also the case with the segregation of the grains, which can be illustrated by splitting the sieve curve into a lower part containing the finer grains and an upper part containing the denser ones (see Figure 15).

The segregation makes both sieve curves more uniform, i.e. steeper, but at the same time, the  $D_{10}$  of the lower curve is reduced relative to the original, and that of the upper curve has increased. According to Carman Kozeny, this implies that the conductivity of the lower curve is reduced and that of the upper curve is increased relative to the original mixture. It is likely that the more uniform fine sand will have highest porosity, but this porosity effect may only partly compensate its lower effective grain diameter.

The CPTs reveal zones of higher and lower relative density, i.e. of lower and higher porosity, rather than conductivity. However, the coarser sand will remain better mixed when placed and, therefore, has the highest relative density. Because the effective grain diameter has a more important effect on conductivity than porosity, the most plausible conclusion is that the higher CPT values correspond to a higher conductivity in land reclamations. Consequently, the grainsize distributions as illustrated in Figure 8, 11 and 13 mimic the conductivity.

It is noted that if the relative density of the fill mass after deposition and/or the underlying

soil do not meet the required design criteria, ground improvement techniques can be applied to improve the properties of the fill and/or subsoil. Ground improvement was not taken into consideration in this study because the available data were without soil improvement.

### Consequences for subsurface freshwater storage in land reclamations

Using the Carman-Kozeny equation, and taking the effective diameter of the actual soil samples of the rainbow-discharged part of the fill of Maasvlakte II study area D2, which are depicted in Figure 4, the conductivity would fluctuate between 2 and 24 m/day; an order of magnitude. This effect goes unseen if only average values are considered and is important for the subsurface storage and recovery of fresh water. The recovery efficiency of freshwater storage systems in land reclamations can be influenced by differences in dispersion and preferential flow resulting from the applied placement methods. The recovery efficiency is expected to be lowest for bottom-discharged fills in which the sand has a wide grainsize distribution. They show the largest grainsize variation on small vertical scales, because of the irregular stacking of lenses in each of which the grains coarsen downward. The recovery efficiency is expected to be highest in rainbow-discharged fills, because they are composed of wellmixed material where the grain size smoothly increases upward over the total depth of the fill.

Despite the small variations in grain-size distribution, the porosity and hydraulic

conductivity of land reclamations that are constructed of sand by bottom discharge, rainbowning and pipeline discharge are comparable to natural dunes and the heterogeneity is more predictable than that of natural soils. Disturbances, such as clay layers, do not occur, because only sand is used for the construction of the land reclamation. Moreover, the content of fine material in land reclamations is usually lower than in the so-called borrow areas, which is due to the overflowing water during loading of the TSHD carrying along fines, and because fines are partly transported beyond the reclamation site during placement. In conclusion, land reclamations that are constructed of sand by bottom discharge, rainbowning and pipeline discharge are suitable for subsurface storage and recovering fresh water.

The degree of segregation caused by a specific placement method still depends on sitespecific circumstances, such as settling depth, grainsize distribution and angularity resulting from grain type. It is impossible to separate these three parameters with a single CPT. Therefore, to verify the hydraulic properties in a specific land reclamation in which the exact placements are not known, (undisturbed) soil samples and pumping tests at different depths and places are indispensable. To advance the development of water storage in land reclamations, field experiments in the form of pumping tests and infiltration tests are helpful. Not only to show the potential but also to research and further develop technologies and operational and management concepts.

Since land reclamations are typically constructed in coastal zones of limited depth of at most a few dozen meters, the potential storage zone is restricted, unless the sea floor itself is highly conductive. The thickness of the potential storage zone may be further restricted where land reclamations are constructed by a sequence of placement methods, because a layer of finer grains is expected to be present at the bottom of the rainbow-discharged fill and at the bottom of the pipeline-discharged fill. Moreover, a band of fines will be present along the edges of pipeline-placed fills wherever closing bunds were applied. Such bundformed elongated bands of fine material may be advantageous for the formation of a freshwater lens. On the



---

other hand, parallel bunds bounding strips of land that mark phases in the construction of the reclamation, will likely result in some degree of compartmentation.

The time required to fill the storage volume to its design capacity depends on the available water resources and the capacity of the infiltration facilities. In tropical and moderate climates with considerable precipitation, the potential growth of the freshwater volume is likely greatest during the construction phase when the reclamation is still unpaved. Smart inclusion of the development of the freshwater storage in the planning and design of the land reclamation is therefore required. The growing capacity of the groundwater storage and recovery system can then be aligned with the growing water demand of the developing area. Another advantage is that gravel packs around wells and under infiltration facilities can be far more easily realised during construction works of the land reclamation. This also applies to the construction of the infiltration facilities, i.e. the infiltration basements, infiltration ponds, storm water attenuation and infiltration crates and wadis.

### Disclaimer

This article is based on the paper 'Distribution of grain size and resulting hydraulic conductivity in land reclamations constructed by bottom dumping, rainbowing and pipeline discharge' that debuted in *Water Resources Management*, Volume 33, December 2018, pages 993-1012, a publication of Springer. The original paper is available through Open Access.

For more information or enquiries, please contact [editor@iadc-dredging.com](mailto:editor@iadc-dredging.com)

---

## Summary

The sandy deposits of land reclamations provide opportunities to create underground freshwater storage capacity. This freshwater can later be recovered and used, contribution to a sustainable management of water on the newly reclaimed land. The structures of the porous media are derived of reclaimed lands constructed by a combination of bottom discharging, rainbowing and pipeline discharge. These are validated by comparison with semivariograms of cone penetration tests of five land reclamations. The consequences for the hydraulic conductivity of different hydraulic filling methods and the feasibility of hydraulically filled reclamations for underground freshwater storage are determined.

---

*The authors acknowledge the Port of Rotterdam for the information they kindly provided. The authors thank several engineers from Van Oord and Boskalis for sharing their knowledge about dredging practices.*

---



### Marloes van Ginkel

Marloes obtained her MSc in Civil Engineering at Delft University of Technology in 2007. From 2008 to present, she has been working as a water resources consultant at Royal HaskoningDHV. While working on the drainage design of a land reclamation project off the coast of Lagos, Nigeria, Marloes became fascinated by the opportunities that the construction of new lands could offer to optimize their subsurface for freshwater storage. She obtained her PhD in 2019; her PhD thesis 'Design of the subsurface of land reclamations for freshwater storage and recovery, a new view on land reclamations' is available at TU Delft repository.



### Theo N. Olsthoorn

Theo Olsthoorn is emeritus professor Geohydrology of Delft University of Technology. Professor Olsthoorn is a former MSc and PhD graduate of Delft University of Technology and has working experience in a number of renowned Dutch hydrological institutes, among others as senior researcher hydrology for Waternet (Amsterdam Water Supply).

## REFERENCES

- Bezuijen A. (1988)  
Het storten van zand onder water 5: ZandWaterstromingen, Verslag experimentele vervolgstudie middelgrof zand (The dumping of sand under water 5: Sandwater mixture flows, Report experimental follow-up study medium sand) Tech. Rep. Bagt. 420/Z261/CO294750, Grondmechanica Delft, WL Delft Hydraulics, the Netherlands.
- Bear J. (1972)  
'Dynamics of Fluids in Porous Media' – Dover, New York, NY, USA.
- Chua L.H.C., E.Y.M. Lo, D.L. Freyberg, E.B. Shuy, T.T. Lim, S.K. Tan and M. Ngonidzashe (2007)  
Hydrostratigraphy and geochemistry at a coastal sandfill in Singapore. *Hydrogeol. J.* 15: 1591-1604.
- Coe A.L. (2002)  
'The Sedimentary Record of SeaLevel Change' – Cambridge University Press, Cambridge, UK and New York, NY, USA.
- De Wit L. (2015)  
'3D CFD modelling of overflow dredging plumes' – PhD. thesis, Delft University of Technology, January 14, 2015. Delft, the Netherlands.
- Hallworth M.A., Phillips J.C., Huppert H.E. and Sparks R.S.J. (1993)  
Entrainment in Turbulent Gravity Currents. *Nature* 362: 829-31.
- Huppert H.E. and Simpson J.E. (1980)  
The Slumping of Gravity Currents. *Journal of Fluid Mechanics* 99(4): 785-99.
- Lee K.M., Shen C.K., Leung D.H.K. and Mitchell J.K. (1999)  
Effects of Placement Method on Geotechnical Behavior of Hydraulic Fill Sands. *J. Geotech. Geoenviron. Eng.* 125(10): 832-846.
- Lee K.M. (2001)  
Influence of placement method on the cone penetration resistance of hydraulically placed sand fills. *Can Geotech. J.* 38: 592-607.
- Lees A., King D.A. and Mimms S. (2013)  
Palm Jumeirah, Dubai: Cone penetrometer testing data from the carbonate sand fill. *Proceedings of the Institution of Civil Engineers Geotechnical Engineering* 166(3): 253-267.
- Lowe D.R. (1982)  
Sediment gravity flows: II. Depositional models with special reference to the deposits of highdensity turbidity currents. *Journal of Sedimentary Research* 52.
- Matheron G. (1963)  
Principles of Geostatistics. *Econ. Geo.* 58(8): 1246-266.
- Miedema S.A. and Ramsdell R.C. (2011)  
Hydraulic transport of sand/shell mixtures in relation with the critical velocity. *Terra et Aqua* 122. International Association of Dredging Companies, The Hague, the Netherlands.
- Morgenstern N.R. and Kupper A.A.G. (1988)  
Hydraulic Fill Structures: A Perspective. *Proceedings of the ASCE Conference on Hydraulic Fill Structures, Fort Collins, Colorado*, pp. 1-31.
- Pyrcz M.J. and Deutsch C.V. (2003)  
The Whole Story on the Hole Effect. *Newsl. Geostat. Ass. Australas.* 18: 3-5.
- Shen C.K. and Lee, K.M. (1995)  
Hydraulic fill performance in Hong Kong. *GEO Rep. 40. Geotech. Eng. Office, Civil Engineering Department, Government of the Hong Kong Special Administrative Region, Hong Kong.*
- Van Ginkel M. (2015)  
Aquifer design for freshwater storage and recovery in artificial islands and coastal expansions. *Hydrogeol. J.* 23: 615-18.
- Van Rhee C. (2002)  
On the Sedimentation Process in a Trailing Suction Hopper Dredger. Ph.D. thesis, Delft University of Technology, December 3, 2002, Delft, the Netherlands.
- Van 't Hoff J. and Van der Kolff A.N. (2012)  
'Hydraulic Fill Manual' – CRC Press/Balkema Taylor & Francis Group, Leiden, the Netherlands.

# DREDGING EVENTS SCHEDULED FOR 2021



The well-known IADC Dredging and Reclamation seminar will be held twice this year.

## COVID-19

Due to the COVID-19 outbreak, events may be postponed or cancelled. IADC has been following the Dutch and Singapore authorities' advisory measures with regard to limiting the spread of the virus and is keeping a close eye on the situation. We advise you to check our website regularly to see whether the seminar is affected by any measures.

## For whom

The seminar has been developed for both technical and non-technical professionals in dredging-related industries. From students and newcomers in the field of dredging to higher-level consultants, advisors at port and harbour authorities, offshore companies and other organisations that carry out dredging projects. Attendees will gain a wealth of knowledge and a better understanding of the fascinating and vital dredging industry.

## In the classroom

There is no other dredging seminar that includes a workshop covering a complete tendering process from start to finish.

## First seminar

21-25 June 2021

Location: Delft, The Netherlands

Level: No prior knowledge required

Fee: € 3.100,--

The seminar is set to take place at the IHE Delft Institute for Water Education.

## Second seminar

4-8 October 2021

Location: Singapore

Level: No prior knowledge required

Fee: € 3.100,--

The exact location will be announced closer to the seminar date.



## EVENTS

The in-depth lectures are presented by experienced dredging professionals from IADC member companies. Their practical knowledge and professional expertise are invaluable for in the classroom-based lessons. Amongst the subjects covered are:

- the development of new ports and maintenance of existing ports;
- project development: from preparation to realisation;
- descriptions of types of dredging equipment;
- costing of projects;
- types of dredging projects; and
- environmental aspects of dredging.

### Site visit: seeing is believing

Practical experience is priceless and it sets aside this seminar from all others. There will be a site visit to a dredging yard of an IADC member to allow participants to view and experience dredging equipment first-hand to gain better insights into the multi-faceted field of dredging operations.

### Networking

Networking is invaluable. A mid-week dinner where participants, lecturers and other dredging employees can interact, network, and discuss the real, hands-on world of dredging provides another dimension to this stimulating week.



### Certificate of achievement

Each participant will receive a set of comprehensive proceedings and at the end of the week, a 'Certificate of Achievement' in recognition of the completion of the coursework. Full attendance is required to attain the Certificate of Achievement.

### Costs

The fee for the week-long seminar is EUR 3,100.-- (including VAT). The fee includes all tuition, proceedings, workshops and a special participants' dinner, but excludes travel costs and accommodations. We can assist you in finding a hotel or accommodations.

### About the seminar

Since 1993, the IADC has regularly held a week-long seminar developed especially for professionals in dredging-related industries. These intensive courses have been successfully presented in the Netherlands, Singapore, Dubai, Argentina, Abu Dhabi, Bahrain and Brazil. With these seminars, IADC reflects its commitment to education, encouraging young people to enter the field of dredging, and improving knowledge about dredging throughout the world.

Visit the IADC website for more information and to register: <https://www.iadc-dredging.com/seminars-courses/seminar-on-dredging-and-reclamation/>.



## Congress Hydraulic Engineering Structures and Dredging

25-26 February 2021

The event will be held in a mixed in-person/online format

The 4th International Congress Hydraulic Engineering Structures and Dredging will be held on 25-26 February 2021. The congress will include the 8th International Forum of Dredging Companies and the 8th Technical Conference 'Modern Solutions for Hydraulic Engineering'.

### Best practices in construction

Infrastructure development is among the real sources of Russia's economy growth. Construction of port facilities and new hydraulic engineering structures in the country's inland waterways constitutes an essential part of all infrastructure projects. It is important to take into account the best international practices to implement these projects effectively.

### Real projects in the spotlights

The programme of the Congress will be devoted to the latest technologies for dredging and hydraulic engineering works. Speakers and delegates will refer to real projects to discuss specific features of dredging works, as well as dedicated fleet and equipment involved.

### Languages and congress materials

The event will be held in two languages, Russian and English, in mixed in-person/online format. Regardless of the format, all participants will be provided with a complete package of the congress materials including presentations.

For more information, see PortNews Media Group [www.portnews.ru](http://www.portnews.ru)

For registration write to [snitko@portnews.ru](mailto:snitko@portnews.ru)

## Dredging for Sustainable Infrastructure Course

11, 12, 25 & 26 March 2021

Online

Due to the success of the first online Dredging for Sustainable Infrastructure course held in December 2020, CEDA and IADC have decided to schedule a second course in March 2021. The course will be held in four half-day online sessions on 11, 12, 25 & 26 March 2021 from 09:00-13:00 CET. In this course, participants will learn how to achieve dredging projects that fulfil primary functional requirements while adding value to the natural and socio-economic systems by acquiring an understanding of these systems in the context of dredging as well as stakeholder engagement throughout a project's development.

### For whom

Are you a professional involved in dredging related activities for water infrastructure development and working in government, port authorities, consultancy firms, dredging companies, NGOs, suppliers or ship-builders? Is your ambition to achieve sustainable and resilient water infrastructure or dredging projects that contribute to the UN Sustainable Development Goals? If the answer to either of these questions is 'yes' then do not miss the opportunity to join this course. Whether you are an ecologist, engineer, scientist, regulator or financier, valuable knowledge that can be put into practice right away awaits every participant.

### Your lecturers

The course is led by three highly experienced lecturers: Erik van Eekelen (Van Oord), Mark Lee (HR Wallingford) and

Thomas Vijverberg (Boskalis). Together they will inform you about the latest thinking and approaches, explain methodologies and techniques, and through numerous practical examples, demonstrate how to implement this information in practice with the use of engaging workshops and case studies. Course materials will be distributed to all participants before the start date.

### Course information and registration

More information about the learning objectives, programme, lecturers, fee and registration can be found here: <http://bit.ly/DfSI-March-2021>. For CEDA members and employees of IADC member companies there is a reduced registration fee.

# BUILDING WITH NATURE:

## CREATING, IMPLEMENTING AND UPSCALING NATURE-BASED SOLUTIONS

Pre-launched on 22 October 2020 during Climate Summit Week, *Building with Nature: Creating, Implementing and Upscaling Nature-Based Solutions* is a somewhat unorthodox addition to the bookshelves of the dredging sector. This book is being published as a collaboration between industry experts and architects by the Dutch publishing house nai010, which focusses on architecture, art, photography and design. It is a deliberate foray into the creative sector and an interesting and readable tome that is both innovatively laid out and accessible to a wide audience. This can only be good news for the concept of building with nature and its wider application. In the present situation of climate change and problematic pollution, plus the realisation that the historical approach to dredging whereby a design was imposed on nature has led to mixed results, harnessing the forces of nature to benefit the environment, economy and society is a timely and relevant subject for all those working with adaptations to water environments.

### A unique and accessible presentation

This is a visually attractive book with a layout that allows the reader to quickly get to the heart of the matter. Plentiful images and graphs illustrate what the texts explain, and line illustrations are particularly good at relaying the changes in landscapes reinforced with vegetation. They present

readers with a clear and concise bird's eye view of building with nature.

The text is uniquely laid out and in such a way that it reads like a chat with colleagues and experts. The reader is made privy to 'discussions' between the experts on the different situation sketches, which range from sandy coasts to ports. A 'roundtable' concludes the case studies. In the present time of Zoom and Teams meetings, facing a row of photographs of experts or colleagues feels very much like our everyday life. The case studies or landscapes themselves are fictional, though they are based on the real research conducted at EcoShape.

### A reference book for sustainable solutions with nature

As a book to discover what is possible when engineers work together with nature to create change, this appears to be an abundant resource. During the pre-presentation, co-author and director of Deltares, Henk Nieboer, remarked that the choice to publish a book was based on the status that physical books still have, as well as their perennial allure. Having only seen a digital file of the manuscript, I am curious to discover the printed pages, to examine them closely, compare and contrast and feel inspired by the prospect of so much collaboration with our at once powerful, fragile and promising environment. As I think many people will be.



**Editors:** Erik van Eekelen and Matthijs Bouw

**Publisher:** nai010/EcoShape

**Published:** November 2020 in the Netherlands and as of 25 January 2021 internationally.

**Language:** English

**Price:** € 39.95

**ISBN:** 978-94-6208-582-4

**Available from**

<https://bit.ly/35VynBx>



---

## Five questions for the EcoShape editor

*Building with Nature: Creating, Implementing and Upscaling Nature-based Solutions* is a new book by the EcoShape Foundation in the Netherlands. It results from their 'Building with Nature II' research programme. One of its editors, Erik van Eekelen, tells us about the book, which is the fruit of a unique collaboration.

### Why did you initiate this particular book?

*Building with Nature* fills a niche. Most recent books about nature-based solutions are aimed at the relatively high level of policy guidance or even design methods. This book can inspire both policymakers

and practitioners to scale up nature-based solutions by showing their full potential in six landscapes: muddy and sandy coast, lakes, rivers, cities and ports.

The book shows that nature-based solutions are the future. It connects higher-level policy work and research to inspire public and private decision-makers such as project developers or regional planners in government but also consultants in development and NGOs.

### When did you begin work on this book?

The idea began to take shape in 2019 when it became clear that the findings from various pilot experiments and research projects could be reformulated as generally applicable concepts. The partnership with One Architecture was formed in 2020 after

the focus of the book was determined. They were the right fit.

### EcoShape and One Architecture: two very different specialisms. Why was it a good fit?

We at EcoShape saw that to inspire with concepts it would be necessary to include creative thinkers and the creative sector. We considered a number of potential partners, and One Architecture had a strong vision with a great deal of interest in the topic. Working together created a real win-win situation. To apply building with nature and its principles, you need to think at the level of the landscape and its systems. Our collaboration brings the concept into the domain of landscape architects and we can encourage them to incorporate building with nature principles at an early stage in the design.



**The book connects to resources about landscapes and technical guidelines on [www.ecoshape.org](http://www.ecoshape.org).**

We found the overlap in our approaches in the visual as well as structural benefits that nature-based solutions offer. In addition, our collaboration has led to a book with a cutting-edge design and layout.

**Your website, [www.ecoshape.org](http://www.ecoshape.org), is also a resource for the concepts in the book. What can readers find there?**

The book connects to resources about landscapes and technical guidelines on

[www.ecoshape.org](http://www.ecoshape.org). This online platform bridges a gap between decision-makers and those who really have to take action and apply the principles. The broader view of the book acts as a stepping-stone to the website with its more detailed insights and practical advice. Do you have questions about a business case for ripening mud? Do you want to know what SDGs a concept serves? Or the eco-based design rules for sand extraction sites? The website is where you need to go.



### **Matthijs Bouw**

Matthijs Bouw is a Dutch architect and the founder of One Architecture (est. 1995), an award-winning Amsterdam and New York-based design and planning firm. He currently serves as the Rockefeller Urban Resilience Fellow for Penn Design at the University of Pennsylvania. Matthijs has been a guest professor at Delft University of Technology (TU Delft), Berlage Institute, TU Graz, University of Kentucky College of Design and Sci-Arc, and was professor of 'Gebaeudelehere und Grundlagen des Entwerfens' at the RWTH Aachen.

### **Erik van Eekelen**

Erik van Eekelen is Lead Engineer Environmental at Van Oord. Erik studied at TU Delft, in the Netherlands, graduating with an MSc on the subject of dynamic behaviour of dredging plumes of TSHDs in 2007. He then joined the environmental engineering department of Van Oord, working worldwide on the full range of environmental aspects of their projects, such as Eco-Design/BwN, stakeholder engagement, protection of marine fauna and turbidity monitoring and management. For Van Oord, he is part of the Management Team of the EcoShape consortium that develops knowledge via pilots and research on the topic of building with nature.

## MAIN MEMBERS

### Adani Ports and Special Economic Zone Ltd.

Head office India  
+91 79 2656 5555  
dredging@adani.com  
www.adani.com

### DEME Group

Head office Belgium  
+32 3 250 5211  
info@deme-group.com  
www.deme-group.com

### Dutch Dredging

Head office The Netherlands  
+31 184 411 999  
info@dutchdredging.nl  
www.dutchdredging.nl/en

### Group De Cloedt – DC Industrial N.V.

Head office Belgium  
+32 2 647 12 34  
office@groupdecloedt.be  
www.groupdecloedt.be

### Gulf Cobla (L.L.C.)

Head office United Arab Emirates  
+971 4 803 7777  
gc-info@gulfcobla.com  
www.gulfcobla.com

### Hyundai Engineering & Construction Co., Ltd.

Head office South Korea  
+82 2 746 1114  
webmaster@hdec.co.kr  
www.hdec.co.kr

### Jan De Nul Group

Head office Luxembourg  
+352 39 89 11  
info@jandenulgroup.com  
www.jandenul.com

### National Marine Dredging Company

Head office United Arab Emirates  
+971 2 5130000  
nmdc@nmdc.ae  
www.nmdc.com

### Penta-Ocean

Head office Japan  
+81 3 3817 7181  
poc\_international\_web@  
mail.penta-ocean.co.jp  
www.penta-ocean.co.jp

### Rohde Nielsen A/S

Head office Denmark  
+45 33 91 25 07  
mail@rohde-nielsen.dk  
www.rohde-nielsen.dk

### Royal Boskalis Westminster N.V.

Head office The Netherlands  
+31 78 6969 000  
royal@boskalis.com  
www.boskalis.com

### TOA Corporation

Head office Japan  
+81 3 6757 3800  
webmaster@toa-const.co.jp  
www.toa-const.co.jp

### Van Oord

Head office The Netherlands  
+31 88 8260 000  
info@vanoord.com  
www.vanoord.com

## COLOPHON

### Editorial

For editorial enquiries, please email [editor@iadc-dredging.com](mailto:editor@iadc-dredging.com) or call +31 (0)70 352 3334.

Articles featured in *Terra et Aqua* do not necessarily reflect the opinion of the IADC Board of Directors or of individual members.

### Editor

Ms Hanneke Teunissen

### Editorial Advisory Committee

Mr Robert de Bruin, *Chair*  
Mr René Kolman, *Secretary General*  
Mrs Vicky Cosemans  
Mrs Heleen Schellinck  
Mr Arno Schikker

### Board of Directors

Mr Frank Verhoeven, *President*  
Mr Junji Katsumura, *Vice President*  
Mrs Els Verbraecken, *Treasurer*  
Mr Theo Baartmans  
Mr Niels de Bruijn  
Ms Mieke Fordeyn  
Mr Neil Haworth  
Mr Philip Hermans

### Front Cover

Photo © Rijkswaterstaat/Boskalis

### Back Cover

Photo © Deltares

### Design

Smidswater, The Hague, The Netherlands

### Production and Proofing

ECC B.V., Hardinxveld-Giessendam,  
The Netherlands

### Printing

Tuijtel B.V., Hardinxveld-Giessendam,  
The Netherlands

All rights reserved.

© 2020 International Association of Dredging  
Companies and individual contributors  
ISSN 0376-6411

The name *Terra et Aqua* is a registered  
trademark. Electronic storage, reprinting or  
abstracting of the contents is allowed for  
non-commercial purposes with written  
permission of the publisher.

### How to Subscribe?

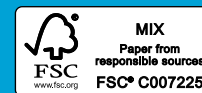
To receive a free print or digital subscription,  
register at [www.iadc-dredging.com/terra-et-aqua/](http://www.iadc-dredging.com/terra-et-aqua/)  
subscribe or email [terra@iadc-dredging.com](mailto:terra@iadc-dredging.com).

### Call for Submissions

Published quarterly, *Terra et Aqua* is an educational  
and professional resource which features cutting-  
edge innovations to disseminate knowledge  
throughout the dredging industry. Are you an author,  
researcher or expert in dredging or a related field?  
Do you want to share your innovative research,  
papers or publications with the dredging industry?  
Then submit your proposals to the editor at  
[editor@iadc-dredging.com](mailto:editor@iadc-dredging.com) for consideration.

*Terra et Aqua* is published four times a year by  
**International Association of Dredging Companies**

Stationsplein 4  
2275 AZ Voorburg  
The Netherlands  
[www.iadc-dredging.com](http://www.iadc-dredging.com)





# ALWAYS READY

TO MEET NEW  
CHALLENGES

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

[www.iadc-dredging.com](http://www.iadc-dredging.com)

